MSc Theses Abstract

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Graduation Year 2003

Thesis Title: **TRANSMISSION LINE FAULT LOCATION ALGORITHM USING SYNCHRONIZED SAMPLING AT TWO ENDS OF THE LINE**

Submitted by: **Kumudini Koirala**

Supervisor: **Associate Prof. Indraman Tamrakar**

ABSTRACT:

Determination of the point at which a fault occurs in an electric power transmission line, is vital for economic operation of power systems. The faults are in the form of a short circuit between the conductors or to the ground. The location of permanent faults will facilitate quicker repair and restoration, while accurate location of transient and temporary faults will aid in preventive maintenance. Hence an accurate fault location technique is of prime importance for the successful and economical operation of the power system.

This thesis deals with a scheme for locating a fault on a transmission line. A time domain representation of voltages and currents is used for the development of fault location algorithm. Two independent equations for each end of the line are written using the synchronized current and voltage data measured at two

ends of the line. Kirchhoffs basic laws of current and voltage are utilized to formulate these equations. These equations are then solved to obtain the expression of fault distance as a function of time.

Finally the fault distance formula is obtained by using the principle of Least Square Estimation. Expression for the fault distance thus derived is dependent on the instantaneous values of current and voltage measured at both ends at normal as well as fault condition of the line.

This thesis mainly focuses upon the development of an algorithm which can prove that whether the direct use of fault voltage and current data recorded at each end of the line can give accurate results of the fault location. For the development of the algorithm a fault is assumed to occur at some known distance on the line. The fault distance is then calculated using the formula derived. Calculated value of the fault distance is then compared with the assumed value in order to see how accurate the results are. Percentage error is estimated and it is quite obvious that lesser the error better is the accuracy of the technique

A fault on a transmission line is generally associated with a fault resistance. The value of the fault resistance is dependent on the physical condition of the soil of the site. Hence the value of fault resistance is normally not known, and its value has to be assumed.

This results in an inaccurate estimation of the fault location. The advantage of the proposed scheme is that it does not require the fault resistance to find the fault location, and hence is more accurate as compared with the single end approach. Because, the formulation of fault distance by the single-end approach requires fault resistance. This statement is discussed by comparing the basic principles of proposed scheme with fault location approach utilizing the current and voltage data monitored at only one end of the line.

Hence, the proposed scheme is a better solution to the single-ended fault location technique, although the proposed scheme is costlier as compared to the single-ended approach, as it requires an additional cost for synchronization and communication equipment to synchronize and communicate between the data recorded at two different locations of the huge and complex transmission line network. The cost can be compromised but not the accuracy.

Thesis Title: **IMPLICATION OF DEMAND SIDE MANAGEMENT ON GENERATION EXPANSION PLANNING: A CASE OF NEPAL**

Submitted by: **Kul Man Ghising**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

Of various available Demand Side Management (DSM) options improvement in energy efficiency is found to be relatively more promising in the developing countries because of rapid growth in demand and less efficient use of energy in these countries than in the industrialized countries. Nepal being a least developed country with only 22% of population having access to electricity, has very low overall efficiency of electricity use, owing to the predominance of less efficient appliances. Thus, there is an ample room for efficiency improvement because of the availability of a huge amount of untapped potential for demand reduction. Further, the load of INPS at peak which occurs at evening time of the day, is heavily dominated by the lighting load of residential sector which accounts for almost 57% of the total demand at that time. This indicates that DSM through efficient lighting in household sector may have significant potential for offsetting the immediate need for capacity

expansion and improvement in load factor of the system. Though there is ample room for efficiency gain in Nepal no attempt has been made to incorporate DSM in integrated approach in the national generation expansion plan by authorities concerned.

This study analyzes the Techno-economic potentials of CFL Lamps in residential sector for reduced power generation and power sector development of Nepal under integrated resource planning (IRP) as compared to that under traditional resource planning (TRP i.e. without DSM). Mixed Integer Programming approach is used for expansion plan in TRP and IRP. General Algebraic Modeling System (CAMS) is used to solve these MIP problems.

Techno-economic analysis shows that the efficient CFL lamps of 20 W (replacing 100 W incandescent bulb) and 11 W (replacing 60 W incandescent bulb) are found to be cost effective in all perspectives (national, utility and User) even at DESMAC of 50% of capital cost of the efficient appliances and discount rate of 50% for users. This shows that DSM through efficient CFL lamps at present price level of electricity would benefit nation utility and consumers in all respects. The analysis also indicated that about 24.24% of the peak demand and 6.19% of the total generation in the business-as-usual (BAU) scenario could be avoided cost effectively in technical as well as economical perspective during planning horizon. However under IRP there

would be a reduction of installed generating capacity and cumulative electricity generation during the planning horizon by only up to 19.31% and 4.7% respectively from that of TRP case. Consequently, total cost and Average Incremental Cost (AIC) could be reduced by up to 19.19% and 19.46% respectively under IRP.

Thesis Title: **OPTIMAL POWER FLOW INCORPORATING FLEXIBLE AC TRANSMISSION SYSTEMS DEVICES**

Submitted by: **Ramananda Mishra**

Supervisor: **Prof. S. A. Sonam**

ABSTRACT:

This project report describes about Optimal Power Flow (OPF) incorporating FACTS devices. The novel approach using Geometric Programming (GP) technique is attempted for formulation of OPF. The major advantage of GP is that all the non-linear constraints can be transformed into linear constraints. Optimization problems with non-linear objective function and linear constraints are easier to solve as compared to those having nonlinear constraints. Feasible decent direction exists only with linear constraints. This simplifies computations.

We illustrate the GP like OPF approach for a 3 bus system. We have solved linear constrained optimization problem using a penalty function approach. It was found that the approach is very sensitive to choice of penalty factors. Hence, it appears that such an OPF solver should use optimization methods based on feasible directions. Considerable amount of research would be involved in developing such an approach for large scale systems. Therefore for large scale OPF implementation we have preferred

a Sequential Linear Programming (SLP) approach. In this approach, sensitivity of the controller is calculated using perturbation technique. An advantage of this technique is that it does not require calculation of load flow Jacobian as in case of Newton's method or reduced gradient method. The approach is also suitable for parallel computing. Another major advantage of this technique is that any new controller or model can be added easily (as we have added FACTS as another controller) without making any major changes in the OPF formulation. The only essential requirement of this method is that it requires a Load flow solver which can model the controllers of interest for OPF.

In this work we have developed a generic OPF program which can handle FACTS devices. The various objectives considered are:

a) Minimization of active power loss

b) Minimization of composite function (loss+ reactive power compensation)

c) Economic Dispatch

d) Overload alleviation.

Results on 39 bus New England system, IEEE 14 and 30 bus system are used to demonstrate the efficacy of the proposed method and utility of FACTS controllers in achieving the above objectives.

Some salient features are

• Series FACTS devices like SSSC, do not play a major role in loss minimization.

• Series FACTS controllers help in MW overload alleviation problem. Absence, of such device, generator MW rescheduling is the only option. In a 39 bus system, it can be sheen that MW rescheduling alone may not do overload alleviation. Conventionally this should call for load shedding. However, with series FACTS controller, it is possible to overcome overload alleviation.

• This further implies that series FACTS devices may play an active role in Economic dispatch. This problem is suggested as future work.

Thesis Title: **IMPROVEMENT OF RELIABILITY INDICES OF DISTRIBUTION SYSTEM OF BANESHWOR AREA**

Submitted by: **Som Nath Kaduwal**

Supervisor: **Dr. L. B. Silpakar**

ABSTRACT:

Reliability evaluation of distribution system has experienced a gradual development over the past three decades. There are many approaches to evaluate the reliability indices of a distribution system like failure mode and effect analysis (FMEA), generalized method, reliability network equivalent approach etc. In this thesis work, a generalized method is applied to evaluate reliability indices of distribution system of Baneshwor area.

The thesis considers the technical and economic aspects of reliability of Baneshwor and Dhobikhola distribution feeders of Baneshwor area. The technical aspect of reliability analysis considers the historical failure data of different components of distribution system and number of consumers of each load point served by the two test feeders. Then, the evaluation of different reliability performance indicators such as average failure rate, annual unavailability, system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI) etc are carried out. Based on the mathematical model, a

simple computer program is developed to cany out the required calculations using C language.

The economic aspect of reliability analysis considers the failure rate, outage time, annual unavailability, average load and number of outage events at load point of the two test feeders. Based on these data, evaluation of reliability worth indices such as expected energy not supplied (EENS), expected cost of outage (ECOST) etc. are carried out. Contingency enumeration method,is applied to evaluate reliability of the two test feeders. This reflects economic value of expected unserved energy. A simple computer program based on contingency enumeration method or failure mode and effect analysis (FEMA is developed to carry out the required calculations.

The thesis work also considers four different reliability improvement options for the two test feeders because the number of outages (more than 80) and annual service outage (more than 30 hours) are very high. The technical as well as economic expects are considered for each reliability improvement options. The reliability improvement options selected for the analysis describe the reduction of failure rate as well as outage time to reduce the overall annual unavailability or to improve the overall availability of supply for the two test feeders.

Thesis Title: **LOAD ESTIMATION (ALLOCATION) ON A DISTRIBUTED FEEDER IN CONTEXT OF NEPAL**

Submitted by: **Subhash**

Supervisor: **A. K. Mishra and N. R. Karki**

ABSTRACT:

For a distribution feeder analysis, almost all loads are estimated based on the data available such as transformer capacities at different nodes and measured data on the feeder from the substation meters. In context of Nepal, the load estimation based on connected transformer capacity is not practical. This is not only because the estimated load during the planning is faulty but also because is the economic status of the Nepal Electricity Authority and of the country itself is severely not good. Most of the distribution systems in the country are ill planned as per short-term needs and are extended from time to time to meet the future requirements of loads. There are several examples in which the installed transformer capacity is not according to the estimated demand.

Various methodologies have been proposed and are in use worldwide for load estimation of an existing feeder. However, the author is fully aware that there does not exist any methodology till date which can be used universally world wide.

The reason is quite simple because the suitability of the methods depends on various factors such as consumers' geographical and economic status, end use pattern, coincidence of the peak load, etc. which are quite different from east to west or south to north and so on.

This thesis addresses load estimation in a distribution feeder based on actual billing records and consumers' types. The thesis also attempts to propose a method to approximate the different required parameters, if not available realistically, for load estimation such as load factor, power factor, contribution factor, etc., based on experimental observations on a practically existing feeder at some selected nodes named as model nodes. A least square error based method as an optimization technique does this work, based on the experimental observations at the model nodes on the real existing feeder.

The next important contribution of the thesis lies in the capability of the methodology proposed to estimate the nodal demands at any instant of time rather than just calculating its peak demand. This is important because a distribution system engineer is very often interested to carry out the loss analysis or voltage profile analysis at the instant of a feeder's peak load rather than the instant at which a particular node has its peak.

Thesis Title: **CHOICE OF ELECTRICITY SUPPLY INDUSTRY STRUCTURE IN NEPAL USING ANALYTIC HIERARCHY PROCESS**

Submitted by: **Soorya B. Shrestha**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

The market economy has penetrated in many of the industrial sector including electricity supply industry (ESI) even in developing countries. The structure of ESI in various countries is changing very fast from monopoly market to competitive market. All structural changes are expected to lead to power sector reform. The choice of ESI structure is a complex phenomenon. The choice of ESI should have taken several factors including economics and interest of the concerned stakeholders. So far the choice of ESI in most countries including Nepal has been made with recommendation of experts on their own sincere belief that the structure chosen will suit the country, but without any scientific research, whether such choice could be palatable to the environment of the country or whether such choice is acceptable to all the stakeholders involved in the power sector.

The present structure of ESI is a regulated monopoly model with power purchase at agreed rate from other sectors. The purpose of

this study is to make findings whether the present level of participation by others are a) enough, b) is more than enough or c) is not yet enough. This is done by making choice by the stakeholders as to what form of structures is suitable for the country. As published papers on the choice of the structure of the electricity supply industry are not seen, this study is expected to prove to be a milestone for choice of electricity supply industry organization in Nepal.

The objective of this study is to determine the appropriate ESI using Analytic Hierarchy Process (AHP). Six groups of stakeholders of the power sectors selected are consumers, experts, power developers, political people, HMGN officials and the utility personnel. More than sixty people from the groups were surveyed. Four structures have been selected for the choice of the ESI. The four structures, which are clustered forms of the different possible structures, are proposed in this study. The stakeholders make pairwise comparison of these structures. These verbal expressions are translated into mathematical model of reciprocal matrix. Each stakeholder's expectations are combined using geometric mean of the stakeholders' expectations. The overall expectations are determined by combining all the expectations by weighted averaging method.

Two groups chose the competitive purchasing agency model and four groups chose the fully deregulated retail competition model,

with the overall choice of the fully deregulated retail competition model. It is interesting to note that the HMGN officials inclusive holding regulatory authority did not choose the fully regulated monopoly model, but gave priority to fully deregulated retail competition model. Furthermore the utility personnel did not choose the existing model but the slight favor towards the fully deregulated retail competition model.

The present study indicated that the choice of the stakeholders is not the present form of the existing model. The present choice indicated high weightage to both the competitive purchasing agency model and the fully deregulated retail competition model with low weightage to the existing model and the fully regulated monopoly model.

Graduation Year 2004

Thesis Title: PRICING TRANSMISSION SERVICES UNDER COMPETITIVE MARKET STRUCTURE: A CASE OF NEPAL

Submitted by: Bigyan Prasad Shrestha

Supervisor: Dr. Rabin Shrestha

ABSTRACT:

This study estimates the transmission pricing under a competitive market structure. The study is based on the single auction bidding power pool also known as Poolco Model. In this Poolco model, Transco or ISO collect bids for capacity and energy from Gencos and bids for load demand from Disco in day ahead market. Then the Transco schedule the generation for optimal dispatch and determine the locational marginal price based on the nodal and zonal price considering network loss and congestion. The transmission pricing obtained under Pooico model is based on the SRMC approach, which cover network losses, congestion and operating cost. Additional fixed annual charge is also determined based on Long Run AIC for recovery of capital investments. The study network is based on the Integrated Nepalese Power System (INPS) under assumption of competitive market structure.

This study utilizes unconstraint optimization program and constraint AC Optimal Power Flow (OFF) program in Nepalese transmission system for determining market clearing price (MCP) and nodal price respectively. The MCP obtained from unconstraint optimization represents nodal price of the loss less and unconstraint network, which is uniform for all nodes. The nodal price represents actual price of dispatched energy including cost of losses and cost of network congestion due to re-dispatching of expensive generators. The difference between nodal price and MCP represents the transmission price under SRMC approach. The approach of nodal pricing is developed for Zonal pricing approach using weighted average of nodal price for simplifying the transmission pricing representation. For this purpose the INPS is represented with three different geographical regions viz. Eastern Zone, Central Zone and Western Zone. an The annual fee representing cost of capital recovery for construction of the planned network expansions is charged to Genco and Disco on the basis of proportionate capacity and demand respectively.

It is found that zonal price of Eastern Zone is higher than that of Western zone. The transmission bottle neck is observed between Bharatpur (112) and Hetauda (113) bus which resulted to network congestion between western and eastern region.

The higher zonal price in the Eastern zone represents deficit of generation capacity in the Eastern zone. The transmission price on account of TUOS charge is higher in this zone. Similarly, lower price in the Western zone represents surplus generation capacity in the Western zone. TUOS charge in this zone is lower and some times give negative value. The negative value represents refund to the Disco on account of reduction in system loss and congestion.

Thesis Title: **VOLTAGE STABILITY ENHANCEMENT USING STATCOM**

Submitted by: **Durga Nanda Bariyait**

Supervisor: **Associate Prof. Indraman Tamrakar**

ABSTRACT:

Due to the stressed operation of the power system, the power utilities are facing the problem of voltage security and voltage instability. The voltage instability occurs in power system networks mainly due to the reactive power shortage or difficulty in transmitting the required amount of reactive power to the loads. A power system becomes more vulnerable to voltage instability due to increase in system loading and due to the outage (contingency) of any branch of its transmission network. Hence, it has become important to consider voltage stability criterion also in system security assessment. For secure operation of power system, it is necessary to identify the contingencies causing voltage instability (critical contingencies) and plan for the on-line remedial actions in order to avert voltage collapse in the system. The voltage stability at the critical buses can be increased by connecting shunt reactive power compensating devices.

There are varieties of shunt reactive power compensating devices which are in use in interconnected power system. This thesis deals with the study of voltage stability enhancement by use of STATCOM as it has better performance and faster response than other conventional shunt compensating devices and SVCs. STATCOM is a switching converter type shunt compensator which can produce or absorb reactive power without using capacitor or inductor: PWM inverter with a dc capacitor on dc side is used as converter linking ac system bus through a coupling transformer. The critical line and critical bus is identified by evaluating the four stability indices for each line. The line with higher value of index (close to 1.0) is identified as critical line and the receiving end bus of the critical line is identified as the weakest bus from the voltage stability point of view. The harmonic analysis of PWM inverter output voltage is carried out and it is concluded that the harmonic components in the current through the STATCOM branch can be reduced by operating the PWM inverter at a higher frequency ratio. The voltage stability study has been carried out on two test systems, namely 6 bus test system and IEEE 14 bus test system.

Thesis Title: **ELECTRICAL POWER DISTRIBUTION SYSTEM STATE ESTIMATION USING ARTIFICIAL NEURAL NETWORK**

Submitted by: **Hari Prasad Pandey**

Supervisor: **Associate Prof. Shashidhar Ram Joshi and Dinesh Ghimire**

ABSTRACT:

State estimation is a basic module in the advanced application software (network analysis) of modem Energy Management System (EMS). Its main function is to provide reliable estimate of the quantities required for monitoring and control of the electric power system. State estimation is first function to be executed at the energy control centers and the output of the state estimator is utilized as input to various advanced functions being carried out at energy management system.

Nowadays, the technology to automatically monitor and control a distribution system is available. In an automated distribution system many meters are installed. Real Time measurements are noisy. Thus techniques have to be developed to screen the measurement data. Due to requirement of filtering, measurement data and having real time systems state for on line operation, the need for a distribution state estimation is realized. In this view ANN method is one of the tool for the state estimation.

Two types of data are required for state estimation, the networks data and the measurement data. The Unbalance natured of the distribution system, accurate study can be accomplished with distribution lines modeled in their a,b,c phase representation. This proposed method considers measurement and assumes that absolute value of voltage can be measured at buses in the distribution system.

It is proposed to solve the problem of distribution state estimation by designing an artificial neural network (ANN) which can be learnt from pattern encountered previously. Many types of networks exist but here we focus on a 3-layer feed forward network with back propagation learning rule. The first layer is the input layer, which represents data to the network. Nodes on this are different from others. In a feed forward network they are strictly linear. The number of input nodes is calculated from the number of data source and nodes require to represent each source. Each input node is connected to several nodes in the second layer. The second layer is referred as the hidden layer, since they are not accessible to the outer environment. To determine the proper number of nodes for hidden layer is difficult

and is often determined through experimentation. The addition of more hidden nodes may degrade performance due to increased difficulty of training and the increased potential for over fitting

the training data. The last layer is referred as the output layer, since the networks output is response of nodes on this layer. The type of expected output determines the number of outputs on ANN.

The operation of this feed forward network consists of passing weighted and summed input signals through a chosen non-linearly. It presumes knowledge of the bias functions and weighted links. Once activation and output function chosen, an ANN is completely described by its weights and biases. Since a given ANNs solves a specific problem or functions, finding weight and biases for the network is equivalent to finding the input/output relationship that describe the functions. Thus ANNs used to find relationships that are difficult to describe explicitly, ANNs are specially appropriate and powerful because weights and biases can represent a given functions

The back-propagation learning rule is an iterative gradient algorithm designed to minimize the mean square error between the actual out put of a multi layer feed forward network and the desired output. An essential component of the rule is iterative method that propagates error terms required to adapt weights back from nodes in the output layer to node in lower layers. At the beginning, we set all weights and nodes off set to a small random value. The input value are presented and desired out puts are specified. Then the network is used to calculate actual output.

A recursive algorithm, starting at the output nodes and working back to the hidden layer, adjusts weights until weights converge to an acceptable value. The training process is repeated by presenting different sets of input data to the ANN. The magnitudes of voltage at different buses are chosen as input to the ANN. Active and Reactive Powers of load are chosen as the outputs.

Training data are obtained by load flow studies. Load flow study is carried out for IEEE- 14 bus distribution system. Three-phase imbalance distribution network model and mathematical formulation in unbalanced system is tested. This thesis has attempted to develop 3 layer feed forward network with Back Propagation learning rule for static estimation (Estimation of load active and reactive power at different Node) of a Radial Distribution system. The network contains 26 nodes in input layer, 13 nodes in hidden layer and 24nodes in output layer. The neural network tested on IEEE-14 bus Distribution system. The Two cases are designed for demonstrating the capability of the developed neural network. With the learning from data, normal and System over loaded conditions are computed with tiny deviations below 2% from the actual. In the view of the effectiveness and efficiencies of the ANNs approach, the developed artificial neural networks may be a valuable tool to assist distribution system operators in state estimation.

Thesis Title: **CONTINGENCY ANALYSIS AND RANKING**

Submitted by: **Birendra Kumar Jha**

Supervisor: **N. R. Karki**

ABSTRACT:

A power system is said to be secure if it is presently in normal state and remains in normal state, if a contingency takes place. Two major functions of power system security are security assessment and security control. The security assessment involves contingency analysis, which can be performed by AC load flow for various outage cases. However, the number of contingencies in practical system is so large that they can not be analyzed on-line by AC load flow methods. In order to reduce the computational time, the contingencies are first ranked in rough order of their severity employing contingency selection algorithm. Then the full AC load flow is run for only severe contingency cases which gives problem to the system.

This thesis is intended for the development of fast and efficient method for voltage contingency analysis. One of the problem faced in the real time execution of security analysis is the unavailability of fast and more accurate method for predicting the post outage conditions of system. Hence, in this thesis a

method has been attempted to suggest a set of distribution factors to predict the post outage voltages.

It has also been attempted to rank the contingencies according to their severity based on the proposed distribution factor method. An attempt has been made to eliminate masking effect during contingency ranking by the proposed distribution factor method by selecting the proper exponent for the performance index.

The proposed distribution factor of this work has been tested against 3-bus test system, IEEE-14 bus system and IEEE-30 bus system.

Thesis Title: **PERFORMANCE EVALUATION OF NEA-DISTRIBUTION CENTERS USING DATA VELOPMENT ANALYSIS**

Submitted by: **Shaligram Acharya**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

Distribution system is one of the important components of an electric utility and plays significant role in determining the overall efficiency of an electric utility. Efficient operation of distribution business means a reduction of the cost of production of electrical energy.

Various reports, published by NEA, indicate existence of significant scope of efficiency improvement in NEA-distribution system. Performance evaluation of each distribution center and formulation of strategy for improvement in efficiency is an important aspect in this context. Proper evaluation of performance efficiency of each distribution center is an important issue in the distribution business of NEA. This study presents the use of DEA, as an effective technique, for the evaluation of relative efficiency of distribution centers. Viewed, from the perspective of desire of performance improvement, present study is an effort to move a step forward.

The basic aim of the study is to evaluate the relative performance of 18 distribution centers of NEA. The Data Envelopment Analysis, a powerful technique for relative performance evaluation of multi-input/multi-output functional units, is used for the purpose. The study bears significant importance, for it combines various inputs used by the distribution centers to the different outputs produced by them in the efficiency evaluation. Said other way, the study provides relative efficiency of each distribution centers, under study, in an integrated manner. This study, in addition, seems to be quite helpful in devising an efficient strategy for faster improvement in efficiency of the distribution center of interest.

From the study, it is found that there is a wide variation in efficiency among the distribution centers. Three, out of 18 distribution centers, are identified as efficient distribution centers, while, four distribution centers are found to be operating inefficiently. In terms of relative efficiency, rests of the distribution centers occupied positions in between these extremities. Based on the study, BUTWAL, POKHARA and PULCHOWK are identified as efficient centers. Upon inspection of the associated parameters in data sheet, it is observed that none of them consumes any of the inputs in minimum quantity. It is also noticed that that none of the outputs produced by them is the largest among the group. Still, they occupied the superior

position in terms of efficiency. This is an important finding, which may be regarded as a verification of the strength of DEA technique in integrated evaluation of activities associated to input/outputs.

Formulation of performance improvement strategy is another important output of this study. For this purpose, the distribution centers are categorized based on their efficiency score. Four groups, so formed, are targeted to attain a specified efficiency level, through perturbation in the parameters, with exception to the distribution centers constituting the efficient group, which are kept aside from this analysis with reasons discussed in the relevant section. From the study, it is found that the measures to be taken to improve the efficiency are comparatively much stringent with the distribution centers suffering from over utilization of any of the input resources and/or very low production of any of the outputs.

Thesis Title: **MEASURING EFFICIENCY OF ELECTRICITY GENERATING PLANTS USING DATA VELOPMENT ANALYSIS: A CASE OF NEPAL**

Submitted by: **Deependra Kumar Jha**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

This study evaluates the performance of grid-connected hydroelectric plants owned by Nepal Electricity Authority (NEA) over the period 2000/01 to 2003/04 using Data Envelopment Analysis (DBA). The efficiency is measured against the best practice, not on average practice scenario. A preferred model specification has been developed for the DEA efficiency modeling. The key inputs to the electricity production process are captured including installed capacity of the power plants, O&M cost and number of employees. Similarly, the outputs specified give a good sense of the electricity production process, which includes energy generation, summer and winter season peaking capacities of the power plants. Input oriented DEA models has been used for various efficiency measurements. Results of the DEA models are realized through General Algebraic Modeling Systems (GAMS) software.

The performance evaluation of electricity generating plants has been carried out through the measurement of technical efficiency, which is an efficiency element that reflects the work and management practices of the various power plants and scale efficiency, which is concerned with the optimal size of the power plants. The overall efficiency of a power plant is combination of technical efficiency and scale efficiency. The average technical efficiency and scale efficiency of the plants under consideration are found to be 73.75% and 71.08% respectively. These figures suggest that there exist inefficiency in both managerial and scale of operation in the power plants under consideration.

The results from slack analysis indicate that there is unnecessary use of resources like human resources i.e. employees and expenditures on operation and maintenance woks by most of the power plants. For example, during the fiscal year 2003/04, NEA hydropower stations spent around 29.40% excess amount of money on operation and maintenance works and there was overstaffing in the powerhouses by 27.86%.

A plant may be scale inefficient if it exceeds the most productive scale size thus experiencing decreasing returns to scale (DRS), or if it is smaller than the most productive scale size thus having not taken full advantage of increasing returns to scale (IRS). Most of the hydropower plants exhibit increasing returns to scale (IRS) characteristics, which indicate that size of the plants are smaller

than the most productive size. Kaligandaki 'A' and Sundarijal power plants are found to be the most efficient plants with highest technical as well as scale efficiencies. That is why, these plants along with Marsyangdi power plant appears in the reference set of most of the inefficient plants. This implies that input-output mix of these power plants can be considered as reference for the inefficient plants.

Sensitivity analysis is carried out in order to evaluate the performance of the power plants considering various 'what-if scenarios. Classification based on the sensitivity analysis is presented and according to which around 80% of hydropower plants fall in the category of distinctly inefficient power plants with base technical efficiency scores below 90%. There are few power plants like Kaligandaki 'A' and Sundarijal that are found robust by having technical efficiency scores of 100% for most of the conditions during sensitivity analysis. Trishuli power plant showed the poorest technical efficiency and it requires a significant reduction in all of its resources as well as increment in the energy production in order to make the power plant efficient.

Graduation Year 2005

Thesis Title: **TECHNO-ECONOMIC ANALYSIS OF RURAL ELECTRIFICATION SCHEMES IN MUSTANG DISTRICT**

Submitted by: **Khem Kumar Basel**

Supervisor: **Dr. Rabin Shrestha and N. R. Karki**

ABSTRACT:

Recognizing the role of energy in multifaceted development of a society, its economy and infrastructure, the 9^{th} plan had emphasized the development of a country's major indigenous resources the hydro power and expansion of electricity services to the rural area, which are until now deprived at such services. Problems associated with rural electrification program are generally enormous. Difficult rugged mountainous terra's with scattered settlements, low level of socio-economic and infrastructure development in hilly rural areas, low local density and poor income levels of the mass are the main constraints for sustainable rural electrification program.

This work carries out the feasibility study for rural electrification program. Different distributed generation technology options as well as gird extension scheme have been taken as power supply

options. Of various available power supply options for rural electrification in four VDC in Mustang District, Diesel Generator scheme is found to be the best from technical and economical point of view.

Thesis Title: **FEASIBILITY STUDY OF HIGHER VOLTAGE TRANSMISSION LINES IN NEPAL**

Submitted by: **Mahammad Badrudoza**

Supervisor: **Nava Raj Karki**

ABSTRACT:

The rapid growth of industrialization and commercial activities all over the world in the last 4-5 decades has resulted in similar growth in demand for electric power and energy. The growth in demand for electric power has been met by addition of generating capacities and simultaneous expansion of transmission facilities. This applies both to the developed as well as developing countries, the only difference being rate of growth in demand. In Nepal, even though, the first hydroelectric power plant was installed more than 90 years ago, the overall power sector development has been dismal. The corporate development of the power sector was started only in 1965 AD with the establishment of Nepal Electricity Corporation (NEC) and Electricity Department (ED) under the Ministry of Water Resources. In 1984 (2040BS), by the merger of NEC, ED and Eastern Electricity Corporation, a single vertically integrated utility, Nepal Electricity Authority (NEA) was established under NEA Act 1984. This was done mainly to enhance the

performance of the electric utility and provide single window for dealing with all power sector related aspects. In 1990 after the scrapping of 402 MW Arun III hydroelectric project, the government took new initiative to attract foreign and domestic investment in power generation by enacting Electricity Act 1992 and Electricity Regulation 1993.This was done to avoid the eminent power shortage in the country. The Electricity Act 1992 and Electricity Regulation 1993 had provisions for foreign and domestic investment in power generation with NEA as sole purchaser. Two private companies with majority overseas investment entered in to Nepal's power sector under Build, Own, Operate and Transfer (BOOT) mode. There are few domestic Independent Power Producers (IPPs) also who are selling power to NEA at long term fixed price rate. Many domestic IPPs have entered into PPA with NEA but their construction is uncertain creating many operating problems for NEA. Despite the entry of foreign and domestic IPPs in Nepal's power sector, it is still the NEA who has to bear the sole responsibility of maintaining adequate generating capacities, transmission facilities and distribution networks throughout the country. This study is mainly focused on long term transmission planning of Integrated Nepal Power System (INPS) currently under NEA. Taking 2005 year as base case, this study analyses the operational aspect of INPS in coming years i.e. year 2007, 2012 and 2017 to establish

the adequacy of the transmission voltage level currently in use in INPS. The load flow studies with 132kV as highest transmission voltage in the year 2012 and 2017 simply do not converge indicating toward only possible solution, i.e., increase in transmission voltage for few new and few existing transmission lines. This study is based on the assumption that the additional generating stations to be commissioned in different years will be operational in these years as identified in NEA Master Plan. The routes of transmission lines, their voltage level, conductors, etc to evacuate power from the new generating stations in the coming years (2007, 2012 and 2017) are also based on NEA Master Plan. The load *flow* analysis is carried out for the year 2005, 2007, 2012 and 2017 by Load Flow Analysis Software ERACS and the power losses for other years are calculated based on the power losses in the years for which full load flow analyses have been carried out. The technical viability of the 220kV lines are established from the fact that with 132kV lines only, the load flow studies simply do not converge in the year 2012 and 2017 whereas the same converges for these years with 220kV lines to transmit power in certain segments of INPS. The economical viability is established from economical-analysis based on Net Present Value (NPV) method. The NPV of 220kV line installed in 2005 at the end of 2025 is calculated as 45359.11 thousand US$ assuming the cost of energy as 6.02 US C / KWh and at

interest rate 10% annually, whereas the same for 132kV lines is 49946.64 thousand US$. The total system loss with only 132kV lines in 2005 and 2007 are 8.37 % and 11.65 % of the total demand supplied by the generating stations. Whereas in 2012 and 2017 when 220kV lines are extensively used the total system active power losses are 4.64 % and 3.76 % of the total demand fed by the generating stations. This shows the reduction in power loss with 220kV lines in the system compared to 132kV lines. The voltage profile at different buses of INPS with 132kV lines only in 2005 and 2007 are as low as 0.84.pu whereas the same with 220kV lines are 0.924. pu. This is despite the use of Static Var Compensators (SVCs) in 132kV system against no use of of SVCs in system with 220kV lines.

Thesis Title: **STATIC LOAD MODEL OF KATHMANDU VALLEY ELECTRIC DISTRIBUTION SYSTEM**

Submitted by: **Manoj Silwal**

Supervisor: **Dr. L. B. Silpakar**

ABSTRACT:

This study determines the parameters of the load model for Kathmandu Valley Electric Distribution System where the electricity is being supplied by NEA. A Composite load model has been chosen that allows the representation of wide range of characteristics exhibited by the various load components. Both the approaches, the *Component Based Approach* and the *Measurement Based Approach* have been implied to determine the load model parameter. The *Static Load Model* expresses the characteristics of the load as algebraic function of bus voltage magnitude and frequency.

The load model parameters determined by the component based approach are the exponents of bus voltage and frequency that are different for both active and reactive power. With the component based approach, the exponents of voltage pV(overaii) that cause the active power variation has been found as 1.256 whereas the exponents of frequency pV(overaii) that cause the active power variation, has been found as 0.827. The bus voltage exponents qv

(overaii) that cause the reactive power variation, has been found as 1.4338 and the exponents of frequency qf (overaii) that cause the reactive power variation, has been found as 0.729.

Using the measurements based approach, the exponents of bus voltage "a" for active power variation has been found as 1.356 and the exponents of bus voltage "b" for reactive power variation has been found as 1.538. The data analysis software named STATISTICA 6.0 has been used to process the data on measurement based approach that determines the parameter "a" and "b" by curve fitting and least square estimation. The load frequency characteristic is possibly be measured in isolated system where the frequency variation can be made. Comparison of the values of the exponents of voltage determined by component" based approach and measurements based approach shows that there is only 6 - 8 % difference between them. This small difference proves the correctness of the determined load model parameter as well as the appropriateness of the methodology implied.

The value of exponent parameters of the voltage obtained from the both component based and measurement based approaches are averaged and final value of parameters of the composite load model are determined as pv = 1.306, pf= 0.827, qv = 1.486 and qf= 0.729. Utilising these parameters on the load model and

taking the load of each Substation, the coefficients of the load model, i.e Kp and Kq (which depends on the magnitude of active and reactive power) are determined. The constants Kp and Kq has been calculated for two period of time, that is Period : I for 24:00 to 12:00 Hours and Period : II for 12:00 to 24:00 Hours, so that required predictions on load and demand can be made much precisely.

The load of the Kathmandu Valley electric distribution system has been found less sensitive to frequency compared to that of voltage. The "pv" value is close to the fluorescent lamp and "qv" value is close to the induction motor running on half load. The load model appreciably represents the load characteristics of Kathmandu Valley electric distribution system.

Thesis Title: **ELECTRICITY PRICING FOR DISTRIBUTION COOPERATIVES OF NEPAL**

Submitted by: **Naresh Kumar Yadav**

Supervisor: **Mahesh P. Acharya**

ABSTRACT:

Rural electrification in Nepal has in the past been quite a top down supply driven activity with more emphasis on generation and establishment of transmission lines than on supplying electricity to maximum number of rural population and has been supported by donors and banks. A low voltage distribution system has not been seen of priority the same way. When carried out, it has been with low rate and poor performance with respect to quality of service and with corresponding low recovery of electricity bills and extensive illegal connections. It can not continue any further and His Majesty's Government has to serve the rural population in a more efficient way. Instead a new delivery mechanism is developed, based on the demand driven rural energy policy, where the communities forms cooperatives, buy electricity at a bulk rate from NEA and distribute to their consumers at retail prices. Responsibility of operation and management of electricity distribution lies with the cooperatives. Under the new scheme of cooperative electricity distribution, the

illegal connections have reduced to almost zero and there is marked improvement of recovery of electricity bill. Thirteen electricity distribution cooperatives are currently operating in Nepal in various parts of the country. All the cooperatives are purchasing electricity at bulk price of Rs. 3.6 per unit from Nepal Electricity Authority. The cooperatives are selling electricity to their consumers at various rates. The rural electricity distribution cooperatives operating in Nepal are at infancy stage lacking expert technical manpower, tools for operation and maintenance and required fund for financial sustainability. The manpower employed by the cooperatives is paid very low salary. The current status of the cooperatives does not provide a sustainable future. The present revenue generation of the cooperatives is not sufficient enough to even pay the employees a good salary. The repair and maintenance fund is lacking. This study assesses the present condition of three cooperatives; South Lalitpur Rural Electric Cooperative of Lalitpur, Alau Vidhyut Upbhokta Sameeti of Parsa and Marshyangdi Electric Cooperative of Chitwan. The three cooperatives differ in terms of number of consumers, geographic location, economic condition of the consumers, purchasing capacity and demand for electricity. A field visit is performed in each of these cooperatives to know their working conditions. The socio-economic conditions of the households of the cooperatives are assessed. For this, house hold

survey was conducted in sample households. The present energy use conditions of the households

are assessed to know their electricity demand when connected to the grid. Maintaining the general customer to employee ratio as in NEA and the prevailing salary paid by the government organizations, the expenditure requirement for successful operation of the cooperatives is formulated. Using these data the average retail electricity price for cooperatives is calculated. The result is in favor of Marshyangdi Electric Cooperative because of its consumers' good purchasing power as well as high electricity demand. The difference of average selling price and buying price is Rs 1.8 per unit of electricity. But the operation of Alau Vidhyut Upbhokta Sameeti is not encouraging because of its low number of consumers and low consumer/employee ratio. The difference of selling and buying price is Rs. 4 per unit to recover the operating cost. The result for South Lalitpur Rural Electric Cooperative is however satisfactory. The report provides general guidelines to the communities interested to involve in electricity distribution service to set the retail electricity tariff for their consumers. The report also provides some information to NEA to set the bulk electricity selling price for cooperatives. This study seeks to assess the revenue requirement for rural electricity distribution cooperatives for their feasible operation. Based on the average energy consumption per consumer, the average

electricity tariff for retail sale to the consumers of the cooperative is calculated in this report.

Thesis Title: **SHORT TERM LOAD DEMAND FORECASTING USING ARTIFICIAL NEURAL NETWORK**

Submitted by: **Bhishma Kumar Chhetri**

Supervisor: **Dr. Rabin Shrestha and Associate Prof. Shashidhar Ram Joshi**

ABSTRACT:

Forecasting of electricity has always been the essential part of an efficient power system planning and operation, especially short term forecasts as it has becoming increasingly important since the rise of the competitive energy markets. The aim of short term load forecast is to predict future electricity demands based on historical load data and other information such as temperature. This thesis proposes designing a model using neural network and wavelet techniques to increase the accuracy of time series load forecast. The model is created in the form of a program package written with MATLAB. The time series data used are historical electricity load data of Integrated Nepal Power System (INPS) under Nepal Electricity Authority and temperature data. Wavelet technique is implemented to the time series data, decomposing the data into number of wavelet coefficient signals. The decomposed signals are then fed into neural network for training.

To obtain the predicted load forecast, the outputs from the neural network are recombined using the same wavelet technique.

The simulation results showed that the model is capable of producing a reasonable forecasting accuracy in short term load forecast of Integrated Nepal Power System. The performance of the model is measured with Mean Absolute Percentage Error (MAPE) index. The MAPE is found to be 4.637 % while forecasting for seven days (336 half hourly data points of 2061 Magh) and it is 3.7347 % while forecasting for a single day (48 points).

Thesis Title: **PRICING TRANSMISSION SERVICES FOR BILATERAL ENERGY TRANSACTION IN A PETITIVE ENVIRONMENT**

Submitted by: **Jayaram Baniya**

Supervisor: **Prof. Luonan Chen**

ABSTRACT:

Accurate evaluation of costs for generation and transmission are needed to provide the correct price signals to foster adequate services and fair competition, as well as to create a stable market and potential profit. To devise an efficient transmission tariff, recently transmission pricing has become one of major research topics in power industries. This paper aims to present a transmission pricing methodology for bilateral energy transactions in voluntary net pool in competitive environment, based on: (a) exact loss contribution of each bilateral energy transactions, (b) associated congestion charge due to generation rescheduling i.e. redispatch of expensive generators for relieving congested transmission lines and (c) long run average incremental cost (LRAIC).

Total transmission cost for bilateral energy transactions includes (i) connection charge, (ii) transmission use of system (TUOS) charge, (iii) transmission loss charge, (iv) Congestion charge, (v)

billing and collection service charge. The connection charges are designed to recover the costs of providing and maintaining connection assets by using capital recovery factor (CRF). The common service charge is charged for the approximation of metering costs, such as billing and collection. The TUOS charges, based on LRAIC calculation for each voltage level, are used to recover all of transmission network expansion costs including the operational costs for using the grid. As a result of deficiency of long run marginal cost (LRMC), LRAIC method is frequently used instead of LRMC to measure the holistic forward-looking costs.

Transmission losses represent up to 5-10% of the total generation, and worth millions of dollars per year even for a small scale system. If users will be charged for the amounts of energy transferred including losses; which is current practices in many electricity markets; it may not be fair to all market participants. Therefore, the exact energy and loss allocation for each transaction are proposed instead of using the fixed percentage loss methodology. In contrast to the conventional single slack bus concept, this paper utilizes transaction pairs from specific bilateral contract. The performance of the proposed loss allocation scheme is better than others, e.g., load flow based loss allocation, OPF based incremental loss evaluation, and sensitivity factor based loss estimation.

One of the most challenging problems for a competitive power market is that congestion may occur frequently, which hinders the transmission open access and finally impairs functioning of the electricity market. If there is transmission congestion, the ISO can resolve it using one of many objectives. These objectives may range from a least cost formulation to those results in the minimum possible adjustments to schedules. In this paper we are formulating the problem by a least cost objective function to resolve the congestion. Total congestion cost (TCC) is obtained from the solution of objective function equations as the objective function output. TCC is allocated to active constraints based on their contribution to congestion. The congestion cost allocated to each constraint is further allocated to loads that use the constraint.

To demonstrate effectiveness of the proposed transmission pricing methodology for bilateral energy transaction. It was applied to modified IEEE 14 bus system, IEEE 30 bus RTS system and finally in Integrated Nepal Power System (INPS) consisting 58 buses, 18 generators, and 91 branches. Test results for various cases made for bilateral transactions indicated that the proposed methodology is effectiveness and consistent with engineering intuition.

Thesis Title: TRANSIENT STABILITY ENHANCEMENT USING SSSC IN POWER SYSTEM

Submitted by: Amit Kunwar

Supervisor: Prof. Indraman Tamrakar

ABSTRACT:

In power systems, where many number of synchronous machines are interconnected through the transmission network it is necessary to maintain there in synchronism; otherwise a standard of service will not be achieved. The transient disturbances are caused by the changes in loads, switching operations, and particularly faults and loss of excitation. Thus, maintenance of synchronism during steady state conditions and regaining of synchronism or equilibrium after a disturbance are of prime importance to the electrical power systems. Further, the present trend of long line interconnection results into increased reactance of the lines. This presents an acute problem of maintenance of stability of system. Hence, it has become important to consider transient stability criterion in system security assessment. For secure operation of power system, it is necessary to analyze various causes along with the possible three phase faults that may lead to loss of synchronism of the system and plan for the remedial action in order to avert transient instability in the

system. The transient stability margin can be increased by connecting series reactive power compensating devices.

There are varieties of series reactive power compensating devices which are being used in modern power system. This thesis deals with the study of transient stability enhancement using SSSC in interconnected power system. SSSC is a switching converter type series compensator which can inject a voltage in series with the line and quadrature to the line current without using real capacitor or reactor. Three phase sinusoidal PWM inverter with a dc capacitor on dc side is used as converter linking ac system transmission line through a coupling transformer. An intentional three phase fault is created at a bus of the interconnected power system and delta versus time plot is drawn for all generators with reference to slack bus generator to check whether synchronism is maintained or not. PWM based SSSC are implemented in multiple lines of interconnected power system and transient stability is compared with previous uncompensated system. The harmonic analysis of PWM inverter output voltage is carried out and it is concluded that the harmonic components in the current through transmission line can be reduced by operating the PWM inverter at a higher frequency ratio. The transient stability study has been carried out on 6 bus test system.

Thesis Title: **PERFORMANCE EVALUATION OF ELECTRICITY DISTRIBUTION CENTERS USING VELOPMENT ANALYSIS**

Submitted by: **Shiva Prasad Pokharel**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

Performance evaluation of Electricity Distribution Centers (EDCs) gives not only their efficiency scores but also identifies the area of inefficiency of the inefficient Distribution Centers (DCs). It also suggests the solutions for the efficiency improvement of inefficient DCs. So, it is very important to assess the performance of DCs. But due to the complex characteristics of DCs, it is very difficult to quantify their efficiency scores without rigorous analysis. Hence, this study evaluates the performance of grid-connected DCs owned by Nepal Electricity Authority (NEA) and Butwal Power Company (BPC) from fiscal year 2001/2002 to fiscal year 2004/2005 by using Data Envelopment Analysis (DEA). DEA models are solved through General Algebraic Modeling Systems (GAMS) software.

Performance evaluation of the DCs has been carried out through the measurement of technical efficiency, which is an efficiency element that reflects the work and management practices of the various distribution centers and scale efficiency, which is

concerned with the optimal size of the DCs. The overall efficiency of a distribution center is the combination of technical and scale efficiencies. The average technical efficiency of the distribution centers is found to be 80.82% while scale efficiency of the DCs is calculated as 89%. These figures suggest that there exist inefficiency in both managerial as well as scale of operation in the DCs under consideration. Also the average technical efficiency and scale efficiency of BPC is found to be 98.85% and 85.71% respectively. Hence, it can be inferred that private distribution centers are more efficient in managerial activity but they are in less efficient in scale of operation. Similarly the average technical efficiency score and scale efficiency score of-NEA owned profit centers is found to be 85.39% and 94.05% respectively. NEA profit centers are found to be the most efficient in their scale of operation while they are found to be technically less efficient than the private distribution centers.

Peer group analysis has been carried out in order to find the reference technology for inefficient DCs for performance improvement. It was seen that distribution centers like Galyang-BPC, Gulmi, and Parbat etc., appeared as reference units for most of the inefficient units. This suggests that publicly owned general distribution centers can also work as reference technology not only for publicly owned profit centers but also for private distribution centers.

Sensitivity analysis shows that around 59% of the DCs fall in the category of distinctly inefficient DCs with base technical score less than 90%. There are four Decision Making Units (DMUs) like Galyang-BPC (2061/62), KTM-east (2060/61) which are found robust by having technical efficiency scores of 100% for most of the conditions during sensitivity analysis. Sindhu distribution center showed the poorest technical efficiency which requires a significant reduction in all of its resources as well as increment in sale of energy and number of consumers in order to make the distribution center efficient.

Graduation Year 2006

Thesis Title: EVALUATION OF ENERGY LOSSES IN NEA POWER SYSTEM

Submitted by: Nawa Raj Subedi

Supervisor: Surya Bahadur Shrestha and N. R. Karki

ABSTRACT:

The accurate evaluation of losses in power system has important technical, economic and regulatory repercussions. Losses are increasingly becoming one of the most important measures of power system performance. Losses do not generate revenues for the utilities and are often one of the controlling factors when evaluating alternative planning and operating strategies and the energy loss costs measure how efficiently the power system is delivering energy to its consumers. In our integrated Nepalese power system we have the information about the total system losses (technical and non-technical) but there is a great contradiction in the actual figure of the technical and non-technical components of the losses.

Generating stations, transmission lines and distribution systems are the main components of the electric power system. Generating stations and distribution systems are connected through transmission lines, which also connect one power system

to another. Thus in delivering power from the generating stations to the electric consumers at their places of consumption and in ready to use form there exist losses of power in different system components.

The thesis has not considered the losses within the generating plants. That is this study is confined to evaluate the losses in power delivery system only. The losses in the power delivery system in general include the losses in transmission/distribution networks and the losses at the transformers. Further it is well known that the no-load losses in transformers have great impact mainly from the energy losses point of view and the thesis has considered this fact wherever applicable.

The loss in transmission level is computed through the load flow analysis using MATPOWER software. The energy loss in transmission lines is then computed using the evaluated peak power loss and a suitable assumption of loss factor. The no-load and load losses of step-down transformers are determined separately and added to these losses.

Technical losses in distribution system are contributed by the losses in high voltage (HV) to the medium voltage (MV) substation transformers, the MV distribution circuits, the MV to low voltage (LV) distribution transformers and the LV distribution circuits. Technical losses in the distribution system

are determined by carrying the load flow analysis using the well-known WindMill software for some typical feeders.

The technical losses in generation, transmission and distribution level of the power delivery system have been evaluated to be 0.653 %, 3.952 % and 6.979 % of the total energy input to the system. So from this study the technical and non-technical losses of INPS have been evaluated as 11.584 % and 13.246 % respectively.

Thesis Title: **PROTECTION COORDINATION IN TRANSMISSION NETWORK**

Submitted by: **Deepesh Poudel**

Supervisor: **Dr. A. K. Mishra and D. P. Upadhyay**

ABSTRACT:

The basic role of a transmission protection system is to sense faults on lines or at substations and to rapidly isolate these faults by disconnecting all incoming current paths. The sensing and switching must occur as fast as possible to minimize damage. However, it should be very selective so that no more of the network is removed from the service than is necessary, hence disrupting as few costumers as possible. The problem is further complicated by the need for performing this task very reliably. This need has led to the practice of providing "primary" protection with the "backup" protection which should function only if one of the primary devices fails. The primary protection system is designed for speed and minimum network disruption while the backup system operates more slowly and generally affects a larger portion of the network.

The most tedious and time consuming part of protection system is selecting and setting protective relays. Many widespread blackouts are either begun or made worse by incorrect transmission relay operation. In this thesis, complete and precise

primary / backup coordination criteria are identified for directional overcurrent relays in a multi loop network. The problem that arises during the setting of the relays in a multi loop structure is solved by using the graph theoretic analysis. Using this analysis, break point set of relays is determined. The break points are the relays which open all the loops of the network. After that, Relative Sequence Matrix (RSM) is determined. The RSM presents the sequence in which the relays are to be set. RSM ensures that when any relay in a particular row is to be set, all other primary relays with which it has to coordinate have already been set. It assures that this relay can be set as backup to coordinate with all its primary relays. From RSM, set of sequential pairs are determined which consists of all primary backup pairs arranged in such a way that backup relays follow the sequence in the RSM.

An algorithm suitable for directional overcurrent protection of multi-loop network is proposed which uses the set of sequential pairs determined from the Graph Theoretic Analysis. For this purpose relay pairs are taken one at a time and the backup relays are set to coordinate with primary relay for all the probable fault currents considered.

Upon completion of one iteration through all the relay pairs, those corresponding to break point set are checked for proper coordination. In the event of miscoordination, the settings of

these break point relays are modified to coordinate and second iteration through the entire set of the relay pairs is made. This process is repeated until satisfactory coordination is obtained for all the relay pairs. For the sample case considered of Kathmandu Valley Section of INPS, this process converges in one iteration only.

Thesis Title: **POTENTIAL OF DEMAND SIDE MANAGEMENT PROGRAM IN NEPAL**

Submitted by: **Madan Raj Chapagain**

Supervisor: **Dr. R. Shrestha**

ABSTRACT:

This study analyzes the potential of selected efficient electrical appliances for reducing the need for power generation in Nepal, from the technical as well as national, utility and user perspectives. The study shows that, from a technical perspective. 4861.4 GWh (6.9% of the total generation) and 14.1% (244.5 MW) of the peak load, using the electricity load forecast from Nepal Electricity Authority, can be avoided during 2007-2020 with the use of the selected efficient appliances. The residential sector accounts for the higher percentage (79.6%) of the total generation that could be avoided. This is followed by the industrial (10.2%) and commercial (10.1%). The residential sector accounts for the higher percentage (13%) of the total peak load that could be avoided. The commercial and industrial sectors account for only 1.1% of system peak load in 2020. The use of efficient appliances in lighting alone would avoid 6.2% of the total cumulative electricity generation during 2007-2020, while EEMs in the industrial sector would avoid less than 1% of the total generation.

All appliances except 13 W CFL in residential sector are cost effective under the base case. The level of power generation that could be avoided through the adoption of cost -effective efficient appliances from this perspective during 2007-2020 is found to be 4602.5 GWh (6.5% of the total electricity generation).

All selected appliances except CFLs in the commercial sector are not viable because the electricity prices are higher than LRMC of the electricity supply in the **sector.** Therefore the generation that could be avoided cost-effectively from this perspective is only 43 80.0 GWh.

The prices of electricity are below the Long-run Marginal Costs (LRMCs) for residential and industrial sectors. The level of avoided generation would therefore be higher from the user perspective if the electricity prices reflect the marginal cost for these sectors.

Thesis Title: **A STUDY ON OPTIMAL LOAD SCHEDULING OF INPS**

Submitted by: **Ramji Bhandari**

Supervisor: **Dr. Arbind K. Mishra and Nava Raj Karki**

ABSTRACT:

Economic load scheduling means to schedule the generation from different generating plants so that the total operation cost is minimum, and at the same time total demand and the losses at any instant must be met by the total generation. This suits for the plants where the operation costs of the generation are considerably high and is best suitable for thermal plants. The largest categories of hydrothermal systems include those where the hydroelectric system is a small fraction of the total capacity. In these systems, the schedules are usually developed to minimize thermal generation production costs, recognizing all the diverse hydraulic constraints that may exists. The economic scheduling of hydro systems is really a problem in scheduling water releases to satisfy all the hydraulic constraints and meet the demand for electrical energy. In all hydroelectric systems, the scheduling could be done by simulating the water system and developing a schedule that leaves the reservoirs levels with a maximum amount of stored energy.

In Nepalese Power System, the hydro generation is the major generation which covers above 90% in most of the time. The diesel plant at Duhabi and Hetauda multifuel are used mainly as reserve plants and run only if the generation is either insufficient to meet the demand or if the technical constraints are not met only by hydro generation. Most of the generating plants are run of river type. Only the two plants KL-1 & KL-2 cascaded plants (Installed capacity of 60 and 32 MW respectively) are the storage type with pondage capacity of $62 * 10^9$ cubic meter.

In INPS running cost parameter seems ineffective in optimal scheduling of generators. However with the proper scheduling of the hydro generating plants at off -peak, the transmission system losses could be minimized and voltage profile could be improved so that there is possibility to save the fuel cost of diesel plants could be saved, indirectly saving the cost of generation.

The thesis presents a simplified two steps approach to achieve this goal. In first step, the generation scheduling based on priority order (e.g. IPP, ROR etc), water discharge availability and the maximum and minimum water storage level at Kulekhani etc are computed by developing a MATLAB software. The computed generation schedule together with the instant demand of INPS at different load center are used as the input data for the load flow analysis using PSS/E software in the step two. The

load flow results are checked for technical constraints (e.g. voltage limit, line overloading etc). These two steps are iterated successively to minimize the technical constraints as far as possible.

The available discharge and installed units are used to determine winter and summer generation scheduling. It has been observed that during off-peak hours it is possible to minimize the constraints violation in most of the cases in summer season. Though the scope is very limited due to insufficient generation capacity of INPS in winter peak and also the IPP agreements with private companies are the major contribution at base load in both the summer and winter.

Thesis Title: TRANSIENT STABILITY ENHANCEMENT USING SSSC IN POWER SYSTEM

Submitted by: Sanjay Kumar Sharma

Supervisor: Prof. Indraman Tamrakar

ABSTRACT:

In a real Power System many numbers synchronous machines are connected through the transmission lines to supply loads located at various load centers and it is absolutely necessary to maintain synchronism between these synchronous generators. Inability to maintain synchronism results in failure of power system. The transient disturbances are responsible for resulting in instability. The transient disturbances mostly caused by sudden loss of large load, tripping of major transmission lines, faults in the system or loss of generation etc. Thus maintenance of synchronism during steady state conditions and regaining of synchronism or equilibrium after a disturbance are of prime importance to the electrical power system. Moreover the present day trend of long line interconnection results into increased reactance of lines, leading to an acute problem of system stability. Hence it has become imperative to consider transient stability criterion in system security assessment. For secure power system operation, it is necessary to analyze various causes along with the possible three phase faults that may lead to loss of synchronism of the

system and plan for the remedial action so as to avert transient instability in the system. The transient stability margin can be increased by incorporating series reactive power compensating devices.

Different reactive power compensating devices are being used in modem power system. This Thesis is an effort to study transient stability enhancement using SSSC in interconnected power system. SSSC is a switching converter type series compensator which is able to inject a voltage in series with the line and in quadrature to the line current without using real capacitor or reactor for the purpose. Three phase PWM inverter using IGBTs as switching elements with a dc capacitor on dc side of inverter is used as SSSC which is connected to the ac system through a coupling transformer. Simulation study is carried out for 7-bus system using Mat Lab-Simulink. For the outage of a particular transmission line, the rotor angle deviation of various synchronous generators is plotted without and with SSSC. The improvement in transient stability due to SSSC is found to be significant.

Thesis Title: **TRANSMISSION PLANNING IN A RESTRUCTURED ENVIRONMENT: A CASE OF NEPAL**

Submitted by: **Tara P. Pradhan**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

This study is done for the transmission investment planning under the restructured environment. The unbundling of generation and transmission functions is fundamentally changing the transmission system planning paradigm. The objective for transmission expansion planning under the restructured environment is different from that in the traditional Electricity Supply Industry (ESI).TraditionaI approaches and methodology to the transmission planning are not suitable in the competitive environment, and new criteria and arrangements are required. The siting, timing and capacity expansion of new generators are becoming uncertain in the new environment. Also, because of distributed generation and small investors' participation, numbers of power plants connection to the transmission grid are increasing. As a result, and because of lengthened lead times for transmission construction, there is considerable uncertainty regarding to the transmission capacity requirement in the future at the time transmission commitments to be made. Also, in the

deregulated and competitive environment, transmission system is more stressed. Hence, increasing reliability is also one of the major factors deciding transmission expansion planning.

This study of Transmission Expansion Planning in a restructured environment is studied on the Integrated Nepal Power System (INPS). Deterministic transmission planning method is applied for the study. The model chosen for the study is Independent Transmission Operator (ITO) model. (TO model represents single national transmission entity model responsible for transmission ownership, system operation, network expansion and market operation. Considering competitive environment, effect of removal of transmission constraint and improvement of system reliability and transmission quality are also considered.

For the transmission planning purpose, the INPS is represented with three different geographical regions viz. Eastern Zone, Central Zone and Western Zone. It is found that eastern, central southern (Birgunj corridor) and Kathmandu region are highly loaded areas of Integrated Nepal Power System (INPS). The transmission bottle neck is observed between Bharatpur-Hetauda 1321KV transmission line which resulted to network congestion between western and eastern region. A number of small and medium scale private generators would be connected in the Marsaungdi-Damauli-Lehknath-Pokhara corridor. As a result,

Marsyangdi-Siuchatar 132kV transmission line and Bharatpur-Damauli-Lekhnath 132kV line would be stressed.

Additional 132kV transmission line between Marsyangdi Hydropower Station and Kathmandu region must be constructed. Marsyangdi Hydropower Station and Damauli substation must be interconnected and additional line between Damauli and Lekhnath is required. These new links would reduce the congestion in the mentioned areas of the INPS and improve transmission quality. Similarly, second circuit stringing in the existing 132kV double circuit towers from Butwal to Kohalpur Substations must be initiated. In order to have higher transfer capability between eastern and western region, 220kV transmission lines from Butwal to Hetauda must be constructed. This 220kV line should further be extended to Kathmandu and eastern region which will act as a "Power Highway" in the deregulated environment. The 220kV transmission lines must be interconnected with existing 132kV systems at Butwal, Hetauda, Kathmandu, Dhalkebar and Duhabi areas. Further. Birgunj corridor is supplied through 66kV double circuit transmission lines from Hetauda Substation in radial mode should be interconnected to 132kV system of Parwanipur Substation to eliminate transmission constraint (congestion) and improving transmission quality in the 66kV system of the corridor. 132/66kV transformers have to be upgraded in Parwanipur,

Hetauda and Siuchatar substations in different years of the planning horizon.

Thesis Title: **REACTIVE POWER CONTROL USING ARTIFICIAL NEURAL NETWORK IN INTEGRATED NEPAL POWER SYSTEM**

Submitted by: **Rochak Bhattarai**

Supervisor: **Dr. A. K. Mishra and Mr. Nawa Raj Karki**

ABSTRACT:

The power sector is very important in the socio-economic growth of the country. Reactive power supply is essential for reliable operation of power transmission system. Reactive power affects system-wide performance in terms of reliability criteria and power transfer levels. Moreover, reactive power has a profound effect on the security of power systems because it affects voltages throughout the system: deficiencies of reactive power cause voltages to fall, while excesses cause voltages to rise. In this regard one of the main requirements in power system is to keep the load-bus voltage within specified limits for the proper operation of equipment.

This thesis evinces new ideas for real time assessment and control of reactive power within a power system using the black box modeling. The study of power system involves highly non-linear and complex cases. An artificial neural network is a black box model capable of modeling highly non-linear cases and its

output can be calculated extremely fast. Mathematically speaking it is capable of modeling any function. Thus, the application of neural network becomes particularly more important in the area of power system engineering. Various application based on neural networks have been reported in the area of power system. Applications are developed for load forecasting, voltage stability management, reactive power control, operational planning, alarm processing and state estimation etc.

In this thesis, an efficient algorithm has been proposed by the appropriate modeling of the power system. The modeling of the system includes the selection of several operating points within the specified limits and constrains. An essential part of the model creation is the selection and extraction of model inputs and outputs, on which the accuracy of the model is mainly based. A multilayer feed forward artificial neural network with back-propagation training algorithm is used and the training data are obtained by solving the load flow solutions at different operating conditions.

In IEEE 6 Bus system and INPS, the number of input neurons of the ANN model **is** defined by the number of load buses. The output neurons in the IEEE 6 bus system are defined by the number of generator bus, shunt capacitors and tap changers.

However in INPS optimum location of reactive power compensation devices are found out using the hit and trial method and the number of output neurons in the ANN architecture are defined accordingly. The ANN network is trained using feed forward back propagation algorithm. The results clearly show that the load bus voltages are within the prescribed range of tolerances after the adoption of ANN control measures.

Graduation Year 2007

Thesis Title: **FINANCIAL IMPACT OF AVAILABILITY BASED TARIFF FOR POWER PURCHASE FROM INDEPENDENT POWER PRODUCERS**

Submitted by: **Ashok Kumar Pandit**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Availability Based Tariff (ABT) is an innovative concept of frequency linked tariff that would be very fruitful to minimize the supply demand gap, enhancing grid security as well as to enable sustained frequency signal for self dispatch of generation.

In Nepal, the dominance of Integrated Nepal Power System (INPS) by mostly run-off-river causes over/under generations 10 the system in wet/dry seasons respectively, causing frequency variations more than 2 Hz daily. NEA grid code 2005 has specified the frequency range: 49.5 - 50.5 as normal frequency range and the frequency range outside the limits of 49.5 and 50.5 Hz but within the limits of 48.75 Hz and 51.25 Hz as alert state frequency range. Nepal Electricity Authority (NEA) as a single vertically integrated power utility in Nepal is suffering lots of

problems and challenges due to the 'take or pay model contracts. The existing tariff structure of PPA being single part tariff does not reflect any pricing mechanism towards drawal pattern and not linked to the system requirements, which signifies only one party (power producers) gets more benefited from the contracts.

This study analyses the impact of ABT on power purchases from Independent Power Producers (IPP). The financial implications were analyzed on excess/deficit energy from major five IPPs; Khimti, Bhotekoshi, Chilime, BPC (Jhimruk and Andhikhola) and Indrawati in FY 2062/063 with UI price corresponding to different system frequency. From the analysis, it is found that there will be big amount of saving to NEA if ABT type tariff is adopted in PPA- The study shows positive signal to implement the frequency linked tariff structure for power purchase from IPPs. The total impact of adopting UI for PPA to NEA for the case: UI (hydro) during worst condition of grid system is NRs. 36,88 lakhs, for the case: UI(hydro) at mean system frequency is NRs. 31.60 lakhs, for the case: UI (hydro) at Min. system frequency is NRs.36.88 lakhs, for the case: UI(hydro-thermal) at Min. system frequency is NRs.60,68 lakhs and for the last case: UI(Indian base) at mean system frequency is NRs.30,18 lakhs during the year.

With the introduction of tariff mechanism such as ABT, the private power producers would be encouraged to build peaking type power plants to gain UI charge producing more power during high demand hours. The IPPs with run of river type plants would be motivated to better harness the river potential forecasting weather and river inflows instead of current practice of optimizing the water basin development. Such mechanism will be applicable in phased approach towards full implementation. The capacity declaration and scheduling process of generations would be made on a day a head basis for a small interval of time; say 15 minutes to overcome the imbalance between deemed and metered generations. Besides these, other associated benefits are restoration of automatic under frequency load shedding, improved power plant performance, reduction in trippings and long term damages.

Thesis Title: **IMPLICATION OF PUMPED STORAGE PLANT IN THE NEPALESE POWER SYSTEM**

Submitted by: **Raju Shrestha**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT:

The yearly plant factor of Nepal is quite low, which is not only due to the seasonally hydrological variance between wet season and dry season in our river, but also due to the asymmetric as well as highly skewed load curve of Nepalese power system.

The study examines the implication of pumped storage plant in the Nepalese Generation System comprising the existing and candidate power plants under Thermal Case and under Thermal Case. The methodology used to evaluate the pumped storage plant is based on long term generation expansion plan. By using the WASP-IV generation expansion planning program, the indices such as capital cost, salvage value, operational cost, energy not served cost, total cost. LOLP and energy for the years from 2007 to 2025 were computed for the base case as well as introducing pumped storage plant in generation expansion.

Under Base Case the pumped storage plant of the capacity 25 MW has been Found most suitable in case of complete utilization of the total generation or the utilization just required by the utility from pumped storage plants. From the avoided cost per kW point of view also 25 MW pumped storage plant is found to be attractive. Whereas, the pumped storage plants of the capacities 75 MW, 50 MW and 100 MW have been found suitable in order of preference. The maximum amount that NEA can pay for 25 MW pumped storage plant is 1649.64 S/kW. For pumped .storage plant to be commercially viable, the capacity cost should not be more than 1649.64 $/kW. Similarly, if NEA purchases all the generated energy from the nun-utility sources then it can pay 12.41 cents/kWh.

Under Thermal Case the pumped storage plants of the capacity 10 MW has been found most suitable in case of complete utilization of the total generation or the utilization Just required by the utility from pumped storage plants- Whereas- the plants of the capacities 25 MW, 50 MW, 75 MW and 100 MW have been found suitable in order of preference from the avoided cost per kWh point of view. On avoided cost per kW basis plants of all other capacities except 10 MW cannot be attractive because of low avoided cost per kW in the Nepalese context. The maximum amount that NEA can pay for 10 MW pumped storage plant

under Thermal Case is 1175.10 $/kW. As thermal plant is used as the peaking plant, the avoided cost per kW under Thermal Case is lower than under Base Case. Similarly, if NEA utilizes all the generated from the pumped storage plant then it can pay 8.S4 cents/kWh.

System load factor has been improved by the use of pumped storage plants in both cases. i.e. under Base Case and under Thermal Case. Weighted average LOLP is decreased for 10 MW pumped storage plant under Base Case indicating improve in generation reliability. All other pumped storage plants would increase the weighted average LOLP which indicate that the generation reliability decreases by introducing the pumped storage plant under Base Case. While pumped storage plant under Thermal Case the weighted average LOLP increases-which indicate that the generation reliability is decreases after introducing pumped storage plant.

Thesis Title: **VOLTAGE PROFILE AND STABILITY ASSESSMENT OF INPS**

Submitted By: **Munindra Thakur**

Supervisor: **Prof. Dr. Indraman Tamrakar**

ABSTRACT

Some networks of Integrated Nepal Power System (INPS) are being operated under highly stressed conditions. So, the voltage profile of some buses of INPS are very poor which has resulted in increased real and reactive power losses in the transmission networks, thereby further increasing the reactive power demand in the system. Hence, the system is facing the problem of maintaining the required bus voltages. There are so many system outage events in INPS which can clearly indicate that the system has become more prone to outage and since no any study has been carried out yet to address such events, it is imperative to assess the voltage profile and stability of INPS.

In this thesis, voltage profile of INPS is evaluated at peak load condition by performing load flow analysis and a simplified method is used to assess the voltage stability of INPS and to determine the appropriate size and locations of the shunt VAR compensators to be installed throughout the system to enhance the voltage profile and stability. The load flow analysis of INPS is carried out by using ERACS software. The output data from

the load flow analysis are used to calculate the line flow indices (LFI) of all the lines of the system to identify the weakest bus of the system from voltage stability point of view. The appropriate size of the VAR compensators to be placed at the critical bus is calculated from the result of load flow solution with the critical bus as P-V bus with P-0 MW and V=T pu.

The study shows that the system outage problem is not due to voltage instability. The system is stable from voltage stability point of view. But, the voltage profile of the existing system is very poor. Blaju-611, Bharatpur-112, and Amlekhgunj-604 are identified as the most critical buses in the system whose bus voltages are 0.835 pu, 0.894 pu and 0.783 pu respectively. The amount of shunt VAR compensation required to boost the bus voltages of these buses to 1 pu are found to be 95.333 MVAR at Balaju-611, 58.108 MVAR at Bharatpur-112, and 63.528 MVAR at Amlekhgunj-604. After injecting the above mentioned MVAR at the critical buses, the voltage profile of the system is highly improved (i.e. 0.946 pu at Birgunj-609 to 1.035 pu at Mahendranagar-101) and voltage stability margin is also increased to some extent. The transmission losses in the system are reduced to 24.312 MW, which is 4.527 % of total system generation. Whereas, the transmission loss was 28.989 MW (i.e. 5.221 %) before compensation.

Graduation Year 2008

Thesis Title: **ANALYSIS OF DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION**

Submitted By: **Nand Kishor Mandal**

Supervisor: **Prof. Dr. Indraman Tamrakar**

ABSTRACT

Several countries around the world are experiencing the energy problems due to booming population, lack of funds to upgrade their electric transmission and distribution grid and urbanization of rural areas. The limitations of the transmission & distribution network to transmit increased power, the environmental concerns, the scarcity of oil reserves and need for huge amount of water are creating a need to push clean technologies for new power generation throughout the world. The traditional approach in electric power generation is to have bulk power plants transporting electricity through an extensive transmission and distribution networks. The newer power generation technology called Distributed Generation (DG) provides electric power at a site closer to the consumers, minimizing the transmission and distribution losses and costs. Since, electricity produced by DGs is directly fed to the distribution network, the need for large transmission infrastructures are minimized. Losses that occur

during electrical power transmission are greatly reduced. More importantly, on-site generation and grid connection allows for the use of new renewable and non- renewable technologies. DG will also lower the emissions of pollutants and minimize the operating costs.

In this thesis, a wind turbine driven Induction Generator (IG) is proposed as DG which can inject variable amount of active power at different wind speed. An IG can not generate reactive power. Rather, it consumes some reactive power to maintain air gap flux and this reactive power has to be supplied by excitation capacitor or grid. The grid authority generally imposes a condition to private DGs that their generator shall generate variable amount of reactive power in a fixed proportion of variable amount of active power generated by DG. Hence, a DG shall have its own reactive power generator to meet the condition imposed by the grid utility. Simulation models of the wind turbine and Static Synchronous Compensator (STATCOM) are developed in this study. Hysteresis band current control principle is utilized in STATCOM to generate variable amount of reactive power to meet the condition imposed by the grid utility. The wind turbine driven IG and STATCOM are connected to the 400 V bus of the distribution network and steady state and dynamic

performance of the distribution system with DG and STATCOM evaluated by simulation study.

The wind turbine generates the mechanical power output of 1 pu (corresponds to full power rating of IG) at a wind velocity of 9.5 m/sec. The proposed controller of wind turbine doesn't change the blade pitch angle (□) of the turbine when the wind speed is varying below 9.5 m/sec and the IG generates the variable amount of active power, men the wind speed is greater than 9.5 m/sec, the controller controls the blade pitch angle (□) to produce a constant mechanical power output of 1 pu.

The simulation result shows that the STATCOM provides the fixed proportion of reactive power (52 % of active power) for the varying active power generated by wind turbine generator continuously. It provides the 48 kVar of reactive power for the active power of 91 kW generated by the wind turbine and 55 kVar for the 107 kW of active power generated by the wind turbine generator and is able to keep the terminal voltage constant at 0.975 pu maintaining constant power factor of 0.8 with the negligible active power loss m the branch of the STATCOM. It draws nearly sinusoidal current with negligible harmonics. It is found that STATCOM provides fast response to settle down the transient in the terminal voltage that appears

while connecting the induction generator to the 400 V bus. The transient in current of induction generator at the switching instant is found to be 8.8 pu which is acceptable for practical purpose. The scheme results constant speed operation at 1.01 p.u. and constant terminal voltage at 0.975 pu.

Thesis Title: **RELIABILITY ASSESSMENT OF MARSYANGDI HYDRO POWER STATION USING FAULT TREE ANALYSIS**

Submitted by: **Bhrigu Raj Bhattarai**

Supervisor: **Dr. Laxmi Bhakta Shilpakar**

ABSTRACT

Run-off-river (ROR) type hydropower plants in Nepal have significant role in fulfilling the electricity demand in the country. Out of 617.478 MW installed capacity, in Integrated Nepal Power System (INPS), 76.17% is shared by ROR type hydro-electric plants. The failure of any ROR type hydropower station causes adverse effects on economy of society and nation as well. Equipment failure in a hydropower station may cause generation failure, lead to unplanned supply outages and hence financial loss to the country. Reliable operation of ROR type hydropower station becomes more important when there is a shortage of supply of electrical energy in comparison to demand. Among ROR type plants, Marsyangdi hydropower station (MHPS) is the second largest hydropower station and shares 11.17% of the total installed capacity of INPS. Most of the power generated from MHPS is transmitted to Katmandu (KTM) valley. KTM valley's ring main distribution system is dependent on the power supply

of MHPS (69MW), Kulekhani (92MW) and Sunkoshi (10.05MW), etc. So, MHPS plays an important role to supply power in KTM valley. Even though, the consumers in KTM valley expect electricity supply to be available continuously, the INPS fails to supply as per the consumers' desire. This is because of the fact that the INPS doesn't get the expected amount of electricity from MHPS, Kulekhani and Sunkoshi, etc for the desired duration of time. Therefore, estimation of overall reliability of MHPS helps for operation, control, maintenance and replacement of components in MHPS for reliable power supply to KTM valley.

Efforts should be made to provide standby units, wherever possible, and to execute scheduled repairs/replacement of components so that outages are minimal. Reliability of a hydropower stations basically depends on the availability of individual generating units and water availability for the operation. Availability of turbine- generating units depends on the availability of different components. Time taken to repair the different equipment is a major parameter in reliability evaluation .Mean time to repair (MTTR), mean time between failures (MTBF), mean time to failure (MTTF), failure rate and probability of failure occurrence can be estimated based on the number of occurrence of failures and total repair time. Data base

generated on the basis of operational history of different components is required for reliability assessment of hydropower plant. It contains various observed causes that lead to the outage of generating units.

As this study involves a case study of ROR type "Marsyngdi Hydropower Station (MHPS), a reliability database has been generated for it. The database has been further used to calculate different reliability indices of basic events.

Hydropower stations are complex systems containing larger numbers of components and no doubt, numerical value of failure probability of any hydropower station will be much less in comparison to the numerical value of success probability. Therefore, assessing of failure in a hydropower stations from success point of view is more complex than assessing the system from its failure point of view. In this regard, Fault Tree Analysis (FTA) seems to be a more useful method for failure assessment of a hydropower station.

The fundamental concept of FTA is the translation of the failure behavior of a physical system into logic diagram. The diagram portrays root causes of fault paths. The logic segment of the model provides a mechanism for qualitative and quantitative

evaluation. There are mainly four steps in FTA viz. system definition, fault tree construction, qualitative analysis and quantitative analysis. Though there are many Computer software developed to carry out FTA, CARA Fault Tree (1999) Version 4.1 has been used in this study.

The probability of failure of Turbine- generating unit calculated (TOP event) from quantitative analysis of FTA gives the electro-mechanical unreliability of each unit on the basis of database generated from the past history. Then the overall reliability of MHPS has been evaluated based on the data base. The partial generation of each unit is not caused due to the partial failure of equipment but due to water unavailability and demand variations. The reliability for generating 23MW, 46MW and 69 MW of MHPS are 99.75%, 94.94% and 64.14% respectively. From qualitative analysis, it has been found that the major contributors to Ml IPS unreliability are failure of excitation system, governing system, and cooling water system. Sedimentation of silt is major contributor to water unavailability. Sensitivity analysis is carried out in order to evaluate the effect of the major contributors on power plant reliability. Sensitivity analysis result shows that the preventive and corrective maintenance of major outage components such as excitation, governor, water cooling system and silt removal improves the reliability of MHPS. For

sensitivity analysis the maximum repair time 641.13 hrs and 15.78 hrs for flushing the settling basin/reservoir and excitation are considered as 100%.The sensitivity analysis result shows that the availability of the each unit can be increased by reducing the repair time(MTTR) of these components

Thesis Title: **REDUCTION OF GREEN HOUSE GASES DUO TO HYDRO POWER DEVELOPMENT IN NEPAL**

Submitted by: **Jang Bahadur Chand**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Nepal has been considering hydro-only development policy in generation expansion planning and the other alternative generation technologies are totally ignored. Whether this policy is rational from economic point of view or not is the matter of discussion. Further, hydropower being clean source of energy, GHG mitigation potential has not been estimated. In this thesis an attempt has been made to determine the least cost generation plan for Nepal and to quantify the amount of emissions of green house gases (GHGs) reduced if any due to hydropower development in Nepal.

In the present work, two types of generation expansion planning; the traditional planning with hydropower projects only as the candidate and the alternative generation expansion planning with hydro power projects and thermal power plants as new candidates have been simulated in WASP-1V respectively and the quantity of emissions of GHGs has been calculated.

The results of present work showed that the least cost generation expansion plan was the one which included both hydro and thermal power projects which was found 405.8 MUS$ cheaper than the generation plan with hydropower only that Nepal has been undertaking. If Nepal adopts the least cost strategies it will emit 1912 thousand tons of CO_2 during planning horizon. By adopting hydropower only development policy, it is contributing to reduce 1703 thousand tons of CO_2. The results also showed that Nepal has been undertaking expensive way of reducing emission of CO_2 as the incremental CO_2 abatement cost was found to be US$ 238 per ton of CO_2 while the international carbon market currently pays around US$10-12 per ton of CO_2.

Further, the study showed that Nepal could claim 17.7 MUSS as the benefit of carbon credit due to its hydropower development policy and ignoring the rational least cost generation plan. But neither the least cost strategy is being followed nor it has obtained any such benefit of carbon credit.

Thesis Title: **ANALYSIS OF SUB SYNCHRONOUS RESONANCE DUE TO SERIES COMPENSATION IN INPS**

Submitted by: **Om Prasad Dahal**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

The limiting factors for transmission capability of a line are thermal limit, voltage limit and stability limit. The thermal limit of a transmission line is completely independent of transmission line length where as voltage limit depends upon the reactive power to be transmitted as well as on the line length. In INPS system, the transmission lines could not be loaded up to their thermal loading limit, the system collapses even when the loading of the line significantly below the thermal limit. The length of transmission line in INPS can be considered long with respect to the system voltage, so stability limit plays important role in INPS system. In general, the transient stability limit has not been focused in transmission line design of INPS therefore in this thesis, stability analysis regarding to steady state and transient state is carried out.

In INPS the generating stations are situated mainly in western region and major demand besides Kathmandu valley is in eastern

region with maximum transmission voltage of only 132 kV. The major generating stations Kaligandaki 144 MW, Marsyangdi 69 MW, upcoming Middle Marsyangdi 70 MW are located further behind Bharatpur. As Kulekhani-I and Kulekhani-II are peaking type, so power has to be transmitted from Bharatpur towards eastern side. So, transmission corridor from Bharatpur to Duhabi has been focused. The length of this corridor is 442 km, with total demand of 273 MW, so at present this corridor is really sensitive from the transient stability point of view.

The main problem of Bharatpur - Duhabi transmission corridor is its power evacuation. The steady state analysis of present system shows that maximum 71 MW and 48 MW load demand at Duhabi can be fulfilled with or without Khimti- Dhalkebar line respectively. In maximum loading case, the voltage at Duhabi decreases to 98 kV and power angle with respect to Kaligandaki comes in the range of 40 degree which is severe in stability point of view. INPS system collapses, when transient condition occurs due to three phase short circuit fault at Marsyangdi or KL -1 bus during maximum loading.

The transient stability limit of the system increases with series compensation. So, series compensation was used in this corridor. The location and maximum level of series compensation was identified by observing the result of steady state analysis. Since

voltage and power angle at Duhabi bus is in critical condition, to improve the power angle series compensation should be used at Lahan-Duhabi section. Maximum compensation of 0.18 p.u. (28 % of Bharatpur- Duhabi corridor) is achieved at Lahan - Duhabi link.

As the voltage and power angle further behind Lahan are in normal range and less sensitive to the load demand at Duhabi, so series compensation is only suitable at this link. The voltage then increases to 121 kV with Khimti - Dhalkebar line and 109 kV without Khimti - Dhalkebar line. Similarly power angle decreased to 25 and 35 degree respectively. The above facts indicate that improvement of transient stability and the result was verified by rotor angle swing curve.

The main disadvantage of series compensation, sub synchronous Resonance, has also been analyzed. Frequency scanning, EMTP analysis and Eigen value analysis are the different methods for analyzing SSR. Here Eigen value analysis is used. On performing the Eigen value analysis, on fixed capacitor compensation, SSR problem was observed. Different techniques HVDC Back to Back system, VSC, SSSC and TCSC can be used to mitigate the SSR problem. Here combination of TCSC and Fixed Capacitor is used. Out of 28% maximum compensation, 10% is accomplished by TCSC and 18 % by fixed capacitor.

Thesis Title: **FAST REPETITIVE POWER FLOW METHOD TO EVALUATE AVAILABLE TRANSFER CAPABILITY**

Submitted by: **Suman Thapa**

Supervisor: **Prof. Dr. Indra Man Tamrakar, Mr. Mahendra A.C.**

ABSTRACT

Many countries have implemented deregulation of their electricity industry in order to bring competition; increase efficiency and costumer focus there by opening the power market to private sector and open access to electrical networks. This has caused the need for adequate computation of the power transfer capabilities that are available in the existing networks above the already committed ones. Computation of the available transfer capability (ATC) is a complex and a major task of a system operator. Out of the methods that are commonly used, modifications are sought that are simple to understand, easy to implement, faster in calculations and yet giving fair results.

A fast repetitive power flow (RPF) method based on the principle of linear extrapolation of simple load flow results has been proposed in this study in order to calculate the ATC of transmission network. The proposed method is tested on

transmission network of Nepalese power system. The performances regarding the accuracy and number of iterations in power flow have been studied relative to the conventional RPF method. In order to improve the ATC of the network in the assumed transfer directions, the location and capacity of shunt reactive compensation have been determined. MATLAB programming has been used to implement the methods while MATPOWER has been used to carry the AC load flow.

The study reveals that the proposed method is fairly accurate and very efficient than a conventional RPF method as it reduces the number of load flows required. From the evaluation results, it is evident that after additional shunt reactive compensation of 25.2 MVAr at bus no. 117 (Anarmani) and 28.31 MVAr at bus no 609 (Birgunj) ATC of transaction T-l, T-2, T-3, T-4**,** T-5, T-6 are 21.57 MW, 25.44 MW, 12.26 MW, 34.86 MW, 13.40 MW and 15.57 MW respectively. The ATC of these transactions are finally limited by the line thermal limits of the line between bus nos. 112 Hetauda and 113 Bharatpur.

Thesis Title: **REINFORCEMENT OF POWER DISTRIBUTION SYSTEM BY OPTIMAL ALLOCATION OF SWITCHES FOR LOSS REDUCTION**

Submitted by: **Shreeram Raj Pandey**

Supervisor: **Er. Dinesh Ghimire**

ABSTRACT

It is becoming more and more important for power distribution companies to meet efficiently the demands of their customers. One of their goals is to find an operating state for a large, three-phase, unbalanced distribution network which minimizes the cost for the power company supplying the power, while satisfying the requirements of the customer. This thesis has proposed a systematic methodology to derive the optimal switching and allocation of new switches to reduce the system loss for the long term operation of the distribution system. The objective of this thesis is to reinforce the power distribution system network by using optimal allocation of switches for loss reduction.

In Nepal, all the switches are manually operated. The operation of switches with the change of load in the feeder is not possible for time to time. Generally the sectionalizing and tie switches are used for maintenance purpose only. Some feeders are loaded

heavily during peak-time period and lead to serious loss problem due to larger line current flow, while some feeders are loaded lightly during the same time period. The optimal allocation of switches makes it possible to redistribute almost balanced load to all the feeders and hence minimize the total system losses. A practical distribution network of Thimi Distribution Centre (TDC), NEA is selected for the application of proposed methodology to reduce energy loss by optimally locating and operating the sectionalizing and tie switches.

The study has shown that the distribution loss of TDC has reduced to 1.1% from 1.79%. The amount of annual net benefit is Rs 683650.48 for the first year and from the second year it will be increased. Though the benefit is marginal, it has been achieved just by relocating some of the existing switches and installing some new switches. In addition to it, the long term benefit has been achieved.

The cost benefit result from the shifting of switches and allocating the new switches in the existing distribution of the Thimi distribution is calculated. It is concluded that significant energy loss reduction can be easily obtained by routinely reconfigurating the distribution system through optimal location of switches.

Thesis Title: **APPLICATION OF ARTIFICIAL NEURAL NETWORK IN OPTIMAL POWER FLOW**

Submitted by: **Suresh Gautam**

Supervisor: **Dr. A.K.Mishra**

ABSTRACT

Power System in general refers to a complex network of generating units, transmission/distribution system and loads/consumers. Optimal Power Flow is an optimization tool which has been widely used in planning and real-time operation of power systems for active and reactive power dispatch to minimize generation costs and system losses.

A lot of researches have been carried out in the field of Optimal Power Flow and different techniques for solving OPF problem have been developed and implemented. The introduction of new objectives and constraints, together with the concern for fast algorithms for online application, forced the researchers to seek for new techniques efficient and robust enough to solve the problem. Different methods have been utilized for the purpose. Researchers are being done with positive results in the possibility of application of Artificial Intelligence (Al) based techniques. Artificial Neural Network (ANN) is an Al based technique which

has potential to be used for the purpose of solving the OPF problem.

This thesis demonstrates new approach for real time assessment and solution of OPF problem using the black box model. The OPF problem is a highly nonlinear and complex optimization problem involving both equality and inequality constraints. ANN is a black box model capable of modeling highly nonlinear and complex problems and has a capability of extremely fast computation speed. Thus the application of ANN has gained more importance in the area of power system engineering. Various applications based on ANN have been reported in the area of power system. Load forecasting, voltage stability management, reactive power control, operational planning and state estimation are some of the examples.

This thesis proposes an efficient algorithm based on ANN for the solution of OPF problem. A multilayer feed forward ANN architecture with back propagation training algorithm is used. The training data are obtained by solving the OFF problem by Newton's method using Matpower Version 3.0.

Thesis Title: **REACTIVE POWER PRICING IN NEPALESE POWER SYSTEM**

Submitted by: **Achyut Babu Ghimire**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Reactive power pricing has always been essential for reliable and efficient system operation whether power market is regulated or deregulated. Since, the Nepalese power market is on the way of restructuring, the issue of reactive power pricing in Nepalese system is emerging. The aim of reactive power pricing is to encourage reactive power generation in the system providing the incentives for reactive sources according to their contribution to the system. The study proposes a capacity based reactive power pricing structure of reactive sources according to their contribution on voltage support and loss reduction contribution. Voltage sensitivity method has been used to evaluate the reactive sources and Reactive Power Value (RPV) of reactive sources considering the shunt capacitors and without shunt capacitor in the system has been analyzed.

The result showed that reactive power value of sources considering the shunt capacitors in the system is as follows: Kulekhani-II has highest value of 7584.43 $/MVAr/yr. This

means the contribution of reactive power generated by Kulekhani-II power station is highest and compared with this, in the second rank is Kulekhani-I (2908.08 $/MVAr/yr), in the third rank is Marsyangdi (1353.77 $/MVAr/yr), in the fourth rank is capacitor of Duhabi (1029.88 $/MVAr/yr), in the fifth rank is capacitor of Birgunj (576.05 $/MVAr/yr), in the sixth rank is Kaligandaki-A (565.77 $/MVAr/yr) and Bhotekoshi power station (502.78 $/MVAr/yr) in the seventh rank.

Similarly, reactive power value of sources without considering the shunt capacitors in the system is as follows: Kulekhani-II has highest value of 12029.27 $MVAr/yr. In the second rank is Kulekhani-I (3360.04 $/MVAr/yr), in the third rank is Marsyangdi (1607.72 $/MVAr/yr), in the fourth rank is Kaligandaki-A (777.03 $/MVAr/yr) and Bhotekoshi power station (562.43 $/MVAr/yr) in the fifth rank.

This shows that RPV of generators without shunt capacitors in the system is higher than RPV of generators with shunt capacitors in the system which is obvious due to the importance of the reactive power from generators in the absence of compensation.

Thesis Title: **NODAL PRICING OF DISTRIBUTION SYSTEM**

Submitted by: **Binod Kumar Yadav**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Normally the price of electricity at the area substation is fixed based on the generation and transmission cost and that at the customer level is by adding the average distribution loss cost. Under deregulated environment, economic efficiency is concerned with sending price signals to users of the network with respect to the costs the users impose on network operation.

The contributions to the distribution loss of different customers are not the same. Hence, the distribution companies (DISCOs) may set the different electricity price for different customers based on their contribution to the system loss. That is at a particular instant of *time, a DISCO wants to find,* -What is the relative contribution to the system loss by different consumers?"

An alternative scenario may be even in deregulated environment, Government regulated body may fix the consumer level price-. Under this condition, suppose there are many distribution feeders emanating from the same area substation. It is well known that

percentage losses for high density area are much lower than that of the area having low load density. In this situation, a utility requires fixing different pricing at the area substation for different DISCOs based on the consumer's they serve. *"What should be this criterion?"* This thesis has basically attempted answers for these two research questions.

The thesis has presented a Distribution Nodal pricing scheme for the consumer and Distribution companies. Nodal prices are continuously adjusted over time and are set for delivered energy, including both the price of energy and the loss component of cost. A novel formulation, for the nodal factor in a radial distribution system has been derived. The accuracy of the proposed formula has been verified from the load flow result using .windmill. The proposed approach has the advantage of computational burden and time. In the conventional approach, the minimum numbers of load flow required at any operating condition are number for nodes in the feeder plus one. Whereas in proposed approach just one load flow is sufficient. Reducing the computational burden by many times, making suitable for online application.

Various factors affecting the nodal factor and hence the nodal pricing has been analyzed. A deterministic criterion for the

electricity price for the consumer served by different distribution transformer based on their location with respect to the substation has been presented. Nodal pricing in a distribution system is observed significant in following cases:

- At or near peak loading condition
- Low load density area. It Is not significant in area with high commercial and industrial activity
- In, feeder with small size conductors

The application of nodal pricing criterion presented in the thesis may be applied for following applications even in monopoly market.

- Demand side management
- Optimal DG location
- Feeder extension planning

Thesis Title: **ANALYSIS OF RELIABILITY INDICES FOR DISTRIBUTION SYSTEM OF KATHMANDU VALLEY**

Submitted by: **Juju Ratna Shakya**

Supervisor: **Dr. Laxmi Bhakta Silpakar**

ABSTRACT

The distribution network of Nepal Electricity Authority (NEA) is operated and controlled by Distribution and Consumer Services, through the network of distribution profit center and branch offices around the country. These centers have been operating under performance evaluation systems which consist of a clause to reward or punish the centers based on their performance. The performance indicators, developed to assess their performance, are based on financial, inventory control and energy loss reduction but not on the reliability of services.

In the era of electric utility deregulation, reliability of service to the customer has become an important subject to the electric utility systems. The regulatory trend is moving to performance-based rates where performance is penalized or rewarded based on reliability indices and NEA should be no exception in this regard. It is well known that competition stimulates economic efficiency and this leads to increased benefit to the society. In order to

highlight significance of a minimization of system outage frequency and duration, an additional set of indices such as system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI) etc can be used to evaluate the overall behavior of the distribution system.

In this Thesis work, the author's effort is to find the reliability performance indicators of the distribution feeders supplying the consumer load points in Kathmandu Valley. Various improvement options are analyzed to acquire better value of reliability indices. The results of reliability performance indices are presented for a base case and three improvement options.

The study shows that the tripping frequency and duration, therefore reliability indices, are high for the distribution network of Kathmandu valley as compared to utilities in other developing countries. The SAIFI index of Kathmandu Valley, calculated as 111.81 interruption/year is found higher than SAIFI index of India 0.05 - 40[20], Hyderabad 45.06 [21], Malaysia (TNB) 1.3 and Malaysia (SESB) 18.77 [22], SAIDI index (43.75hrs) of Kathmandu Valley when compared with India 1.3m - 28Hour [20], Hyderabad 17.55 hrs [21], Malaysia (TNB) 2.15hrs, Malaysia (SESB) 29.65 hrs [22] for year 2004 is in higher side. Similarly, when CAIDI index (0.48hrs) of Kathmandu Valley is

compared with Hyderabad 0.39hrs [21], Malaysia (TNB) 1.65hrs, Malaysia (SESB) 1.68 hrs [22], it is better as compared to TNB and SESB. Compared to developed country like Canada, [the reference figure for 2001] the SAIFI is 0.9 and SAIDI is 1.5 hrs. The distribution system of NEA which is constructed without appropriate planning, without proper sectionalization and high rate of system outage may have contributed to the high value for the reliability indices.

When the indices were compared for the networks within Kathmandu Valley, the SAIFI & SAIDI index for Bhaktapur district (144.05, 54.48hr) is found higher than that of Kathmandu (105.79, 43.44) and Lalitpur District (130.44, 52,00hr). The reason for high index value for Bhaktapur can be attributed to the rural nature of the distribution lines which are long in length, improper maintenance practice with avoidable shutdown.

The CAIDI index is higher in case of Kathmandu District (0.43 for FY 2061/062) as compared to Bhaktapur (0.39hr) and Lalitpur (0.41hr). The increase in the value of CAIDI can be attributed to the higher repair time due to inaccessible narrow roads, traffic etc which are common in the urban areas under the Kathmandu district. The Reliability Indices for Urban and rural feeders are also calculated. The study observes that the rural

feeders have high failure rate and duration than as compared to urban feeder.

In order to improve the reliability indices, four reliability improvement options are analyzed. The result shows that the reliability performance indices are improved as compared to base case values for each of the reliability improvement options. Due to increased reliability, the utility, customers and the society will acquire more benefit. The revenue gained due to avoided energy loss is the benefit to the utility. Similarly, the benefit to the customers is due to the reduction in monetary loss incurred due to the power interruptions and inconvenience.

- It is found that the among the options evaluated, OPTION III which deals with hotline maintenance, is the best option from technical as well as economic aspects of reliability evaluation with maximum avoided ENS of NRs. 17,574,207 and improvement in SAIFI and SAIDI are 96.07 and 27.71 respectively. However OPTION I, use of auto-reclosure at originating point, is found best from the investment point of view but needs to sacrifice the SAIDI value.

Thesis Title: **CONTINGENCY ANALYSIS: A CASE STUDY OF INTEGRATED NEPAL POWER SYSTEM**

Submitted by: **Prabal Adhikari**

Supervisor: **Dr. Dinesh Kumar Ghimire**

ABSTRACT

Contingency analysis is an important component of the security function, which is considered to be an integral part of the modern energy management system at energy control centers. In this thesis, the contingency analysis of the Nepalese power system as a case study has been performed from line loadability as well as voltage security point of view.

DC load flow method has been used as a research tool for the analysis since it has a number of advantages such as the capability of very fast computation and high accuracy in overload checking during contingency analysis as compared to other methods. It is therefore quite relevant to review the existing transmission system of Nepal from the overload-checking point of view in the present context by performing contingency analysis on it using DC load flow method. In this thesis, a DC load flow program has been self-developed by the author for

contingency analysis including ranking based on line security performance index in all single line or single plant outage cases.

The analysis also includes full AC load flow results for contingency screening purposes. It has been facilitated by the use of Power System Simulator for Engineering (PSS/E) program available at the System Planning Department of Nepal Electricity Authority.

The other problems, besides the overload of transmission lines that arise in contingency cases are the voltage problems. In this thesis, post-contingency voltages at different buses have been computed by simulations in the PSS/E program. The convergence of the solution was achieved by keeping shunt compensations at four locations, Duhabi, Lahan, Birgunj and Balaju at free mode and at other five locations, Kohalpur, Dhalkebar, Anarmani, Siuchatar-2 and Patan at fixed mode with' shunt compensations of 10,7.5,15,10.20 and 10.20 MVAR respectively. The post-contingency voltages are used to compute voltage security Performance Index (PI_V). The ranking list of the contingencies is finally prepared, which is different from the ranking list obtained from the line loadability point of view since the contingencies that cause line flow problems may not necessarily cause bus voltage problems and vice versa.

The system analyzed within the scope of the thesis consists of power stations at Kaligandaki, Kulekhani, Marshyangdi, Bhotekoshi, Khimti, Trishuli, etc. The power generated from these stations is evacuated to load centers by 66 kV and 132 kV transmission lines, whereas the sub-transmission as well as 11 kV and low voltage lines are not considered here. Also, generation plants below 5 MW are ignored and, all together, there are 75 transmission lines and 53 buses in the system for the analysis. Out of these transmission lines, only 59 lines are tested since the remaining 16 lines, if outaged either lose the link with the slack bus or give rise to multiple contingencies, which is beyond the scope of this thesis work.

Since each contingency is assigned a degree of severity using performance index (PI) algorithm, the system planners and operators can use the results for enhancing the power system performance by implementing various feasible control strategies to prevent the system or a part of it from undergoing the potential damage which could be imposed on it in case of contingency occurrence. The critical contingencies, though quite large in number in Nepalese power system, have been picked out by NR load flow method and many useful conclusions have been derived through the graphical representations and discussions on them.

When the PSS/E software was run for contingency screening, starting from the contingency with the lowest PI value, 66 KV Kushaha-Duhabi transmission line at contingency number 17 was identified as the one with its cut-off value of PI at 0.294661.

All the contingencies above the cut-off value have been identified as critical contingencies in the context of Nepal, which is passing through many system constraints including generation shortage, mal-operated status of transmission lines, etc.

The DC load flow result shows that there are all together 58 critical contingencies (17 generation plants and 41 transmission lines) out of 76 ones tested in the Nepalese power system, suggesting that power system planners should immediately expedite the process of installing new generation plants to bring them into the system as early as possible to remove its 'inevitable' present state of load shedding and start implementing proper control strategies.

Two separate ranking lists are found as the result of DC load flow analysis and the post- contingency voltage security analysis. The lists reveal that the contingencies which are more severe ones as observed in DC load flow analysis don't posses the same status while ranking them on the basis of voltage security

performance indices. For example, the first list comprises KL1 Power plant, Hetauda Diesel and 66 KV Hetauda Cement-Amlekh transmission line as the top three severe-most contingencies, while the latter one ranks 66 KV Chabel-Bhaktapur transmission line, Sunkoshi Power House and Marsyangdi Power House in the respective placements.

- Further, the study has revealed that the Nepalese power system has been undergoing a keen shortage of reactive power sources, too, thereby putting a strong threat to its voltage security. Duhabi Multifuel Plant's role has been observed as a highly crucial one for the reasons not only generating the real power in the present context of generation shortage, but also fulfilling the reactive power demand of the system to a large extent.

Thesis Title: **IMPLICATION OF DISTURBED GENERATION IN INTEGRATED NEPAL POWER SUPPLY**

Submitted by: **Prem Bhakta Devkota**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Nepalese power system is characterized with high losses in the system because the generation plants are located far from the load centers and load/consumer density is low. The system has poor load factor which is around 52% in average that means only 52% of time the plants are in operation on their rated capacity. The capital cost of hydro power plants is relatively high and the system planning is reciprocating to the peak demand of the system.

Distributed Generation (DG) is emerging technology which has given interest under competitive electrical markets. Small sizes DG with good efficiency are budding nowadays. So, DG technologies are also considered in generation expansion planning. The DG technologies IC Engines, Gas Turbines and Micro Turbines have low capital cost but the operating cost is very high because of expensive fuel. Similarly, Fuel Cells and Photo Voltaic technologies have high capital cost and relatively

low O & M cost. Besides those five DGs, two types of micro hydro plants having 40 kW and 70 kW are also considered as DG. This study analyzes the implementation of DG in INPS.

Mixed Integer Programming (MIP) approach is used for generation investment plan with and without DG. General Algebraic Modeling System (GAMS) is used to solve these MIP problems.

The results show that all DG technologies are found cost effective except Photo Voltaic (PV) technology. PV technology seems cost ineffective even the system loss increases to 30%.

From the introduction of DG, the average incremental cost (AIC) reduces from NRsl.82 /kWh to NRsl.61/kWh with capacity and generation mix around 16.4% and 4.0% respectively. Generation expansion planning with DG reduces the total capacity of hydro to be added in planning horizon from 1773.38 MW to 1232.91 MW. The DG technology to be added in the study period is 381 MW. The result shows that the *capacity addition avoided in the study period is 159 MW, Up to 60% increase in fuel* cost on its prevailing economic price, the capacity and generation mix in the system are 12% and 3.1% respectively.

Thesis Title: **VOLTAGE STABILITY AND CONTINGENCY ANALYSIS USING FAST VOLTAGE STABILITY INDEX: A CASE STUDY OF INTERGRATED NEPAL POWER SYSTEM**

Submitted by: **Sanjay Kumar Lal**

Supervisor: **Dr. Laxmi Bhakta Silpakar**

ABSTRACT

The increasing energy demands on power systems coupled with a low rate of additional capacity installation are causing the power systems to be operated close to their security limits. Traditionally, these limits are associated with the problems of thermal loading and transient stability. Thermal limits have become less restrictive. Fast fault clearing, high performance excitation systems, and other controls have raised the transfer limits in stability limited systems. Voltage instability has become the limiting constraint for many power systems. It can be ascribed to the lack of reactive power support needed to maintain the voltage profile at a specified value. Unpredicted events known as contingency have been found as the main reason to lead the system to voltage instability.

Much attention has been given to the study of voltage stability and contingency analysis and the development of analytical tools to be used for voltage stability assessment. There is variety of analytical methods in literature for analysis of voltage instability. Among the many methods, performance index to determine voltage stability condition and contingency ranking are widely used in literature. Musirin and T K Abdul Rahaman [14] has developed a new index called Fast Voltage stability index (FVSI) which is used for the voltage stability analysis and contingency ranking.

FVSI is defined by,

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X}$$

Where,

Z= Line impedance

X= Line reactance

Q_j = reactive power at the receiving end

V_i = Sending end voltage

It is evident that FVSI is a simple mathematical relation which depends on bus voltage, line reactive power flow and line parameters. Increase in line reactive power flow and or decrease

in the bus voltage will increase the value of FVSI of the line. Thus the change in line flows or change in bus voltages is reflected in the change of the value of FVSI. The value of FVSI of lines in a power system indicates the voltage stability condition of the system. For a system to be voltage stable the FVSI for all lines in the system must be less than one. If the FVSI of any line is greater than one then it implies that the voltage of the buses at the extremities of the line has some imaginary value which indicates voltage instability. FVSI is also used to identify the weak bus, critical line and ranking of contingencies.

Due to the lack of construction of new generation plants and transmission lines to match the growing power demands INPS is operating under highly stressed condition. The heavy loading of the transmission line has resulted low voltage problems in the industrial corridor namely Birgunj and Duhabi. In addition to this, the bottleneckness of the transmission corridor makes INPS vulnerable to the voltage instability and line outage contingencies. So it is imperative to assess the voltage stability condition of INPS and to identify the critical contingencies.

In this study, FVSI has been used to study the voltage stability condition and single line outage contingency of Integrated Nepal Power System (INPS).

The objectives of this study are:

- To assess the voltage stability condition of INPS.
- To evaluate the loadability of the buses in the INPS from voltage stability point of view.
- To identify the critical lines in the INPS from voltage stability point of view.
- To rank the single line outage contingency in INPS.

The study has been done based on the data for the FY starting from 2007/8 to 2011/12. Voltage instability prediction is important in power system planning and operations so that the occurrence of voltage collapse could be avoided. To predict the voltage stability condition of INPS using FVSI, initially a load flow program is run to obtain the power flow solution of the INPS. The results from the load flow computations are used to calculate FVSI value for each line in the system. If the FVSI values of all lines are less than 1.00 then it indicates that the INPS is voltage stable and if the FVSI values of one or many lines exceed the value 1.00 then it indicates that INPS is voltage unstable. The results show that INPS is voltage stable in FY starting from 2007 to 2011/12 as value of FVSI of all lines is

obtained less than unity. Line connecting bus no. 602 & 610 and 112 & 113 are found as the critical lines as their FVSI value were found to be high due to the high reactive power flow in these lines.

Different Buses in a power system has different capacity of loading. Some buses in the system may be overloaded while some may be in under loaded condition. As overloading of any bus could disrupt the stability of whole system, it becomes important that maximum permissible load of different buses be identified. Identification of loadability of all buses INPS will help to determine the weakest and strongest bus in the system. Bus 116 i.e. Duhabi, 115 i.e. Lahan, 112 i.e. Bharatpur and 108 i.e. Butwal are found to be stronger buses in INPS.

Contingency ranking is very important for the power system security so that proper control action can be planned when critical contingencies occurs. The single line outage contingency is conducted by removing the lines in the system in sequence. Load flow computation is run with one line outage at a time and with results of load flow FVSI index of all lines are evaluated and sorted in descending order. The highest FVSI index for every line outage is then sorted. The line outage which produced the highest FVSI index is termed as the most severe outage. The

outage of line between Bhaktapur and Banepa is seen to lead INPS into voltage instability m the -year 2009/10 and outage of Vine connecting Shivpur and Butwal can cause voltage instability in INPS in the year 2011/12.

Graduation Year 2009

Thesis Title: **RELIABILITY EVALUATION OF RADIAL DISTRIBUTION FEEDER CONSIDERING DG IMPACT**

Submitted by: **Hari Prasad Poudel**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

It is important to plan and maintain reliable power systems because cost of interruptions and power outages can have severe economic impact on the utility and its customers. The goal of a distribution system is to supply electricity to its customers in an economical and reliable manner. This study proposes a method for evaluating the reliability of radial distribution feeder when DGs are connected in the feeder. Distributed generations cover saving world fuel, saving transmission and distribution cost. Output power of DG depends on the amount of available resources at each moment. Therefore, the power produced by distributed generation may experience more fluctuations. Because of the uncertainty of DG's output power, a 3-state model of DG is used for the analysis. The three state models of DG are available state, derated stated and down state. The modeling of DG is done using frequency and duration technique. Connection

of DG on the feeder can supply the power in the feeder when utility power is disrupted by making island.

Instead of traditional analytical methods this thesis work uses a Sequential Monte Carlo Simulation (MCS). The Monte Carlo method is a stochastic simulation of the operation of a network. The failure and repair histories of components of Koteshwor distribution feeder are simulated using random variables with probability distributions of the component states, which mimic the random behavior of the system operation such as component failures, unavailability etc. The main objective of the Monte Carlo Simulation is to generate the expected or average value of failure rate and unavailability of different sections, load points and distribution system reliability indices.

The outage data of Koteshwor distribution feeder from the fiscal year 2060/2061 to 2064/2065 are used for analysis. The Koteshwor feeder consists of fifteen load points and fifteen feeder sections. The location and sizes of distributed generations are chosen arbitrarily. Four numbers of DG are connected in different section of feeder. The reliability of the test feeder employing Monte Carlo Simulation is evaluated with and without distributed generation. Monte Carlo Simulation is run for 20000 numbers of trials for finding the reliability parameters

with and without DG. The reliability parameters of the feeder SAIFI, CAIFI, SAIDI, CAIDI, ASAI, ASUI, ENS, AENS and ACC1 without DG are found 206.698117, 410.64026, 312.584437, 621.001082, 0.964317, 0.035683, 846856.4255, 284.180009 and 564.570950 respectively. The reliability of the feeder is then evaluated for seven different cases with DG varying location of the DG on the feeder. It was observed that an improvement of reliability parameters with DG interconnection depends on the locations and number of DG in the feeder. Degree of reliability improvement increases by placing the DG in feeder section having higher load demand and more number of consumers. All these parameters are calculated for seven different cases after connection of DG. In every case, reliability parameters have improved by comparing without connection of DGs.

Thesis Title: **OPTIMAL PLACEMENT OF FACTS CONTROLLER FOR CONGESTION MANAGEMENT**

Submitted by: **Anant Upreti**

Supervisor: **Prof. Dr. Indra man Tamrakar, Mr. Mahendra A.C**

ABSTRACT

The limitations of a power transmission network arising from environmental, right-of-way and cost problems are fundamental to both bundled and unbundled power systems. Patterns of generation that results in heavy flows tend to incur greater losses, and to threaten stability and security, ultimately make certain generation patterns economically undesirable. Congestion occurs when one or more of network limits is reached. Limits are simple line capacity limits and other is more subtle system constraints arising from voltage or stability limits. FACTS (Flexible AC Transmission Systems) controllers are increasingly being used in power system networks for improving the system security and power transfer capability without expanding the transmission network. . Electrical networks, throughout the world, are undergone major restructuring and introducing competition at different levels. In this new environment, all parties can have open access to participate in the market activities. Since it offers

a competitive market, all trading parties will have tendency to purchase power at the lower cost. If these transactions are not controlled properly, transmission congestion takes place due to the unplanned power exchanges between two areas.

This thesis presents a method by which an optimal location of FACTS devices can be determined. Here, three kinds of FACTS devices namely; Thyristor controlled series capacitor (TCSC),Thyristor controlled phase angle regulator (TCPAR) and Unified power flow controller (UPFC) have been considered. A sensitivity indices method is applied for optimal location of the FACTS devices which after all alleviates the congestion. Two approaches; line loss sensitivity indices and total system loss sensitivity indices are used for optimal location of FACTS controller. In order to calculate these indices value, load flow is run using power system tool box version-2 (pstv) and the results of the load flow are called into the subroutine coded in Matlab-7. The test has been carried out on IEEE 5- bus system and 9-bus system. In this thesis only static modeling of the FACTS controllers are considered.

Thesis Title: **IMPROVEMENT OF VOLTAGE STABILITY MARGINS IN INTEGRATED NEPAL POWER SYSTEM USING REAL POWER SCHEDULING**

Submitted by: **Amod Kumar Yadav**

Supervisor: **Mr. Mahendra A.C**

ABSTRACT

In the present day power system planning and operation, considerable interest is being shown in the system security and stability analysis. Pattern of load sharing/ generation scheduling that results in heavy flows tend to incur greater losses, threaten stability margin, security and ultimately making certain generation patterns undesirable. Generation schedules mainly based on economic criteria may lead to lower reserve margins and therefore diminished reliability is a serious concern of the power system. With increased loading of the existing power transmission systems, the problem of voltage stability and voltage collapse has also become a major concern in power system planning and operation. As it is well known that voltage stability is more dependent on the reactive power sources and voltage profile in the system, the voltage stability is also a function of real power flows in the system.

This thesis has introduced the use of existing generating stations based on existing network configuration called "Relative Proportion of Generation (RPG)". This research relates the network sensitivity between the load voltages and source voltages to compute the voltage stability index. The load is shared based on the Relative Proportion of Generation. The voltage stability margin as well as system profiles of the power system improve when the load is shared based on RPG. The voltage stability indices of each load bus are used as the basis for evaluating the most suitable real- power generation scheduling. The voltage stability index is the function of elements of F_{lg} matrix which are derived from the transmission network parameters and complex voltages of load and generator buses.

It has been observed that this method of load sharing/ generation scheduling improves the voltage stability margin as well as system profiles of INPS. The power system is stable from angular point of view as the separation between the internal angles of the generators is low when the load is shared with the Relative Proportion of Generation. The voltage of the load buses improves and the real power loss of the network is low when the load sharing is with RPG. This approach is very useful for the contingency case also. The voltage of the Dhuabi bus has improved to 0.85 pu from0.82 pu and the voltage stability index

of that bus has decreased to 0.1999 from 0.4127 when the load is shared with based on RPG. The internal angles between the generators have decreased making the system stable from angular point of view as shown in figure 5.2. The voltage stability index of Birgunj bus has improved to 0.1484 from 0.3771. The real power loss is reduced to26.50 MW from 27.05 MW. When the Bharatpur-Hetauda line is made outage, the real power loss is 21.32 MW. The loss decreases to 20.20 MW when the load has shared according to RPG. The voltage stability index of Dhuabi bus jumps to 0.5637. But when the load is shared with RPG, the voltage stability index improves to 0.2562 and voltage to 0.80 pu from 0.77 pu and maximum bus angle is decreased from -32.20 to -23.87 degree giving reduction of bus angle by 8.33 degree. The power limits of KL-I and KL-II have gone beyond its MW limit when the Bharatpur-Hetauda line is made outage.

Thesis Title: **OPTIMAL LOCATION AND SIZING OF DISTRIBUTED GENERATION**

Submitted by: **Dipesh Lamsal**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Traditionally, due to "economy of scale" the power generating stations were often large and their capacities are in the range of 150-1000MW. Clearly, such big power stations require large facilities, including land and personnel needed to operate, and high capital cost. Moreover, since these big power stations cannot be constructed closer to load center for some obvious reasons, necessities for long Extra High Voltage (EHV) or Ultra High Voltage (UHV) transmission lines, including transmissions substations. Similar to power stations, these transmission lines and substations need an ample amount of money in design, construction, operation and maintenance.

In general the , the term " distributed generation" includes all use of small electric power generation whether placed on the utility system or at an isolated location , which is not yet connected to the central grid . On the other hand "dispersed generation" is basically, a subset of distributed generation that is located at customer facilities or off the utility system. Usually, the

generation facilities in a very small range, 10 to 250 KW are classified as dispersed generation.

DG affects the flow of power and voltage conditions on the system equipment. These impacts may manifest themselves either positively or negatively depending on the distribution system operating conditions and the DG characteristics. Positive impacts include improved power quality; loss reduction; transmission and distribution capacity release, improved utility system reliability. On account of achieving above benefit, the DG must be of the proper size and at proper locations.

Various methods have been proposed for optimal sitting and sizing of DGs in a distribution networks. The methods differ basically based on objective functions, assumptions and methodology or approach employed to solve the optimization problems. The heuristics approaches [3, 4, 9, 10] uses more realistic conditions however their slower convergence feet is well known ,whereas many of the analytical approaches [2,11] can give only a theoretical concept as the assumptions made to simplify the formulation makes it far from realistic. This thesis proposes a new analytical approach which is much simpler and faster in convergence in comparison and. problem formulation is more realistic in comparison to analytical approaches. The

proposed method employs objective function to maximize the overall saving considering saving in energy loss, feeder peak loading reduction and generator cost into account. The proposed method can be employed for varying load power factor as well as it can be employed for any number of DG along the feeder. Hence, the method indirectly also can be used to search for the optimum number of DG in a particular distribution feeder.

In this thesis work, the overall problem is subdivided into following.

I. Optimal Sizing sub problem

This sub-problem finds the best size of the DG for a set of their known location to maximize the peak power loss reduction. A special formulation based on B-coefficient network loss evaluation method has been developed for the purpose.

II. Optimal location sub- problem

In this sub-problem relocation and sizing of one by one DG is done assuming the rest of DGs are optimally located and sized. This reduces the number of trial significantly. Sub- problem I and II are repeated in successive iterations to achieve the best locations and sizes for their combination. Finally, the best number of DG is finalized for which overall objective function is maximum. Whatever the technological choice of DG is made, it

does not affect the possible number of DG to be placed in the feeder rather the saving due to DG placement for each technology may change.

The proposed algorithm is tested and verified for various distribution feeders. Based on the study, it can be concluded that size and location is guided by the feeder loading and placement of DG is more suitable for large network making saving significant. Not only iMs change in power factor does not guide the size and location but the amount of loss reduction is more.

Thesis Title: **VOLTAGE STABILITY ASSESSMENT OF INPS RADIAL DISTRIBUTION NETWORKS**

Submitted By: **Jagdish Chandra Joshi**

Supervisor: **Prof. Dr. Indraman Tamrakar**

ABSTRACT

Voltage stability of a power system is ability of system to maintain steady acceptable voltages at all the buses of the network at normal operating conditions and after subjected to a disturbance for a given initial operating conditions. It can appear as a major problem for the system which are heavily loaded and further loading will lead fast decrease in voltage. The conditions of voltage stability in distribution system generally evaluated by determining the voltage stability index at each node, identifying the weakest node of the system and by finding the maximum loading capacity beyond which voltage instability takes place.

The objective of this thesis is to make an assessment of voltage stability of INSP primary radial distribution networks by evaluating the voltage stability index at each buses of the system. For the purpose, different 11 kV and 33 kV primary distribution feeders are modeled using SimPowerSystem tool box ot Matlab-Simulink simulation toll and load flow is performed. The

simulation midels of line, transformer and load are available in the Matlab-Simulink library. However, the simulink model for composite load with different composition of constant power and consent impedance load models are not available in Matlab-Simulink library. Composite load model is developed in this study to represent more practical load connected to the distribution system.

The result obtained for voltage stability index showed that all the buses of the selected 11 kV primary distribution system are stable and secure for voltage instability. However, the distribution feeder mostly feeding indeustrial type loads have minimum value of voltage stability index. Hence, the buses of this feeder are more sensitive to voltage stability than the other feeder considered.

In the similar manner, one 33 kV distribution feeder (33 kV Rampur Feeder) from Galyang 53/33 kV substation is also taken for study and analyzed in the same way. Due to the higher voltage level, short length of line and light line loading (as this feeder supplies mostly the domestic loads in Syangja and Palpa district), the result obtained are slightly higher than 11 kV feeder, Also, all the buses of this feeder are four, stable on the basis of the voltage stability index.

This Thesis proposed a model based approaching to address the voltage stability issues and with comparing similar literature the results obtained are accurate. However, more detailed and exact load measurement and load modeling is necessary for more accurate results from the real system.

Thesis Title: **OPTIMAL LOCATION OF SVC BY USING PARTICLE SWARM OPTIMIZATION**

Submitted By: **Shambhu Kusiyait Yadav**

Supervisor: **Dr. A.K. Mishra**

ABSTRACT

Restructuring of electricity supply industry introduced competition and established markets wherever possible. In a competitive electricity market, better utilization of existing power system network to maximize the profit is a major concern. The installation of FACTs devices at optimal position with optimal rating may be one of the best options for better utilization of the existing power system. The power system objective function related with the rating and location of devices is highly non-linear, non-differentiable, non-continuous function and also has large number of possible combinations. It is difficult to handle optimization problems having such type of objective functions by the conventional optimization methods, since these methods may either fail to obtain feasible solution or get trapped on local optima.

This thesis has introduced the use of recently (1995) developed Particle Swarm Optimization (PSO), a population-based, inspired

by the social behavior and random search directed algorithm to find the optimal location and rating of SVC simultaneously considering the generation cost function minimization, SVC investment cost function minimization, system real power loss function minimization, buses voltage constraint function maximization and optimization of their proper combinations. PSO has the excellent ability to easily handle nonlinear, non-differentiable, discrete as well continuous objective functions.

It has been observed that PSO easily handles discrete (position) and continuous (rating) variables simultaneously and provides superiority among other heuristic methods. The simulation results have also conformed fast convergence of PSO in reaching optimal value for all the considered objective functions and proved its robustness.

PSO to solve optimal location and optimal rating for above mentioned power system objective functions are used for the first time in this study. The merit, demerit and similarity between considered objective functions and their combinations have been analyzed and also identified the best combination with their best weightage factor in the combinations. The generation cost objective function is indirectly but exactly same as the real power loss minimization function.

The combination of SVC investment cost function with other functions is superior than the any single objective function from economic point of view. For example, optimization of generation cost function along with the SVC investment cost function gives superior and unique result than the objective function considered generation cost function alone. Consideration of SVC investment cost function has automatically optimized the number of SVC to be required. Similarly, optimization of combined functions of generation cost, SVC investment cost and bus voltage within pre-defined limits function with proper weightage factor has good ability to keep the buses voltage economically within pre-defined limit and exhibits its superiority among all other combinations.

Thesis Title: **ELECTRICAL ENERGY AUDIT AND LOAD MANAGEMENT FOR DOMESTIC CONSUMERS OF NEA**

Submitted By: **Tek Nath Tiwari**

Supervisor: **Dr. A.K. Mishra**

ABSTRACT

This study has analyzed the current use of electrical energy by domestic consumers connected to INSP. By shifting the load from peak time period to off-peak period, the load factor of the system can be increased. Here, the types or list of equipments which will be operated in different time of the day are considered from the consumers' point of view. The management process can be implied from utility's side as generation management transmission management and distribution management and from consumers' side as' demand s.de management; here the bad management is proposed from consumers' side.

From the energy consumption pattern survey, it is revealed that 39.60 % of total numbers of domestic consumers are rural domestic consumers with 11.69 % of total energy consumed by the domestic consumers whereas 60.40 % of total numbers of domestic consumers are urban domestic consumers with 88.11 % of total energy consumed by domestic consumers. Also, 47.61 %

of total consumers are taking 12.26 % of total energy consumed by the domestic consumers with average monthly energy consumption less than 22 units, the minimum energy waived for domestic consumers by NEA. Only 3.88% of total consumers are consuming energy more than 250 units per month and they are consuming 25.54% of the total energy consumed by domestic consumers.

The survey has revealed that the rural consumers are having incandescent bulb till today also. There are various types of load connected to the system and it is somehow difficult to get the exact contribution of all types of equipment without detail load survey of all diversified domestic consumers. The load survey has revealed that from fighting load only, we can reduce around 32.59 MW from peak in which the contribution from rural domestic consumers will be of around 3.68 MW whereas that of urban domestic consumers will be of around 28.91 MW. In this case, it is assumed that the consumers with average energy consumption more than 50 units per month have to participate in load management.

In per unit, the load of domestic consumers a, all time of day is not less than 0.1663 of peak load 72,.73 MW which means the minimum load is 120.01 MW and also the maximum load is

291.36 MW. Due to lack of sound data that could not be verified and is quite low figure compared to the load obtained by the projection from the sample survey or the consumers.

Also, the per unit data of the sample data has resulted the load factors of industrial consumers, commercial consumers and non-commercial consumers as 56.29%, 56.65% and 39.65% with peak of each category as 187.46 MW, 32.56 MW and 31.79 MW respectively. The deduced load curve has given load factor of the domestic consumers as 22.44% and the peak load has resulted of 490.89 MW. Actually the peak load is of one hour duration from calculation. If maximum load of obtained from per unit value is taken in consideration then this peak can be assumed prevailing for 1.68 hours, which seems appreciable. For exact figures, this analysis should be done by taking the reference of more number of sample data of industrial consumers, commercial consumers and noncommercial consumers.

From, Kathmandu Mid DCS and Kathmandu East DCS in summer, 20% load shift and CFL replacement will result 5.21% reduction in peak demand from 47.56 MW whereas 50% load shift and CFL replacement will result 28.95% reduction in peak. The contribution of lighting, kitchen appliances, recreation, water pumps, computer in peak are 33.19%, 28.00%, 9.48%,

22.22% and 7.11% can be manage with the reduction in peak to 33.79 MW having contribution 32.69%, 21.64%,20.02%, 15.64% and 10.01% respectively.

Also in winter, 20% load shift and CFL replacement will result 20.37% reduction in peak demand from 59.49 MW whereas 50% load shift and CFL replacement will result 38.58% reduction in peak. The contribution of lighting, kitchen appliances, recreation, heating or cooling, water pumps, computer in peak are 26.53%, 21.60%, 11.37%, 17.05%, 17.76% and 5.68% can be manage with the reduction in peak to 36.54 MW having contribution 30.24%, 18.28%, 18.51%, 13.88%, 14.46% and 9.87% respectively. So, it is strongly recommended to the utility to do necessary actions motivating the consumers to change their demand shifting the load to off peak period from peak and also consumers' awareness program is necessary.

Thus, the survey has revealed that the domestic consumers have more or less same type of needs based on the energy consumption range. The loading time is also same too some extent. So, number of sample should be increased from all geographically diversified districts where the consumers have similar socio-economic status. Then exact figures can be

achieved and that can be done by the utility having approach to all the consumers.

Graduation Year 2010

Thesis Title: **REALLOCATION OF SECTIONALIZER SWITCHES OF RADIAL DISTRIBUTION FEEDERS TO MINIMIZE CUSTOMER INTERRUPTION COST**

Submitted by: **Lunar Shrestha**

Supervisor: **Dr. Rabin Shrestha, Dr. Arbind Kumar Mishra**

ABSTRACT

It has been reported that 80% of the customer service interruptions are due to failures in the distribution network. Predicting distribution system reliability performance is normally concerned with the electric supply adequacy at the customer load point. Deregulation of electric power industry has motivated electricity customers to pay more attention in evaluating both the direct cost of electric service and the monetary value of reliable electric service. This has been recognized by the utilities and the value-based aspects are introduced into the planning and design of power systems to consider the outage costs. The relocation of sectionalizers makes it possible to minimize the interruption cost. In context of Nepal, all the switches are manually operated. The operation of switches with the change of load in the feeder is not

possible for time to time. The case study of NEA radial distribution network of Thimi Substation considered here for the proposed methodology application. This thesis has proposed a systematic heuristic methodology to relocate the existing sectionalizer switches of radial distribution feeders to minimize the customer interruption cost and improvement of reliability without investment of any cost.

This study has shown that the customer interruption cost of radial feeders Sallaghari, Thimi and Balkumari of Thimi substation has reduced with the movement of sectionalizer switches. For Sallaghari feeder in case study 1,2,3 CIC has reduced with 7.66% , in case study 4,5,6 CIC has reduced with 4.55%, in case study 7,8,9 CIC has reduced with 17.22%. For Thimi feeder in case study 1,2,3 CIC has reduced with 11.58% , in case study 4,5,6 CIC has reduced with 11.56%, in case study 7,8,9 CIC has reduced with 11.80%. For Balkumari feeder in case study 1,2,3 CIC has reduced with 22.12%, in case study 4,5,6 CIC has reduced with 19.59%, in case study 7,8,9 CIC has reduced with 33.28%.

The CIC reduction resulting from the movement of the sectionalizers of feeders of Thimi Substation is calculated and it is concluded that significant CIC can be easily reduced through the relocation of sectionalizers.

Thesis Title: **DETERMINATION OF VOIDED COST OF NON-UTILITY GENERATION FOR NEPAL ELECTRICITY AUTHORITY**

Submitted by: **Khagendra Prasad Awasthi**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Non utility generation is major force in the way electricity is now being produced and marketed and electric utility are reacting to the growth of this new industry. When a utility buys electric energy from a non utility generation one of the difficult issues encountered by the utility is the evaluation of the rate (buyback rate) it should pay the non utility generation such that the utility maximizes to its economic benefit. Utility calculates this purchase rates based on a number of different formulae. Long term buyback rates should be based on the capital and operating cost that a utility avoids by utilizing energy from non-utility generation. This cost is termed as avoided cost in this thesis.

The study focus specifically on the economic assessment of the incorporation of non-utility generation in the long term planning of the power system at generation level. The least cost generation planning and it's ability to supply adequate electrical energy for the system load growth is determined. Study was performed by

taking different cases of hydro only system and hydro thermal system. System Expansion Planning method is used to determine avoided cost of non utility generation. The WASP IV model is used as software tool for least cost generation planning and calculation of avoided cost.

The results show that avoided cost of hydropower is project specific and it is higher in hydrothermal system than the hydro only system. Moreover avoided cost of the hydropower project increases with increase in discount rate. Among the hydropower plants studied Chilime has the highest avoided cost of 6.2 c/kWh and 16.41 c/kWh for 16% discount rate in hydro only and hydrothermal system respectively. In case of thermal power plants 50 MW gas turbine has avoided cost 23.72 c/kWh in dispatchable case, which is the highest for thermal plants considered. The study of import shows that avoided cost is higher for dispatchable condition then the non dispatchable condition and 100 MW import has the highest avoided cost in hydro only system. In case of hydrothermal system 50 MW import has the highest avoided cost.

Thesis Title: **PERFORMANCE EVALUATION OF TRANSMISSION GRID USING DATA ENVELOPMENT ANALYSIS**

Submitted by: **Ram Pramod Shah**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

Performance evaluation of Electricity Grid Substation gives not only their efficiency scores but also identifies the area of inefficiency of the inefficient Grid Substation. It also suggests the solutions for the efficiency improvement of inefficient substation. So, it is very important to assess the performance of grid substation. But due to the complex characteristics of substation it is very difficult to quantify their efficiency scores without rigorous analysis. This study evaluates the performance of grid substation owned by Nepal Electricity Authority (NEA) from fiscal year 2062/063 to fiscal year 2065/066 by using Data Envelopment Analysis (DEA). DEA models are solved through General Algebraic Modeling System (GAMS) Software.

Performance evaluation of grid substation has been carried out through the measurement of technical efficiency, which is an efficiency element that reflects the work and management practices of the various grid substations and scale efficiency,

which is concerned with the optimal size of the grid substation. The overall efficiency of a grid substation is the combination of technical and scale efficiencies .The average technical efficiencies of the grid substation is found to be 66% while scale efficiencies of the grid substation is 69%. These figures suggest that there exist inefficiency in both managerial as well as scale of operation in the grid substation under consideration. Sensitivity analysis shows that around 70% of the grid substation fall in the category of distinctly inefficient grid substation with base technical score less than 90%. Also, the overall efficiencies, technical efficiencies and average overall and technical efficiencies scores are evaluated. There are altogether 10 DMUs that are overall efficient. The maximum and minimum value of overall efficiency score for the grid regions during the period of analysis is 100% and 32% respectively. The technical efficiency score of 16 DMUs have score of 100% during entire period of analysis. The average efficiency score of the grid region is found in the range of 92.33% to 97.33% for the last four years. On the basis of average overall and technical efficiency score during the study period shows that far western grid region has excelled among the grid region with 98.25% score, while Bagmati grid region has excelled among the grid region with 100% score and each ranked 1.

Thesis Title: **OPTIMUM ALLOCATION OF CONTROL DEVICES IN DISTRIBUTION SYSTEM USING ANT COLONY OPTIMIZATION**

Submitted by: **Bishnu Prasad Bhattarai**

Supervisor: **Prof. Dr. Kozuo Ohmi, Dr. Arbind Kumar Mishra**

ABSTRACT

The primary emphasis of power systems has been on providing a reliable and economic supply of electric energy to their customers. Achieving high-distribution reliability levels and concurrently minimizing capital costs are two conflicting objectives and are considered as the main issues in distribution system planning. Traditionally, the acceptable level of distribution system reliability is guided by individual utility practices and experience which led to a number of standard protection engineering practices to ensure adequate service. However with the deregulation and competition in the electricity market, utilities are forced to maintain an acceptable level of service reliability while carefully controlling capital and maintenance expenditures.

Distribution system reliability can be improved either through preventive measures or by appropriate remedial actions in response to a disturbance. Preventive measures include tree trimming on a regular basis, construction design modification, e.g., lightning arresters to prevent flashover, animal guards, and so on. Remedial measures include those provided by protective device response, fault locators and other sensors, and various distribution automation functions. Any attempts to improve the reliability level of the system will incur more expenditure to the utility and hence ultimately to the consumers and staying at the lower level of reliability will result higher cost associated with the outage to the consumer and loss of revenue to the utility.

The number, type and location of the protective devices on a distribution feeder have a direct effect on the reliability of the system. Proper allocation of these devices is considered as one of the effective method of achieving the desired level of reliability. Optimum allocation of protective device and their proper coordination not only improve the reliability of the system but also minimize the total cost on the system which is a function of outage cost to the consumer, revenue loss to the utility, capital cost and repair and maintenance expenditures.

Thesis Title: **OPTIMAL CAPACITOR PLACEMENT IN RADIAL DISTRIBUTION SYSTEM USING FUZZY REASONING APPROACH**

Submitted by: **Niranjan Sah**

Supervisor: **Mr. Dinesh Kumar Ghimire, Mr. Yuba Raj Adhikari**

ABSTRACT

Distribution system provides the final link between the high voltage transmission system and the consumers. The power loss in a distribution system is significantly high because of lower voltage and hence high current, compared to that in a high voltage transmission system. The pressure of improving the overall efficiency of power delivery has forced the power utilities to reduce the loss, especially at the distribution level. There are various methods for loss reduction such as distribution transformer load management. Reconfiguration, reconductoring, shunt capacitor installation etc. Shunt capacitor installation reduces the power losses arising from the flow of reactive power in the system.

Shunt capacitors are connected in parallel with the primary distribution feeders of a system. They supply the out-of-phase

component of the current required by inductive loads. Typically, for distribution loads, the current lags the voltage. Thus, a shunt capacitor draws leading currents that counteracts against the lagging component of the current at the point of its installation. As a result, the power factor of the circuit is improved; a voltage rise occurs at the point of the capacitor installation, and more importantly, the reactive component of the current is reduced to lower the I^2R losses When reactive power is supplied by generation, ratings of generators, transformers, transmission and distribution lines must be increased accordingly. However, when shunt capacitors are installed in a distribution system, the reactive power demand from generation is decreased, thus releasing savings in the capacity for generators, transformers, and distribution lines.

The problem of capacitor allocation in distribution system involves maximizing energy and peak power loss reductions and improving voltage profile by means of capacitor installation. This thesis presents a novel approach using fuzzy reasoning to determine suitable candidate nodes in a distribution system for capacitor placement. In this word fuzzy approach is used to determine suitable locations for capacitor placement. 1 v objectives are considered while designing a fuzzy logic for identifying the optimal capacitor locations. The two objectives

are: (i) to minimize the real power loss and (ii) to improve the voltage profile of the system. Voltages and power loss indices of distribution system nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to determine the capacitor placement suitability of each node in the distribution system. Capacitors can be placed on the nodes with the highest suitability.

For the capacitor placement problem, approximate reasoning is employed in the following manner: when losses and voltage levels of a distribution system are studied, an experienced planning engineer can choose locations for capacitor installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of capacitors. Whereas a low loss section with good voltage is not ideal for capacitor placement. A concern for the development of fuzzy systems is the assignment of appropriate membership functions. Construction of membership functions can be based on human experience, intuition, rank ordering or probabilistic methods. The construction of membership functions for the power loss index and capacitor placement suitability been created based on rank ordering. Especially relevant to this application of capacitor allocation, the interest lies in the ranking of nodes which are

suitable for capacitor installation, and the tuning of membership functions is less significant. After determining the suitable location for capacitor placement, a simple optimization method is used for optimal sizing of the capacitors. In the optimization method, power loss saving is optimized with respect to capacitor currents. This size of the capacitor gives the value of fixed capacitor. The fixed capacitor produces losses instead of reducing losses during off peak period. Therefore, there will be needed switched capacitor during off peak period. In this work, a Fuzzy expert system identifies nodes that are likely require a switched capacitor.

At last, developed algorithm is applied to II KV. 30 node Gothatar feeder of M distribution system.

Thesis Title: **MARGINAL LOSS PRICING FOR TRANSMISSION CONGESTION**

Submitted by: **Surendra Kumar Sah**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

With the increasing trends of restructuring in electricity industry, a competitive market is being created to provide cheap power and offer more choices to the customers. In deregulated electricity market, due to the open access to the transmission system for all GENCOs and DISCOs, possibility of transmission line congestion is high. When transmission congestion begins to take place under heavy demand, congestion creates different zones in the system and it is essential to find out marginal loss cost and actual congestion cost at each node. This study has developed a unique and novel method for calculating the marginal loss price using B-coefficient matrix at each node based on AC OPF during transmission line congestion.

In this study locational marginal price (LMP), which is most economical and logical way to charge electricity usage is determined at each node based on AC OPF and this LMP during transmission congestion is decomposed into three different components namely system energy component or reference bus

energy component, marginal loss component and congestion component. One of the main challenging issues in implementing LMPs and marginal loss pricing methodology is the pricing of marginal loss, which requires analysis of marginal loss and incorporating the effects of marginal losses into the optimal generation scheduling process. Marginal loss price is found by using the concept of delivery factor that is found by using B-coefficient matrix. As reference bus energy component is the price of energy at reference bus, congestion component is found by subtracting the sum of reference bus energy cost and marginal loss cost from the LMP at each node.

This study is tested on INPS for three fiscal years i.e. 2010, 2013 and 2015. From this study, it is found that the 132 kV line between Bharatpur and Hetauda is very sensitive from the congestion point of view upto FY 2012. When 220 kV line from Bharatpur to Hetauda and from Marsyangdi to Matatritha are isolated due to any reason, congestion occurs on 132 kV line between Bharatpur and Hetauda at its designed thermal capacity during summer peak of FY 2013. During transmission congestion, it is found that LMPs are low at zone-1 and high at zone-2 and hence congestion cost is also low at zone-1 and high at zone-2.

It is very interesting that the LMPs found in this study are independent of reference bus. However, the component of LMPs are dependent on the reference bus, difference of loss/congestion component between two bus is not dependent on reference bus which is more meaningful and used for marginal loss/congestion cost of an additional power transaction between these two buses.

Thesis Title: **SIMULATION OF FAULT CURRENT DISTRIBUTION IN GROUNDING GRID BY INFINITE ELEMENT METHOD**

Submitted by: **Suresh Kumar Mahato**

Supervisor: **Prof. Dr. Indra Man Tamrakar, Dr. Arbind Kumar Mishra**

ABSTRACT

In order to provide a way to ground for currents generated by some fault or disturbance, a proper grounding system is needed. Furthermore, the Earth Surface Potential (ESP) due to discharging current into grounding system in case of abnormal conditions has to be known. The main objectives of the grounding system are: i) To guarantee the integrity of the equipments and continuity of the service under the fault conditions (providing means to carry and dissipate electrical currents into ground). ii) To safeguard those people working or walking in the surroundings of the grounded installations are not exposed to dangerous electrical shocks.

To attain these targets, the equivalent electrical grounding resistance (Rg) of the system must be low enough to assure that fault currents dissipate mainly through the grounding grid into the earth, while maximum potential difference between close

points into the earth's surface must be kept under certain tolerances (step, touch, and mesh voltages). A lot of efforts had been taken to answer the very important question, which is, how the Earth Surface Potential due to discharging current into grounding system can be calculated.

Similar type of study has been carried out by different traditional methods like Analysis of Transferred Earth Potential in grounding system by Boundary Element Method (BEM), External Charges Method in grounding grid design, Moment Method in Galerkin's form, Complex image method in numerical simulation of substation grounding grid etc and these are based on circuit theory or combination of electric field and circuit theory. Using these methods we need to calculate the equivalent parameters of the grids such as the grounding grid's self-resistances and grounding grid's mutual- resistances and so on, then calculation of the current distribution in the equivalent circuit. Usually the leakage current of the grids is taken into account equivalent resistances in the middle of the grids. That means in these calculation models the leakage current are supposed to leak only from the middle of the grids. But in reality this leakage current is distributed everywhere around the grids. More or less such equivalence has some approximated factors.

So, traditional methods can't simulate this phenomenon very well.

So there is need to develop a novel method to analyze fault current distribution in grounding grid and Finite Element Method may be one of them. The Finite Element Method can be applied in mechanics, acoustics, thermal fields, electric fields or coupled problems analysis In domains with a complex geometry finite element method (FEM) is one of the most common techniques for spatial discretizations of partial differential equations (PDE). The main idea of the method is to divide the domain into many small subdomains (elements) and define on each element a number of local basis functions. Then the unknown solution of the PDE, which is transformed into a weak formulation, is approximated by linear combinations of the basis functions on all elements. This method, combined with modern mesh generation techniques, allows us to solve partial differential equations on complex domains accurately and use them in mathematical modelling.

This study of fault current distribution in grounding grid is based on electric field theory. The Finite Element Method (FEM) is used for finding approximate solutions of partial differential equations (PDE) as well as of integral equations such as the heat

transport equation and electric field equation. The most attractive feature of the FEM is its ability to handle complex geometries (and boundaries) with relative ease.

The FEM overcomes the disadvantages of the traditional variation methods by providing a systematic procedure for the derivation of the approximation functions over sub regions of the domain.

The Finite Element Method is used to calculate the nodal voltage of each grid and then current distribution in each element can be calculated. By using 1-D model for grounding grid and 3-D model for surrounding soil, the performance of real substation grounding grid can be analyzed. Without the equivalence of the grid's parameters, the accuracy of calculation is improved a lot and the both the current flowing in the grids and leakage current distributed in the soil can be easily obtained. *ANSYS* Software, which is based on FEM, is used as research tool.

The study is carried out for 3MVA,33/11 KV Substation of physical dimension of 39x39 m^2 with fault current equal to 1575 A. These data can be directly used for any realsubstation but the data used in this study are based on substation design [1]. The depth of model equal to 10 m, conductor resistivity equal to 10m,

conductor resistivity equal to 10^{-7} Ω-m, size of grid conductor equal to 100mm^2 ,depth of burial equal to 1 m ,relative permittivity of soil equal to 3 are considered for this study. The study is carried out for different case like increasing and decreasing soil resistivity, increasing and reducing the number of elements in the grid. By selecting LINK68 element for modeling of 1-D grounding grid and SOLID231 element for modeling of 3-D surrounding soil, the performance of real substation grounding grid can be analyzed.

Theoretical Ground potential rise (GPR) of grid with size 39x39 m , no of mesh equal to 13, soil resistivity equal to 177.5Ω-m, conductor resistivity equal to 10^{-7} Ω-m, section area of grid conductor equal to 100 mm ,depth of burial equal to 1.0 m, fault current injected equal to 1575 A, relative permittivity of soil equal to 3, is 3263.4 V and FEM GPR by ANSYS software is 3096.3612 V and the error is 5.118%.

When soil resistivity is increased (=300Ω-m) and all other parameter are constant, theoretical Ground potential rise (GPR) is 5515.6056 V and FEM GPR by *ANSYS* software is obtained as 5302.1937 V i.e. GPR increases and error decreases (=3.86%).

When soil resistivity is decreased (50Ω-m) and all other parameter are constant, theoretical Ground potential rise (GPR) is 919.2676 V and FEM GPR by *ANSYS* software is obtained as 846.6937 V i.e. GPR decreases and error increases (=7.89%).

Thesis Title: **DETERMINATION OF THE SENSITIVITY OF REACTIVE POWER SUPPORT TO SYSTEM SECURITY**

Submitted by: **Deepak Gautam**

Supervisor: **Dr. Rabin Shrestha, Mr. Dinesh Kumar Ghimire**

ABSTRACT

This work presents an assessment of marginal support of reactive power on system security by formulating modified optimum power flow. The System Loading Factor defined as the amount of additional loading of a certain transmission corridor for a specific dispatch model that does not violate thermal, voltage and stability limits ^{k} decreases with the increased transaction whereas it increases with the reactive power support on buses. The system security can be increased safely to certain extent making additional loading feasible with reactive power support. The economic value of reactive power is realized based on sensitivity of reactive power. The sensitivity of reactive power is the marginal support of the reactive power on system additional loading in particular bus.

The model for this work is a single period non-linear optimization problem with maximization of Loading Factor as

the objective function subject to system constraints. The problem is solved applying branch and bound algorithm under GAMS. The model is applied and tested in INPS (FY 2013) during normal operating conditions and contingencies.

The study determines the System Loading Factor to be 0.1280 per unit during normal operative condition with voltage variation limited to ± 10 % and system is found in alert state with respect to system security. Howerver System Loading Factor is found to be 6.28 % with restriction on voltage to vary ± 5 %. The maximum sensitivity value of 0.00585 per MVAR of reactive power demand has been achieved at Birgunj corresponding to the lower limit voltage of 0.95 per unit. The sensitivity values of 0.00445, 0.00382, 0.00318 and 0.00227 have been determined at Parwanipur 66 kV, Simara, Amlekhgunj and Parawanipur 132 kV respectively corresponding to the lower values of voltages. The System Loading Factor has improved from 6.28 % to 20.49% with reactive compensation of 54 MVAR at Birgunj with the decrease in sensitivity of reactive power support.After that Loading Factor began to decrease with further reactive power support. Based on cost of capacity use of transmission system NRs. 1,739,000.00/MW/yr and marginal value of 6.631 MW/MVAR at Birgunj, the

economic value of marginal reactive power support results NRs.l 1,531,309.00/MVAR/yr in the present loading scenario.

The study, however, determines the System Loading Factor of 3.99% during Marsyangdi- Matatirtha 220 kV transmission line identifying the insecure state of system. It has reduced to a value of 3.81%, 5.29%, and 9.41% during Kulekhani-I, Marsyangdi and Kulekhani II contingency, again falling in insecure state. The sensitivity of reactive power at different buses changes with each contingencies and economic value of reactive power changes with sensitivity and additional loading available in the system.

Graduation Year 2011

Thesis Title: **TRANSMISSION EXPANSION PLANNING BASED SURPLUS CAPACITY**

Submitted by: **Abdhesh Kumar Dubey**

Supervisor: **Mr. Dipesh Lamsal**

ABSTRACT

A power transmission expansion planning model with consideration of transmission surplus capacity and network load factor is presented. With traditional planning model, some transmission lines will operate on high load factors due to ignorance of the load 1evels of transmission lines. This may lead to network congestion or degrade the dispatch flexibility of future network.

Traditional planning model has put more emphasis on investment cost rather than other aspects such as operation environment, transmission benefit, etc. The transmission expansion planning model in this paper aims to maximize network transmission surplus capacity and optimize network load factor distribution with least investment.

The Optimal Power Flow (OPF) is a non-linear programming and highly constrained optimization problem. Every OPF has a specific objective function such as transmission line cost, surplus capacity and/or the transmission loss minimization etc. and is responsible for obtaining the optimized value of objective function. The suitable objective function that is used in this thesis is to minimize the new transmission line cost and maximize the surplus capacity and keeping the power outputs of generators, bus voltages and line flow constraints in their secure limits.

Besides the usefulness of cost minimization as objective function, Optimal Power Flow also automatically adjusts all the parameters in their respective limits. The OPF can be solved through numerous classical methods but the use of Artificial intelligence has great significance in reducing the complexity of deriving the solution of OPF. The classical methods are weak in handling qualitative constraints. The major advantage of the GA is that it has high quality of handling various qualitative constraints leading to Local or Global optimal solution.

Genetic Algorithm is a powerful and broadly applicable stochastic search and optimization techniques and perhaps the most widely known types of evolutionary computation method in today's context. GA is more flexible than other type of searching

methods because they require only information concerning to the solution produced by each parameter set (i.e. objective function values) and not like other optimization methods where derivative information, or worse yet, complete knowledge of the problem structure and parameters is required .

This paper describes new objective which aims to maximize network transmission surplus capacity and to set load distribution factor within desired limit with minimizing the investment. Genetic Algorithm (GA) is introduced and used to solve this nonlinear integer planning optimization problem. The GA based OPF is done in MATPOWER and the proposed model and methodology is tested with IEEE-6 Bus and IEEE-9 Bus systems.

Thesis Title: **LOCATING FAULT IN RADIAL DISTRIBUTIONS SYSTEM USING ARTIFICIAL NEURAL NETWORK**

Submitted by: **Prabin Mali**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

The power generated in the generating stations is delivered to the consumers through transmission lines and the distribution lines. These lines experience faults that must be cleared before the lines are returned to service. For the fault clearance, it is necessary to find the fault and location of the fault. Since most of the distribution systems are of radial type, the fault in one of the part in the distribution system makes the consumers supplying through that point out of service making the system less reliable. So the fault should be cleared as soon as possible, for which the exact fault location should be known, otherwise it could take a long time to find the fault location which would make system even less reliable.

The radial distribution system is generally equipped with less number of measuring devices, the limiting case being the measuring devices at the substation only. The proposed method

attempts to locate the fault by taking the measurements at the substation only.

The proposed method uses Artificial Neural Network (ANN) and Support Vector Machines (SVM) to locate the fault. The SVMs are used to classify the fault types and the SSC levels and for the particular fault type and SSC level, the ANN determines the fault location. Due to the variation in SSC level, also under the same SSC level category, the same data has many distances to map. So, the fault distance could not be made target and the impedance is made as the target.

The three layered Feed Forward Neural Network (FFNN) with back propagation learning rule is used as the artificial neural network. The Lavenberg Marquardt (LM) algorithm is used as the training algorithm due to its proven advantages over other conventional methods. The advantages are faster learning, reliable convergence, etc. The LM algorithm is basically a Hessian-based algorithm that allows the network to learn more subtle features of a complicated mapping. The numbers of neurons for the training are selected depending upon the complexity; typically number of neurons used is from 5 to 9 per layer for input and hidden layers and 1 for output layer.

Thesis Title: **ECONOMIC BENEFITS FROM REACTIVE POWER COMPENSATION IN A REAL TIME PRICING REACTIVE POWER MARKET**

Submitted by: **Amit Gopal Vaidya**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

The power utilities have been under great pressure to serve load economically ever since power system deregulation was introduced. However, reactive power, a critical part of power system operation, has not received much attention until recently. Reactive power may be supplied by several different sources, including transmission equipments (such as capacitors, reactors, static VAR compensators and static compensators), generators and synchronous condensers. Reactive power compensation can effectively control the reactive power that flows through the system, improving the performance of the overall ac power system. It is well known that reactive power does not travel very far over long transmission lines and Is difficult to transport due to its many physical requirements. So, local reactive power compensation is considered very efficient.

All the market participants should be compensated for the reactive power that they provide, in order to ensure an adequate, reliable, and efficient supply of reactive power. The real time pricing option for the compensation of generators for providing reactive power is the option, in which the generator is paid in real-time for the reactive power that it actually produces. In real time pricing the generator is paid for the amount of kVARh it has generated.

Several previous works have discussed the cost and the technical benefits of dynamic reactive power compensation. However, the cost of local dynamic Reactive power sources is unfortunately high and there is a lack of a standard method to evaluate the economic benefits. These issues along with an undeveloped reactive power market make it difficult to economically justify the installation of a dynamic reactive power sources. In order to address these issues, this thesis demonstrates a quantitative approach to assess the economic benefits of reactive power compensation in real time pricing reactive power market, which may increase the interest of utilities in local VAR installation and influence their decision-making process. In this assessment, the economic benefits from reactive power compensation are discussed through a quantitative method. The method developed presents a systematic approach to quantify some important

benefits from reactive power compensation in terms of monetary values like benefits from reduced reactive power generation from the generators, reduced transmission line losses, shifting from reactive power flow to real power flow and increased power transfer capability in the transmission line constrained by voltage stability limit.

This thesis assesses the economic benefits from local reactive power compensation in four different categories by formulating Optimal Power Flow (OPF) Model. The OPT will be solved for minimizing the real power generation cost and reactive power generation cost with respect to transmission limits and inter-tie transfer capability limit. The economic benefits will be obtained for all the categories separately. The methodology is tested in the standard 7-Busltest system and 14- Bus test system. The results show that the economic benefits from the reactive power compensation can be significant. Thus it can be suggested that the future reactive power market should consider local Var providers.

Thesis Title: **OPTIMAL LOAD SHEDDING INCORPORATING OUTAGE COST OF CUSTOMERS**

Submitted by: **Deepak Chand**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

In any power system network when there is shortage of energy due to imbalance in demand and generation, it causes fluctuation in security constraints, sometimes up to the worst case of power system collapse. So, in order to avoid this condition and bring the power system in balance, load shedding or load curtailment is essential. The methods of curtailing electric load may be different depending on the operating condition of the system. If load (deficit in generation and demand) from the power system network is curtailed in such a way that effect of load shedding is minimum for customers as well as utility as far as possible, that is known as optimal load shedding. It depends on the importance of customers, utility, law, economics, location of all customers, security parameters, accuracy limit as well as time for load shedding etc.

Normally, load shedding occurs due to power crisis and energy crisis. But in the present scenario of Nepal that is very tragic. In

the context of Nepal, It occurs due to not only one reason but caused to both. In general, load shedding is caused to minimize the cost of load shedding so as to minimize power loss as well as to minimize peak load of the system. In most of the literatures, importance is given to optimal load shedding such as peak load clipping, power loss minimization and system stability in distribution of electrical energy. When amount of load to be shed is significant, it is important to emphasize minimizing outage cost of different customers rather than giving importance to minimization of power loss and minimization of peak load clipping in distribution of electrical energy only.

The optimal load shedding is a nonlinear programming and highly constrained optimization problem. The objective function of the optimal load shedding is minimization of power loss and outage cost of different customers so as to obtain optimized value of new demands of all loads. The load shedding is caused when there is scarcity of power. The new optimized loads can be obtained by different approaches. In this thesis, two different approaches namely classical approach and using genetic algorithm approach have been introduced. In the classical approach, all

loads are categorized in residential, industrial and commercial loads. Sequence of tested in IEEE-14 bus power system network . The theme of this approach can be implemented in higher order IEEE-n bus system. The parameters that are used as control variable are the active power demands of all customers. The result obtained using classical optimization technique gives optimal solution even after taking more time which is tedious to calculate. But these complication are eliminated by GA based optimization technique, the most optimized loads are obtained with optimal power loss and minimum effect of outage value of customers within short period of time , thousands times faster than classical approach.

Thesis Title: **SMALL SIGNAL STABILITY ANALYSIS OF POWER SYSTEM WITH PRNETRATION OF DISTURBED GRNERATION**

Submitted by: **Prakash Poudel**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Deregulation in the power market has encouraged the move towards distributed generation, where many smaller generating plants located close to major loads, as opposed to a few large centrally located power stations, are penetrating into interconnected power systems. If the penetration level of distributed generation continues to grow while grids remain unchanged, a chain of technical conflicts may develop, unless such issues as operation, control, and stability of networks with DG installations are properly addressed.

The behavior of the distributed generator is difficult, depending on DG technologies and penetration levels. When the penetration of DG is high, the generated power of DG units not only alters the power flow in the distribution system, but in the transmission system as well. The connection of distributed generation to the grid may influence the small signal stability of the power system.

Therefore, it can be expected that a need will emerge for an in-depth study of the mutual impact that power systems and DG have on each other. There are several aspects which need to be fully understood in order to obtain maximum benefits from both DG and grid.

In power system mainly two types of DG technologies i.e. asynchronous (Induction) distributed generator and synchronous distributed generator have been used as distributed energy resources. Extensive case study of impact of these DG technologies on small signal stability by taking proper and balanced power system network is very essential. The study is aimed at identifying whether these two types of distributed generator technology affects the small signal stability of power systems in a negative or positive way. Standard IEEE -14 bus test system will be used to investigate the impact on small signal stability due to connection of asynchronous and synchronous DG. Eigevalue analysis will be run on PSAT software to analyze the small signal stability problem.

From the eigevalue analysis, it has been found that the system without distributed generation is small signal stable.lt has been observed that the impact of distributed generation on small signal stability of power system depends both on the penetration level

and the technology of the distributed generators. With the connection of DFIG DG and increasing the penetration of DFIG DG at each load bus individually or at all become aperiodic (non-oscillatory) unstable. It has been found that the eigevalues become more positive for higher penetration.

Similarly with the connection of Synchronous DG with & without Automatic Voltage Regulator (AVR) and increasing the penetration of Synchronous DG at each load bus individually the original system become stable only for large power output of Synchronous DG equipped with automatic voltage regulator. Similarly with the connection of Synchronous DG with & without Automatic Voltage Regulator (AVR) and increasing the penetration of Synchronous DG at all load buses simultaneously the original system become aperiodic (non-oscillatory) unstable but the eigevalue become less positive at higher penetration level which indicate improvement of small signal stability at higher penetration level. It has been noticed that eigevalue is less positive for DG equipped with AVR. Therefore, the Automatic Voltage Regulator (AVR) has positive impact on small signal stability because it helps to increase synchronizing torque which gives more stable system than DG without AVR. Also the power system with the high penetration of Synchronous DG with AVR

at individual bus is found to be more small signal stable than high penetration at all buses simultaneously.

With the equal contribution of power from DFIG DG and Synchronous DG with & without Automatic Voltage Regulator (AVR) at load buses and increasing the penetration of both DGs equally the original system become stable only for large power output of DFIG DG and Synchronous DG equipped with automatic voltage regulator .It has been noticed that mix of two types of DGs technology have positive impact on small signal stability of the power system if DGs are equipped with controller like AVR.

Thesis Title: **HYBRID OPTIMIZATION OF THE ECONOMIC LOAD AND EMISSION DISPATCH BY THE FAST GENETIC ALGORITHM**

Submitted by: **Paritosh Kumar Chaudhary**

Supervisor: **Dr. Nava Raj Karki, Dipesh Lamsal**

ABSTRACT

It is important to plan and schedule the generators based on their cost of operation. Then, it is ensured that system operating constraints should not violated resulting optimal power flow in the system. In an interconnected power system, it is possible to supply a given load demand in many ways, and hence it is natural for the operator to look for the best or optimum operation strategy. Thus optimal generation scheduling in a power system implies the determination of a strategy which would optimize stipulated operating criterion. Because of increased environmental concerns, in addition to Economic Load Dispatch (ELD), Emission Dispatch (ED) also has to be included in deciding the combination of generators to meet the imposed demand. This thesis presents the idea of a new Multi-Objective Fast Genetic Algorithm (FGA) method to solve the Economic Load Dispatch (ELD) and Emission Dispatch (ED) problems. The Combined Economic Emission (CEED) is a bi-objective

optimization problem that considers two objectives such as fuel cost and CO_2 emission. It is converted into a single objective optimization problem using weighted sum method. The EED is a two-objective optimization problem that considers the fuel cost and CO_2 emissions as objectives. The proposed approach is tested in IEEE 30 bus network limiting to steady state prospective only. The simulation results show the great potential for FGA in power system optimization problems. The results demonstrate the capabilities of the proposed approach to generate well-distributed Pareto optimal solutions of the multi-objective problems in a single run. The results demonstrate the superiority of the GA as a promising multi objective evolutionary algorithm to solve different power system multiobjective optimization problems. The problem is handled as a multiobjective optimization problem where both cost and emission are optimized simultaneously with the proposed approach. The proposed optimization method applicable in electric power system is increasing rapidly to meet the energy requirements. A number of power plants are connected in parallel to supply the system load by interconnection of power stations. The development of grid system has made it necessary to operate the plant unit most economically. The economic generation scheduling problem involves online economic dispatch. This problem is of importance for thermal plants as for other types of

generation such as hydro; their operating cost and start up times are negligible so that their on-off status is not important. A simple but suboptimal approach is to impose priority ordering, wherein the most efficient unit is loaded first to be followed by the less efficient units in order as the load increases. The function of the online economic dispatch is to distribute the load among the generating units actually paralleled with the system in such a manner as to minimize the total cost of supplying the minute-to-minute requirements of the system. Thus, economic load-dispatch problem is the solution of a large number of load flow problems and choosing the one, which is optimal in the sense that it needs minimum cost of electric power generation. Accounting for transmission losses results in considerable operating, economy. I n this thesis work, the genetic algorithm with few modifications, though retaining the basic inherent property of GA, is applied in the solution of live problem of optimal generation scheduling in a thermal-dominated power system for fuel cost and emission optimization.

Thesis Title: **RELIABILITY ASSESSMENT OF A MINIGRID**

Submitted by: **Shyam Kumar Yadav**

Supervisor: **Dr. Arbind Kumar Mishra, Mr. Jebachh Mandal**

ABSTRACT

Micro Hydro (MH) has been one of the popular renewable resources for rural electrification in hilly a country like Nepal. Micro hydropower installed in the isolated areas in the rural parts is serving mostly the lighting needs in the vicinity of MHP. Though the connections of multiple end uses seem to be possible and tends to increase the utilization factor, it is impossible to achieve the required target due to some constraints associated with isolated plants. Due to complex series components in the hydro system reliability is found to be very low. So designed capacity can never be achieved through out 24 hour and in 365 days. Due to wear and tear of mechanical parts and ageing of components, failure rate increases gradually and thus reliability is also decreasing over time. At the same time load factor is also low and can't feed bigger load due to inrush current. Also, planner and designer should think of increasing the reliability of the systems as well as the possibility of transferring spare power from one area to another area, where it can have more productive

use and hence can increase the overall utilization of the generated energy. Therefore, concept to formulate a local Minigrid has evolved.

Users expect that the products and systems they purchase should be reliable and safe. A prediction of reliability is an important aspect in the process of selecting equipment for use by utility service providers and other buyers of electricity. Reliability is a measure of the frequency of equipment failures as a function of time. Reliability has a major impact on maintenance and repair costs and on the continuity of service. High reliability level implies high investment and maintenance costs for the network and generation infrastructure. Hence, overall reliability of minigrid needs to be evaluated.

For the first time in Nepal "Uija Upatyaka minigrid in Baglung (UUMB)" has formed a minigrid by connecting seven micro hydro powers (MHP) scattered along around eight kilometers of length. The project is supported by Rural Energy Development Programme (REDP), Nepal and Alternative Energy Promotion center (AEPC), Nepal.

This study proposes a method to evaluate the reliability of Minigrid under planning stage by evaluating reliability of

components of MHP and sequentially synthesizing those components for evaluating reliability of MIIPh and thus that of ft Mineral at last. As real data of outages, operation and maintenance are not known in planning phase, a Sequential Monte Curio Simulation (MC'S) is used. The MCS method is n stochastic simulation of the operation of a network. The failure and repair histories of components are simulated Using random variables, which mimic the random behavior of the system operation such as component failures, availability, unavailability, reliability, etc. The main objective of the Monte Carlo Simulation is to generate the expected or average value of reliability, failure rate and unavailability of different components ofMHP Ac Minigrid.

As failure probability of Micro Hydro components varies over time and failure are due to fatigue of the electromechanical components, Weibull distribution should be suitable. Hence, the failure and repair histories of components of minigrid are simulated using random variables with versatile double parameter Weibull probability distribution. Standard double parameter Weibull distribution function need scalc factor/life data (η) and shape/slope factor (β) of the component. Life data has been taken from Nepal Electricity Authority manuals and different manufacture's brochures. For slope parameter detail

analysis has been done to confirm Weibull slope factor P equals to 1.5 suitably. If β=l, Weibull distribution takes shape of exponential distribution which has property of constant failure rate and if β≥2 takes shape of Normal distributions which has property of constant increasing failure rate. Hence, range of Weibull slope is l<β<2. Actually if p is taken higher, reliability at starting age is higher and decreases faster but failure rate is lower and increases faster and vice versa.

The simulation studies show that the reliability of a MHP depends upon the components used. Short life gives fast decaying reliability value hence few cheaper components like bearing, rubber belts, seal and gasket should be replaced regularly without waiting for their failure. And, inventory should be maintained in proper quantity accordingly.

Assuming Weibull slope parameter p value 1.5 the reliability value of a MHP is around 77% and this is decreasing gradually with ageing. It is observed that overall reliability of the minigrid under consideration for all seven number of MHPs are available in the minigrid; different peak loading 132 kW, 118 kW, 93 kW, 81 kW, 72 kW, 46 kW and 24 kW have reliability 13.43 %, 26.81 %, 64.41%, 81.68%, 87.75%, 98.40% and 99.81% respectively. Result shows that for load at installed capacity of 132 kilowatt is 13.43% only which seems to be lower to

consumer expectations. But as peak load decreases, reliability increases. Hence, according to the acceptance of reliability level system can be loaded.

For system peak load 81 kW, if minigrid capacity is 81 kW then reliability is only 0.3175 or (31.75%), but for same peak load reliability increased to 39.67%, 69.34% and 81.68% for increased minigrid capacity of 93 kW, 118 kW and 132 kW respectively. In other words, for a particular peak load, reliability of the minigrid increases with the increase in minigrid capacity. Hence, desired reliability of Minigrid can be achieved with addition of new MHP. Addition of new MHP adds the cost to the system on per kilowatt basis; hence the incurred cost shall be compensated with the increased system reliability. Based on these assumptions, sensitivity analysis has been also carried out. Sensitivity for different peak loads have been observed by increasing largest size MHP of 26 kW by 14 kW so that raising total capacity of minigrid up to 146 kW, then reliability values of 132 kW, 118 kW, 93 kW, 81 kW and 72 kW are found to be increased by 0%, 11.9%, 10.4%, 4.9% and 3.3% respectively. Similarly, by reducing the smallest size of MHP in the minigrid by 5 kW reducing the total capacity of minigrid to 127 kW, the reliability values of 132 kW, 118 kW, 93 kW, 81 kW and 72 kW loads are decreased by 13.4%, 4.5%, 8.9% and 2.13% respectively.

Thesis Title: **IMPACT OF REACTIVE POWER INJECTION ON WHEELING RATES UNDER MARGINAL COST PRICING**

Submitted by: **Nav Raj Ojha**

Supervisor: **Mr. Dipesh Lamsal**

ABSTRACT

JP Wheeling is the transmission of electrical power from a seller to buyer through a transmission network. The wheeling rate is an area of intense research at present in view of increased deregulation. With the increasing trends of deregulation in electricity industry, a competitive market is being created to provide cheap power and offers more choices to the customers. Any increase or decrease in the pricing of transmission system will increase or decrease the total cost of the electricity to the customers. Many strategies are being used to obtain the optimal transmission pricing.

This thesis uses a wheeling rate based on marginal cost based pricing. Marginal cost is the incremental cost of power (or energy) consumption in optimal operating conditions. The flow of reactive power affects the marginal cost of the system.

This thesis presents an approach for optimization of marginal wheeling rate by injecting the additional reactive power in the system. Shunt capacitors are used to inject the additional reactive power in the system. In this thesis, a method based on marginal cost theory is presented for calculation of the pricing of real power and reactive at each bus in the system. Minimization of the production cost of real and reactive power and minimization of real power loss are used as objective function of the optimal power flow problem. The results obtained from OPF are used to calculate the marginal wheeling rate. Then shunt capacitors are installed to the system. The numbers, sizes and locations of the capacitors placement is decided based on minimization of total annual cost. The total annual cost is the sum of annual wheeling cost, annual cost of real power loss and annual cost of capacitor. The marginal wheeling rate corresponding to minimum total annual cost is the optimal marginal wheeling rate. This optimal solution provides decision support to reactive compensation planning for reduction of marginal wheeling charge. This study is tested on IEEE - 14 bus test system. From this study it is found that the marginal wheeling rate can be reduced by installing the shunt capacitors in the system. The optimal sizes and locations of the capacitors are selected at which total annual cost is minimum. The marginal wheeling rate keeps on decreasing with the increased number of capacitors. The total annual cost also

decreases with the increased number of capacitors up to some value. When the number of capacitors of optimal sizes and locations are increased more than three (3), the total annual cost starts increasing. This gives the conclusion that even though the marginal wheeling rate continuously decreasing with the increased number of capacitor, it is not beneficial to the wheeling utility if the total annual cost increases. This study concludes that &MVAR at bus -14, 20MVAR at bus - 5 and 6MVAR at bus - 13 are the optimal sizes and locations of capacitors and 0.93785$/MWh is the optimal marginal wheeling rate. This marginal wheeling rate is 6.96% less than the original marginal wheeling rate when there is no shunt capacitor is installed

Thesis Title: **OPTIMAL PHASOR MEASUREMENT UNITS (PMUS) PLACEMENT FOR SYSTEM OBSERVABILITY USING NETWORK PARTITIONING THEORY**

Submitted by: **Subarna Sapkota**

Supervisor: **Mr. Nava Raj Karki, Mr. Dipesh Lamsal**

ABSTRACT

Phasor Measurement Units (PMUs) are widely acknowledged as one of the most promising developments in the field of real-time monitoring of power systems. By aligning the time stamps of voltage and current phasor measurements that are consistent with Universal Coordinated Time (UTC), a coherent picture and MRI quality over X-ray quality of traditional SCADA of the power system state can be achieved through either direct measurements or simple linear calculations. With the growing number of PMUs planned for installation in the near future, both utilities and research institutions are looking for the best solutions to the placement of units to avoid huge capital investment due to high cost of PMUs over SCADA system. PMUs are designed to measure real time the positive, negative, and zero sequence phasors of voltages and currents, in addition to the system frequency and the rate of change of frequency, through numerical algorithms implemented in the unit. The

microprocessor determines the positive sequence phasors according to the recursive algorithm because positive phasor is important for system monitoring and control than the corresponding phasor quantities.

In recent years, the placement of phasor measurement units (PMUs) in electric power systems has gained much attention because the conventional SCADA-based state estimators cannot give a real-time picture of the power system due to the technical difficulties in synchronizing measurements from distant locations. The PMUs, when placed at a bus, can offer time-synchronized measurements of the voltage and current phasor at that bus.

This work presents a strategy that is practical and addresses three important issues: network partition, placement algorithm, and installation scheduling for minimum PMUs set for the system observability. Power system observability refers to the fact that measurement sets and their distribution are sufficient for solving the current state of power systems. To be practical, PMUs placement strategy should strive for full observability, work well within the heterogeneous nature of power system topology, and enable system planners to adopt the strategy to meet their unique needs and system configuration. Practical considerations for the

three important placement issues are discussed, and a specific strategy based on these considerations is developed and demonstrated on real power system models.

Two levels approach for solving optimal PMUs placement (OPP) problem in order to achieve complete observability of the power system is presented in this work. The proposed approach utilizes a new and efficient algorithm for partitioning a power system network into two or more sub-networks. The partitioning algorithm, which utilizes the Kruskal spanning tree algorithm of an observable network is based on Markov chains and has a stochastic nature, rather than a heuristic derivation. A spanning tree of a graph is just a sub graph that contains all the vertices and is a tree of the network. It finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized. This algorithm is faster and provides all the possible optimal partitions of a spanning tree. After network partitioning through markov chain algorithm, PMUs are placed optimally in the sub networks in older to minimize their number and consequently their cost. The Binary Integer Linear Programming (BILP) has been formulated based on the adjacency matrix of the spanning tree. A new algorithm has been formulated between one sub spanning trees to other sub spanning tree to relate the effect of calculated placement of

PMUs during the optimization. This method aims at finding the minimal set of PMUs which ensures complete observability of the system network.

PMUs placement algorithms developed for specific applications are no optimal for other applications. Ultimately, only *a* PMUs placement algorithm for full observability of the system would be beneficial to most monitoring and control applications. The performance of the proposed method has been evaluated on IEEE 14 bus, 30 bus and Integrated Nepal Power System (INPS). To summarize on the PMUs, it is reasonable to assume that synchronized phasor measurements will serve the needs of all monitoring and control functions in power system control centers in future. This technology has the potential of becoming a standard form of all power systems measurements and control.

Thesis Title: **ANALYSIS OF MICRO-HYDRO GRID**

Submitted by: **Surraj Bhandari**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Electricity these days has become the basic needs of the human being. In general, electricity generated at power stations, which are located far away from the consumer's premises, brought all the way via transmission and distribution networks. For the country like Nepal where its most of the land is covered with hills and mountains and the population is sparsely distributed the extension of national grid is not financially feasible due to high investment in the transmission line. Generation of electricity from a locally available renewable energy source is the suitable option for electrification .Since the country has profound resources of water ,the generation of electricity from micro-hydro's and interconnecting them to a grid to supply the local electricity demand can be practical and reliable option.

Micro-Grid can be" defined as a low voltage distribution system to which small modular generation systems are connected. In some sense, a micro-grid corresponds to an association of electrical loads and small generation systems through a low voltage distribution network. This means the load and sources

are physically close so that a Micro-Grid can correspond for instance to the network of a small urban area, to an industry and large shopping center. Micro generation systems can include several types of devices as fuel cells, wind turbines, pv systems, micro- hydros etc.

Most of the existing MHP plants have Electronic Load Controller (ELC) for frequency control. ELC is a kind of isochronous governor without droop characteristics. An isochronous governor works satisfactorily when a generator is supplying an isolated load or when only one generator in a multi-generator system is required to respond the change in load [8]. When many numbers of MHP Plants with their ELC are interconnected to form a mini-grid system, their respond to the change in load may not be guaranteed. Their operation may not be satisfactory and the sharing of the load by each generators connected to the grid is not proportional according to their rating. So for the stable and proportional sharing of load; droop characters of each generator are essential.

This study includes only the parallel connection of micro-hydro plants having separate ELC in isolated mode for forming a small gird system. MATLAB Simulink is used as the simulation tool Development of the mathematical models and simulink models

of Electronic Load controller and regulation characteristics of micro-hydro schemes connected in parallel are the main work of this thesis.

The simulation studies show that the responses of the system parameters are within the acceptable range when a single micro-hydro is simulated with an isolated load. It is also observed that as micro-hydro is synchronized with another micro hydro they share the load according to their proportion only if the load connected to them is below both the generators rating. However if the load in the grid is above the generation capacity of any one of the generator the sharing of the load between the generators is not satisfactory. With the incorporation of the speed droop characteristic along with ELC as proposed in this thesis in each of the micro-hydros the load sharing among the generators is found to be satisfactory at all conditions of loading.

Thesis Title: **DEVELOPMENT OF DETAIL SIMULINK MODEL OF SSSC**

Submitted by: **Gaurav Thaiba**

Supervisor: **Prof. Dr. Indraman Tamrakar**

ABSTRACT

Electricity is the most popular and clean form of energy, being utilized in the world today. In general, electricity generated at power stations, which are located far away from the consumer's premises is brought all the way via transmission and distribution networks. In Power systems almost all the power supply systems are widely interconnected. Therefore, it is very essential to maintain their synchronism, power flow stability and reliability. Disturbances like transients, large load change, and faults cause damage and failure of the system. Worldwide growth in the economy raises the socio-industrial structure, causing hefty rise in the need of power consumption. The environmental concerns, scarcity of oil reserves, necessity for huge energy demand are creating to push more on research and development towards clean technologies for new power generation. Traditional approach in generating electricity requires bulk power plants transporting electricity through an extensive transmission and distribution networks. Installing new power plant may not be viable due to various constraints. Therefore, to overcome these

factors, a recent development is in the field of power electronics controllers, Flexible AC Transmission System (FACTS) technology. This technology is a fast acting thryristor based power electronic device. This technology opens up new opportunities for controlling power flow and enhancing the usable capacity of the line.

Among the FACTS devices, Static Synchronous Series Compensator (SSSC) is used as series compensator. In contrast with the traditional method of series compensation, the SSSC is capable of maintaining a constant compensating voltage in the presence of variable line current, or controls the amplitude of the injected compensating voltage independent of the amplitude of the line current.

Experimentation with power system components is expensive and time consuming. Therefore, simulations are a fast and economic method to analyze and select the appropriate parameters of the components, their ratings and pre-establishing their responses before finalizing, fabrication and installation. For the modeling and simulation study, different types of software are available, among those MATLAB® is one of the most powerful, effective, handy and popular simulating tool. Simulink® is a MATLAB environment for multi-domain and

model based simulation designed for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implements, and test a variety of time - varying systems.

This research study focuses on developing a simulation model of SSSC, the FACTS device. This study underlines on the detail modeling of SSSC and its various supportive components, finding out its dynamic responses and performances of transmission line at various conditions. As described by the documentations available in MATLAB Simulink, the phasor model of SSSC as available in library is not a detail model. It does not include the detail modeling of power system devices like Inverter, series transformer and other electronic devices. In addition, the Phasor SSSC model does not consider the harmonic components of the series injected voltage. However, practically the injected voltage contains fundamental as well as other harmonics. Therefore, this research draws more attention about the detail modeling of SSSC with detail modeling of power devices and considering the harmonic contents in injected voltage. The study will further help for in-depth analysis of SSSC, its dynamic behavior in the interconnected system with transmission line at different condition.

In this study, the performance analysis of a transmission line is evaluated for the following three cases:

Case-1: 132kV Transmission line without SSSC.
Case-II : 132kV Transmission line with phasor model of SSSC available in MATLAB-Simulink library.
Case-Ill: 132kV Transmission line with detail model of SSSC developed in this study.

From the observation of simulated results, the receiving end power for the Case-I is Pr =96.6MW, Case-II is Pr =114.4MW, and Case-Ill is Pr =116MW. The observation shows that power flow increases by 18.55% and 20% in cases II and III respectively when compared to case-I. For the comparative study between cases-II and III, the degree of compensation selected is 3.78% i.e; the series injected voltage is 5kV for both the cases. Showing the similar nature of power flow as that of phasor model, the advantages of the developed SSSC model over phasor model are its detail modeling, consideration of harmonic as well as inverter switching losses that gives more accurate results and flexibility in required output ports for the analysis.

Thesis Title: **OPTIMAL REACTIVE POWER DISPATCH BASED ON REAL CODED GENETIC ALGORITHM**

Submitted by: **Kamal Acharya**

Supervisor: **Mr. Dipesh Lamsal**

ABSTRACT

This thesis presents the idea of real coded genetic algorithm (RGA) for active and reactive power optimization. Real coded genetic algorithm is simpler than binary coded GA that minimizes convergence time and gives more accurate result. RGA combines Economic load dispatch (ELD) and optimal reactive power dispatch (ORPD) problem to relate generator fuel cost directly with the location and size of SVC. Instead of usual approaches of solving optimal reactive power dispatch for loss minimization which relates the power loss with fuel cost of generator for cost comparison with the placement of new SVC, optimization using cost minimization is possible directly. In this approach, for every dispatch of reactive power, active power generated by different generator is VE1 changed to share variable loss according to their cost characteristics verifying the fact that higher total loss can result less fuel cost. So the generator having lower fuel cost shares higher proportion of loss resulting better cost comparison than past approaches.

The proposed optimization method is applicable in power system both for reactive power j planning as well as operational prospective. The planning problem is related to investment decision and minimizes the allocation cost of investment of additional reactive power sources placed to compensate higher reactive demand. Operation also has to meet quality and reliability by maintaining bus voltages within limits with minimum fuel cost. The optimization problem is solved in two steps. Firstly, optimization is done ING using total reactive support vector to find optimal size and location of SVC where as in next step optimization solves operational vector for optimal VAR setting of SVC, tap changer and generator output to minimize fuel cost.

The proposed approach is tested in modified IEEE 14 bus network limiting to steady state prospective only. The SVC cost characteristics is taken from Siemens product catalogue. The simulation results show the great potential for RGA in power system optimization problems. Result concludes SVC Compensator to be installed at critical buses and coordinated with other devices like transformer tap for saving in energy and installment cost, avoiding violations of voltage and reactive power limits.

Thesis Title: **OPTIMAL SIZE AND LOCATION OF THERMAL POWER PLANTS IN INPS**

Submitted by: **Satish Chandra Shah**

Supervisor: **Dr. Rabin Shrestha**

ABSTRACT

The study focuses on the optimal size and location of thermal power plant in Integrated Nepal Power System (INPS). The specific objective of the study are screening of thermal power plants, identification of thermal mix in long term generation capacity and to locate tje site for thermal power plants. But the main question is what capacity to install to ensure an appropriate level of reliability? When is the proper time to incorporate them into the system? How to pick the best combination among the different technologies at present or later- on? To answer these entire questions we have to run least cost generation expansion by which system load growth is determined. Study was performed by taking different cases of hydro and thermal system and hydro thermal system. Least cost system expansion planning method is used to determine the optimal sizing of thermal power plant. The WASP IV model is used as software tool for determining the optimal sizing of thermal power plant.

For year 2011-12 existing hydro generation contributes 572.8 MW and the proposed thermal plant 180 MW the remaining load will be supplied by 49 MW existing thermal power plant and 120 MW of purchase from India. The total cost for hydro thermal system for year 2011-12 is 412.103 MUSS. For same fiscal year additional 129 MW hydro power plants is required for hydro-only system. If hydro-thermal combination is installed, then it results in a saving of 272.13 MUSS.

Similarly, for year 2013-14 existing hydro generation contributes 659.8 MW, the proposed hydro plant contributes 129 MW, proposed thermal plant 230 MW, the remaining load will be supplied by 39 MW existing thermal power plant and 120 MW of purchase from India. The total cost for hydro thermal system for year 2013-14 is 674.231 MUSS. For same fiscal year additional 101MW hydro power plant is required for hydro-only system. If hydro-thermal combination installed then 344.538 MUSS saving occurs.

Thesis Title: **SHORT TERM GENERATION SCHEDULING OF HYDRO-DOMINATED POWER SYSTEM USING GENETIC ALGORITHM**

Submitted by: **Pramod Rijal**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

In an interconnected power system, it is possible to supply a given load demand in many ways, and hence it is natural for the operator to look for the best or optimum operation strategy. Thus optimal generation scheduling in a power system implies the determination of a strategy which would optimize stipulated operating criterion. A particular choice of this criterion in power system operation is the cost of generation and the objective is to minimize the same. The optimal generation scheduling of hydrothermal system is different from a purely thermal system in the sense, no fuel cost is associated with hydro stations and the total amount of water that is available for power generation over a specified period is limited. Hence the solution to this problem at any given time consists of determination of a plan for withdrawal of minimum amount of water from hydro reservoirs for power generation.

In this study, the possible sources of power in general are identified. To meet a particular load demand, power allocation among the available power sources is achieved. Then, based on the concept of unit commitment and economic load dispatch, a best combination of available power sources is searched, for an optimum total cost of generation, satisfying several constraints. Moreover, optimization process focuses on the PROR type of plants. So, besides considering all the cost components associated with power generation, the result of optimization also ensures the minimum usage of water.

Economic operation and control of interconnected power systems involves the solution of difficult optimization problems that require good computational tools. Genetic Algorithm is one such tool, based on genetics and evolution theory, that has shown its ability in solving complex optimization problems. In this work, the genetic algorithm with few modifications, though retaining the basic inherent property of GA, is applied in the solution of the problem of optimal generation scheduling in a hydro-dominated power system.

Graduation Year 2012

Thesis Title: **OPERATION AND CONTROL OF DOUBLY-FED INDUCTION GENERATOR IN ISOLATED MODE**

Submitted by: **Amit Kumar Karna**

Supervisor: **Dr. Arbind Kumar Mishra, Dr. Netra Prasad Gyawali**

ABSTRACT

In recent years, interest towards the use of renewable energy sources is increasing due to the associated environmental problems and eventual shortage of fossil fuels. Wind energy has gained the most interest of all the renewable energy sources due to the progress in wind related technology. Modern wind-power systems are designed to achieve maximum efficiency over a wide range of wind speed by incorporating the AC/DC/AC converters with advanced control techniques. These systems have additional benefits of improved power quality, reduced mechanical stress and reduced noise emission. The Doubly Fed Induction Generator (DFIG) based wind turbine with variable-speed variable-pitch control scheme is more efficient and can incorporate independent control of active and reactive power. Hence DFIG is the most popular wind power generator in the

wind power industry. This machine can be operated either in grid connected or standalone mode. The studied system here is a variable speed wind generation system based DFIG.

In remote areas where utility lines are uneconomical to install due to terrain, the right- of-way difficulties or the environmental concerns, stand-alone power system may be a viable solution. DFIG operating in isolated mode may be one of the best solutions for stand-alone system. Hence in this thesis, analysis has been done to investigate the control strategy for DFIG operating in isolated mode. Also, due to the stochastic nature of wind power the energy storage system becomes necessary for isolated mode operation of DFIG. Battery Energy Storage System (BESS) is the oldest and reliable source for energy storage hence used for this study. Almost all energy storage system requires some kind of DC interconnection. In DFIG, the capacitor between the two converters acts as DC bus. Hence, to utilize the structure of DFIG, the BESS has been connected in the DC bus of DFIG. A bidirectional DC-DC converter is used to match the battery voltage to the DC bus voltage and to control charging and discharging of the battery.

In this thesis, a detailed model of a DFIG-based wind turbine system, which is suitable for control system dynamic

performance study, operating in isolated mode, with integrated battery energy storage is developed in the Matlab/Simulink environment and its corresponding control structure is implemented. Stator flux oriented control using PI controller has been used to control the frequency and the voltage of the system. Also, the size of the battery has been determined based on mismatch between the generated power and the load demand considering 24 hour time span. The wind speed data and the load data has been assumed for a particular case. The size of the storage system has been determined for a system consisting of a DFIG of rating 1.5 MW (1 pu) which supplies a load with maximum demand of 1.2 MW (0.8 pu). The power generated by the wind turbine is calculated with the help of the wind speed data and the wind turbine characteristics curve. Three different types of disturbances were created to analyze the dynamic response of the system. First, the system has been analyzed for change in wind speed from 7 m/s to 12 m/s after 5 sec. Second, the system is initially connected with a main load of 0.8 MW and 0.6 MVAR, another auxiliary load of 0.4 MW and 0.3 MVAR has been added to the system after 10 sec to create disturbance. Third, a three phase fault has been simulated in the main load after 15 sec to check the stability of the system. The outputs show that the frequency and voltage of the system is regulated to their nominal values i.e. 50 Hz and 1 pu respectively. Also the

total power generated is equal to the sum of load demand and battery power meaning that the battery is maintaining the mismatch between the generation and demand. Thus, the simulation results verify the effectiveness of the control philosophy used to control the system.

Thesis Title: **VOLTAGE CONSIDERATION IN DYNAMIC UNDERFREQUENCY LOAD SHEDDING**

Submitted by: **Anil Gautam**

Supervisor: **Dr. Nava Raj Karki, Dr. Netra Prasad Gyawali**

ABSTRACT

Load shedding is an emergency control action to ensure system stability by curtailing system load. Most common load shedding schemes are underfrequency load shedding scheme. Underfrequency load shedding (UFLS) is a common practice for electric power utilities for preventing frequency drop in power systems after disturbances causing imbalance between the load and generation. The main goal of UFLS is to gradually shed portions of the load when the system frequency reaches values lower than allowed. The undervoltage load shedding (UVLS) schemes on the other hand, are used to protect against excessive voltage decline.

Usually the location bus and the amount of load to be shed in UFLS is determined on the basis of load importance, cost, distance to the contingency location or from a fixed predetermined load bus, etc. and not looking the voltage aspect but in this work the amount of load to shed in the process of

UFLS is determined based on the voltage sensitivities of load buses.

The main theme is UFLS. Based on the rate of change of frequency, magnitude of disturbance is estimated which is the total amount of load to be shed. The allocation of total amount of load to shed to each load bus is done on the basis of voltage using one of the indices used to detect voltage collapse. Voltage sensitivity index is used which helps to identify weak bus in the system. Larger this index, weaker is the bus and vice versa. If higher amount of load is shed from weaker bus rather than stronger one, it might help to improve the voltage profile than that shed based on load importance, cost or from a fixed predetermined load bus.

Although voltage is considered, this work is not the case of UVLS. The main theme is still UFLS because UVLS action is initiated only when voltage magnitude is not in acceptable level but in this work, the method is triggered by under frequency and even if due to disturbance voltage is still within acceptable level, this method still tries to improve voltage levels by removing more load from relatively weaker buses in the course of UFLS.
The tests are performed on IEEE 14 bus test system by simulating two kinds of disturbances - random increment in load and disconnection of generator. The frequency of the system and

voltage plots of the load buses without and after load shedding has been presented. The results show that more amount of load has been shed from relatively weaker buses in comparison to stable ones and thus voltage improvement is more in weaker buses in comparison to relatively stable ones. Voltage sensitivity index has been evaluated after applying the load shedding action and compared with the index obtained before disturbance. The results showed some changes.

When load is shed using the voltage sensitivity only, in which ever bus there is random increment in load for the same magnitude of disturbance, the amount of load that is shed from each bus will be same. If the random increment in load is in weaker bus, then the method is justified because load shed will be more in weaker buses but when random increment in load is in stable bus then also the amount of load shed will still be more in weaker bus and less in relatively stable ones. So a different case is also presented to incorporate such conditions in which high penalty factor is applied for the load bus that caused higher amount of increment in load. The amount of load to be shed is then determined based on weighted average of the mix of factors obtained from voltage sensitivity index and from amount of increment in load.

Thesis Title: **ALLOCATION AND SIZING OF THYRISTOR CONTROLLED SERIES CAPACITOR FOR AVAILANLE TRANSFER CAPABILITY ENHANCEMENT USING GENETIC ALGORITHM**

Submitted by: **Anup Bajracharya**

Supervisor: **Mr. Surendra Rajbhandari, Mr. Dipesh Lamsal**

ABSTRACT

Deregulation of the electric industry throughout the world aims at creating competitive markets to trade electricity, which generates a host of new technical challenges to market participants and power system researchers. For transmission networks, one of the major consequences of the non-discriminatory open access requirement is a substantial increase of power transfers, which demands adequate available transfer capability to ensure all economic transactions. However, tight restrictions on the construction of new facilities due to social problems, have led to a much more intensive shared use of the existing transmission facilities by utilities and independent power producers (IPPs). These concerns have motivated the development of strategies and methodologies to boost the ATC

of the existing transmission networks. The capability of flexible power flow control and rapid action, Flexible AC Transmission System (FACTS) technology has a wide spectrum of impacts on the way the transmission system operates, in particular with respect to thermal, voltage and stability constraints.

The insertion of FACTS devices in electrical system seems to be a promising strategy to enhance ATC. There are different FACTS devices namely Thyristor Controlled Series capacitor (TCSC), Static VAR Compensator (SVC), Thyristor Controlled Phase Angle Regulator (TCPAR), Unified Power Flow Controller (UPFC). TCSC is a capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide smoothly variable series capacitive reactance. SVG is a shunt connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control the bus voltage. SVC is voltage dependent. So, when voltage goes down compensation also decreases. UPFC is versatile FACTS device and is combination of series and shunt compensator but its modeling is complex. TCPAR is used to regulate phase angle. TCSC as compared to other devices can be modeled simply by power injection models and it has been used as an effective solution for transient stability enhancement, voltage stability

imprcyement, damping of power oscillations and mainly for sub synchronous resonance (SSR) mitigation. So, TCSC is considered for this study.

This thesis analyses the viability and merits of boosting ATC using TCSC. This thesis presents a method by which an optimal location of TCSC can be determined. A method basedon Power Transfer Distribution Factors (PTDF) is presented for placement of TCSC and optimal size of TCSC is determined using Genetic Algorithm for maximum ATC increment of the system. In order to calculate these factors and ATC values, load flow is run using MATPOWER tool box version 4.1 and all programming are done in MATLAB version 7.6.0. The test has been carried out on IEEE 14-bus system and IEEE 30-bus system. ATC values calculated considering bilateral transactions and also for line outage conditions. In this thesis only static modeling of the FACTS devices are considered.

The results for IEEE 14-bus and IEEE 30-bus system shows that ATC values in normal and also in outage condition can be improved by inserting TCSC in the limiting branch. Limiting branch is determined as the branch having minimum transfer limit value. The value of ATC in normal condition is found to be more than in branch outage condition. In IEEE 14-bus system

addition of TCSC has resulted in increment of ATC of the system from *3%* to 26% and in 30-bus system increment of ATC of the system from 48% to 192% is found depending upon the seller and buyer bus. Cost of TCSC is determined from the reactive compensation offered by it in limiting line. Also from the result, it is seen that the cost of adding FACTS device (TCSC) in the limiting branch is much less compared to the cost of new transmission line to be built for increasing the power transmission from seller to buyer bus, justifying the addition of TCSC from economic point of view. Cost of increased ATC is determined as the cost of new transmission line to be built for same increment in power transfer. For IEEE-14 bus system, total installation cost of TCSC is found to be about 3 to 8 times less than cost of increased ATC and for IEEE-30 bus system, it is found to be about 5 to 30 times less than cost of increased ATC for different seller and buyer bus combinations.

The analysis reveals that ATC in transmission system can be improved by adding FACTS device in the system. It eliminates the problem of ATC between seller and buyer bus in deregulated environment and helps for the increased transaction between them without the need of new transmission line to be built by operating transmission line in their full capacity near thermal limit and also saving the time and money needed to build new

transmission line for incorporating increased transactions. But TCSC placement cannot be an alternative to new transmission line once the thermal limit of existing transmission line is reached. Under such circumstance construction of new transmission line is inevitable.

Thesis Title: **GENERATOR CONTRIBUTION FOR LINE LOSS BY USING POWER FLOW TRACING**

Submitted by: **Binod Lohani**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Power systems, ail over the world, have been forced to operate in almost full capacities due to economical constraints. Transmission access is the vehicle for promoting the necessary competition in generation. The electric power transmission network plays an important roie in the delivery of energy from outlying generation to demand centers located far away. Because power plants are interconnected via the transmission network-together they can provide improved reliability and lower overall generation costs. Recent years have seen a worldwide trend towards deregulation and unbundling of services provided by utilities throughout the world, especially in power market. This trend separates the traditional vertical-integrated power system structure into generation, transmission and distribution independently companies. And, the goal is always lowering of the average consumer price and introduction of competition. While competition is introduced in generation and retail due to increased competition and willingness to maximize the profit.

GENCOs are looking for solution to minimize the transmission cost.

It is widely agreed that transmission network is a natural independent and monopoly. Therefore, the transmission network company should remain neutrality and centrally controlled to make the market is operating fairly. Transparency is one of the most important ingredients in the operation of the transmission system. It is necessary to find accurate and indisputable answers to questions as "which GENCOs are using this transmission line?" or "which GENCOs are supplying this load?" In other words, the network operating company or ISO must find out the capacity usage of individual transactions happening at the same time, and then a fair use-of-transmission charge can be allocated to individual GENCO. This problem relates to how to allocate the total cost of transmission between all electrical users in an equitable and non-discriminatory manner, which also provides a correct, market-based economical signal to every participant at the same time. In order to determinate usage-of-transmission, it needs to know the contributions of individual participants to the line flow and loss, and how participants utilize the system by the AC power flow tracing.

Fair and transparent allocation of transmission loss among market participants is essential in the present restructured

electricity markets. This paper proposes a direct method to find the line flow and the loss allocation.

The proposed method for the allocation of line flow and line loss to each generator in the deregulated power system is based on a converged AC load flow solutions. A new formulation is developed from the engineering standpoint to trace the AC power flow by considering dominant and counter flow approach. This method considers both contributions of the active-power and the reactive-power injection where power flow equations and the basic circuit theories are satisfied. Equivalent admittance and equivalent Current injection are applied in developing this methodology. That is, a circuit theory based method where all the electrical theories are satisfied without the involvement of any assumption. With the exact calculation, contribution of counter flow can be well presented. Then, the power flows contributed by every generator in the system could be traced. The loss contributed by each GENCO is calculated by summing the forward flow and backward flow.

Case study of the proposed power flow tracing and loss allocation methodology is conducted on the three bus test system, the IEEE 9-bus test system and IEEE 14-bus test systems to illustrate the proposed approach. The net line flow and net line

losses are compared with the line flow and loss derived by performing the load flow solution of that network to show the effectiveness and validity of this method. The result of case study shows that for the same line, some GENCOs contribute dominant flow component (flow toward the direction of net flow), whereas some GENCOs have counter flow component (flow opposite to the direction of net flow) at the same time. The GENCOs, which contribute dominant flow component on the line increases the line loss however those GENCOs, which contribute counter flow component on the line reduces the line loss.

Thesis Title: **COMPOSITE CRITERIA BASED NETWORK CONTINGENCY RANKING USING FUZZY LOGIC**

Submitted by: **Laxmi Jha**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Maintaining power system security is one of the challenging tasks for the power system engineers .The security assessment is an essential task as it gives the knowledge about the system state in the event of a contingency. Contingency analysis technique is being widely used to predict the effect of outage like failures of equipment, transmission line etc, and to take necessary actions to keep the power system secure and reliable. The offline analysis to predict the effect of individual contingency is tedious task as a power system contains large number of components. Practically, only selected contingencies will lead to severe condition in power system. The process of identifying these severe contingencies is referred as contingency selection and this can be done by calculating performance indices or severity indices for each contingency.

In this thesis selection of power system contingency is done by calculating the performance indices for transmission line outage

using Newton Raphson load flow (NRLF) analysis. The objective is also to compare the performance of the method employing fuzzy logic and NRLF for various power system networks. The main motivation of the work is to carry out the contingency selection by calculating the two kinds of performance indices; active performance index and reactive performance index for single transmission line outage, with the help of Newton Raphson Load Flow (NRLF) in MATLAB. Further, the contingency selection has been done by using Fuzzy Logic.

In the present day power system planning and operation, considerable interest is being shown in contingency analysis. Contingency screening and ranking is one of the important components of on-line system security assessment which is done with the help of various computer softwares which employ iterative methods like Newton Raphson and Fast Decouple Load Flow Methods for obtaining the magnitudes of various parameters. The objective of contingency screening and ranking is to quickly and accurately select a short list of critical contingencies from a large list of potential contingencies and rank them according to their severity. Suitable preventive control actions can be implemented considering contingencies that are likely to affect the power system performance. Network

contingencies often contribute to overloading of network branches, unsatisfactory voltages and also leading to voltage collapse. To maintain security against voltage collapse, it is desirable to estimate the effect of contingencies on the voltage stability. This thesis presents a new approach using fuzzy logic to evaluate the degree of severity of the considered contingency and to eliminate masking effect in the technique.

The performance of the developed methodology is demonstrated by a IEEE 5-bus and IEEE 30-bus systems. The study results show that the Ranking done by composite criterion based fuzzy logic eliminates the masking effect.

Thesis Title:	**ECONOMIC EXTENSION OF TRANSMISSION LINE IN DEREGULATED POWER SYSTEM FOR CONGESTION MANAGEMENT**
Submitted by:	**Pravin Kumar**
Supervisor:	**Mr. Dinesh Kumar Ghimire, Dr. Netra Prasad Gyawali**

ABSTRACT

The competitive environment has spread widely into all sectors so that electricity market cannot do away from it. During nineties many electric utilities around the world were forced to change their way of operation and business from vertically integrated mechanisms to open market systems in order to enhance competition and bring consumers new choices and economic benefits. This concept is popularly known as 'deregulation' or 'restructuring'. Deregulation of electricity supply industry has now become a global trend after the successes of markets in pioneering countries. Those countries which are still under the process of reforming their electricity market can learn lots from successful market established by those countries.

Transmission system is one of the major components of the electric power system**.** In deregulated power systems**,**

transmission system provides the environment for competition among power market participants. As electric loads and generations grow, transmission expansion planning should be carried out in timely and proper way to facilitate and promote competition.

In deregulated power systems participants take their decisions independently. They change their strategies frequently to acquire more information from the market to maximize their benefits. ConsiEners adjust their loads according to the price signals. In deregulated power system, there are choices of GENCOs and DISCOs for consumers. The competition is based on the bidding price, reliability, power quality and mutual agreement In order to deliver the power from GENCO to DISCO, transmission line is used. The power flow from transmission line also depends upon market participant's choice**.**

The chances of congestion in deregulated market are quite high as compared to monopolistic market as the customer**s** would like to purchase electricity from cheapest available sources. Congestion management is one of the most challenging tasks of the system operator (SO) in deregulated environment. Consequences of Congestion are Unsolved congestion will threaten system security and Congestion will bring extra cost 1

electrical users. Ways for Congestion management are: Generation reschedule Interruptible load curtailment, Transmission system expansion etc.

Generator rescheduling and interruptible load curtailment are startup way for congestion management. Transmission expansion planning is the last way for congestion management if congestion is not managed by Generation rescheduling and Interruptible load curtailment.

A high mean of LMP at a bus indicates no access to cheap generation and a low mean of LMP indicates access to excess cheap generation and no access to enough loads. Hence, constructing a new line between two buses with low and high mean of LMP will allow the dispatch of the excess cheap generation and flow of energy from low LMP bus to high LMP bus due to price potential difference. Consequently, the flatness of price profile is improved.

Therefore, between each two buses that have LMP difference greater than a specified value (say SV), a new line is suggested as transmission expansion candidate. SV must be selected so that reasonable number of candidates is suggested. If SV is increased the number of transmission candidates will be decreased and vice

versa. If this method suggests many candidates, the ineffective candidates can be eliminated by increasing SV and determining the candidates again. The final plan is selected by economic analysis.

Thesis Title: **RELIABILITY WELL-BEING ASSESSMENT OF ISOLATED PV-WIND BASED HYBRID SYSTEM**

Submitted by: **Sunil Kumar Kushwaha**

Supervisor: **Dr. Nava Raj Karki**

ABSTRACT

The Utilization of renewable energy resources such an wind and solar energy for electric power generation has received considerable attention in recent years mainly due to adverse environmental impacts and fuel cost escalation associated with conventional generation .At the present time wind and/or solar energy sources are utilization to generate electric power in many application. Wind and solar energy are likely to become important sources for power generation in the future because of their environmental social and economic benefits together with public support and government incentives.

The wind und sunlight arc variable energy sources and electric power generating system based on these resources behave far differently than conventional power sources. Energy storage systems are often required to smooth the fluctuating nature of the energy Conversion system especially in small isolated applications, the work presented in this thesis is focused on the

development and application of reliability well-being assessment associated with incorporating wind, solar energy and energy storage in power generating systems. A probabilistic approach using sequential Monte Carlo simulation has been employed and numbers of analyses have been carried out for well being assessment of generation systems containing wind energy, solar energy and energy storage. Deterministic and probabilistic techniques are combined in this thesis using a system well-being approach to provide useful adequacy indices for small isolated systems that utilize renewable energy. The concepts presented and examples illustrated in this thesis will help power system planners and utility managers to assess the reliability and economic benefits of utilizing wind energy conversion systems, solar energy conversion systems and energy storage in electric power systems and provide useful input to the managerial decision process.

The sequential Monte Carlo Simulation has been performed in MATLAB with different combination of solar, wind and battery storage system utilizing the data of Lele obtained from Department of Hydrology and Metrology, Nepal. The annualized cost/worth analysis of various combinations of solar and wind energy recourses has also been done in this thesis work. The results obtained from the analysis shows that 60 kW PV system

with no wind energy system has a healthy state probability P(H) value of 0.81. Similarly, the value of healthy state probability P(H) is 0.822 in the system with no solar and 60 kW wind energy system. The system with 20 kW solar PV systems and 40 kW wind system with 300 kWh energy storage has healthy state probability 0.98. The annualized cost/worth analysis of the system shows the system with 20 kW solar PV and 40 kW has least cost. Thus, the well-being indices obtained from the simulation presents that he some of the combinations of Hybrid Solar Wind system is reliable in the climatic conditions of Lele, where the hypothetical system is assumed to be installed.

Thesis Title: **STUDY AND ANALYSIS OF NEPAL'S POWER SYSTEM PLANNING**

Submitted by: **Surendra Prasad Paneru**

Supervisor: **Dr. Nava Raj Karki, Dr. Arbind Kumar Mishra**

ABSTRACT

The main focus of this thesis work is on the study and analysis of Nepal's existing power system. The transmission expansion planning is required to find the optimal structure and a least cost transmission investment alternative for the forecasted load and generation configuration. The purpose of a least cost transmission planning along with generation planning is necessary in order to meet the growing demand and energy needs of the nation at a least cost.

Study and analysis from existing facilities has been taken as the basis for identifying the requirements for new lines, new substations, up-gradation of existing substations and addition of reactive power compensation devices in coming years. The long term plan is aimed at enhancing national power generation by identifying new generation, location and supply sources to ensure that the Integrated Nepal Power System (INPS) meet the future

demand and energy requirements with reasonable level of reliability.

The voltage level of existing transmission system of INPS is limited to 66 kV and 132 kV up to now. New transmission line having voltage level of 220 kV is under construction between Hetauda-Bharatpur-Bardhghat and Khimti-Dhaklebar. The significant length of transmission line (132 kV) outside Kathmandu Valley that caters the load extends from Anarmani in East to Mahendranagar in West are on double circuit tower. It has been planned to string the second circuit 132 kV line on existing double circuit tower from Butwal-Kohalpur-Mahendrangar section and is expected to complete by 2015. The Kathmandu Valley gets the power supply through 132kV lines and 66kV ring mains. Similarly, one of the major load centers Birgunj corridor also gets power supply through 132kV lines and 66kV lines. The existing INPS does not incorporate modern transmission planning criteria causing poor system voltage, high line loss and poor stability.

INPS has experienced rapid increase in energy and power demand in the last 5 years. This rise in energy and power demand and forecasted load requires a corresponding augmentation in generation capacity and expansion of transmission network. The

least cost power generation plan gives the requisite plan to implement various plans on both generation and transmission.

This work studies and analyzes the status and performance of existing transmission system in the base case 2012 and develops a long term transmission plan upto 2031 by using PSS/E or MATPOWER software. The study shows that voltages at different buses serviced by Hetauda-Birgunj 66 kV line are below acceptable level and found as low as 0.7 p. u. The study further shows that by year 2015 some of the existing transmission lines and power transformers in Kathmandu Valley will be overloaded and hence necessary remedial action are recommended.

The expansion of existing 1NPS, generation and transmission facilities to meet the forecasted load growth from 2012 to 2031 taking LOLE of 10 days per year has been proposed. The load forecast data has been gathered from NEA upto 2025 and extrapolated to 2031. The commissioning dates for committed projects, hydrological data, costs of generating plants and transmission system requirements for least cost power development plan has been envisaged. The tools such as excel for load forecasting, WASP for the generation expansion plan

optimization and MATPOWER for transmission planning have been used for modeling and analysis.

The load forecast results indicate that the peak demand of the system lies in the range of 1.128.3 MW in 2012, 2,256.1 MW in 2021 and 4,695.8 MW in 2031. Thus, the current peak load is expected to grow by over 3 times in 2031. The long term plan aims at enhancing national power generation and supply by identifying new generation and supply sources to ensure that the national electric power supply meets the forecasted load 2256.1MW with planned LOLE by 2021. From 2012 to 2014 LOLE increases in the absence of generation project and in 2015 the LOLE slightly decreases due to addition of Chameliya HEP and KL-3 HEP to the system. In 2019, LOLE decreases because of addition of Upper Karnali HEP and Tamor-Mewa HEP along with Mistri HEP and Kabeli A HEP to the system. The result from WASP analysis shows that the LOLE should increase in 2020 if the optimum configuration of generator were undertaken. In 2021, LOLE is found to be within acceptable level owing to the addition of West Seti and NalsingGad HEPS. Candidate generation resources considered in the system expansion plan includes hydropower plants only. The optimum solution indicates that the capacity should be increased from current 526 MW to 4,897.6 MW by 2031. The present value of the total

system expansion cost over the period 2012-2031 amounts to U.S. $7,354 billion, expressed in current prices 2012.

In 2015 new transmission lines, stringing of second circuit 132 kV line from Butwal -Kohalpur-Mahendranagar and 132 kV double circuits from Hetauda to Birgunj is proposed to overcome overloading condition of existing 66 kV lines. Similarly in 2015 onwards 220 kV line from West Seti to Dhalkebar-Duhabi-Khimti and 400 kV lines from Muzffarpur to Dhalke are proposed. The transmission development plan indicates the need to develop approximately 7733.75km of new lines at an estimated present cost of U.S. $ 3.22 billion.

In 2015, the study reveals that !32/66kV transformers at Parwanipur S/S need to be upgraded and similarly 132- kV transmission line is proposed in Birgunj corridor to overcome overloading of existing 66 kV lines. When there is outage of Jhimruk HEP, the decrease in voltage will be 0.941 from 0.973 at Jhimruk bus. When there is outage of Kali Gandaki-A HEP, the bus voltage at Syangja shall decrease to 0.923 p. u. from 0.99 p. u. In 2018, The Bhaktapur-Baneswor 66 kV (44 MVA capacity) line shall be upgraded to 112 MVA capacity.

In 2019, the study reveals that 132/66kV transformers at Siuchatar and Balaju needed to be upgraded or added. Likewise, 132/66kV power transformers at Kohalpur S/S and Parwanipur S/S need to be added. When there is outage of Upper Tamakoshi HEP, the bus voltage at Anarmani shall reduce from 0.963 p. u. to 0.82 p. u.

In 2020, the study reveals that 132/66kV transformers at New Duhabi and Mulpani needed to be upgraded or added. Similarly, the loading of Chahbel-Chapali (51 MVA capacity) and Baneswor-Patan line needs to be upgraded.

In 2021, the study reveals that when there is outage of West Seti HEP, then the bus voltage at Mirchaya shall reduce to 0.010 p.u. from 0.967 p.u. and when there is outage of Tamor-Mewa HEP, the bus voltage at Lahan reduces from 0.968 p. u. to 0.943 p. u .

In 2025, the study reveals that another Lainchaur-Chabhbel 66 kV line and Chahbel- Chapali lines (112 MVA capacity) need to be added. The study aso reveals that when there is outage of Tamor-Mewa HEP, the bus voltage at Duhabi shall reduce from 0.970 p. u. to 0.943 p. u. and similarly when there is outage of West Seti HEP, then the bus voltages at Anarmani reduces to 0.043 p. u. from 0.961 p. u . .

In 2031, the study reveals that Parwanipr-Pathlaiya lines (142 MVA capacity) and Siuchatar-Teku lines need to be upgraded. When there is outage of Tamor-Mewa HEP, the bus voltage at Lahan shall reduce to 0.943 p.u. from 0.964 p.u. The study reveals that when there is outage of West Seti HEP, then the bus voltage at Anarmani shall reduce to 0.756 p. u. from 0.968 p. u.

In the wet off peak period, the generation is high and load is low. In this situation, it is recommended to install FACTS devices like Statcom (Static Compensator) and SVC (Static Var Compensator). The purpose of the installation is to bring about increased power transmission capability over the central interconnected system by means of raising the system stability for steady-state as well as contingency conditions in INPS. The normal mode of operation is automatic voltage control. In adverse conditions, like multiple outages, the planning of the 220 kV line in the plain area is not sufficient. There is need of another line of 220 kV which should be passed through Mid hill region from Ilam Hub, Dhankuta Hub, Khimti Hub, Marsyangdi Hub. Kaligandaki Hub, Dailekh Hub, and Dadeldhura Hub which is in loop with the 220kV transmission line in the plain region from Anarmani to Mahendranagar.

Thesis Title: **OPTIMAL RECONFIGURATION OF DISTRIBUTION SYSTEM USING ANT COLONY SYSTEM ALGORITHM**

Submitted by: **Bijay Mahato**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Power distribution systems have tie and sectionalizing switches whose states determine the configuration of the network. Reconfiguration of distribution network is achieved through switching operation on switches of distribution network branches. Power companies are interested in finding the most efficient configuration for minimization of real power losses, improvement in voltage profile and relieving of overloads among distribution feeders to save the energy and enhance the operational performance of distribution system.

The network reconfiguration problem is usually formulated as a single objective optimization problem with equality and inequality constraints. The network reconfiguration is a complex combinatorial optimization problem. This is because there are multiple constraints which must not to be violated while finding an optimal or near optimal solution to the distribution network

reconfiguration problem. As a result, more efficient approaches are required to handle this combinatorial problem.

In this thesis, a new and powerful intelligent evolution method, called ant colony system optimization (ACSO) is adopted for solving the optimization problem. It is a population based approach that uses the exploration of positive feedback as well as greedy search. The proposed method was inspired from natural behavior of the ant colonies on how they find the food source and bring them back to their nest by building the unique trail formation. Artificial ants are able to search for the successively shorter feasible route by using information accumulated in the form of a pheromone trail deposited on the edge of their traveling path. The algorithm required for carrying out the steps of the ACS is not unique. In this research, a new algorithm for ACS has been proposed. The proposed algorithm is coded using MATLAB. Then, Ant Colony Search (ACS) algorithm has been applied to the distribution system reconfiguration through the optimization of objective functions. This study focuses a method for optimal reconfiguration of distribution system with simultaneous minimization of real power loss, voltage deviation and feeder overloading. In this study, the system loads are assumed three phase balanced and constant load. Therefore this research proposes one time reconfiguration. It can also be

implemented for time varying load reconfiguration if time varying load data is available.

In classical methods for solving multi-objective problems, for a given multiple objectives and preferential information about these objectives, the MO problem is converted into an SO problem by either aggregating the objective functions or optimizing the most important objective and treating others as constraints or prioritizing the objective functions. The SO problem then can be solved using traditional scalar-valued optimization techniques. This technique gives a single solution according to the preferential information provided by decision maker. However these classical techniques has serious drawback that once scenario change, the solution procedure has to be reapplied after modifying design criteria. Another approach is to search the solution space for a set of Pareto optimal solutions, from which the decision maker may choose the final solution. Pareto solutions are those for which improvement in one objective can only occur with the worsening of at least one other objective. Thus, instead of a unique solution to the problem (which is typically the case in traditional mathematical programming), the solution to a multi-objective problem is a set of Pareto optimal solutions.

The performance of two distribution networks of different sizes (IEEE 33 bus distribution system and Taiwan practical distribution system) has been evaluated using to test the effectiveness and validity of the proposed algorithm. The obtained results reveal that the proposed method is promising in distribution system reconfiguration. In IEEE 33 bus test case, the solution proposed algorithm reduces the power losses from 202.677 to 139.551, voltage deviation index (VDI) from 1.4691 to 1.0435 and load balancing index (LBI) from 2.6297 to 1.7559 respectively. Similarly in Taiwan practical distribution system, the proposed algorithm reduces power losses from 780.877 to 687.330, voltage deviation index (VDI) from 1.311 to 1.032 and load balancing index (LBI) from 5.433 to 4.941 as compared to that of existing system when treating power loss (PL), voltage deviation index (VDI) and load balancing index (LBI) as single objective function. Thus proposed algorithm improves the objective functions (PL, VDI and LBI) by 31.15%, 33.23% and 28.97% respectively as compared to existing system in case of IEEE 33 bus system and by 11.98%, 9.06% and 21.31% respectively as compared to existing system Taiwan practical distribution system. When power loss (PL) and voltage deviation index (VDI) treating as multi-objective, the proposed algorithm reduces the power loss (PL) from 202.677 to 139.551 and voltage deviation index (VDI) from 1 4691 to 1.0435 in IEEE 33

bus system to that of existing system while in Taiwan practical distribution system reduces power losses from 780.877 to 687.892, voltage deviation index (VDI) from 1.311 to 1.035 respectively. Similarly When power loss (PL) and load balancing index (LBI) treating as multi-objective, the proposed algorithm reduces the power loss (PL) from 202.677 to 139.551 and load balancing index (LBI) from 2.6297 to 1.7559 in IEEE 33 bus system to that of existing system while in Taiwan practical distribution system reduces power losses from 780.877 to 692.639 and load balancing index (LBI) from 5.433 to 5.061 respectively. But when power loss (PL), voltage deviation index (VDI) and load balancing index (LBI) treating as multi-objective, the proposed algorithm reduces power losses from 202.677 to 139.551, voltage deviation index (VDI) from 1.4691 to 1.0435 and load balancing index (LBI) from 2.6297 to 1.7559 respectively. Similarly in Taiwan practical distribution system, the proposed algorithm reduces power losses from 780.877 to 692.703, voltage deviation index (VDI) from 1.311 to 1.092 and load balancing index (LBI) from 5.433 to 5.125 as compared to that of existing system. This proposed algorithm allows the utility to obtain optimal reconfiguration of distribution system with simultaneous minimization of power loss, feeder overloading and voltage deviation.

Thesis Title: **OPTIMAL SIZE AND LOCATION OF DISTRIBUTED GENERATOR**

Submitted by: **Suraj Gautam**

Supervisor: **Mr. Dipesh Lamsal**

ABSTRACT

There are many methods of loss reduction techniques such as feeder reconfiguration, capacitor placement, high voltage distribution system, conductor grading & DG unit placement. All these methods are involved with passive element except DG unit placement. Both capacitor and DG unit placement reduce the real power loss.

The Distributed Generations (DGs) have created a challenge and opportunity for developing various novel technologies in power generation. DG reduces line loss, increase voltage profile & stability margin, reduces peak load, provides energy saving, improve system reliability & power transfer capacity and relaxes thermal constraints of transmission and distribution feeders. Distributed Generator (DG) such as gas fired, coal fired, solar, diesel, micro turbines, fuel cell wind plants etc are installed in demand side of power system. Such DGs can reduce distribution losses significantly if they are placed with appropriate size and locations in distribution system.

This paper proposes a new methodology for placement of Distributed Generator (DG) in a power system to minimize the total real power loss and for voltage improvement. This method is easy to be implemented and fast for given accuracy. Newton Raphson method is used to calculate the exact loss. The candidate location for DG placement is identified on the basis of profit maximization of objective function.An algorithm is applied to three test systems, i.e. (7-bus, 14-bus & 30-bus system). The 7-bus system has 6 sections with total load 1800 KVA. Optimal size and location of DG is 1541 KVA and node-3 respectively. Total real power loss reduction in the system is 48 KW (from 52 KW to 4 KW). The 14-bus system has 13 sections with total load 3800 KVA. Optimal size and location of DG is 2125KVA /1735 KVA and node-9/'node-2 respectively. Total real power loss reduction in the system is 580 KW (from 620 KW to 40 KW). Similarly, the 30-bus system has total load 353 MVA. Optimal size of the DGs are 119MVA, 75MVA & 79 MVA and corresponding optimal locations are at node-21, node-12 & node-2 respectively. Total real power loss reduction in the system is 35.174MW (from 43.252 MW to 8.078 MW). From the above results, we conclude that this proposed methodology is suitable for large network because of present worth saving maximization and power loss reduction is within reasonable level. The proposed algorithm is suitable for the allocation of

single or multiple DGs in a given networks. Result indicated that, if the DGs are located at their optimal locations and have optimal sizes, the total losses in the system is reduced .It is also concluded that optimal size and location of DG is more appropriate for large losses as well as large distribution network.
A multi-objective function is used in this paper, which comprehensively considers the total operation cost of DG and power network loss. Optimal location of DG is achieved when the solution represents a compromise between network benefits and capital, O&M & fuel cost. Study also shows that if the DG units are connected at non- optimal locations or have non optimal sizes the system losses may increase.

MatLab programme is used to calculate the optimal size and location of DG in test radial distribution system.

Thesis Title: **AN EFFICIENT ALGORITHM FOR OPTIMAL DISTRIBUTION SYSTEM CONFIGURATION**

Submitted by: **Jitendra Kumar Jha**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

Distribution network configuration is a combinatorial optimization problem because it accounts for various operational constraints in distribution systems. Unlike the exact mathematical methods, the heuristic ones are different to provide a solution which is the optimal one, saving time of processor. With the appearance of the Tabu Search, by Fred Glover in 1986, diverse applications have arisen from the procedure to solve diverse problems as for the classic problem of the route of the vehicle (also known as the travelling agent problem) and the allocation of a plant. Here an adaptation to an existing code appears, applied to the problem of the travelling agent, for the reconfiguration of distribution expansion in five electric distribution networks. The model provides results which are optimal or very near them in time of relatively little calculation, in comparison with the manual reconfiguration.

In this thesis, the objective of the distribution network expansion planning problem is to determine an investment schedule to ensure an economic and reliable energy supply. This is done by constructing a minimum cost radial distribution network under the constraints of network line load capacities, voltage drops and load demands. The complexity comes from the combinational nature imposed by the radial network constraint and various options for transformer and substation location, several alternatives for cable or the line sizes and routes, multistage investment decisions, complex objectives and uncertainty about demand variation and location.

Optimal expansion of medium-voltage power networks is a common issue in electrical distribution planning. Minimizing total cost of the objective function with technical constraints and reliability limits, make it a combinatorial problem which should be solved by optimization algorithms. This thesis presents a new hybrid simulated annealing and tabu search algorithm for distribution network expansion problem. Proposed hybrid algorithm is based on simulated annealing method and an auxiliary tabu search algorithm controls the main algorithm. Also, another auxiliary simulated annealing based algorithm has been added to local searches of the main algorithm to make it

more efficient. The numerical results show that the method is very accurate and fast comparing with the other algorithms.

This thesis proposes a Simulated Annealing (SA)/Tabu search (TS) based method for distribution network expansion. It may be introduced as a combinatorial optimization method that determines the location and capacity of feeders and substations while minimizing the network loss and installation cost. It also proposes a new objective function considering the installation cost of equipments (feeders, substations) and cost of losses. The proposed method is successfully applied to planning of distribution network. In order to show the capability of the proposed algorithm for solving distribution network expansion, the five different distribution networks are solved. One of which consists of 65 load nodes, 2 existent substations and 6 candidate substations. The optimal distribution network which has the average objective function, resulted from several running of the proposed hybrid SA/TS algorithm. This thesis shows that two substations out of six only are needed to feed the new load points.

Thesis Title: **ANALYSIS AND DEVELOPMENT OF COMPETITIVE ELECTRICITY MARKET IN NEPAL**

Submitted by: **Navin Kumar Labh**

Supervisor: **Mr. Surendra Rajbhandari, Mr. Dipesh Lamsal**

ABSTRACT

In the new era of modernity, the competitive environment has spread widely into all sectors including the electricity market which began since 1980s. During the nineties many electric utilities around the world were forced to change their way of operation and business from vertically integrated mechanisms to open market systems in order to enhance competition and bring consumers new choices and economic benefits. This is the basic concept of deregulation popularly known as 'restructuring'. "Deregulation of electricity supply industry has now become a global trend as a method of best practice adopted after the success of markets in pioneering countries". Those countries which are still under the process of reforming their electricity market can learn lots from successful market established by these countries. There are different market structures adopted in different countries. The market structure successful in one country can prove failure in another country. It is very important

to develop the type of market suitable for Nepalese power industry as it is influenced by various factors governing the electricity market. Nepal is also considering deregulating its own power sector in future. The Bill for deregulating the Nepalese power industry is under consideration in the parliament. So sooner or later Nepalese power sector will be restructured and will adopt a particular model suitable for its environment. This thesis, therefore, aims at developing a preliminary market model for the competitive electricity market for Nepalese power industry.

The current Nepalese power industry represents one characteristics of the single buyer model in which Nepal Electricity Authority purchases power from these generation companies and sells to the consumers. However, there is no competition among generation companies to sell energy produced as the energy purchase by NEA is based on the power purchase agreement. The prices remain as governed by the terms and conditions of the PPA. As the size of the Nepalese power industry is small and full choice to customers will not be offered in the beginning of the deregulation, single buyer model can be adopted with small modifications easily. For the trading of electric energy/power in the proposed single buyer model, pool market model can be applied. Hence, single buyer industry

structure with pool market has been adopted for analysis of the electricity market in Nepal. The studies determine the price of electricity for two basic market pricing structures: uniform market pricing (mostly used in Europe) and locational marginal cost based pricing (LMP) (mostly used in North America) by simulating the power network in Power World Simulator. For the purpose of simulation, Nepalese power system has been divided into three areas: Eastern, Central and Western. The LMP based prices are developed for each bus and then the average value is calculated for each area. Similarly, Uniform prices are calculated for different load ranges taking into consideration demand forecast and bid offer of different generating companies under constrained condition on merit basis. Generation costs and network losses are also calculated in both market models. The results reveal that the price of electricity reduces comparatively in LMP based market but increases in Uniform price based market due to must take or pay condition of *IPPs*. The average market price comes down by 33.91% for LMP based market but increases by 15.21% as compared to the existing system. The network losses also reduce in the competitive market as compared to the existing systems. It can be concluded that LMP based electricity market is suitable for Nepal Power System.

Thesis Title: **TECHNICAL LOSS REDUCTION IN DISTRIBUTION NETWORKS BY ANT COLONY OPTIMIZATION**

Submitted by: **Dhupendra Kumar Jha**

Supervisor: **Dr. Arbind Kumar Mishra**

ABSTRACT

The distribution system is the most visible part of the power supply chain, and as such the most exposed to the critical observation of its users. About 30 to 40 % of total investments in the electrical sector go to distribution systems, but nevertheless, they have not received the technological impact in the same manner as the generation and transmission systems. Loss minimization in power system is one of the biggest challenges before power engineers. The challenge is more pronounced in case of distribution systems. In developing countries, the percentage of active power losses is around 20%; therefore, utilities in the electric sector are currently interested in reducing it in order to be more competitive, since the electricity prices in deregulated markets are related to the system losses. Utilities strive to reduce the distribution losses by using the best strategies in network planning and operation. Hence it is of great benefit to investigate methods for minimizing technical losses.

In all electric power systems, energy (power) is continuously dissipated in electrical system components. The electric losses (dissipated power) through the lines are proportional to the square of the currents, termed as Technical loss or I R Loss. Technical loss, caused by actions internal to the power system due to the physical properties of the components of the power system, is possible to compute & control, provided system loads are known. Reduction of technical losses (in electric power distribution networks) can be regarded as a source of energy. There are many alternatives available for reducing technical losses at the distribution level: network reconfiguration, load balancing, capacitor installation, introduction of higher voltage levels. This research focuses on the Network reconfiguration alternative.

Power distribution system feeders contain number of switch/es that are normally closed (sectionalized switches) and switches that are normally open (tie switches) whose states determine the configuration of the network. The choice of closing the tie switch/es and opening the sectionalizing switch/es depends on the criteria adopted to ensure that all the loads are served. Reconfiguration of distribution network is achieved through switching operation on switches of distribution network branches. Feeder reconfiguration is done during emergency for

load restoration and in normal conditions for loss reduction and load balancing. Network reconfiguration can be used as a planning tool as well as a real- time control tool.

The network reconfiguration problem is usually formulated as a single objective optimization problem with equality and inequality constraints. Because there are many candidate-switching combinations in the distribution system, network reconfiguration is a complicated combinatorial, non-differentiable constrained optimization problem. For this reason, more efficient approaches are required to handle this combinatorial optimization problem.
This thesis is intended for reduction of technical loss of the electrical distribution system by network reconfiguration technique for minimization of power losses and load balancing index of the feeders by using Ant Colony Optimization (ACO) algorithm.

In this thesis, a powerful intelligent evolution method, called Ant Colony Optimization (ACO) algorithm is adopted for solving the optimization problem. ACO algorithms are stochastic search procedures based on a parameterized probabilistic model called pheromone model. ACO algorithm is inspired from natural behavior of the ant colonies on how they find the food source

and bring them back to their nest by building the unique trail formation. In ACO, a number of artificial ants build solutions to an optimization problem and exchange information on their quality via a communication scheme that is reminiscent of the one adopted by real ants.

The proposed ACO algorithm is coded in MATLAB for finding an optimal radial configuration among all possible radial configurations generated with the switch/es condition changes that minimize the objective function. The proposed ACO algorithm has been tested against two test systems 16-bus and 33-bus distribution system. The simulation results showed that the proposed ACO algorithm is capable of finding an optimal solution and hence the proposed algorithm is promising in distribution system reconfiguration for power loss minimization and load balancing purposes.

Graduation Year 2013

Thesis Title: **ADEQUACY ASSESSMENT OF INTEGRATED NEPAL POWER SYSTEM**

Submitted by: **Bharat Chetry**

Supervisor: **Dr. Nava Raj Karki**

ABSTRACT

Generation reliability assessment of electrical power systems is vital in ensuring proper decision making in generation expansion planning and system operations in the face of stochastic system performance such as equipment failures and variations of generation and load. This thesis presents the results of generation reliability evaluation of the INPS using the probabilistic approach. Traditionally, power systems in developing countries have been using deterministic criteria for system expansion and operational planning. As the deterministic approach does not reflect the true risk level of power system, it is necessary to quantify the actual risk level that can be carried out by probabilistic approach only. The system is analyzed under several scenarios in order to investigate the effect of each of these scenarios on the reliability of the system. The analytical method is applied to evaluate the stochastic system performance and reliability indices. In this study, the reliability of the INPS is

carried out considering the existing generation capacity. The system is also analyzed considering generation and load of different geographical areas separately, dividing the whole INPS into three regions. As INPS has generation capacity potential available in all the three regions and it is a common practice to have generation near to load if possible and avoid the requirement of strong transmission link. When analyzed area wise it is found that area 2 (eastern region) has very low generation compared to its load demand. Thus, the generation system reliability model and calculations in this study are based on the analytical method. In addition, all the data used in the study are sourced from NEA. Therefore, the purpose of the study is to assess the adequacy of INPS generation system to meet the load requirements taking into consideration the existing electricity demand. The results show that the INPS electric system is not adequate even after considering the full capacity of Diesel Power Plant of Hetauda and Bansbari. Furthermore, the system risk is expected to increase if no new generations are added to the system immediately.

Thesis Title: **RELIABILITY ASSESSMENT OF GENERATING SYSTEM INCORPORATING WIND ENERGY CONVERSION SYSTEM**

Submitted by: **Deepa Shrestha**

Supervisor: **Prof. Dr. Nava Raj Karki**

ABSTRACT

Renewable energy resources are receiving considerable attention in the continued growth and development of electric power systems in the global arena. The most promising renewable electrical energy generating sources at the present time are wind power and solar power. Among these two, wind is an important and fastest growing energy source and is regarded as an important alternative to traditional electric power generating sources. Enhanced public awareness of the environment has led to rapid wind power growth throughout the world in order to reduce greenhouse gas emissions associated with conventional energy generation. Hence it is the known fact now that the wind power penetration in electric power system around the world is increasing rapidly and considerable attention is being paid to the integration benefits and issues.

Wind is highly variable, site-specific and terrain-specific. Hence the power generated utilizing the same is also highly varying and unreliable. Wind generators behave quite differently from conventional generators because of the random nature of wind and therefore it is important for power system planners and engineers to carefully consider the reliability issues associated with wind energy sources. Hence its fundamentally different operating characteristics therefore affect power system reliability in a different manner than those of conventional systems. The research work presented in this thesis is focused on the development of appropriate models and techniques for wind energy conversion system and to assess the adequacy of composite power systems containing wind energy. A probabilistic approach using Monte Carlo simulation has been employed for the analysis.

An essential step in the reliability evaluation of a power system containing Wind Energy Conversion Systems (WECS) using sequential Monte Carlo analysis is to simulate the hourly wind speed. Nagarkot is selected as the wind station site and wind speed data of 3 different years of 2003, 2004 and 2005 were obtained from Alternative Energy Promotion Centre (AEPC). The time-series model has been generated using available hourly wind speed data and various characteristics of the simulated wind

speeds (average wind speed and standard deviation) are compared with that of the actual observed data.

The ARMA (Auto Regressive Moving Average) model of order (2, 1) has been used to generate the series of wind speed data and is utilized in generation of the wind power and order of ARMA was selected by means of F-test. The simulated wind speed was converted into corresponding power by means of the WTG and its characteristic properties. 2 units of WTG of 500Kw were considered to be installed at Nagarkot having FOR of 0.045. Since Nagarkot has been selected as wind site then load feeder is also selected as Nagarkot feeder. Nagarkot feeder is being fed form Bhaktapur S/s so for this thesis study, Bhaktapur S/s has been considered as analogous to the conventional generator as there is not any real existence of hydro power in Bhaktapur. The modeling of Bhaktapur S/s was done by taking FOR to be 0.045. Since load feeder is Nagarkot feeder and hence to model load, hourly load data of Nagarkot feeder of 2 different years of 2067 and 2068 were collected. The complete modeling of wind speed, wind turbine generator, conventional generator and load were done. Then finally, wind power generated is combined with that of the conventional power and is then superimposed with load model so as to evaluate the various reliability parameters.

The ARMA modeling and the sequential Monte Carlo Simulation has been performed in MATLAB with different combination of wind and conventional generation. The reliability indices LOLE (Loss of Load Expectation) and LOEE (Loss of Energy Expectation) were calculated and analyzed. During analysis, three different cases were considered. Firstly, LOLE and LOEE were calculated only by the combination of conventional generation and load. Then for next cases, conventional generation and wind generation (without considering FOR of WTG) was combined and superimposed with load so as to calculate reliability parameters. Lastly, conventional generation and wind generation (considering FOR of WTG) was combined and superimposed with load and reliability indices were obtained. From the analysis it was found that there was improvement in reliability parameters by incorporating wind generation in the system. Further, the parameters were even more improved in the condition of not considering FOR of WTG.

Thesis Title: **MARKET CLEARING PRICE FORECASTING OF COMPETITIVE ELECTRICITY MARKET USING ARTIFICIAL NEURAL NETWORK**

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ABSTRACT

In order to enhance the operational and commercial efficiency, power sector throughout the world, is undergoing major restructuring to introduce competition at various levels, The conventional integrated monopolistic structure is being unbundled and corporatized leading to formation of several market entities such as, generation company, transmission company and distribution company, retailers; and allowing them to compete with each other. The restructuring of power sector is expected to benefit the ultimate customer in varieties of way, i.e., choice of supplier, low cost, safe, reliable and quality electric power to customers through the competition, better customer services and improved system efficiency.

In competitive electricity market, producers and consumers rely on price forecast information to prepare their corresponding bidding strategies. The electricity market clearing price (MCP)

forecasting became essential for decision making, scheduling and bidding strategy planning purposes. With a good next-day market clearing price forecast, a market participant would be able to delineate better financial decisions. That is, a power producer can develop appropriate strategies to maximize its payoff and a consumer can minimize its utilization cost. Electricity has distinct characteristics as compared to other commodities; it cannot be stored economically and transmission congestion may prevent a free exchange of power among control areas also the bidding strategy, market power and unethical business behaviors impose an unrealistic burden on the forecasting process. Thus, electricity price series can exhibit a major volatility and the large errors in electricity price forecasting.

The aim of this thesis is to develop a technique for the prediction of hourly market clearing price in a competitive electricity market environment using only a minimum set of publicly available information. This thesis focused to discover a straight forward, simple and easy-to-use Artificial Neural Network model for the forecasting of MCP with better accuracy. The correlation analysis is done for selecting most critical inputs. This research also examined and searched the best training period, number of hidden layers, proper activation functions for hidden layers and the best set of inputs data on the basis of forecasting performance

(MAPE) to determine the optimum ANN architecture of proposed model. This research considers the relation of electricity price with the electricity demand, time indices, calendar effect and the cyclic characteristic (such as daily, weekly, and monthly) of market clearing prices and quantities. It will be trained and tested by the publicly available historical data from the electricity market of Queensland of Australia (http://www.aemo.com.au.). The 3-layers (with 2-hidden layers, 1-output layer) feed-forward back-propagation neural network has been used for forecasting electricity price. Scaled conjugate gradient algorithm is used to train the network. The transfer functions used for the hidden and output layers are, respectively, tansig, logsig and purlin. Four typical weeks such as, summer week, winter week, autumn week and spring week of Queensland Electricity Market were considered to verify the predictive ability of the proposed method. Similarly four typical months such as, April, July, September and November were considered to show the validity and applicability of the proposed methodology in other electricity markets such as DK-2 region of Nord Pool. In this research, the price forecasting performance in terms of MAPEs computed by proposed method and similar days approach based on the Euclidean norm; Literature [4] were compared for Victorian Electricity Market to show the superiority of proposed approach in terms of better accuracy as

well as simplicity. The case studies concluded that the input set containing price factor, demand factor and time slots provide better accuracy than other set of inputs. The MAPEs in Queensland market of One hour ahead MCP forecasting for 1-days to 7 days in autumn week varies from 6.85% to 9.76%; in winter week it varies from 8.09% to 14.65%.; in summer week it varies from 6.91% to 11.28 % ; in spring week it varies from 6.087% to 7.93%.The MAPEs obtained ,in DK-2 region of Nord Pool, of One hour ahead MCP forecasting for 7 days in April-2010 week was 13.88%; in July week was 11.99%.; in September week it was 4.29 % ; in November week it was 4.41%. The MAPE obtained, in our study, was 10.56% for the one week in September month (September 01-07, 2003), whereas, in literature [4], the MAPE obtained was 10.69%.These test results showed that the proposed forecasting method could provide improvement of the forecasting accuracy, especially as the MAPE results confirm that the proposed model is good tool for price forecasting compared to other complex methods in terms of accuracy as well as convenience.