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Distribution Network Performance Management for emerging load in Urban Area

Case Study of Balaju Distribution Center

by

Bidhan Pokhrel

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A THESIS

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The undersigned certify that they have read, and recommended to the institute of engineering for the acceptance, a thesis entitled **"Distribution Network Performance Management for emerging load in Urban Area, Case Study of Balaju Distribution Center"** submitted by **Bidhan Pokhrel** in partial fulfillment of the requirements for the degree of master of science in Renewable Energy Engineering.

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ABSTRACT

The study focuses on the technical performance analysis of a typical distribution network at a rapidly urbanizing area under the current scenario, future scenario, and distribution network optimization. The Control area in this research is Tarkeshwor Municipality, Nepal, which lies in the outer stretch of Kathmandu, representing the urbanizing loads. In this research, the electric cooking load has been added to the forecasted load up to ten years from now, representing emerging technology as well load that adds to peak load in the daily load curve of the control area. The placement of reactive power suppliers as distributed generation in various distribution network branches is done in this research as an optimization tool that exhibits improved power quality and reliability with the forecasted load. The peak load along with baseload was found to be increased to 21.94 MVA at the end of the tenth year, including targetted electric cooking load. This increment of load at the feeder increases the loss significantly, and the voltage profile is also out of the limits, which are improved by the optimal placement of distributed generation on optimal buses. Similarly the financial contributions to be made by the utility to manage the forecasted load along with the investment to be made for electric cooking load has been analyzed. It is believed that the analysis and discussion in this research will be helpful to the policymakers as well as the electric utility for planning the supply and utilization pattern of electricity in the future

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LIST OF ABBREVIATIONS

EPRI : Electric Power Research Institute

CEC : Clean Energy Council

THD : Total Harmonic Distortion

kHz : Kilo Hertz

MW : Mega Watt

kWh : Kilo Watt hour

KVL : Krichhoff’s Voltage Law

KCL : Krichhoff’s Current Law

G-S : Gauss-Seidel

N-R : Newton Raphson

ENS : Energy Not Supplied

DG : Distributed Generation

AI : Artificial Intelligence

GA : Thegenetic algorithm

PSO : Particle Swarm Optimization

UNDP : United Nations Development Programme

UNFCCC : United Nations Framework Convention on Climate Change

SDG : Sustainable Development Goals

MOEWRI : Ministry of Energy, Water Resources and Irrigation

DR : Demand Response

EM : Energy Management

NEA	: Nepal Electricity Authority
DSO	: Distribution System Operator
EV	: Electric Vehicle
DTR	: Distribution Transformer
F/Y	: Fiscal Year
DC	: Distribution Center
IEEE	: Institute of Electrical and Electronics Engineers

CHAPTER ONE: INTRODUCTION

1.1 Background

Energy is essential for the well-being and prosperity of people, the economy and infrastructural development of the country. Similarly energy use in domestic household sector is also significant. It affects the country's economy, internal air quality and health, and overall well-being (Malla, 2022). In the context of Nepal, about two-thirds of the country's total final energy is consumed by households, which varies across the provinces, districts, and ecological belts. Energy Consumption Pattern and per capita energy consumption are increasing due to urbanization (Rajbhandhari et al., 2019). Electricity has been the primary demanded form of energy, not only in conventional stationary lighting and industrial load but also in the technologies like cooking and transportation.

Electricity is distributed to the consumers through radial feeders emerging from substations. The distribution network in the context of Nepal has been in a continuous improving scenario to manage the current and future loading in the feeders. The upgradation of Substations and technical and technological advancement works are carried out regularly in the feeders. These works could indeed increase the reliability and decrease the vulnerability of the Distribution Network and would maintain the increasing demand for electricity in the future.

In Nepal, electric cooking has been seen as the critical factor for increasing electricity demand in the domestic sector. Various factors such as reducing the dependency on imported fuels, environmental benefits, different plans and policies formulated by the government, and the excess of electricity in the National grid have promoted the consumers to shift the energy for cooking from petroleum energy to electrical energy (Division, 2021). Induction cooking is considered one of the most efficient cooking technologies among electrical cooking. Using this technology, up to 90% of the energy consumed is transferred to food, compared to 74% for traditional electric systems and 40% for gas. Due to such energy-efficient electrical cooking technology, the trend shift in cooking is still predicted to increase in the future in alignment with various governmental strategies and policies. In this context, Nepal also has submitted its Second Nationally Determined Contribution, 2020, to UNFCCC, where it is ensured that 25% of households use the electric stoves as their primary means of cooking by 2030 from 6% in the current scenario of 2020 (Nepal, 2020). Similarly, electric mobility has also been considered the primary sector that could account for the increase in electrical demand in the future. So the planning for the future scenario of the distribution network would have to include the electrical demand by the cooking and mobility sector.

The penetration of large scale of demand in the future with base loads increasing as usual and electric cooking loads rising as per the targets may arise problems on the loading of distribution feeder. Some of the issues can be solved by various optimization techniques like installing distributed generation in the distribution network, bundling of the conductor, upgradation of feeder, and many more (Rajendran & Narayanan, 2017).

This research focuses on forecasting the current loading scenarios up to ten years based on the historical five years data of energy consumption and consumers with the addition of targeted induction cooking load and examining the technical impacts in the medium voltage residential distribution feeder system. This future loading condition could affect the distribution feeder's conductor and transformers, which ultimately increases power losses and decreases voltage beyond the limit, so the optimization of such distribution feeder is carried out to reduce loss and enhance the voltage profile. Financial analysis is also carried out related to the cost of using induction cooking and the price for the utility to optimize the distribution network for incorporating the electrical cooking load. Control Area has been selected as Tarkeshwor Municipality where Balaju Distribution Center feeds through Dharmasthali feeder primarily and gradually through Goldhunga and Jarankhu Feeder with the increase in consumers and demand.

1.2 Problem Statement

Rapid Urbanization and energy shift towards electricity, including emerging technologies as electric cooking, are increasing the current distribution network's load, reducing the reliability and power quality. In the context of electric cooking technology, the trend shift in cooking is still predicted to increase in alignment with various governmental strategies, policies, and National targets. Without proper planning and optimization of the Distribution Network to cope with increasing load demand in the future, including baseload and electric-cooking loads, the electricity distribution system becomes more vulnerable with increased loss, degraded voltage profile, and multiple system failures.

1.3 Objective

The main objective of the research is to analyze and resolve the impact in distribution network due to increasing load in urban areas prioritizing electric cooking load ten years from now.

Several specific objectives have been defined to achieve the main objective, which is listed below:

- To fit the hourly load data in sinusoidal curve and make a trend line to predict the load demand in the future.
- To perform a grid impact analysis at the present case (considered as the base case)
- To perform grid impact analysis considering predicted load at the end of the tenth year from now.
- To suggest the appropriate solution for the distribution network to cope with the increased load in the future.

1.4 Research Gap

The gap for which this research work is carried has been listed below.

- Researches in feeder optimization are done on business-as-usual scenario and have not considered emerging household electric load.
- Overall electricity demand forecasts have been predicted caused by switching cooking service technologies to electric but its impact on distribution network has not been studied yet.
- Various studies have reported the fragile condition of distribution network as a major hindrance for decarbonizing residential sector but the capital requirement for upgrading/reinforcing distribution network and its cost-benefit analysis is not carried out.

1.5 Limitations

Following are the limitations of the study

- The voltage profile and power loss are evaluated for the case of the radial feeder.
- Other than projected current loading scenario electric cooking load is only considered as emerging load in the future.
- Induction cooking is only selected as electric cooking
- Technical parameters are based on only on distribution network.
- Technical performance parameters are calculated for rated load conditions.
- Average hourly load demand was generalized as the average of load data throughout all the seasons of the year.
- Cost for capacitor banks placement is the only cost considered in optimization of distribution network in financial analysis.
- Electricity transmission costs are not included in financial analysis.
- Financial analysis is based on regular calculations for supporting technical analysis.
- Per unit cost of electricity is assumed to be the same as base case for the end of the forecasted period.
- For calculating the cost of future median time is regarded with inflation rate for increase in price
- The case for feeders of Tarkeshwor Municipality is studied and is generalized

CHAPTER TWO: LITERATURE REVIEW

2.1 Distribution Network And Scenario in Nepal

An electrical power distribution system is the final stage in delivering electric power where it carries electricity from the transmission system to individual consumers. Distribution network consists of 11kV medium voltage lines connecting to the distribution transformers (DTR) which further lower the voltage to the utilization voltage of 400V and supply electrical power to the consumers through low voltage distribution lines. Distribution networks are generally classified into two types, Radial Distribution System and Ring Main Distribution System (Rupa & Ganesh, 2014)

In the ring main system, one ring of the primary distribution network is supplied by more than one feeder. In such a case, if one feeder is under fault or maintenance, the ring distribution network is still charged by other feeders connected to it. Generally ring main system is more expensive than the radial system because more switches, protections, and conductors are required to construct the ring main system, but on the other hand, it is more reliable than the radial distribution system. Different feeders emerged from a substation and feeding the consumers at only one end is called a radial system. Radial distribution is the type of electric power distribution where the power is delivered from the main branch to the sub-branches. The radial structure implies no loops in the network, and each bus is connected to the source through only one path. It is the cheapest but the least reliable network system. The Radial distribution system is generally used in lightly populated areas. The advantage of the radial distribution system is that it is the least expensive type of distribution and the easiest to operate and analyze the system. The major disadvantage is that failure in any protection device or equipment will interrupt all consumers ahead of the failure point. The feeder systems are sometimes constructed as a ring network and operate radially.

In the context of Nepal, almost all of the Distribution feeders are operating in radial structure. With the increasing load, the feeders are expanded by the concerned Distribution Centers of Nepal Electricity Authority. Nepal Electricity Authority is the only utility in Nepal currently for the construction, operation, and maintenance of generation, transmission and distribution networks in Nepal. However, plans and policies have been formulated for unbundling of NEA. Capacity enhancement, up gradation, and undergrounding of distribution network has been ongoing in different areas of Nepal through various Projects implemented by NEA (*A yearbook Fiscal year 2077/078(2020/021)*, 2021).

Although various works are being carried out for the smooth operation of the Distribution Network, the networks are not seen as reliable and have some vulnerability within. This can be seen mainly due to the radial nature of the feeders, rapidly increasing urbanization and industrialization, also the consumer behavior for shifting use of any other forms of energy to electrical energy. On the other hand, developing new feeders through the core city and residents is difficult due to various social issues. Maintaining the power flow for the increasing demand has been challenging for the Distribution network operators in Nepal.

Whatever the present scenarios, we hope that the works being carried out in the Distribution Network would fulfill the increasing demand and maintain reliability to the highest level in the years to follow.

2.2 Increasing Load Demand and Technology

With the pace of development, modernization and high population growth rate, more cities and towns have come into existence in which the material well-being of the people has increased tremendously (Dhungel, 2009). Since then, the production and consumption of goods have also increased where accordingly increase in demand for electricity follows. The demand will gradually change due to efficiency improvements, de-industrialization, and electrification of heat and transport over the time (Boßmann & Staffell, 2015).

In the fuel-switch scenario, where electricity is switched from conventional fuel energy to avoid fossil fuel import cost, for environmental security, and for efficient fuels, the demand for electricity will be immense. It is evident that with the technological advancement and increase in people's income level, people will eventually switch to electricity due to the efficiency and environmental friendliness of electricity (Shrestha & Nakarmi, 2015). To meet this growing future demand for electricity, the installation of new power plants or increasing the import, scalability and improvisation of transmission and distribution networks seems inevitable shortly. The government, utility, and the end-user must cooperate in developing and implementing the necessary policy to narrow the gap between the supply and demand of electricity. (Shrestha & Nakarmi, 2015)

Two major sectors in which the load demand has seen increasing currently and the possibility to grow exponentially with technological advancement have been discussed in the following headings.

2.2.1 Electric cooking

Using electricity as a major energy source for cooking purposes is called electric cooking. Electric cooking has been transforming the worldwide cooking scenario, shifting from traditional cooking methods in which gas, wood, and petroleum products were the major energy sources. Momentum is building behind the changing potential of electric cooking to achieve a range of financial, environmental and social impacts (Leary et al., 2021). However, the uptake of e-cooking can be affected by perceptions around cost, taste, and safety and the lack of awareness/availability/after-sales service. That change could be driven forward rapidly by urbanization and changing lifestyles (Chheti et al., 2017). To achieve major change for electric cooking on a global scale, exploring the opportunities in a broader range of geographies, specially, studying the transition pathways of industrialized nations where electric cooking has already broken through into the mainstream, is required. Hot plates, microwave, and induction cooking are the modernized technology currently in electric cooking around the globe (Sweeney et al., 2014).

2.2.1.1 Induction Cooking

Induction cooking has many benefits over other cooking technology. The process of induction cooking is carried out using direct induction heating of cooking vessels. Induction cooking allows high power and rapid temperature increases to be achieved, and changes in heat settings are instantaneous. Significant advantage of Induction cookers is that the coil stays cool, has higher efficiency, has constant power output, is temperature control is flexible, cooks food fast, and has no shock hazards in cooking vessels (Chheti et al., 2017). In contrast, major disadvantages can be regarded as the higher initial cost, and only heating vessels with high resistivity and relative permeability can be used.

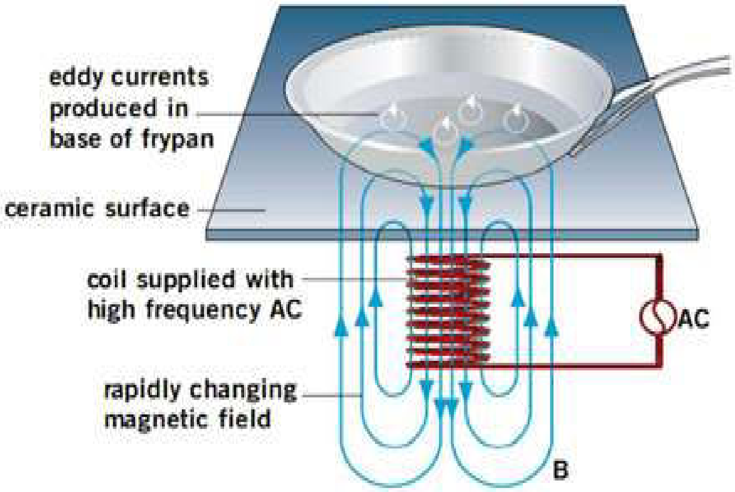

Figure 1 Working Mechanism of Induction stove (*Infographic*, 2022)

(i) Benefits and Grid Impacts

Energy Saving is the major Benefit of Induction cookers due to their technology and efficiency of up to 90%. Apart from energy savings, induction cooking offers several other benefits to the user. Firstly, most of the induction cooking units are equipped with an automatic shutdown feature that powers off the unit when the cooking vessel is removed due to which it is much less likely to cause fires or related injuries (Sweeney et al., 2014). Similarly, the surface of IC remains cooler than available other electric cooktops because heat is not generated in or beneath the cooktop. Another feature of induction cooking that is the level of control at low power settings (Rodríguez et al., 2019) which can provide continuous heat at less than the rated capacity.

Further with the heat generated directly in the cookware, induction cooking allows a much faster response, similar to natural gas. The effect of any consumer electronics device on the power quality of the distribution network apart from energy consumption can be analyzed. Evaluation by EPRI (CEC 2014) found the current harmonics of induction cooking technology to be relatively low, below 6% THD (of current) for all load levels (Sweeney et al., 2014). In addition, the power factor was measured at 0.98 and above. Although induction cooking uses high-frequency switching power electronics, these devices exhibit good power factors unlike switch-mode power supplies because their voltage is unregulated (Chheti et al., 2017). Instead, power flow control is done in induction cooktop by changing the switching frequency of the resonant converter driving the magnetic coil. The induction stoves generate more voltage harmonic distortion during its "ON" mode than in a standby mode. Current harmonic distortion is higher during induction stoves operation than in the stand-in mode(Rodríguez et al., 2019).

(ii) Fixed Cost and Operating Cost

Energy Savings being the significant advantages for Induction Plates, the fixed and operating costs are the major things to consider. Fixed costs are related to the purchase and installation of products, whereas Operating costs are energy costs. The fixed costs can be further broken down into induction cooktop and the utensils required. The induction cooktop/plate can be averaged to about NRs. 3200.00 (Daraz, 2022; Hamrobazaar.com, 2022) with a capacity up to 1500W, whereas the cost for the basic utensils required can be averaged to NRs. 3500.00 (Daraz, 2022; Hamrobazaar.com, 2022). Considering that the household is currently using a 5A electrical load, the upgradation to charge to maintain 15A to the utility is also considered the fixed cost. Nepal Electricity Charges NRs.100.00 (Authority, 2021) currently for upgradation of the capacity of single-phase meter and the cost of 15 A MCB is NRs.618.00 (Committee, 2021) as per the District rate of Kathmandu for the Fiscal Year 2078/079. So the fixed cost can be aggregated to NRs. 7418.00.

Now for the operation cost for the 1500W Induction Cooker, we can assume that around one hour is required for cooking in the morning and evening. The total energy use could be 3 kWh or three electricity units per day. Taking into account the highest unit price for 15A consumers, NRs. 12.00 per unit (Authority, 2021), the daily energy or operating cost amounts to NRs. 36 and a monthly total of NRs. 1,080.00 for 90 units.

On the other hand, according to an analysis done on cooking energy of Nepali households by Saligram Pokharel, a family of five people would consume a minimum of 3.8 GJ of final energy for food (Pokharel, 2004). Considering the efficiency of Induction cooking to be a minimum of 84%, 376 MJ of energy is required by a family monthly, which turns to be 104.7 kWh, pricing to NRs. 1,256.6 per month (Jayasekara & Fernando, 2020).

Considering the same amount of final energy analysis could be done on LPG gas energy, which is currently the most common cooking practice. Taking 55% efficiency for LPG gas to food, 575.75 MJ of energy is required by a family, which turns to be 12.51 kg of LPG as 1kg of LPG can be taken as equivalent 46MJ energy (Jayasekara & Fernando, 2020). According to Nepal Oil Corporation, the current price to refill per kg of LPG is 157.77 with subsidy (Limited, 2022). The total energy price for cooking by using LPG turns out to be NRs. 1973.7 per month.

2.3 National Policies, Targets, and Data

Nepal has been developing various plans internally through National Five Year Plans, Budget Speech, Ministries, and various organization within and have defined a set of targets to achieve those plans. Similarly, plans and targets are also set in coordination with international organizations such as UNFCCC and UNDP. Many plans and targets are directly related to energy and electricity consumption. The Government of Nepal formulates various policies to achieve these targets through related line ministries and organizations within the ministries. Ministry of Energy, Water Resources and Irrigation (MOEWRI) had issued an Energy white paper in 2018 with plans for Electric cooktop in every home, 50% of imported vehicles to be electric, upgraded/developed substations for reliable supply to an industrial corridor with a capacity of at least 5000 MW and others plans to be implemented within next five years.

Similarly, the 15th National Five Year plan has prioritized the electricity distribution master plan. In addition, the Government of Nepal, through budget speech for 2078/079, has reduced the customs duty on electric cooking appliances and reduced excise duty on electric vehicles to encourage consumers to increase the electrical load in their household and surrounding. Nepal also has submitted its Second Nationally Determined Contribution, 2020 to UNFCCC, where it is ensured that 25% of households use the electric stoves as their primary means of cooking and increase the sale of electric vehicles to cover 90% of all private passenger vehicle sales, including two-wheelers and 60% of all four-wheelers public passenger vehicle sale by 2030 (Nepal, 2020). Similarly, Nepal has set an SDG target through UNDP for accessibility of 99% of households to electricity, improve universal use of high-efficiency appliances, and per capita, electricity consumption increased to 1500 kWh all by 2030. According to the report published by the Ministry of Forests and Environment in the year, 2020 around 6% of the household use electric stoves as their primary medium of cooking (Division, 2021). Although the targets have been set, without proper intervention from the Government and related line agencies in the policies and promotions, it would be difficult to achieve the targets.

Along with these targets, it would be justifiable to mention the Nepal census preliminary report issued recently by the Government of Nepal as the targeted numbers could be more specific. The total population of Nepal has been published as 2,91,92,480, with an annual growth rate of 0.93% in the last ten years. Similarly, there are seen 67,61,059 numbers of total families living in 56,43,945 households throughout the country with 24.57% family rate increased in last ten years and current persons per family being 4.32 (Statistics, 2022).

2.4 Load Forecasting

The term forecast refers to projected load requirements, determined using a standardized approach of defining future loads insufficient quantitative detail to permit important system expansion decisions to be made. Load Forecasting is generally done for capacity and network planning for distribution and transmission systems, capital investment for generation and transmission, financial forecasting, efficient power procurement, selling and buying excess power, optimum supply scheduling, and fuel mix selection. The ability to forecast the long-term electricity demand is a fundamental prerequisite for developing a secure and economic power system (Hahn et al., 2009). Also, the demand forecast is used as a basis for system development and for determining tariffs for the future. Decision making is a complex process in the electricity sector, as various levels have to be considered which comprise the planning of day to day operation of generation units and their optimal use as well as the flow of power. These decisions address and affect widely different aspects of the system and time-horizon. For such planning and decision-making, load forecasts are very important. Forecasts made for day-to-day operation of the power system (Kyriakides & Polycarpou, 2007) requires the prediction of the load for a day ahead, whereas the decision whether to invest in major structure requires a far longer horizon of prediction. Load forecasts can be classified in the horizon of time as : short-term load forecasts which usually aim to predict the load up to one week ahead; medium-term load forecasts which predict the load from up to one year, and long-term load forecasts are usually up to 20 years although longer lead times of 25–30 years can be found. The decision-maker is faced with the task of selecting an appropriate model type as well as determining important external factors such as weather conditions over seasonal effects to socio-economic factors which are usually depend on each other. Various methods are applied to load forecasting (Feinberg & Genethliou, 2005; Kyriakides & Polycarpou, 2007; Taylor & McSharry, 2007).

Regression is one of the most commonly used statistical techniques used in load forecasting. For electric load forecasting, regression methods are usually used to model the relationship between load consumption and factors such as weather, day type, and customer class. Time-series methods assume that the data have an internal structure, such as autocorrelation, trend, or seasonal variation and have been used for decades in such fields as economics, digital signal processing, and electric load forecasting. Artificial neural networks (ANN or simply NN) have been a widely studied electric load forecasting technique since 1990. Neural networks are essentially nonlinear circuits with the demonstrated capability to do nonlinear curve fitting (Taylor & McSharry, 2007). The outputs of an ANN are some linear or nonlinear mathematical function of its inputs which may be the outputs of other network elements and actual network inputs. Among the mentioned models, Regression models are quite common in load forecasting (Kyriakides & Polycarpou, 2007). They have used rate to model the relationship between the load and external factors, for instance, weather and calendar information or customer types (Feinberg & Genethliou, 2005). Regression methods are relatively easy to implement where the relationship between input and output variables is easy to realize. Regression models also allow comparatively simple performance evaluations (Hahn et al., 2009).

2.4.1 Least Square Regression Model

The regression technique is a standard statistical approach to approximate future demand. Regression techniques are used to model the electric load as a function of load consumption in relationship with different dynamics like seasonal patterns, meteorological changes, day type, consumer social class, etc. In the regression technique, the correlation between a dependent variable, and one or more independent variables are modeled for analysis. The dependent variable is the response variable, while independent variables are called descriptive or predictor variables (Halepoto et al., 2014) . The Least Squares Regression method is the optimal approach when the model's form is known already, and the only interest is to find its parameters. The least-squares approach minimizes the difference of the independent estimators of the coefficients so that the estimated error is minimized to zero (Halepoto et al., 2014). In comparison with the linear and nonlinear approach, the non-linear regression method generates more precise results because it can fit the broad range of data sets and functions.

2.5 Power Flow Analysis in Distribution Feeder

A power system's power flow or load flow model basically used for operation and planning, is developed using the appropriate network, load, and generation data and used to calculate the voltages magnitude and angle for a provided load, generation, and network condition. Line flows and losses can be calculated once voltages are known for all buses (Albadi & Volkov, 2020). Power flow problem solving is identification of the known and unknown variables in the system based on which, the available buses are classified into three types: slack, generation, and load buses. The slack bus commonly considered as the reference bus because voltage magnitude and angle being specified, must provide the difference between scheduled generations the total system load, including losses and total generation. Slack bus is also called the swing bus. The remaining generator buses or PV buses are regulated because the net real power is specified and voltage magnitude is regulated. Load buses are called PQ buses because both net reactive and real power loads are specified. For load (PQ) buses, both voltage magnitudes and angles are unknown, whereas, for PV buses, only the voltage angle is unknown (Rupa & Ganesh, 2014). Most of the buses in real power systems are load buses.

Efficient and reliable load flow solution techniques, such as Gauss-Seidel (G-S), Newton-Raphson (N-R), and fast decoupled load flow, have been developed and widely used for power-system control, operation, and planning. However, it has been seen that these methods may become inefficient in analyzing distribution systems due to the special features of networks such as radial structure, high R/X ratio and unbalanced loads along with laterals. In addition to these, distribution network matrices are generally ill-conditioned, which may cause numerical problems for the conventional power flow algorithms (Eminoglu & Hocaoglu, 2008). These characteristic features make the distribution systems' power flow computation different and somewhat difficult to analyze compared to the transmission systems' load flow analysis.

Methods developed to solve ill-conditioned radial distribution systems may be divided into two categories. The first method is utilized by proper modification of existing methods such as N-R and G-S. On the other hand, the second group of methods is based on the forward and backward sweep process. In particular, the second method convergence ability of these algorithms is much faster when evaluated under different loading conditions and R/X ratios. This is more reliable than other methods.

2.5.1 Forward/Backward sweep based Algorithm

Forward/backward sweep-based load flow algorithms normally use benefit of the radial distribution network and consist of forwarding and backward sweep processes. In these algorithms, the forward sweep is the node voltage calculation from the sending end to the far end of the feeder and branches. The backward sweep is the branch current and power summation from the far end to the sending end of the feeder and laterals (Rupa & Ganesh, 2014). In addition to the branch current and power summation, some algorithms compute the node voltages in backward sweeps. These sweep-based power flow algorithms can be classified into Kirchhoff's formulation and the quadratic equation-based algorithms. Most of the distribution network power flow algorithms use Kirchhoff's Current Law (KVL) and Kirchhoff's Current Law (KCL) to calculate the node voltages in the forward and backward processes (Eminoglu & Hocaoglu, 2008). The backward and forward propagation iterative equation carries the distribution power flow. The forward/backward sweep based algorithm is mainly used in this research work because the iterations have fast convergence ability and are most suitable for radial structure.

2.6 Optimization and Techniques

Electricity distribution network are the major aspect of the power system which are generally complicated than other aspects as generation station and transmission networks. Due to the wide spread and complex nature of the distribution network, the power loss and involvement of manpower for maintenance and reliable operation are the fundamental parameters. The subject of reducing the manpower through partial automation and reduction of distribution losses are the major discussion scenarios for Distribution network operators. Therefore, much of the current research on distribution network automation has focused on the minimum-loss configuration problem (Kahouli et al., 2021). Various techniques are used for reducing losses at the distribution level such as reconfiguration, capacitor or DG installation, load balancing, and introduction of higher voltage levels.

Furthermore, to ensure a reliable, financially optimal electricity supply, it is crucial to reconfigure the distribution network to find the best possible solutions based on the requirements and constraints defined by the operators. Distribution network reconfiguration or optimization is adjusting or improving the branches or components of the distribution network to make the grid more reliable and efficient based on the power loading scenario. This process can improve the system's performance according to different particular objectives and constraints (Olamaei et al., 2008) .

The reliability of an electrical distribution network is the power system's ability to supply consumers uninterruptedly electricity supply. Some methods used for reliability improvement are addition of new devices for protection, deployment of more reliable equipment, fast switching and reclosing methods, precise fault allocation techniques, fast crew to speed up the repair process, and system topology reconfiguration (Abdelaziz et al., 2009).Distribution network reconfiguration is most effective to reduce active power losses if planned accordingly. The objective functions for the network reconfiguration are considered as the active power losses reduction and reliability of the distribution network.

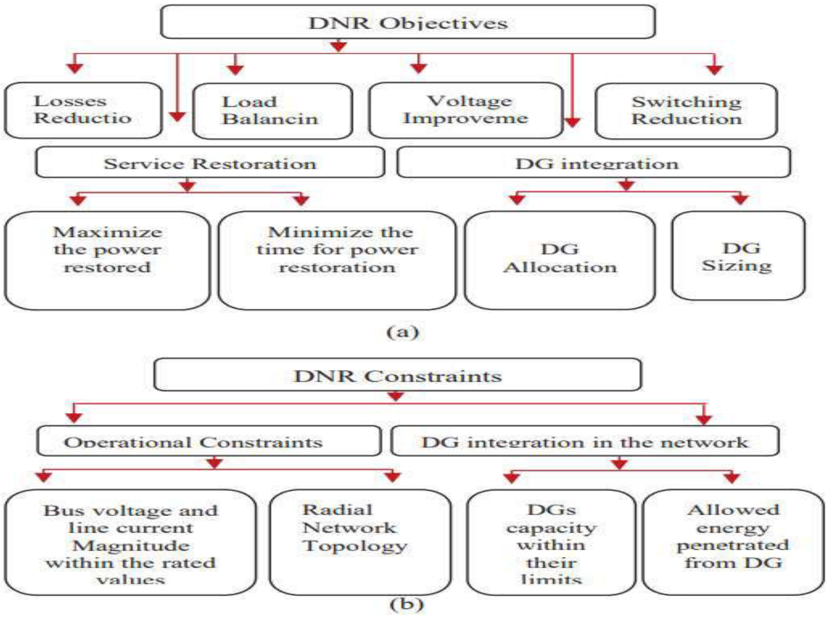

Figure 2 DNR Objectives and Constraints (Abdelaziz et al., 2009)

The reconfiguration algorithms can be classified by the solution methods they employ: those based upon a blend of heuristics and optimization methods, those using heuristics alone, and those using some form of artificial intelligence (AI). Numerous researchers advocate the use of a blend of heuristics and optimization techniques. Combining the two types of techniques permits the problem to retain a certain degree of accuracy while assuring convergence and an acceptable solution time. Comparative studies on different optimization methods show that the genetic algorithm (GA) and particle swarm optimization (PSO) approaches are the most widely used methods for solving problems (Abdelaziz et al., 2009). One of the advantages of these algorithms is that the problem's solution can still be obtained even there is no analytical solution for the problem.

2.6.1 DG Technologies

Distributed Generationo is basically generation of electric power within distribution networks or on the customer side of the network. Distributed Generation technologies can be generally classified based on their generation characteristics of active and reactive power, as illustrated in Figure below (Ackermann et al., 2001). Unique DG generation characteristics for each configuration can be represented by combining different energy sources with varying energy converters (Mahmoud et al., 2015). For this research, the DG was chosen as the reactive power supplier type because supplying reactive power statically helps to improve the voltage profile as well as recover overused currents in the branches, thereby reducing losses also.

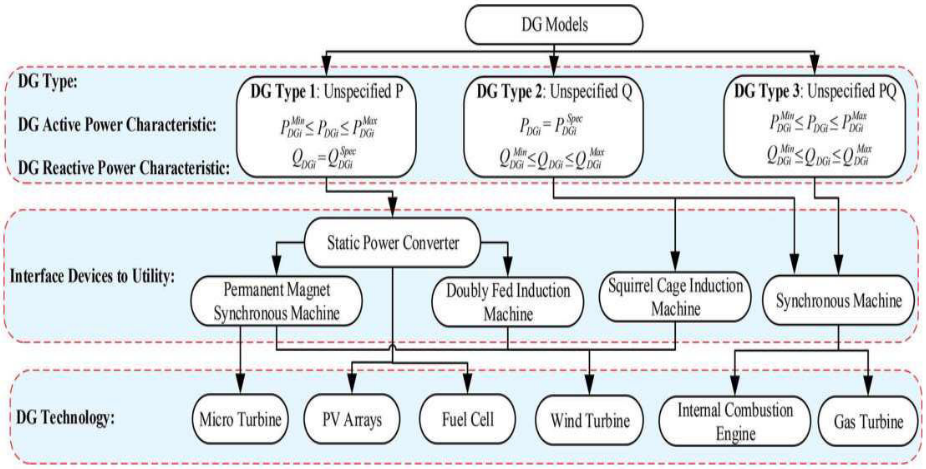

Figure 3 Classification of steady-state models of different DG technologies

2.6.2 PSO Approach

Particle swarm optimization (PSO) was first introduced by Kennedy and Eberhart in 1995 as a new heuristic method. The primary objective of this method was to graphically simulate the social behavior of bird flocks and fish schools which as progressed to discover that their social behavior model could serve as a powerful optimizer (Atteya et al., 2016). The first version of PSO was intended to handle only nonlinear continuous optimization problems that gradually elevated capabilities to handle a wide class of complex optimization problems.

PSO is a population-based technique that has major key advantages like it is a derivative-free algorithm unlike many conventional techniques, it has the flexibility to be integrated with other optimization techniques to form a hybrid tool, it is less sensitive to the nature of the objective function. Also this optimization technique is easy to implement and program with basic mathematical and logic operations and it can handle objective functions with stochastic nature (Abdelaziz et al., 2009). This approach was used in this research work as it is the best medium when using the continuous data that was available in the research to find the optimal location and sizing of distributed generation.

CHAPTER THREE: RESEARCH METHODOLOGY

This study is targeted at fulfilling the objective of the mentioned title. The control area is Tarkeshwor Municipality fed by three feeders; Dharamasthali, Goldhunga, and Jarankhu Feeder of Balaju Distribution Center, NEA. The feeders starts from Balaju Substation to Dharamasthai, Phutung, Goldhunga, and Nag Pokhari.

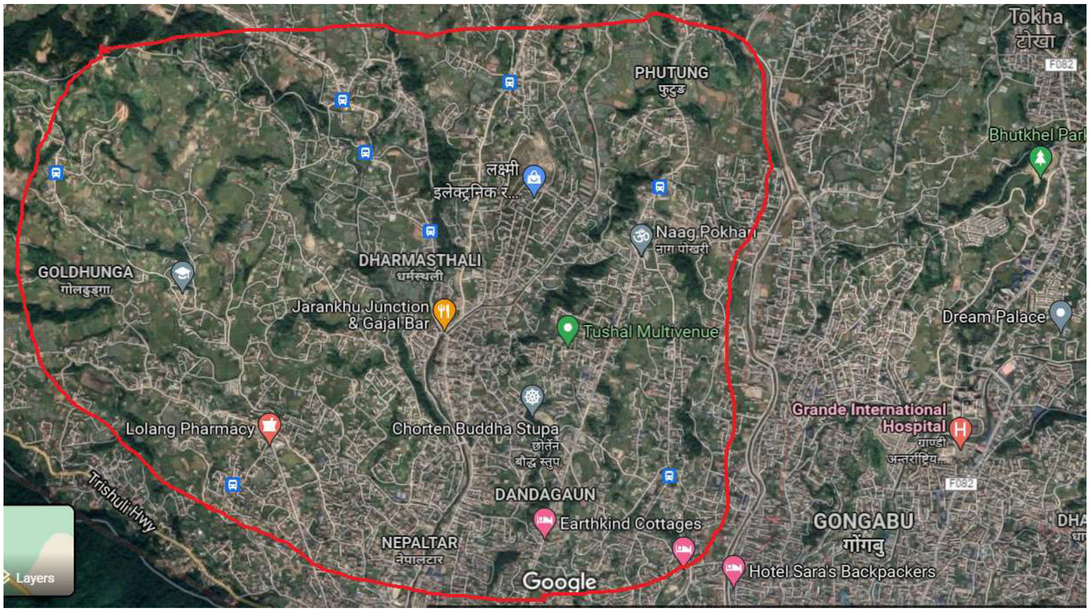

Figure 4 Areas supplied by Dharmasthali, Goldhunga and Jarankhu Feeders.

The past load demand was modeled with the sum of sine curve fitting, then the peak load and the base load were forecasted for the next ten years with the addition of emerging load to obtain the aim of the research. The grid impact analysis was performed during the base case and at the end of the tenth year. The research methodology was carried out with the steps shown in the stepwise flow chart, as shown in following Figure 5.

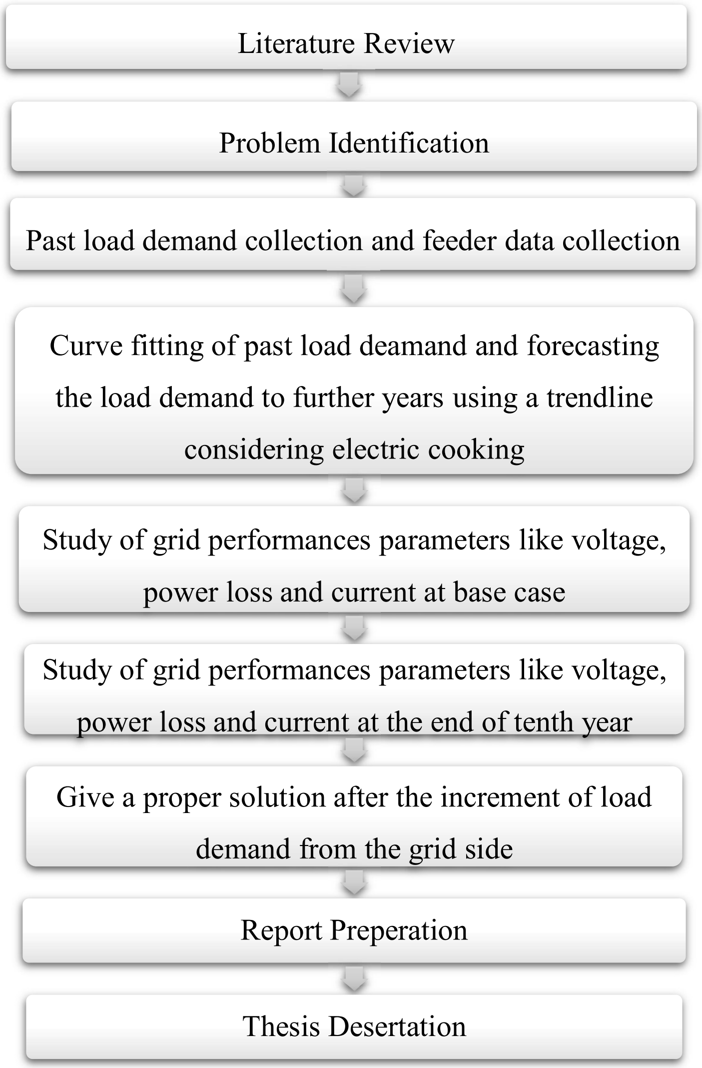

Figure 5 Stepwise flow diagram of the research

The analysis and finalization of research work in the above mentioned flowchart may be detailed with the following steps:

3.1 Data collection

There are the requirements of load demand data for the past few years. The data taken includes the hourly load current data for six Fiscal years (F/Y) and the total energy consumption throughout the year, with the increased number of domestic consumers. The Balaju Distribution Center (DC), NEA, provided these data. The feeder data at the chosen site was also taken from Balaju Substation, where the feeders started. The chosen site of the control area has been selected as Tarkeshwor Municipality, where Balaju Distribution Center feeds through Dharmasthali feeder primarily and gradually through Goldhunga and Jarankhu Feeder with the increase in consumers and demand. Then analysis was carried out in the following steps.

3.2 Curve fittings and load forecasting

For curve fitting of the hourly load demand, the sum of the sine algorithm was performed. The sum of the sine function works as shown in the algorithm below:

a) set the iteration index

   $i = 0$,

b) Make an initial estimation of the recorded data frequency f_0. For this task, you can use the DFT (for all or a part of the record), taking the inverse of the average period between zero crossings or taking into account the best result when applied input frequency. A very effective method is to use the Fast Fourier interpolation.

c) Perform Preliminary matching using three-parameter fit algorithm to determine A_0,B_0, C_0

d) set $i = i + 1$ for the next iteration

e) create matrices presented below:

$$x = \begin{bmatrix} x[1] \\ x[2] \\ \vdots \\ x[M] \end{bmatrix}$$

$$Do = \begin{bmatrix} \cos(2\pi f_i t_1) & \sin(2\pi f_i t_1) & 1 & -A_{i-1} t_1 \sin(2\pi f_i t_1) & B_{i-1} t_1 \sin(2\pi f_i t_1) \\ \cos(2\pi f_i t_2) & \sin(2\pi f_i t_2) & 1 & -A_{i-1} t_2 \sin(2\pi f_i t_2) & B_{i-1} t_2 \sin(2\pi f_i t_2) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \cos(2\pi f_i t_M) & \sin(2\pi f_i t_M) & 1 & -A_{i-1} t_M \sin(2\pi f_i t_M) & B_{i-1} t_M \sin(2\pi f_i t_M) \end{bmatrix}$$

$$x = \begin{bmatrix} A_i \\ B_i \\ C_i \\ \Delta f_i \end{bmatrix}$$

f) determine the solution of least squares using the following equation (1)

$$\hat{s_i} = (D_i^T D_i)^{-1}(D_i^T x) \tag{1}$$

g) Update frequency estimation using the relationship in equation (2) where for i = 1 the value = 0.

$$f_i = f_{i-1} + \Delta f_{i-1} \tag{2}$$

h) Determine the amplitude and phase in the equation (3) using relationships shown below in equation (4) and equation (5).

$$[n] = A\cos(2\pi f_i t_n + \varphi) + C \tag{3}$$

$$A = \sqrt{A_i^2 + B_i^2} \tag{4}$$

$$\varphi = -\arctan(B_i, A_i) \tag{5}$$

i) Repeat sequence of steps from (d) to (h), converting the model using the new values of A_i, B_i and f_i calculated from the previous iteration. Based on experiments, it was determined that the number of iterations should be accurately specified. The best results were achieved with six repetitions for the entire calculations cycle. This method doubles the number of significant digits in the parameter "f" with each iteration and converges very quickly.

j) The residuals of the fit and its error can be obtained from equation (6) and equation (7)

$$r[n] = x[n] - A_i\cos(2\pi f_i t_n) - B_i\sin(2\pi f_i t_n) - C_i \tag{6}$$

$$\varepsilon_{rms} = \sqrt{\frac{1}{M}\sum_{n=1}^{M} r[n]^2} \tag{7}$$

After curve fitting was performed using the inverse linear least square method, the peak load of the forecasted data was studied using a polynomial trend line. The polynomial trend line can be used for predicting the future value from the past trend. The polynomial trend line can be carried out with the 'n' numbers of expression as shown in equation (8).

$$F(x) = \sum_{k}^{n} a_k n^k = 0 \tag{8}$$

3.3 Grid parameters calculation

Grid impact can be studied by load flow analysis. For the radial distribution feeder, the best, easy and efficient way to perform load flow is by the Backward/Forward sweep algorithm. The backward forward sweep algorithm is shown in Figure 6.

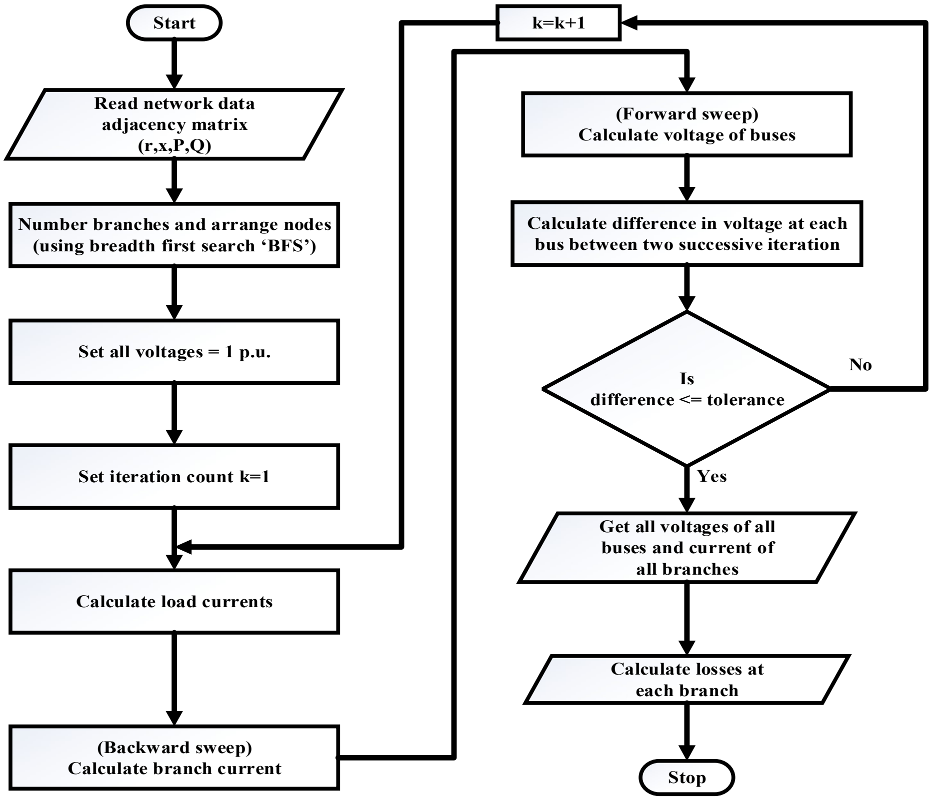

Figure 6 Backward forward sweep algorithm

The basic flow chart of the backward/forward algorithm is shown in Figure 6. The load flow was carried out with two propagation. On backward propagation, the branch currents are calculated with the initial bus voltage set to 1 p.u. On forward propagation, the bus voltages at each bus are calculated.

As shown in Figure 6, the load flow starts with the radial distribution feeder's input of line data and bus data. Then after the branches were arranged using the breadth-first search method. This helps in finding the end node of the feeder. After arranging the nodes and branches as per our requirement, we can move forward. The forward step is setting the initial guess, set all setting voltages at buses to 1 p.u. Now, starting the iteration count k=1, the load current is calculated for the first initial guess, and branch current is calculated using the backward sweep method. This is calculated using the Equations (9) and (10) below.

$$I_i^{(k)} = \left(\frac{S_i}{V_i^{(k)}}\right)^* - y_i V_i^{(k-1)} \tag{9}$$

$$J_l^{(k)} = -I_{lr} + \sum J_{lr} \tag{10}$$

Where,

i = 1, 2, 3,..................., n

S_i = power output at node i

V_i =voltage at node i

y_i = shunt admittance at node i

l= b, b-1, ... l

I_{lr} = current injection of node lr calculated from step 1

$\sum J_{lr}$ = currents in branches emanating from node lr

lr = 1, 2, 3,.......................b

Then in forward sweep methods calculation of voltages at each bus is carried out. The bus voltages are calculated using the Equation (11).

$$V_{lr}^{(k)} = V_{ls}^{(k)} - Z_l J_l^{(k)} \tag{11}$$

Where,

ls and lr denote the sending end and receiving end of the branch l

Z_l = series impedance of branch l

These backward and forward sweep methods are continuously iterated until the convergence criteria are met. Here the convergence criteria are checking the voltage difference at each bus of two successive iterations. The difference in voltage between two successive iterations should be less than 0.001. After the iteration criteria are met, the voltage and the branch currents are saved and power loss at each branch calculated. The branch losses are calculated using the equation (12) and (13) shown below.

$$P_l = \sum \left(\frac{P_i^2 + Q_i^2}{V_i^2} \times R_i \right) \tag{12}$$

$$Q_l = \sum \left(\frac{P_i^2 + Q_i^2}{V_i^2} \times X_i \right) \tag{13}$$

Where

P_i and Q_i are the total real and reactive power fed through i^{th} node

R_i= resistance of i^{th} branch

X_i= inductive reactance of i^{th} branch

3.4 Optimal location of DG

Here, to perform the optimization it requires an objective function followed by some boundries (i.e. constraints), which is named under as problem formulation.

Problem formulation

Stability problems are encountered in distribution system networks by power supply scarcity or mismatches, and that can be remedial by introducing the integration of DG units. While the distribution system is integrated with DG, the static DG units are equipped with power electronics converters which affect the voltage stability margin of the system. The DGs are integrated into an RDS to improve the voltage stability within a limit of 1±0.05 pu.

The objective function of the proposed methodology is to minimize the total active power loss under given constraints and conditions. The objective function is the sum of unlimited losses of the RDS and is provided in equation (14).

$$Objective\ function = minimize \sum_{i=1}^{total\ branch} P_{i,loss} \tag{14}$$

P_{loss} is the active power loss in a bus.

The given constraints are:

$$0.95\ Pu \leq V_{bus} \leq 1.05\ Pu$$

$$0 < Q_{DG,\ Size} \leq 60\% * Q_{total}$$

V_{bus} is the bus voltage, Q_{DG} is the sizes of DG units and Q_{total} is the sum of the total reactive power load of buses. Reactive power supplied by the DG unit is less than or equal to 60 % of the total load with DG.

3.5 Optimization using PSO

There are many types of DG available to be connected to the grid. All types of DG have their specifications and purpose. For our research, the DG was chosen as the reactive power supplier type (i.e. Capacitor banks). Capacitor bank was chosen because it doesn't need lots of space for installment. The optimization technique used is PSO. The PSO is most appropriate for locating the optimal size of DG at the optimal location. The basic flow chart of PSO is shown in the figure 7 below.

The optimal allocation of DG units is found by particle swarm optimization and it firstly generates the population of the solution. The objective function defined in Equation (14) is evaluated for each particle of the population and after the initialization of personal best (P_{best}) and global best (G_{best}), the position and velocity of a particle are updated using the given Equations (15) and (16) below and then P_{best} and G_{best} are updated. The optimized solution is evaluated after a defined number of iterations.

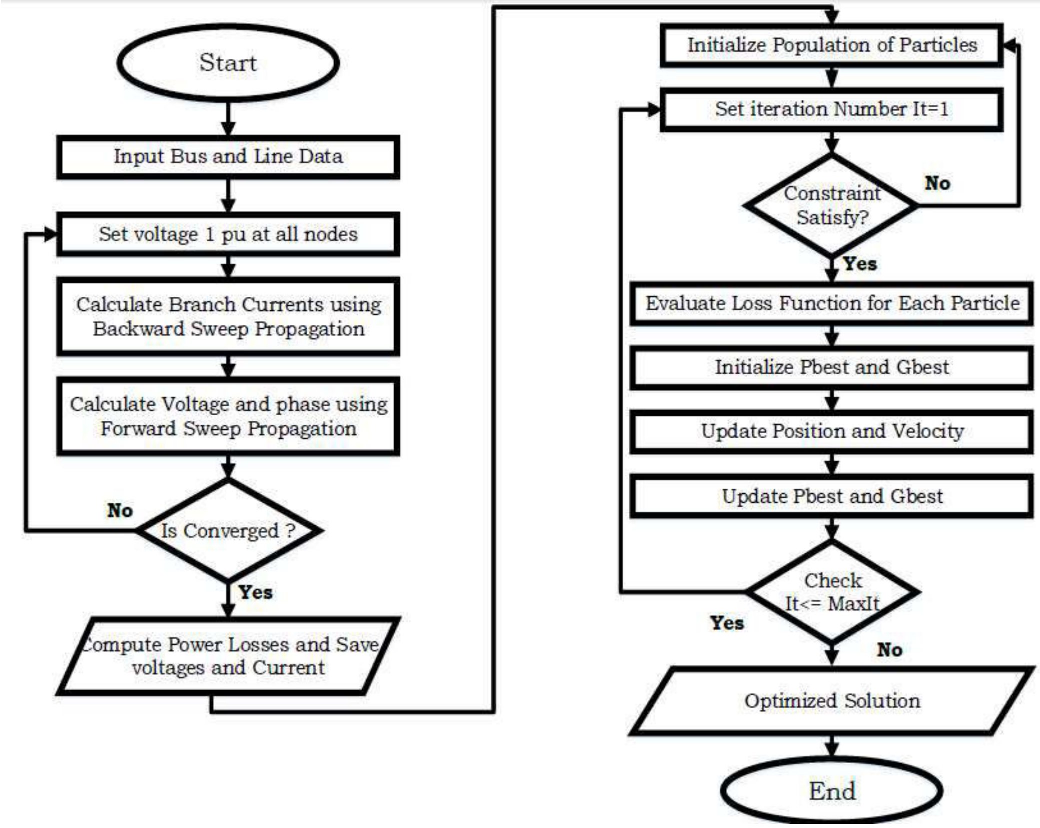

Figure 7 Flow chart of PSO with sweep algorithm

The optimal solution gives the minimum loss under subjected constraints, position of DG with its' size, and individual bus voltages and losses.

$$V_{id} = w * V_{id} + c_1 * rand( ) * (p_{id} - x_{id}) + c_2 * rand( ) * \left(p_{gd} - x_{id}\right) \qquad (15)$$

$$x_{id} = (x_{id} + V_{id}) \qquad (16)$$

In the proposed methodology, the size of the population is assumed to be 200 and the maximum number of iterations to be 100. The value of constants *c1* and *c2* both are assumed to *c1* = *c2* = 2. The inertia weight (w) is updated by the Equation (17) as:

$$w = w_{max} - \frac{w_{max} - w_{min}}{Maximum\ Iteration} * Iteration_{number} \qquad (17)$$

CHAPTER FOUR: RESULT AND DISCUSSION

The required load demand (current (amperes)) and the number of consumers at Dharmasthali feeder for the domestic consumer were taken from the NEA Balaju distribution Center. With the increasing load and consumers, the Dharamasthali feeder gradually split into three feeders; Dharamasthali, Goldhunga, and Jarankhu Feeder. The data also includes the total unit consumptions. The unit consumption following the number of consumers in the fiscal year for six years is shown in Table 13 in Appendix A. The feeder supplies 21821 numbers of domestic consumer at present. The domestic consumer constitutes of different sizes of load (5 A, 15 A, 30 A, and 60 A).

4.1 Number, energy consumption and load demand of domestic consumer

4.1.1 Number of domestic consumers

The table shown in Appendix A is shown graphically. Figure 8 shows the number of consumers' growth throughout the six fiscal years. The number of the consumer at 2072/2073 was about 13964, for F/Y 2073/2074 was 15350, for F/Y 2074/2075 was 17268, for F/Y 2075/2076 was 18980, for F/Y 2076/2077 was 20362 and for F/Y 2077/2078 was 21821.

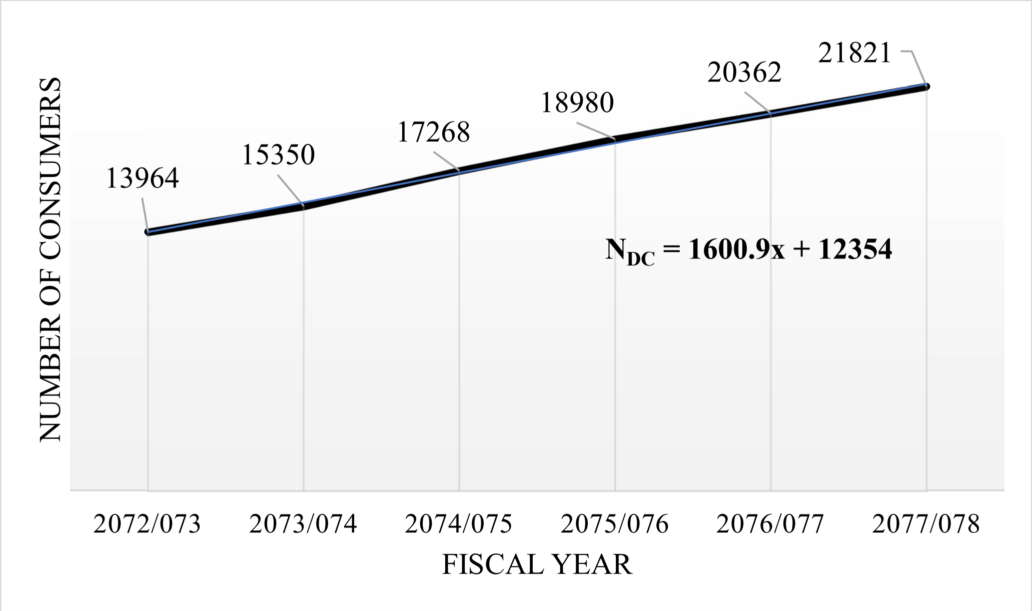

Figure 8 Domestic consumer growth at six fiscal years

The consumer growth rate at the end of F/Y 2072/073 was around 9.93%. Similarly, at the end of F/Y 2073/074 was 12.49%, at the end of 2074/075 was 9.92%, at the end of

2075/076 was 7.28% and at the end of 2076/077 was 7.16%. The consumer growth rate is almost constant except on the F/Y 2073/074, so the growth of consumers can be linearized (i.e., the consumer growth can be considered linear growth). While linearizing the graph, the coefficients of the linear Equation is shown in Equation (18).

$$N_{DC} = 1600.9 \times X + 12354 \qquad (18)$$

Where,

N_{DC} is the number of domestic consumers

X is the Fiscal year in number. i.e. x=1 is F/Y 2072/073.

From this linearization we can assume the number of domestic consumers increases by 1600 per year approximately.

4.1.2 Total energy consumption by domestic consumer

Figure 12 shows the energy consumption by domestic consumers in different six F/Y. The total unit consumption on 2072/073 was 1180275 kWh, for F/Y 2073/074 was 1451 kWh, for F/Y 2074/075 was 1603167 kWh, for F/Y 2075/076 was 1892155 kWh, for F/Y 2076/077 was 1993300 kWh and for F/Y 2077/078 was 2669173 kWh The unit energy consumption at the end of F/Y 2072/073 increased by 22.9% than before. In the same way, the energy consumption rate increases by 10.47% at the end of 2073/074,

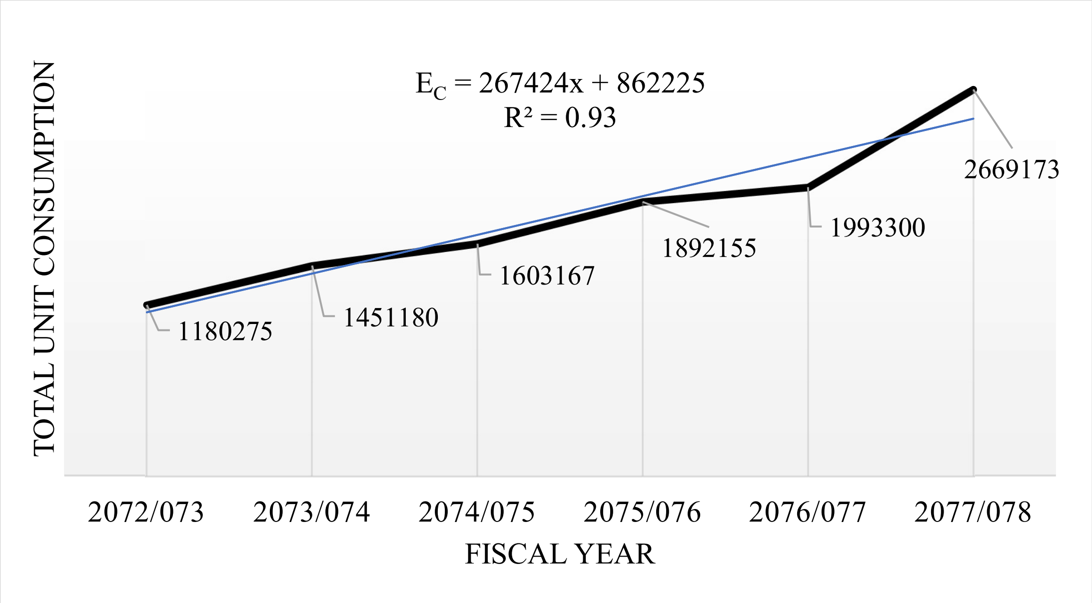

Figure 9 Total energy consumption for six fiscal years

18.02% at the end of 2074/075, 5.34% at the end of 2075/076, and 33.9% at the end of 2076/077.

The energy consumption rate can also be linearized by the equation (19) shown. R-Square is measured as the goodness of fit for linearization and found to be 0.93. This value of R-Square can be considered good for approximation.

$$E_C = 267424 \times X + 862225 \tag{19}$$

Where,

E_C is the total energy consumption in kWh

X is the number of F/Y, i.e. if X=1 then it represents F/Y 2072/073

From this linearization, as shown in Equation (19), the energy consumption rate can be assumed as 267424 kWh per year for approximation.

4.1.3 Total ampere load of the area

The total average load demand for five fiscal years throughout the day is shown in Figure 10. This graph shows domestic consumers' yearly average load demand in the control area. As shown in Figure 10, it can be seen that there are two peaks, one starting from 6th hours to 9th hours and the other starting at 17th hours to 22nd hours. It is also noticed that the average load demand is increasing yearly.

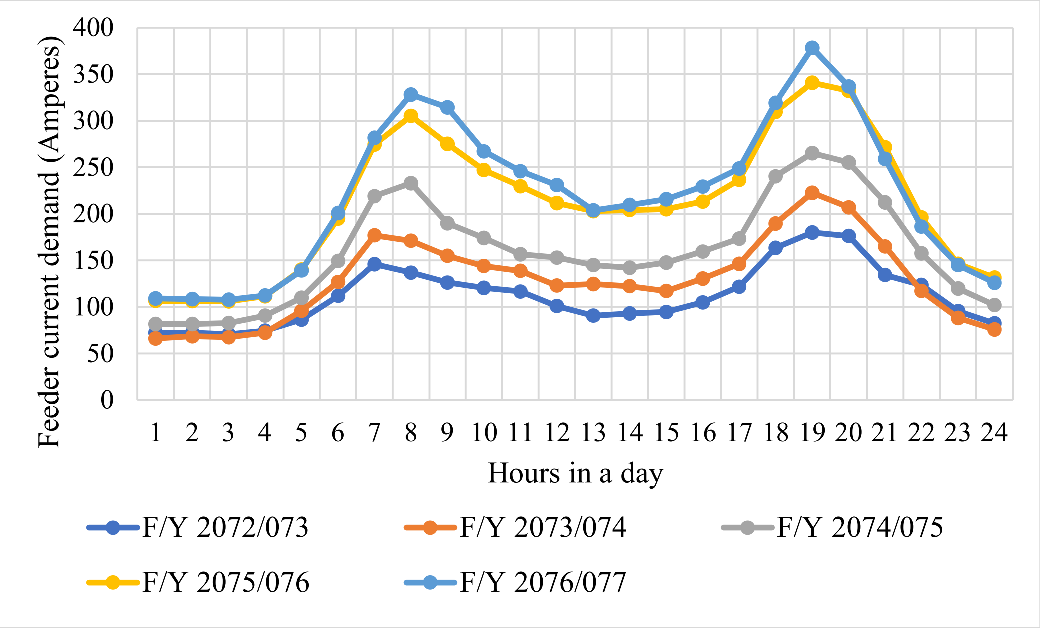

Figure 10 Hourly load demand for different fiscal years

Here the hourly load data is averaged for hours throughout the year irrespective of seasonal fluctuation of demand because the seasonal increment of load in any time of the year can be managed by alterations of branches and tie lines and up gradation of DTRs which is a regular process in any distribution service provider. Also various branches of the feeders are very less occupied in the capacity of current it can handle and have enough opportunities of shifting the load. Average hourly load throughout the year gives the scenario of the feeders loading in a holistic approach and to analyze with loading of the years to be forecasted.

The increasing trend of average hourly load demand was fitted to a curve using Sine summation function. This was done in MATLAB® 2014a curve fitting toolbox. The Figure 11 shows the snip of fitted curve from MATLAB® 2014a.

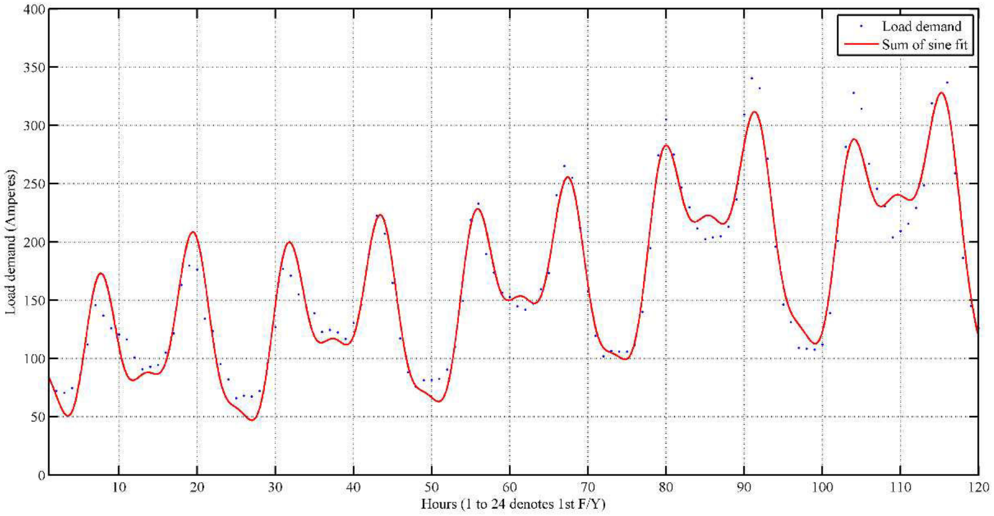

Figure 11 Average load demand fitted with the sum of sine curve

For checking the goodness of fit, R-Square was determined and was found to be 0.95009 for 8 number of summation terms of sine function. The Equation 20 shows the formulation of sine summation found by fitting the data. All the coefficients of sinusoidal function are determined with 95% confidence bounds.

$$Load_{Hourly} = F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7 + F_8 \qquad (20)$$

Where,

$$F_1 = a_1 \times \sin(b_1 \times \mathrm{x} + c_1)$$

$$F_2 = a_2 \times \sin(b_2 \times x + c_2)$$

$$F_3 = a_3 \times \sin(b_3 \times x + c_3)$$

$$F_4 = a_4 \times \sin(b_4 \times x + c_4)$$

$$F_5 = a_5 \times \sin(b_5 \times x + c_5)$$

$$F_6 = a_6 \times \sin(b_6 \times x + c_6)$$

$$F_7 = a_7 \times \sin(b_7 \times x + c_7)$$

$$F_8 = a_8 \times \sin(b_8 \times x + c_8)$$

Note: x denotes the hours for different F/Y. i.e. for first F/Y x starts from 1 hours to 24 hours. And F_n denotes the load demand data. With n starting from 1 to 8.

The values of coefficients within the 95% confidence bounds are tabulates as shown in Table 1. Here, all the values of coefficients are in radian. These coefficients are found by using nonlinear least square method.

Table 1 Coefficients for sum of sine fit

Coefficients	Coefficients	Coefficients
$\boldsymbol{a_1 = 298.6}$	$b_1 = 211.5$	$c_1 = 0.3109$
$\boldsymbol{a_2 = 211.5}$	$b_2 = 0.0493$	$c_2 = 2.474$
$\boldsymbol{a_3 = 61.62}$	$b_3 = 0.5227$	$c_3 = -2.444$
$\boldsymbol{a_4 = 44.64}$	$b_4 = 0.2588$	$c_4 = -2.253$
$\boldsymbol{a_5 = 112.9}$	$b_5 = 0.09187$	$c_5 = 3.207$
$\boldsymbol{a_6 = 19.9}$	$b_6 = 1.047$	$c_6 = 0.02586$
$\boldsymbol{a_7 = 67.86}$	$b_7 = 0.1083$	$c_7 = 5.3$
$\boldsymbol{a_8 = 19.79}$	$b_8 = 0.223$	$c_8 = 2.136$

The load demand is now forecasted using Equation (20) with the coefficients shown in the Table 1 above. The forecasted value with the actual demand comparison curve is shown in Figure 12. There are some of the outliers that are not taken into account while fitting the demand. The R-Square is found to be around 95%, so the fitted data with the sum of sine wave can be taken for approximation for the further years.

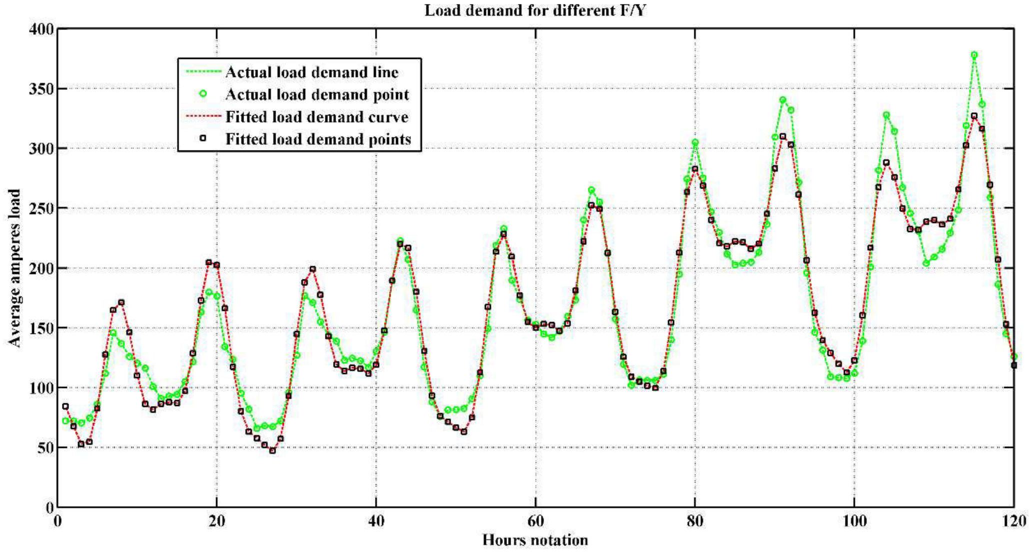

Figure 12 Comparison between actual demands vs. average demands

The curve fitted demand and the actual average demand is the current (Amperes) of feeders of the domestic consumer. As shown in Figure 12 above, the demands are of five F/Y with 24- hours load (each hourly load). The demand from 1 to 24 shows the first F/Y i.e. 2072/073, demand from 25 to 48 shows the hourly demand form first hour to 24th hours for 2nd F/Y i.e. 2073/074 and so on.

4.2 Performing load forecasting of peak loads and base load.

The load forecasting done here is the long term load forecasting. The average yearly amperes load is forecasted using the sum of sine function with 8 terms. While performing load forecasting the following points are taken as assumptions:

1. Demand forecasted was carried out for the next 10 years form the F/Y 2077/078.
2. The growth rate of domestic consumers was considered as increased by 1600 numbers each years.
3. The energy consumption by electric cooking growth rate was considered as 15% for the first five years and next five years as 10%. This was considered in accordance to the nations goals.

4 By the use of electric cooking loads, peak load of the system increase. So, peak load and base load demand was only forecasted for every F/Y.

5 The size of electric cooking was taken as an average size of 1500 Watts for each domestic consumer.

By considering all the above points, the peak load and base load forecasting for ten years from now is shown in Figure 13.

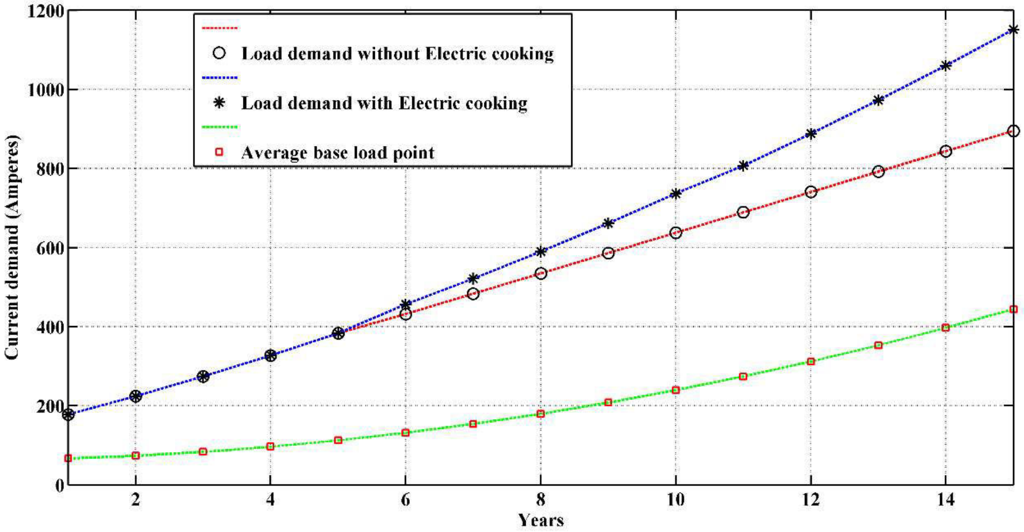

Figure 13 Peak load and base load forecasting for next 10 years with and without EC

As shown in figure 13, the forecasted value using the sum of sine wave fitting trend lines gives the peak load demand as 452.048 Amperes for the first forecasted year and at the end of the tenth year, the peak load demand current values will be 1151.31 Amperes. Similarly, for baseload demand, forecasted values will be 131.584 Amperes for 1st forecasted year and at the end of the 10th year, the forecasted baseload demand would be 443.89 Amperes.

Table 2 below shows the apparent power forecasted demand for peak load and baseload for the further ten years.

Table 2 Forecasting demand for next Ten Fiscal Year

S.N.	F/Y (B.S.)	Peak Load with EC (MVA)	Peak Load without EC (MVA)	Base Load (MVA)
1.	2078/079	8.697	8.224	2.507
2.	2079/079	9.936	9.2048	2.932
3.	2079/080	11.234	10.186	3.416
4.	2080/081	12.600	11.166	3.959
5.	2082/083	14.030	12.147	4.561
6.	2083/084	15.374	13.128	5.222
7.	2084/085	16.919	14.109	5.942
8.	2085/086	18.527	15.090	6.721
9.	2086/087	20.199	16.070	7.560
10.	2087/088	21.935	17.051	8.457

As shown in Table 2 above, it can be seen that the load demand increases by three times in 10 years from now. There will be around 4.8 MVA more load while considering the electric cooking. The existing grid system may or may not support this increment in the load; therefore, it is necessary to do the grid impact performance.

4.3 Grid impact analysis

In the grid impact analysis the parameters studied were voltage profile, power losses and branch currents were studied. For testing the code written in MATLAB®, the grid impact analysis was performed in IEEE-34 bus system. After verifying the test the same code was used for three feeders erected from Balaju substation.

4.3.1 Parameter calculation for IEEE-34 Bus system

The bus data and load data for the IEEE-34 test bus were taken from the reference (Soroudi & Ehsan, 2010), situated in the Appendix section. The feeder diagram of the

IEEE-34 bus is shown in the Figure below. As we can notice, the feeder's total active power demand is 4636.5 kW, and the reactive power demand is 2873.5 kVAr.

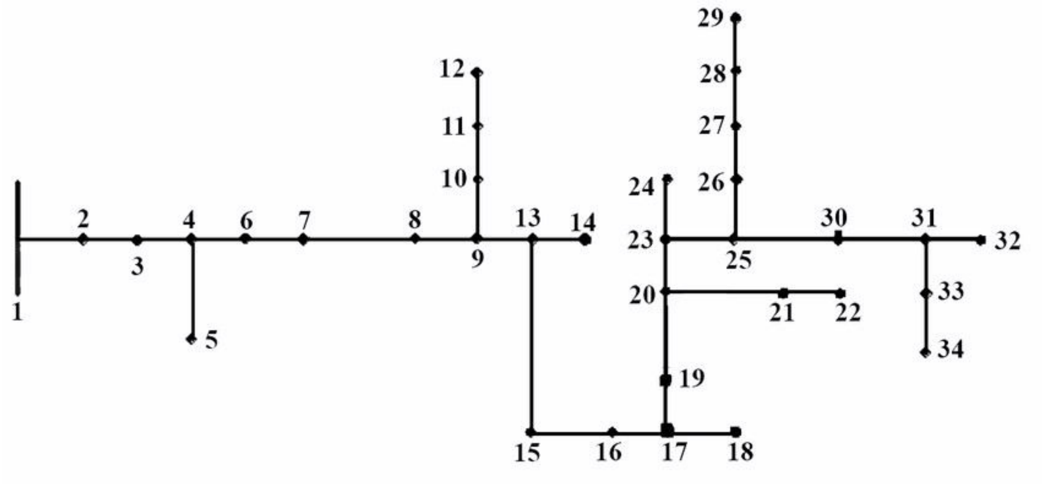

Figure 14 Distribution network configuration of IEEE-34 test bus

Power losses and branch currents load flow were determined using the backward/forward sweep algorithm to determine the voltage profile. The sweep algorithm gives the voltage profile of the radial feeder at the base case, which is shown in Figure 15. The voltage profile shown here is the per unit value with the base voltage of 11 kV.

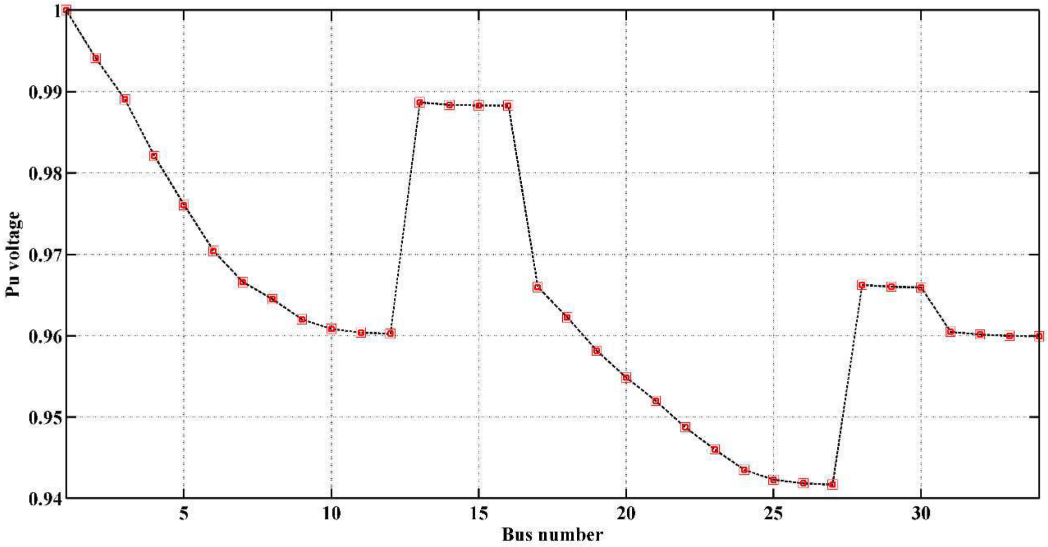

Figure 15 Voltage profile of IEEE-34 bus at base case

The figure shown above was obtained with the base voltage of 11 kV and base power of 100 MVA. The voltage values are compared with the standard value obtained by paper citation (Soroudi & Ehsan, 2010). It almost has the exact nature as the compared standard and got the minor error if calculated. Moving to the power loss, we obtain for the IEEE-34 test bus a total active power loss of 221.7199 kW and a total reactive power loss of 65.109 kVAr. While comparing to the reference paper (Soroudi & Ehsan, 2010), we can tabulate the loss result as shown in Table 3

Table 3 Comparison of calculated loss with reference paper

Parameters	Calculated Loss	From paper	Absolute error
Active Power loss	221.7199 kW	221.29 kW	0.4299 kW
Reactive power loss	65.109 kVAr	65.1 kVAr	0.009 kVAr

From the table above it can be clearly seen that, the program can be used for predicting the grid impact parameters (i.e. Voltage profile, loss calculation, and branch currents).

4.3.2 A case study in Balaju Distribution Center area.

The study was carried out for three feeders of Balaju Distribution Center. The three feeders outing is dharmasthali feeder, goldhunga feeder, and jarankhu feeder, supplying significant portions of Tarkeshwor Municipality. The substation delivers the total demand of 8036 kW of active power through these feeders. All three feeders deliver power to domestic consumers with a base voltage of 11 kV. The grid impact study for three feeders is performed and listed here.

Base case study of Dharmasthali feeder

The feeder has 50 buses with a total active power demand of 2476 kW. The load flow using the sweep algorithm was studied with a base voltage of 11 kV and a base power of 100 MVA. The voltage profile obtained from the load flow at the base case is shown in Figure 16.

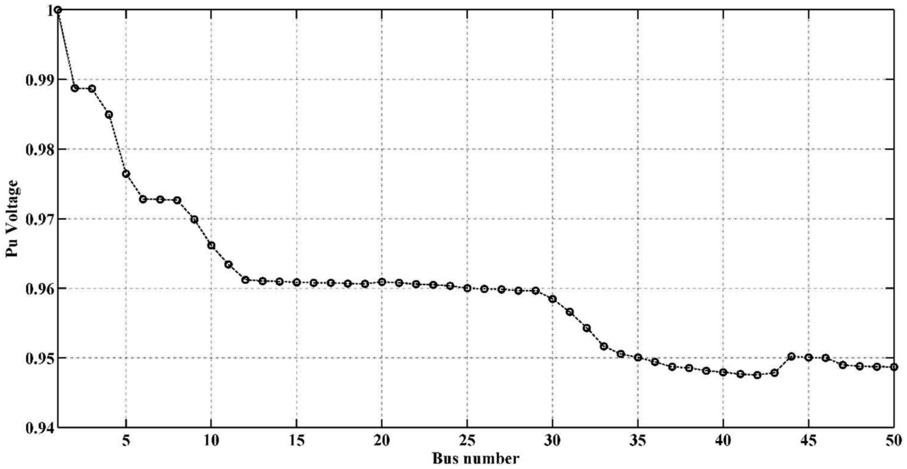

Figure 16 Pu voltage profile of Dharmasthali feeder at base case

As shown in Figure 16 above, the minimum voltage is 0.947 Pu at bus number 42, and the maximum is 0.988 Pu at bus number 2, excluding slack bus (i.e., Balaju substation). The other buses have a voltage between 0.947 Pu and 0.988 Pu. The feeder has a total active power loss of 122 kW (around 5% of the total active power demand), and reactive power loss is about 61 kVAr.

Base case study of Goldhunga feeder

The feeder starting from the Balaju substation to Thulo Khola II has 55 buses with a total active power demand of 2720 kW. As in the Dharmasthali feeder, the sweep algorithm was carried out with a base voltage of 11 kV and a base power of 100 MVA. The voltage profile obtained from the load flow at the base case is shown in Figure 17.

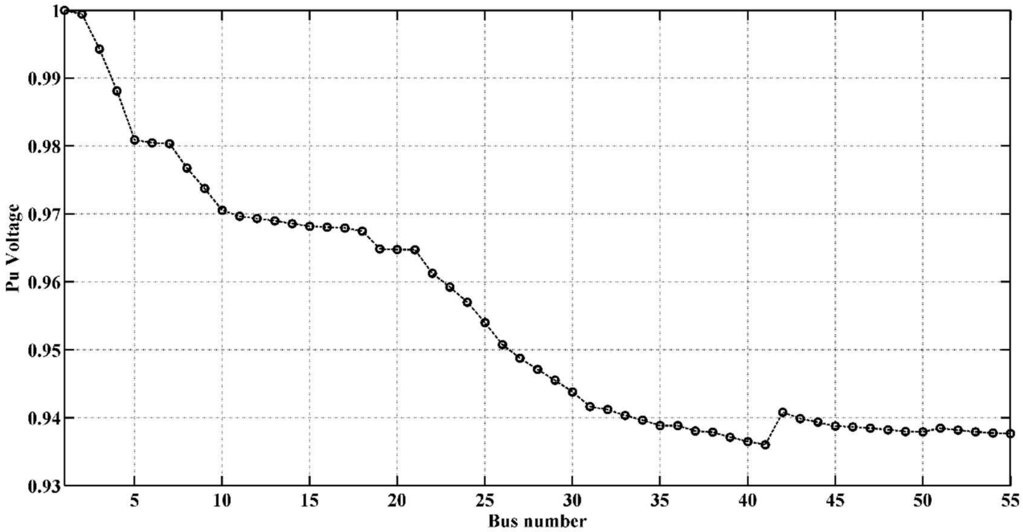

Figure 17 Pu voltage profile of Goldhunga feeder at base case

As shown in Figure 17 above, the minimum voltage is 0.936 Pu at bus number 41, and the maximum is 0.999 Pu at bus number 2, excluding slack bus (i.e., Balaju substation). The other buses have a voltage between 0.936 Pu and 0.999 Pu. The feeder has a total active power loss of 151.37 kW (around 5.56% of the total active power demand), and reactive power loss is about 60.548 kVAr.

Base case study of Jarankhu feeder

Jarankhu feeder starting from Balaju substation to paiyatar having 38 buses with a total active power demand of 2840 kW. The sweep algorithm was carried out in the Dharmasthali feeder and Goldhunga feeder with a base voltage of 11 kV and base power of 100 MVA. The voltage profile obtained from the load flow at the base case is shown in figure 18.

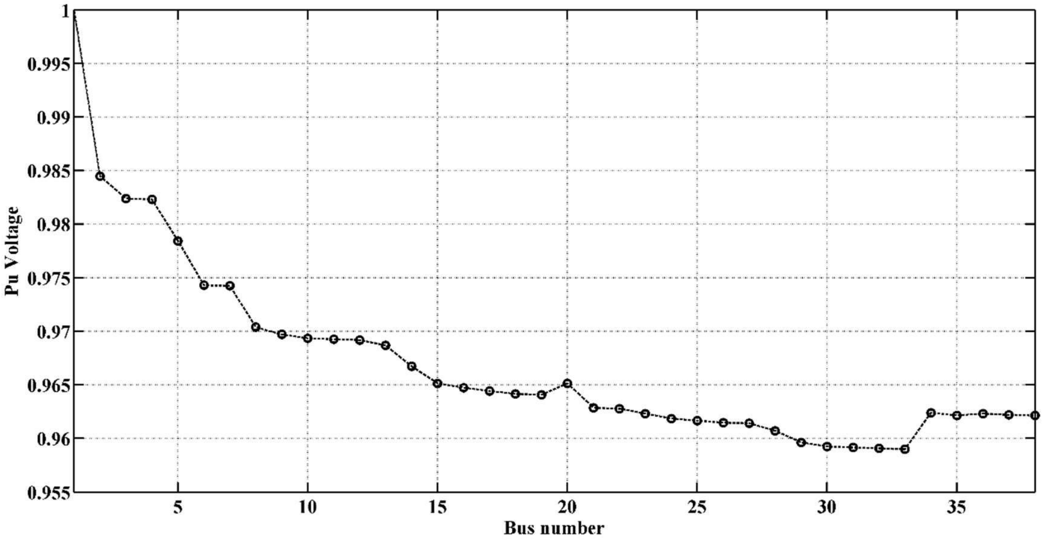

Figure 18 Pu voltage profile of Jarankhu feeder at base case

As shown in Figure 18 above, the minimum voltage is 0.959 Pu at bus number 33, and the maximum is 0.984 Pu at bus number 2, excluding slack bus (i.e., Balaju substation). The other buses have a voltage between 0.959 Pu and 0.984 Pu. The feeder has a total active power loss of 109.28 kW (around 3.85% of the total active power demand), and reactive power loss is about 43.712 kVAr.

4.4 Grid parameters for forecasted value at the tenth year

As viewed from the above section (i.e., forecasted peak value), it can be seen that the total demand for the tenth year was found to be 21.935 MVA. This increased demand is a total of three feeders (i.e., Dharmasthali feeder, Goldhunga feeder, and Jarankhu feeder). This load increase was distributed to all the three feeders by their weightage. Three feeders fulfill the total demand by the following assumptions.

- The total load is shared as 30.81% by Dharmasthali feeder, 33.84% by Goldhunga feeder and 35.34% by Jarankhu feeder. So with this ratio, the increased ratio was distributed as 6.75 MVA by Dharmasthali feeder, 7.422 MVA by Goldhunga feeder and 7.75 MVA by Jarankhu feeder.
- The increase load in each feeder was considered to be shared by all of the transformers, (i.e. all the transformers loading will be increased by their installed capacity ratio).

4.4.1 Grid performance parameters for forecasted load at Dharmasthali feeder

The predicted load demand at the end of tenth year for Dharmasthali feeder is around 7.75 MVA, which is shared by all the transformer in accordance to their weightage. Figure 19 shows the voltage profile at base case compared with forecasted case.

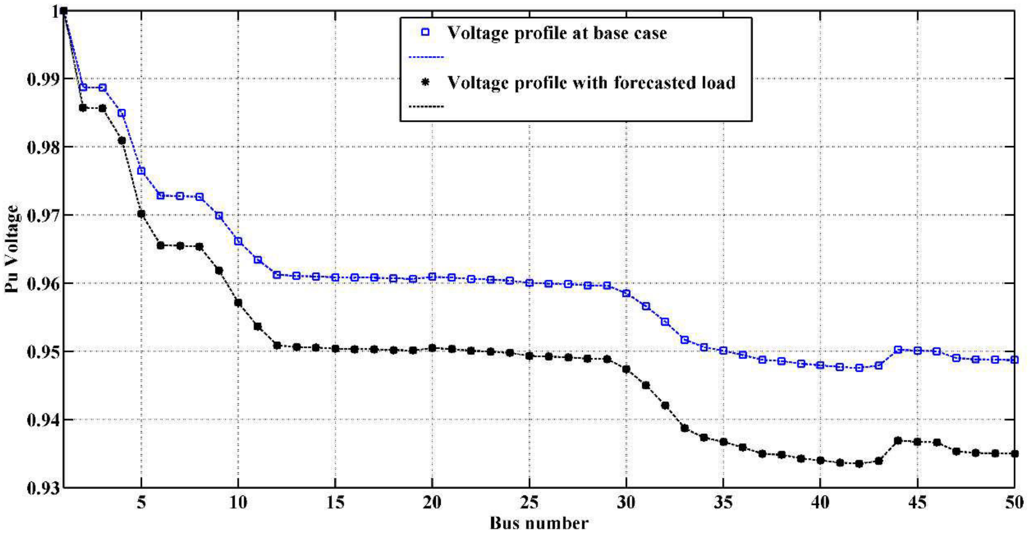

Figure 19 Comparison of voltage profile of Dharmasthali feeder

As shown in Figure 19, the addition of load after the tenth year will result in the voltage drop. After forecasting, the predicted voltage drop was found to be 0.933 Pu at bus number 42, and the maximum voltage was 0.985 Pu at bus number 2, excluding slack bus. The minimum voltage was changed from 0.947 Pu to 0.933 Pu, and the maximum voltage changed from 0.988 Pu to 0.985 Pu at the respective buses 42 and 2. The predicted active power loss increased to 392.2 kW (increased from 122 kW, i.e., by 221%), and reactive power loss increased to 196.1 kVAr (increased from 61 kVAr). The current rating at each branch is shown in Table 4 below.

Table 4 Branch current of Dharmasthali feeder

Branch number	Current (A)	Branch number	Current (A)
1	**429.43**	26	17.312
2	3.3335	27	10.388
3	**412.76**	28	6.9255
4	**406.06**	29	210.49
5	**399.29**	30	203.55
6	6.8063	31	196.6
7	13.614	32	182.65
8	**372.06**	33	168.65
9	**356.69**	34	91.432
10	**349.82**	35	84.417
11	**336.04**	36	77.395
12	27.656	37	70.366
13	20.743	38	63.337
14	13.83	39	56.303
15	6.9151	40	35.194
16	27.663	41	14.079
17	13.832	42	14.073
18	6.9164	43	63.195
19	13.829	44	14.032

20	6.915	45	7.0161
21	49.493	46	35.136
22	42.576	47	21.084
23	41.539	48	14.057
24	38.079	49	7.0285
25	6.923		

Table 4 clearly shows that, branch number 1, 3, 4, 5, 8, 9, 10 and 11 have a high current rating that a DOG conductor cannot support. So, either current rating should be reduced by certain compensation or the conductor for that branches should be replaced. If replacement is preferred then ampacity of conductor should withstand the maximum current rating.

4.4.2 Grid performance parameters for forecasted load at Goldhunga feeder

Forecasted load for Goldhunga feeder at the end of tenth year is 7.42 MVA. As in Dharmasthali feeder the load is assumed to be shared by all the transformer in accordance to their weightage. Figure 20 shows the voltage profile at base case compared with forecasted case.

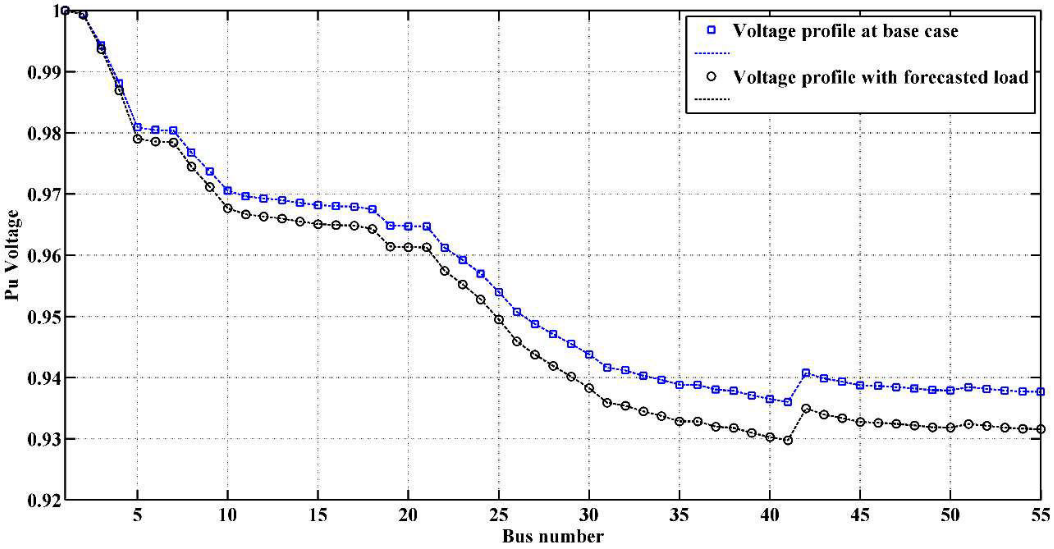

Figure 20 Comparison of voltage profile of Goldhunga feeder

As shown in Figure 20, the addition of load after the tenth year will result in the voltage drop. After forecasting, the predicted voltage drop was found to be 0.929 Pu at bus number 41, and the maximum voltage was found to be 0.99 Pu at bus number 2, excluding slack bus. The minimum voltage was changed from 0.936 Pu to 0.929 Pu, and the maximum voltage didn't change at the respective buses 41 and 2. The predicted active power loss increased to 364.6 kW (increased from 151.37 kW, i.e., by 241%), and reactive power loss increased to 145.84 kVAr (increased from 60.54 kVAr). The current rating at each branch is shown in the table below.

Table 5 Branch current of Goldhunga feeder

Branch number	Current (A)	Branch number	Current (A)
1	**409.52**	28	187.31
2	**398.06**	29	172.08
3	**392.29**	30	169.03
4	**386.49**	31	76.894
5	17.566	32	75.363
6	11.711	33	69.232
7	**363.07**	34	63.097
8	**351.31**	35	1.5354
9	**339.52**	36	55.419
10	59.326	37	49.272
11	47.472	38	43.123
12	35.614	39	36.969
13	29.683	40	30.811
14	23.75	41	86.011
15	17.813	42	79.883

16	5.9382	43	73.749
17	268.35	44	67.611
18	262.41	45	30.73
19	11.92	46	24.587
20	5.96	47	18.442
21	238.57	48	12.296
22	235.58	49	6.1483
23	223.58	50	30.739
24	211.56	51	24.594
25	205.52	52	18.448
26	199.47	53	12.3
27	193.4	54	6.15

Table 5 above clearly shows that, branch number 1, 2, 3, 4, 7, 8, and 9 have a high current rating that a DOG conductor cannot support. So, as in case of Dharmasthali feeder, either current rating should be reduced by certain compensation or the conductor for that branches should be replaced. If replacement is preferred then ampacity of conductor should withstand the maximum current rating.

4.4.3 Grid performance parameters for forecasted load at Jarankhu feeder

As in Dharmasthali feeder and Goldhunga feeder forecasted load at the end of tenth year is 6.75 MVA. For this feeder also the load is assumed to be shared by all the transformer in accordance to their weightage. Figure 21 shows the voltage profile at base case compared with forecasted case.

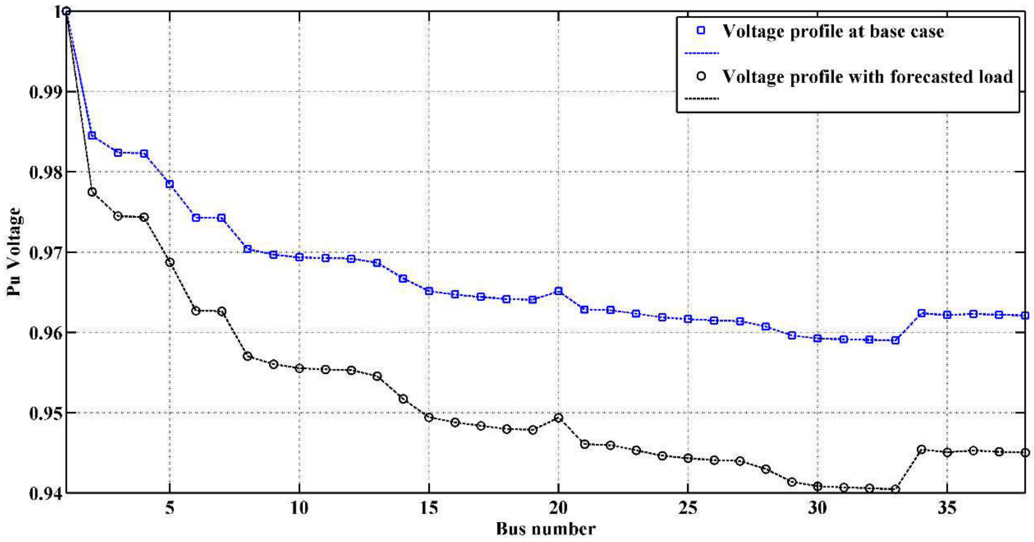

Figure 21 Comparison of voltage profile of Jarankhu feeder

As shown in Figure 21, the addition of load after the tenth year will result in the voltage drop. After forecasting, the predicted voltage drop was found to be 0.94 Pu at bus number 33, and the maximum voltage was found to be 0.977 Pu at bus number 2, excluding slack bus. The minimum voltage was changed from 0.959 Pu to 0.94 Pu, and the maximum voltage changed from 0.984 Pu to 0.977 Pu at the respective buses 33 and 2. The predicted active power loss increased to 306.4 kW (increased from 109.28 kW, i.e., by 280%), and reactive power loss increased to 122.5 kVAr (increased from 43.7 kVAr). The current rating at each of the branches is shown in Table 6..

Table 6 Branch current of Jarankhu feeder

Branch number	Current (A)	Branch number	Current (A)
1	**371.4**	20	156.09
2	**320.3**	21	10.561
3	10.253	22	87.419
4	**299.8**	23	31.738
5	**284.33**	24	21.163
6	10.378	25	15.873

7	**263.57**	26	10.583
8	47.042	27	45.113
9	31.369	28	39.816
10	20.914	29	29.204
11	10.457	30	18.587
12	211.31	31	13.277
13	200.85	32	5.3111
14	198.22	33	42.276
15	31.606	34	10.57
16	26.342	35	5.284
17	15.808	36	15.855
18	5.2696	37	5.2854
19	5.2612		

Table 6 clearly shows that branch numbers 1, 2, 4, 5, and 7 have a high current rating that a DOG conductor cannot support. So, as in the case of Dharmasthali and Goldhunga feeder, either the current rating should be reduced by specific compensation or the conductor for that branches should be replaced. If replacement is preferred, then the conductor's ampacity should withstand the maximum current rating.

As seen from the above analysis, the active power loss was increased by more than 200% for all three feeders. It was also noticed that the branch currents for some of the feeders mentioned above at the mentioned feeders also exceed the ampacity rating of the existing conductor. So, it is first suggested to place the optimal size of DG at optimal locations to reduce loss. If the current rating still doesn't reduce, a twining of the conductor may be suggested.

4.5 Optimal placement of DG for different feeders

To reduce the grid impact due to forecasted load, optimal placement of capacitor was considered using PSO. The Methodology section shows that the particle swarm optimization algorithm was coded in the MALAB® code environment. The PSO termination criteria were 100 iterations with constants c1=c2=2 and the population to be 200. The results obtained from the code are shown below:

4.5.1 Optimal placement of capacitor at Dharmasthali feeder

After 100 iteration the PSO was converged was converge as shown in Figure 22. The plot is between the numbers of iteration versus best power loss per iteration.The optimal size of the capacitor with the respective optimal bus number is shown in Table 7. The optimal buses for placement of capacitors are found to be bus number 2 with optimal size 3000 kVAr, and another bus is 31 with 1500 kVAr size of the capacitor, next bus was determined as bus number 34 with the optimal size 1125 kVAr and bus number 41 with an optimal size of the capacitor of 750 kVAr.

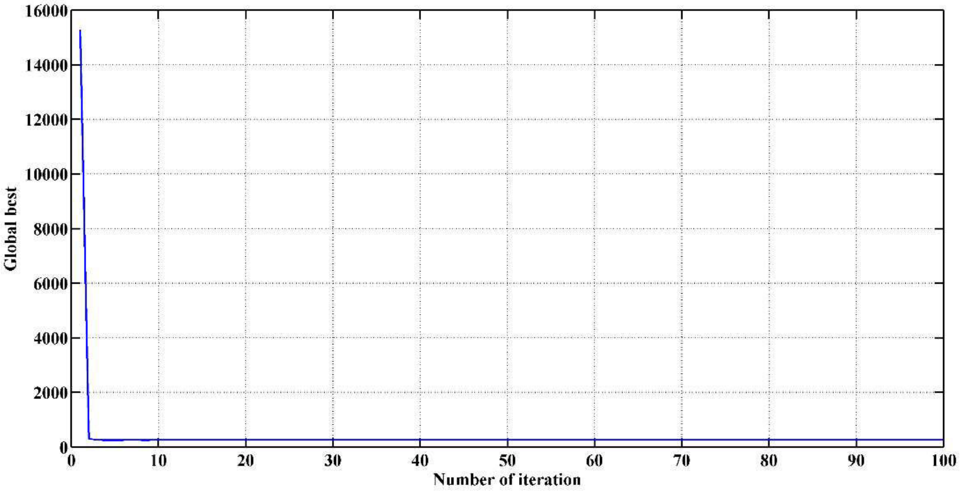

Figure 22 Convergence curve of PSO of dharmasthali feeder

With the placement of these values of the capacitor, the active power loss of the feeder after the forecasted load was found to be 253.84 kW (which is around 35% less than the increased load).

Table 7 Optimal sizes of Capacitor at Dharmasthali feeder

S.N.	Optimal buses	Capacitor size (kVAr)

1.	34	1125
2.	2	3000
3.	41	750
4.	31	1500

Optimal placement of the capacitor not only reduce active power loss but also improve the voltage profile. The voltage profile improvement after placement of the capacitor to the Dharmasthali feeder is shown in Figure 23.

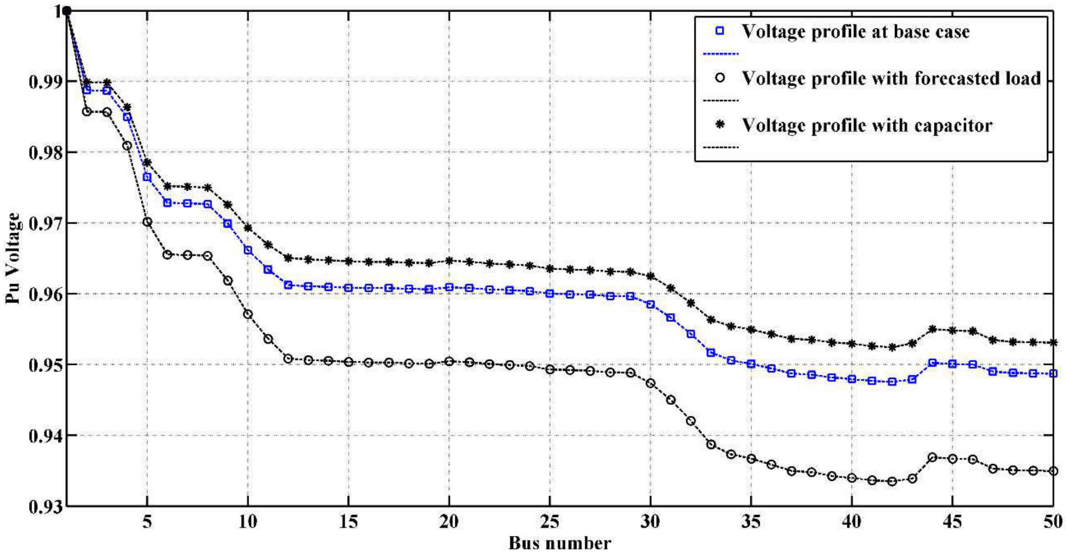

Figure 23 Voltage profile improvement of Dharmasthali feeder

The minimum voltage after placement of capacitor was found to be 0.952 Pu at bus number 42 and maximum voltage at bus number 2 with a value of 0.991 Pu. The voltages were within the limit, and power loss was reduced. Moving towards the branch current in the feeder, Table 8 shows the branch current after optimization.

Table 8 Branch current of Dharmasthali feeder after optimization

Branch number	Current (Amperes)	Branch number	Current (Amperes)
1	**338.31**	26	17.056

2	3.3195	27	10.235
3	**325.43**	28	6.8232
4	**319.92**	29	165.5
5	**314.42**	30	159.86
6	6.739	31	154.3
7	13.48	32	143.51
8	292.91	33	133.25
9	281.21	34	73.066
10	276.11	35	66.938
11	266.12	36	60.967
12	27.248	37	55.208
13	20.437	38	49.736
14	13.626	39	44.658
15	6.8132	40	34.494
16	27.255	41	13.799
17	13.629	42	33.402
18	6.8145	43	61.995
19	13.625	44	13.765
20	6.8131	45	6.8831
21	48.763	46	34.468
22	41.948	47	20.683
23	40.926	48	13.789
24	37.517	49	6.8948
25	6.8208		

As seen from the current Table 8 above, the branch numbers 1, 3, 4, and 5 still exceed the current limit of the DOG conductor used for distribution. Another method to reduce current is to bundle the branches. So, it is recommended for bundling these branches, which will not only reduces the current values but also reduce the loss.

4.5.2 Optimal placement of capacitor at Goldhunga feeder

As in Dharmasthali feeder, PSO converges after 100 iterations at Goldhunga feeder as shown in Figure 24. The plot is between the numbers of iteration versus best power loss per iteration. As in the Dharmasthali feeder, the optimal size of the capacitor with respective optimal bus number is shown in Table 9. The optimal buses for placement of capacitors are found to be bus number 23 with optimal size 1500 kVAr, and another bus was found to be bus number 37 with 375 kVAr size of the capacitor, next bus was determined as bus number 41 with the optimal size 750 kVAr and bus number 43 with an optimal size of the capacitor of 1500 kVAr.

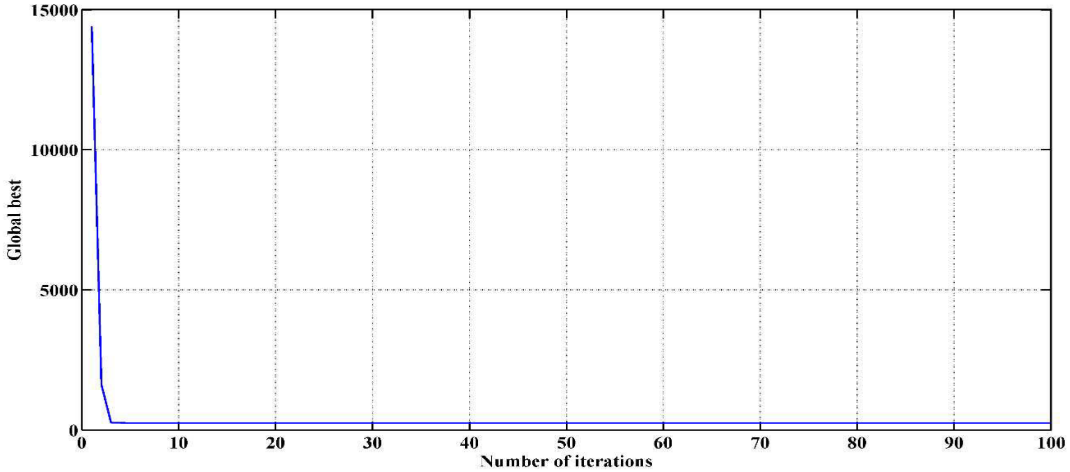

Figure 24 Convergence curve of PSO of Goldhunga feeder

With the placement of these values of the capacitor, the active power loss of the feeder after the forecasted load was found to be 237.67 kW (which is also around 35% less than the increased load).

Table 9 Optimal sizes of Capacitor at Goldhunga feeder

Optimal bus	Capacitor size (kVAr)
41	750
23	1500
43	1500
37	375

As in Dharmasthali feeder, the voltage profile improvement after placement of capacitor of the Goldhunga feeder is shown in Figure 25. For the Goldhunga feeder, the minimum voltage after placement of capacitor was 0.95 Pu at bus number 41 and maximum voltage at bus number 2 with a value of 0.999 Pu. The voltages were within the limit, and power loss was reduced.

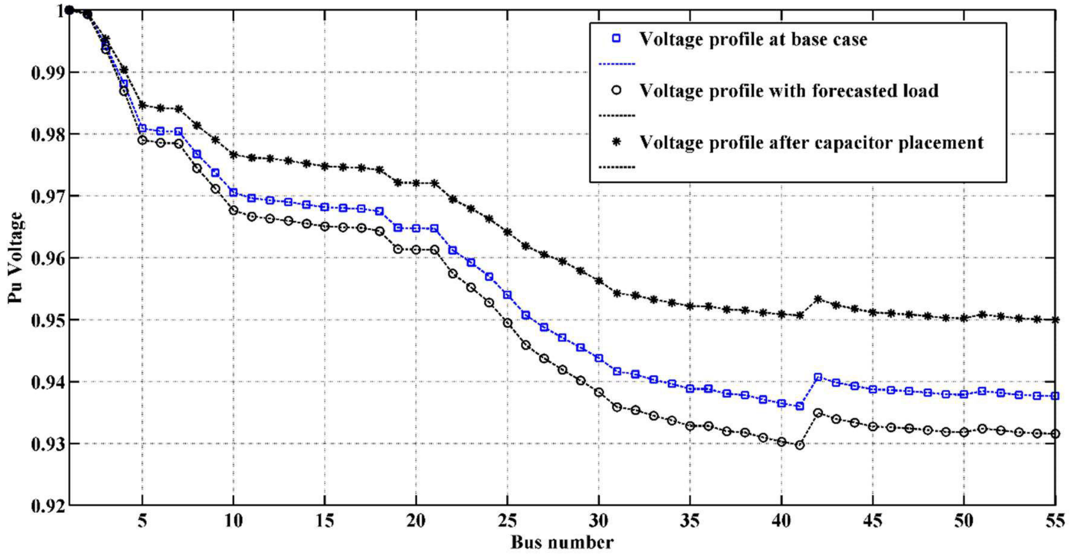

Figure 25 Voltage profile improvement of Goldhunga feeder

Moving towards the branch current in the feeder after optimization, Table 10 shows the branch current.

Table 10 Branch current of Goldhunga feeder after optimization

Branch number	Current	Branch number	Current
1	**329.5**	28	156.99
2	**315.83**	29	142.71
3	**311.49**	30	139.86
4	**307.18**	31	61.141
5	17.466	32	60.111

6	11.644	33	56.204
7	290.42	34	52.693
8	282.38	35	1.5043
9	274.6	36	48.997
10	62.459	37	46.708
11	61.114	38	45.112
12	35.26	39	44.29
13	29.388	40	44.284
14	23.513	41	84.347
15	17.636	42	78.337
16	5.879	43	72.321
17	213.19	44	66.302
18	208.98	45	30.135
19	11.788	46	24.111
20	5.8941	47	18.085
21	193	48	12.058
22	191.11	49	6.0292
23	183.85	50	30.144
24	177.08	51	24.118
25	173.9	52	18.091
26	170.87	53	12.061
27	168.01	54	6.0308

As seen from the current Table 10 of the Goldhunga feeder, the branch numbers 1, 2, 3, and 4 still exceed the current limit of the DOG conductor used for distribution. So as suggested as in the Dharmasthali feeder, to reduce the current limit is to bundle the branches. So, it is recommended to bundle these branches, which will not only reduces the current values but also reduce the loss for Goldhunga feeder.

4.5.3 Optimal placement of capacitor at Jarankhu feeder

As in Dharmasthali and Goldhunga feeder, PSO converges after 100 iterations at Jarankhu feeder as shown in Figure 26. The plot is between the numbers of iteration versus best power loss per iteration.

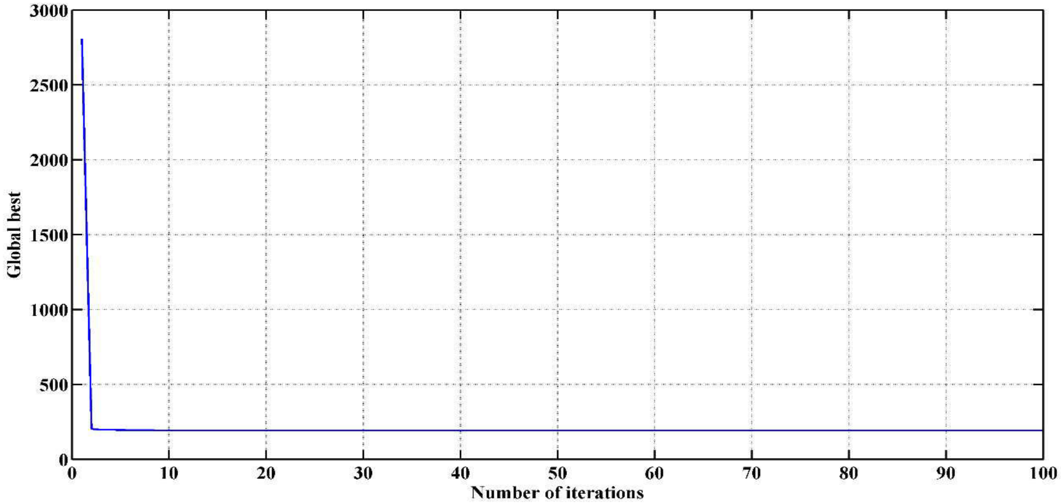

Figure 26 Convergence curve of PSO of Jarankhu feeder

As in Dharmasthali and Goldhunga feeder, the optimal size of the capacitor with respective optimal bus number is shown in Table 11. The optimal buses for placement of capacitors are found to be bus number 2 with optimal size 1200 kVAr, and another bus was found to be bus number 10 with 900 kVAr size of the capacitor; next bus was determined as bus number 21 with the optimal size 1500 kVAr and bus number 30 with an optimal size of the capacitor of 600 kVAr. With the placement of these values of the capacitor, the active power loss of the feeder after the forecasted load was found to be 194.94 kW (which is also around 36% less than the increased load).

Table 11 Optimal sizes of Capacitor at Jarankhu feeder

Optimal bus	Capacitor size (kVAr)
2	1200

21	1500
30	600
10	900

As in Dharmasthali and Goldhunga feeder, the voltage profile improvement after placement of capacitor of the Jarankhu feeder is shown in Figure 27.

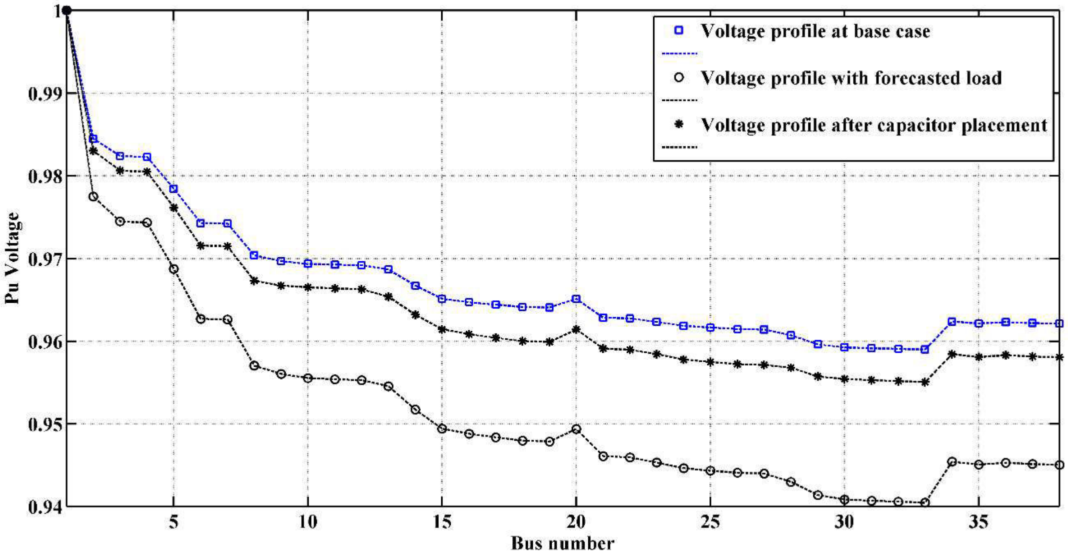

Figure 27 Voltage profile improvement of Jarankhu feeder

For the Jarankhu feeder, the minimum voltage after placement of capacitor was found to be 0.954 Pu at bus number 33 and maximum voltage at bus number 2 with a value of 0.982 Pu. The voltages were within the limit, and power loss was reduced. Moving towards the branch current in the feeder, Table 12 shows the branch current after optimization at the Jarankhu feeder.

Table 12 Branch current of Jarankhu feeder after optimization

Branch number	Current	Branch number	Current
1	293.89	20	125.22
2	254.72	21	10.417
3	10.189	22	71.472
4	237.41	23	31.302

5	224.73	24	20.872
6	10.283	25	15.655
7	208.32	26	10.437
8	42.721	27	36.109
9	39.136	28	32.762
10	20.676	29	27.857
11	10.339	30	18.303
12	167.15	31	13.074
13	158.6	32	5.23
14	156.49	33	41.702
15	31.21	34	10.427
16	26.011	35	5.2122
17	15.61	36	15.64
18	5.2035	37	5.2136
19	5.1954		

As seen from the current Table 12 of Goldhunga feeder, all the branches are under the limit of DOG conductor used for distribution. So as suggested as in Dharmasthali and Goldhunga feeder, bundling of conductor is not needed for Jarankhu feeder.

4.6 Financial Analysis

As per the basic financial calculation done and included in Table 18, Appendix B, it is seen that Nrs. 3,23,27,946.00 is required at the end of the tenth year to optimize the distribution network, whereas Nrs. 6,00,50,36,448.96 is required for the forecasted generation resulting in a total of Nrs, 6,03,73,64,394.96 as per the technical recommendations above, among which Nrs. 1,32,27,86,538.93 is seen to be required for managing the load to supply for the forecasted electric cooking load. It is also seen that per month electricity cost using electric cooking amounts to Nrs. 73,35,360.00 at the end of the forecasted period, and for the same number of consumers, the monthly cooking cost using LPG gas amounts to Nrs. 1,34,05,424.64 assuming the rate per kg of the base year, and the government does not provide any subsidy. Even though the cost per kg of LPG is used from the base year, it seems more costly than using electric cooking at the end of the tenth year. Similarly, the fixed cost for consumers using electric cooking at the end of the forecasted period amounts to Nrs. 6,64,75,137.84. The utility has to make a huge investment to supply peak demand, but the distribution network could not be fully utilized as per the investment due to the huge gap between peak and base demand. The cost of supplying only to electric cooking load is also a significant amount for the utility; still, the utilization factor shall be very low in off-peak hours. The utility seems to be gaining revenue of Nrs. 73,35,360.00 per month from electric cooking loads only. In this scenario, the country has to spend a minimum of Nrs. 1,34,05,424.64 less on importing the LPG gas, which can be seen as the positive aspect as well.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conslusion

Electrical energy is the most versatile form of energy; with emerging technologies and an increasing share of electricity in the spectrum of energy use among domestic consumer in the modern era, the electricity distribution network required frequent optimization and hence resources. In this research, the optimized structure of the distribution network supplying load to the consumers of Tarkeshwor Municipality as a control area in ten years from now is analyzed. The way the government is committed to increase clean and modern cooking and the trend the electric cooking is taking on the market as an emerging technology is seen to have a considerable share of the electricity load in coming days such that the existing distribution infrastructure is fully exhausted and highly unstable. With the increasing load in the distribution network, optimum placement of distributed generation in various branches helps maintain the power quality and the reliability of the grid. Reactive power supplier used in this research as a form of distributed generation improves the voltage profile of the distribution network, decreases the losses and allows more current to flow through the same network. The study finds that optimization of the network, at the current status, can potentially improve the power quality and decrease the power loss. Similarly, financially analyzing the investment to be made by the utility has also been discussed where huge investments has to be made only to cover up the peak demand. The investments made could be well justified if the difference between peak load and base load decreases. Alongside the high investment made by the utility for managing the load of electric cooking in forecasted scenario generates significant monthly revenue and accounting for reduced petroleum import as well although the utilization factor in the off peak hours remains low.

5.2 Recommendation

With the increased use of electricity in the coming days, the gap between the baseload and the peak load in the hourly load curve will also grow, which needs to be fulfilled to justify the technical and financial arrangements made to the distribution network in consideration of the peak loading. The gap can be minimized by changing the behavior of the consumers in shifting the time of electricity use or development of sector like enterprises that smoothens the load curve which further needs to be studied through social and economics lens.

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APPENDIX A

Table 13 Unit consumption and number of consumers in last six F/Y of Control Area

Control Area per /F/Y	**2072/073**		**2073/074**		**2074/075**	
Tarrif	**No. of Conusumer**	**Consumption Unit**	**No. of Conusumer**	**Consumption Unit**	**No. of Conusumer**	**Consumption Unit**
Commercial	53	29611	59	103747	85	68591
Domestic	13964	1180275	15350	1451180	17268	1603167
Industrial	132	73117	142	96838	153	110391
Irrigation	3	0	4	569	4	746
Non Commercial	34	13377	36	11885	40	9749
Non Domestic						
Religious and Cultural	4	679	4	109	7	1117
Street Light						
Temp Supply	1	83	1	70	1	47
Water Supply						
Total	**14191**	**1297142**	**15596**	**1664398**	**17558**	**1793808**

Control Area per /F/Y	**2075/076**		**2076/077**		**2077/078**	
Tarrif	**No. of Conusumer**	**Consumption Unit**	**No. of Conusumer**	**Consumption Unit**	**No. of Conusumer**	**Consumption Unit**
Commercial	104	94136	115	96998	128	111226
Domestic	18980	1993300	20362	1892155	21821	2669173
Industrial	168	130110	178	60696	185	114521
Irrigation	3	511	4	1753	4	679
Non Commercial	46	12105	58	23416	59	15451
Non Domestic	1	190	23	793	26	15906
Religious and Cultural	19	2160	20	3791	23	1690
Street Light	1	162	3	115	5	596
Temp Supply	1	110	1	101	1	98
Water Supply			2	1	2	0
Total	**19323**	**2232784**	**20766**	**2079819**	**22254**	**2929340**

Table 14 IEEE 34 bus data

Branch no.	From bus	To bus	R (ohms)	X (Ohms)	P (kW)	Q (kW)
1	1	2	0.0922	0.0477	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1840	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.0700	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0400	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70

Branch no.	From bus	To bus	R (ohms)	X (Ohms)	P (kW)	Q (kW)
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40

Source : (Elsaiah et al., 2014)

Table 15 Dharmasthali feeder data

From bus	To bus	R (ohms)	X (ohms)	Length	Bus number	P (kW)	Q (kVAr)	kVA
1	2	0.19131	0.09566	700	1	0	0	0
2	3	0.15988	0.07994	585	2	80	60	200
2	4	0.06696	0.03348	245	3	20	15	50
4	5	0.15305	0.07652	560	4	40	30	100
5	6	0.06696	0.03348	245	5	40	30	100
6	7	0.04783	0.02391	175	6	40	30	100
6	8	0.07652	0.03826	280	7	40	30	100
6	9	0.05739	0.0287	210	8	80	60	200
9	10	0.07652	0.03826	280	9	90	67.5	225
10	11	0.05739	0.0287	210	10	40	30	100
11	12	0.04783	0.02391	175	11	80	60	200
12	13	0.04783	0.02391	175	12	40	30	100
13	14	0.0287	0.01435	105	13	40	30	100
14	15	0.05739	0.0287	210	14	40	30	100
15	16	0.07652	0.03826	280	15	40	30	100
12	17	0.11615	0.05808	425	16	40	30	100
17	18	0.05739	0.0287	210	17	80	60	200
18	19	0.03826	0.01913	140	18	40	30	100
12	20	0.16398	0.08199	600	19	40	30	100
20	21	0.12435	0.06218	455	20	40	30	100
12	22	0.09292	0.04646	340	21	40	30	100
22	23	0.0164	0.0082	60	22	40	30	100
23	24	0.0246	0.0123	90	23	6	4.5	15
24	25	0.06833	0.03416	250	24	20	15	50
25	26	0.08609	0.04304	315	25	80	60	200

25	27	0.06696	0.03348	245	26	40	30	100
27	28	0.12299	0.06149	450	27	40	30	100
28	29	0.02733	0.01367	100	28	20	15	50
12	30	0.09566	0.04783	350	29	40	30	100
30	31	0.06696	0.03348	245	30	40	30	100
31	32	0.08609	0.04304	315	31	40	30	100
32	33	0.10659	0.05329	390	32	80	60	200
33	34	0.04783	0.02391	175	33	80	60	200
34	35	0.03826	0.01913	140	34	80	60	200
35	36	0.05739	0.0287	210	35	40	30	100
36	37	0.06696	0.03348	245	36	40	30	100
37	38	0.0164	0.0082	60	37	40	30	100
38	39	0.04783	0.02391	175	38	40	30	100
39	40	0.0287	0.01435	105	39	40	30	100
40	41	0.05739	0.0287	210	40	40	30	100
41	42	0.06696	0.03348	245	41	120	90	300
40	43	0.03826	0.01913	140	42	80	60	200
34	44	0.03826	0.01913	140	43	80	60	200
44	45	0.07652	0.03826	280	44	80	60	200
45	46	0.08609	0.04304	315	45	40	30	100
44	47	0.25964	0.12982	950	46	40	30	100
47	48	0.06833	0.03416	250	47	80	60	200
48	49	0.0287	0.01435	105	48	40	30	100
49	50	0.03826	0.01913	140	49	40	30	100
					50	40	30	100
Total				13300		2476	1857	

Table 16 Goldhunga Feeder Data

From Bus	To Bus	R (ohms)	x (ohms)	Length	Bus number	P (kW)	Q (kVAr)	kVA
1	2	0.00957	0.00383	35	1	0	0	0
2	3	0.08609	0.03444	315	2	80	60	200
3	4	0.10522	0.04209	385	3	40	30	100

4	5	0.12435	0.04974	455	4	40	30	100
5	6	0.16261	0.06505	595	5	40	30	100
6	7	0.06696	0.02678	245	6	40	30	100
5	8	0.07652	0.03061	280	7	80	60	200
8	9	0.05739	0.02296	210	8	80	60	200
9	10	0.06286	0.02514	230	9	80	60	200
10	11	0.10112	0.04045	370	10	80	60	200
11	12	0.04783	0.01913	175	11	80	60	200
12	13	0.05739	0.02296	210	12	80	60	200
13	14	0.09566	0.03826	350	13	40	30	100
14	15	0.11479	0.04591	420	14	40	30	100
15	16	0.04783	0.01913	175	15	40	30	100
16	17	0.12435	0.04974	455	16	80	60	200
10	18	0.07652	0.03061	280	17	40	30	100
18	19	0.06696	0.02678	245	18	40	30	100
19	20	0.05466	0.02186	200	19	80	60	200
20	21	0.0287	0.01148	105	20	40	30	100
19	22	0.10112	0.04045	370	21	40	30	100
22	23	0.05739	0.02296	210	22	20	15	50
23	24	0.06696	0.02678	245	23	80	60	200
24	25	0.09566	0.03826	350	24	80	60	200
25	26	0.10522	0.04209	385	25	40	30	100
26	27	0.06696	0.02678	245	26	40	30	100
27	28	0.05739	0.02296	210	27	40	30	100
28	29	0.05739	0.02296	210	28	40	30	100
29	30	0.06696	0.02678	245	29	100	75	250
30	31	0.08609	0.03444	315	30	20	15	50
31	32	0.03826	0.0153	140	31	40	30	100
32	33	0.07652	0.03061	280	32	10	7.5	25
33	34	0.06696	0.02678	245	33	40	30	100
34	35	0.08609	0.03444	315	34	40	30	100
35	36	0.02733	0.01093	100	35	40	30	100

35	37	0.09566	0.03826	350	36	10	7.5	25
37	38	0.02733	0.01093	100	37	40	30	100
38	39	0.11479	0.04591	420	38	40	30	100
39	40	0.11479	0.04591	420	39	40	30	100
40	41	0.10522	0.04209	385	40	40	30	100
31	42	0.06696	0.02678	245	41	200	150	500
42	43	0.07652	0.03061	280	42	40	30	100
43	44	0.04783	0.01913	175	43	40	30	100
44	45	0.05739	0.02296	210	44	40	30	100
45	46	0.0287	0.01148	105	45	40	30	100
46	47	0.04783	0.01913	175	46	40	30	100
47	48	0.08609	0.03444	315	47	40	30	100
48	49	0.14348	0.05739	525	48	40	30	100
49	50	0.06696	0.02678	245	49	40	30	100
45	51	0.06696	0.02678	245	50	40	30	100
51	52	0.07652	0.03061	280	51	40	30	100
52	53	0.10522	0.04209	385	52	40	30	100
53	54	0.08609	0.03444	315	53	40	30	100
54	55	0.07652	0.03061	280	54	40	30	100
					55	40	30	100
Total				15055		2720	2040	6800

Table 17 Jarankhu Feeder Data

From Bus	To bus	R (ohms)	X (ohms)	Length	Bus num	P (kW)	Q (kVAr)	KVA
1	2	0.36896	0.14758	900	1	0	0	0
2	3	0.05739	0.02296	140	2	400	300	1000
3	4	0.08609	0.03444	210	3	80	60	200
3	5	0.11684	0.04673	285	4	80	60	200
5	6	0.12913	0.05165	315	5	120	90	300
6	7	0.04304	0.01722	105	6	80	60	200
6	8	0.13118	0.05247	320	7	80	60	200
8	9	0.12913	0.05165	315	8	40	30	100

9	10	0.10044	0.04018	245	9	120	90	300
10	11	0.04304	0.01722	105	10	80	60	200
11	12	0.05739	0.02296	140	11	80	60	200
8	13	0.07174	0.0287	175	12	80	60	200
13	14	0.08609	0.03444	210	13	80	60	200
14	15	0.07174	0.0287	175	14	20	15	50
15	16	0.11479	0.04591	280	15	40	30	100
16	17	0.10044	0.04018	245	16	40	30	100
17	18	0.15783	0.06313	385	17	80	60	200
18	19	0.11479	0.04591	280	18	80	60	200
15	20	0.01435	0.00574	35	19	40	30	100
15	21	0.12913	0.05165	315	20	40	30	100
21	22	0.08609	0.03444	210	21	120	90	300
21	23	0.05534	0.02214	135	22	80	60	200
23	24	0.12913	0.05165	315	23	80	60	200
24	25	0.08609	0.03444	210	24	80	60	200
25	26	0.10044	0.04018	245	25	40	30	100
26	27	0.05739	0.02296	140	26	40	30	100
23	28	0.31566	0.12626	770	27	80	60	200
28	29	0.24392	0.09757	595	28	40	30	100
29	30	0.11479	0.04591	280	29	80	60	200
30	31	0.04919	0.01968	120	30	80	60	200
31	32	0.05124	0.0205	125	31	40	30	100
32	33	0.15783	0.06313	385	32	60	45	150
21	34	0.09839	0.03936	240	33	40	30	100
34	35	0.20088	0.08035	490	34	80	60	200
34	36	0.14143	0.05657	345	35	80	60	200
34	37	0.11274	0.04509	275	36	40	30	100
37	38	0.10044	0.04018	245	37	80	60	200
					38	40	30	100
Total				10305		2840	2130	7100

APPENDIX B

Table 18 Financial Analysis

Particular	Unit	Cost	Remarks
Cost of Capactior Bank per kVAr at BAU	Rs.	1,389.90	Cost from Store rate of Balaju Distribution Center, NEA
Cost of Capactior Bank per kVAr at Future Scenario	Rs.	1,832.65	Price forecast with inflation rate using compounding method (inflation rate: 5.7%)
Total kVAR	kVAR	14,700.00	From analysis
Cost of Total Capacitor at future Scenario	Rs.	26,939,955.00	Calculation
Installation cost @ 20% Material Cost	Rs.	5,387,991.00	Calculation
Cost of Capacitor Installment at 2087/088 (D)	Rs.	32,327,946.00	Calculation
Cost of Generation per MW at BAU	Rs.	218,500,000.00	From Nepal ratra bank journal
Cost of Generation per MW at Future Scenario	Rs.	288,287,875.61	Price forecast with inflation rate using compounding method
Total MW	MW	20.83	From analysis
Cost of Total MW at 2087/088 (G)	Rs.	6,005,036,448.96	Calculation
Total cost for Optimization of Distribution Network on 2087/088	Rs.	6,037,364,394.96	D+G
Total cost for Optimization accounting for cooking only	Rs.	1,322,786,538.93	21.91% from analysis
Fixed Cost for Electric Cooking at BAU	Rs.	7,418.00	From Analysis
Fixed Cost for Electric Cooking at 2087/088	Rs.	9,787.27	Price forecast with inflation rate using compounding method
Number of consumer in control area in 2087/088 using electric cooking	Nos.	6,792.00	25% * (Forecasted number of current consumer based on Nepal Census Data)

Total Fixed Cost for monthly electric cooking in control area	Rs.	66,475,137.84	Calculation
Per Unit cost of Electric cooking at Future Scenario	Rs.	12.00	From Analysis & Limitation
Unit Required for Daily electric Cooking	kWh	3.00	based on analysis
Unit Required for Monthly electric Cooking	kWh	90.00	Calculation
Operating Cost for Monthly electric cooking in 2087/088	Rs.	1,080.00	Calculation
Number of consumer in control area in 2087/088 using electric cooking	Nos.	6,792.00	25% * (Forecasted number of current consumer based on Nepal Census Data)
Total Operating Cost for monthly electric cooking in control area	Rs.	7,335,360.00	Calculation
Cost of per Kg LPG including subsidy amount at Base case	Rs.	157.77	From NOC including Nrs 665.34 subsidy per cylinder'
LPG required per household per month for cooking in kg	kg	12.51	From analysis
Cost for LPG for cooking per household	Rs.	1,973.71	Calculation
Number of consumer in control area in 2087/088 replacing LPG	Nos.	6,792.00	25% * (Forecasted number of current consumer based on Nepal Census Data)
Total Cost for monthly LPG cooking in control area for consumers replacing to electrical cooking (based on base year rate)	Rs.	13,405,424.64	Calculation

Distribution Network Performance Management for emerging load in Urban Area

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