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ANALYSIS OF KATHMANDU GRID DIVISION AND INTREGATED NEPAL POWER SYSTEM WITH OPTIMAL PLACEMENT AND SIZING OF CAPACITOR

BY

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Analysis of Kathmandu Grid Division and Integrated Nepal Power System with Optimal Placement and Sizing of Capacitor**" submitted by Manisha Shahi Thakuri in partial fulfillment of the requirements for the degree of Master in Energy System Planning and Management.

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ABSTRACT

The lower voltage of transmission system in the Integrated National Power System (INPS) has been a major concern for the Nepal Electricity Authority (NEA). The lower transmission voltage induces the lower voltage in the sub-coordinates (sub-transmission and distribution system) causing reduced voltage and overall higher system loss. The loss in the transmission system has increased from 4.35% to 4.51% in previous year. A total of 97.5km 132kV line and 182km of 220kV line in the FY2076/77 along with 72.5 MVAR of capacitor bank has been augmented in last couple of years. Though such appreciable effort, considering the system enhancement, has been done in the improvement of the transmission system, the problem is still existing. The main reasons for the existing problem can be: the higher increase in demand than the supporting infrastructures. So, this research aims to study the existing system during the system peak and perform an impact analysis in the system with the addition of the optimum sized capacitors in the optimum location for the voltage improvement and overall loss reduction.

The study also emphasizes the economic aspect with the addition of the capacitors analyzing the various economic parameters. The sub-objective of the study also includes analysis of the loading status of the transmission lines in the Kathmandu valley. For the acknowledgement of system, the Electrical Transient Analyzer Program (ETAP) has been used as simulation tool. Adaptive Newton-Raphson has been used for the load flow and the Optimum Capacitor Placement (OCP) module inbuilt with Genetic Algorithm (GA) to determine the optimum placement and sizing of the capacitor banks. Moreover, a techno-economic analysis has been performed for the determination of the most suitable voltage level for the capacitor placement.

From the analysis it has been found that the system suffers a transmission line loss of 4.16% in the system peak. Also, 6 optimum substations with the total reactive power of 80 MVAR needs to be added in the system for the energy savings of about 16.02 GWh per annum. The economic analysis shows that the implementation of the study has an is economically sustainable with the payback period of 5.97 years and 19.69 % Internal Rate of Return when the capacitors are placed at the most financially suitable voltage level i.e., 11kV determined from the results obtained.

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LIST OF ACRONYMS, SYMBOLS AND ABERRATIONS

BCR	Benefit to Cost Ratio
ETAP	Electrical Transient Analyzer Programme
GD	Grid Department
GWh	Giga watt - hour
HP	Hydro Power
INPS	Integrated Nepal Power System
IRR	Internal Rate of Return
kV	kilo volt
LFA	Load Flow Analysis
MWh	Mega watt - hour
NEA	Nepal Electricity Authority
NPV	Net Present Value
OCP	Optimum Capacitor Placement
pf	power factor
pu	per unit
SCA	Short Circuit Analysis
SLD	Single Line Diagram
SS	Substation
SVC	Shunt VAR Compensator

CHAPTER ONE: INTRODUCTION

1.1 Background

The transmission system is an integral part of the power system responsible for the bulk transfer of power from the generation plants to the substations. With the flow of power in AC system, the electrical and components produce as well as consumes two kinds of power: the active or real power, responsible for the useful work in the circuit, and the reactive power, which moves back and forth between the load and the source and does not do any useful work.

However, reactive power is critical to maintaining the voltage level in the electrical transmission system and plays a substantial role for the consistent operation of the system. The deficiency of reactive power in system has been the major cause for the voltage collapse of several major systems globally. Moreover, reactive power is also essential as it can also improve the efficiency with which the real power is delivered to the consumers(Sasson, 2005). So, the reactive power also needs to be maintained in the system as it controls the steady-state and temporary overvoltage and can avoid system blackouts.

With the bulk amount of active element of power, basically, proportionate inductive reactive power also flows through transmission lines increasing the overall current flow. With this increased current flow, the I^2R loss increases, and eventually, the voltage drop in the system also increases. So, as the demand increases, the inductive reactive power also usually increases in the same proportion causing more power flow in the distribution, and hence the transmission lines resulting significant drop in the efficiency and voltage level in the power lines.

With the lower amount of reactive power flow through the transmission lines, not only lessens the system losses (by reducing the current flowing through lines) but also releases the additional capacity on the lines. It means that the reactive compensation increases the capability to transfer power without lacking the new infrastructures with larger sized conductors. To compensate for this inductive reactive component of power flow, the reactive power can be supplied through various sources including synchronous condensers, generators, and more often used transmission equipment such as capacitors, reactors, and static var compensators. Usually, the reactive power compensation is done at the remote level near the load center, as it can reduce the flow of reactive power in the transmission lines resulting in lower transmission loss and improved voltage profile. Thus, the capacitors with the purpose of voltage improvement with increased efficiency are used in the power system.

The support for the reactive power can be divided into two categories: static and dynamic. The static reactive compensator when connected to the system cannot quickly vary the level of reactive power with the voltage level remaining constant. The generation of the reactive power varies with the change in the voltage. The higher terminal voltage results in more reactive power production and eventually drops with the lower voltage. Capacitors and inductors are responsible for the production and consumption of the static reactive power. They are cheaper and less reliable, as it depends on voltage and the ability to produce more reactive power is low when the voltage level is low or the necessity to produce the reactive power is high.

On the other hand, the dynamic reactive power is produced from the equipment with the ability to change the reactive generation quickly without the alteration of the voltage. So, this equipment can increase the level of reactive power generation even as the voltage level drops and can prevent a system collapse. The synchronous condensers, static VAR compensators, and generators can produce the dynamic reactive power and are more reliable.

Similarly, the high voltage shunt capacitors can be used as support for the transmission system voltage. It is often necessary for the utilization of the transmission grid beyond the normal designed capacity which results in decreased capital spending on network upgrades. And as the transmission voltage increases, the lower amount current is necessary to supply power to the load, so transmission losses decrease furthermore.

Ideally, the smaller sized shunt capacitors need to be placed at every point to eliminate the flow of the reactive power in the system. However, this being unconventional and economically unfeasible, optimum sized capacitors are placed at the optimum location to ensure minimal loss with economic advantage.

In Nepal, the powers are transmitted at a voltage in range 66kV- 400kV with substations commonly called grid substation at 58 locations to ensure the flow of power to the stepped-down distribution systems. However, in some industrial hubs, and the Kathmandu valley the 66kV voltage is also used as the sub-transmission lines. 546.144

MVAR of capacitor banks has been connected to the grid substation, is shown in Table A.1, with 72.5 MVAR of them in the last two years(Transmission Directorate, 2020).

1.2 Problem Statement

The shunt capacitor placement has been practiced in some of the grid substations throughout the country. Though the capacitor placement has been emphasized by the NEA, the existing resource seems to be insufficient and organized and is somehow responsible for the 4.51% loss in the transmission system(NEA, 2020). Moreover, the voltage level, though are within the specified standard level, at the grid substations can be improved causing enhanced voltage in the subordinate distribution system and improving voltage profile of the overall networks.

So, the following research gap has been observed:

- Though the capacitors are placed at various grid substations, there is a quite significant need to assess the optimum placement of the capacitors for the transmission system of Nepal and the scenarios need to be analyzed.
- Capacitors have been placed at various voltage levels in the INPS 11 kV, 33 kV, 66 kV, and 132kV. Techno-economic analysis of the capacitor placement at the various voltage levels needs to be carried out to find the most suitable voltage level for the capacitor to be placed.
- A detailed analysis for the Kathmandu Valley needs to be made featuring the current scenario and the effect on the loadings and loss of the transmission lines with the capacitor placement.

With the placement of the capacitor, the loss of the overall grid system can be minimized along with the augmentation in the system voltage. This can lead to the increment of the voltage in the distribution substations and the lower side decreasing the overall system loss. So, from the study the technical and financial impact with the optimal placement of the capacitor on the overall network can be perceived. Also, the loading of the lines can be analyzed which can provide a validation for the need of the upgradation of conductor as well.

Moreover, the suitable voltage obtained from the result can be used for the future placement of the capacitor in the INPS. In general, the result would provide an insight of the techno-economical impact of the capacitor placement and the suitable voltage level for the placement both technically and financially viable.

1.3 Research Objectives

The main objective of the study is to find the suitable size and optimum location as well as the voltage level for the placement of capacitors in the transmission grid system of the overall country.
Specific objectives of the study include:

- To perform load flow analysis considering the grid substations of INPS.
- To analyze the effect on the voltage of the system with the optimum addition of the shunt capacitors at various voltage levels
- To find the power transfer capability of the transmission network within Kathmandu Valley and compare the scenario before and after the capacitor placement
- To perform an economic analysis of the effect of the addition of capacitors in the system as varying voltage levels in the system

1.4 Limitations

The following are the limitations of the study:

The assessment will analyze both the technical and the economic benefits of the reactive power compensation with a capacitor placed at various voltage levels at the time of system peak. The system peak of FY 2076/77 was on 23rd of Bhadra at 17:05 hour (NEA, 2020). As the instantaneous load flow of the system is not possible without the availability of load data in the same instant. So, the load flow was carried out considering the peak data from the third week of Bhadra of FY 2076/77 BS. Similarly, the generation from the NEA and IPPs hydropower was considered from the average of the generation peak for the particular month. With the common practice of switching of the transmission lines, the LFA was carried out with the radial configuration followed in the particular time.

For the optimum capacitor placement, the parameters of the cost of installation and maintenance was considered from the NEA as well as the energy savings cost from the average NEA tariff structure. The objective function of cost in the OCP will be the minimization of overall cost with increased voltage in the range 0.9-1.1pu and increased energy savings. A comparative analysis with the capacitor placed in the various voltage level of the optimum location was carried out.

For the financial analysis, the benefit includes the benefit from the reduced system loss after the addition of the capacitors, the project lifetime was considered to be 20 years with annual inflation of 10%. The cost of the capacitors, though considered from the NEA can vary with the market price by some margins. The financial analysis was carried out for the effect of a capacitor placed in the various voltage levels with the comparison of the financial parameters (NPV, IRR, BCR).

CHAPTER TWO: LITERATURE REVIEW

During the course of thesis, various literatures were reviewed. Those literatures included the various methods of performing the analysis related to the research. The various methodologies for the load flow and capacitor placement in the scenario of the other countries and the INPS of Nepal put forth by the scholars since the past some years is presented herewith in brief.

2.1 Real and reactive power flow

The power demand of consumers in Nepal is increasing (NEA, 2020). With the growth in the power consumption, reactive power that needs to be supplied also increases thus increasing the overall power flow in transmission lines. This increases the line loading and majorly, the loss. The active loss reduction during the power transmission plays an important role for the system to operate economically and reliably (Taylor, 2008).

The prominent practice to reduce loss is to transfer the power at the higher voltage with considerably the higher size of the conductor. The line loss of the system decreases with the correspondence decrease in the power flow. The active power is to be utilized by the consumer and serves the major purpose of the line. So, theoretically only reactive component of the power can be decreased from the sending end for the overall reduction in the line loss. However, the reactive power is the basic requirement for maintaining the system voltage stability and its insufficiency is the most frequent cause for a blackout of the system (Edris & Mehraban, 1998).

Moreover, during a contingency in the system, the reactive component of line loading can change intensely without significant change in the active component of the power (Leonardi & Ajjarapu, 2008). The reason for this is that with the drop in bus voltage resulting from component failure, the generation of reactive power from charging of the line and shunt capacitors also decreases. So, the adequate reserve for the supply of the reactive power should be available to meet the VAR requirement following a abnormality (Edris & Mehraban, 1998). So, the best way to reduce the line loss without disturbing the stability of system is to the generate reactive power at load center and reduce reactive power that needs to flow through the transmission line. The reactive power compensation not only reduces the active and reactive network power loss but also maintains the required voltage level to improve the stability of the power system

(K. Yang & Gong, 2015). So, proper understanding of the real and the reactive power flow in the system needs to be understood first.

2.2 Load flow analysis

For the understanding of a system, load flow analysis needs to be carried out. It helps to determine the steady-state condition of system in terms of active and reactive component of power with the magnitude and phase angle of the voltage at each bus (Alsulami & Kumar, 2017). Generally, the load flow studies are performed for planning of the power system as well as in operation and control. Load flow studies data are also used for contingency analysis, outage security assessment, as well as for optimal dispatching and stability.

Several methods have been applied in solving the non-linear algebraic expressions of the load flow problem. Out of which the most commonly used iterative methods are Gauss Siedel, Newton-Raphson and Fast Decoupled method. A research makes a comparison of the load flow methods and illustrates that the Newton-Raphson method is reliable for the higher voltage load flow analysis and is also rapid in convergence, whereas the Gauss-Siedel method is slower and under severe-ill conditioning may even fail to converge (Keyhani et al., 1989). So, this study will be carried out using the load flow in Electrical Transient Analyzer Program (ETAP) software before and after the reactive power compensation.

2.3 Reactive power compensation

There are various methods for the generation of the reactive power. The major of those includes: Synchronous alternators, Synchronous Compensators (SC), Static VAR Compensators (SVC) and banks of static capacitors (Edvard, 2015). A study was done for the Integrated Nepal Power System (INPS) for the future scenario of 5 and 10 years with the reactive power supplied by the synchronous alternators of the Independent Power Producers (IPPs). The study shows that with some compensation provided to the IPPs, it would be techno-economically feasible (Poudel & Kumar Mishra, 2020).

Furthermore, a study presents the impact of the placement upon the IEEE 14 Bus system with the Static VAR Compensator to improve the voltage (Daw & Salih, 2019). Similarly, a research was intended to improve the problem of voltage drop and power loss problem in Kalimantan electric power station, Indonesia. The study models the system with the placement of 62 MVAR static var compensator among one of the substations resulting the voltage improvement in all of the 150kV buses with an average of 0.613 kV (Susilo et al., 2018). Moreover, a paper presents the procedure for modeling and simulation of Distribution Static Synchronous Compensator (D-STATCOM) for the power quality problems and voltage sag based on the Sinusoidal Pulse Width (SPWM) Modulation Technique (Madhusudan & Rao, 2012). Similarly, various other study and research was carried out with different method of reactive power compensation. Ideally, the reactive power compensators need to be placed in all of the load centers to minimize the flow of the reactive power through the transmission lines. But it may not be economically feasible and may not provide the best results. So, the capacitors should be placed in the optimum location.

2.4 Optimum Capacitor Placement

Numerous methods for the optimum placement of the capacitor were reviewed. Many of which required the development of an objective function which is both continuous and differentiable. Such function required various assumptions to be made for the simplification. These required the apprehension over the size and cost of the capacitor, their types and number, relative placement and switching times (Eajal & El-Hawary, 2010). A major drawback of the mentioned method is that depending upon the starting locations the solutions will be different.

So, several other techniques have been suggested for the optimization with an aim of augmenting the quality of solution for the problem. These techniques include simulated annealing (Mekhamer et al., 2006), the tabu search (H. T. Yang et al., 1995), expert system(Al-Ammar et al., 2018), dynamic programming (Dura, 1968). While the mentioned methods are able to handle discrete variables, they have several drawbacks. The major drawback is speed on those techniques and the fact that certain control parameters are used in the optimization which are system dependent and difficult to be determined.

This thesis work will use the widely used optimization technique called genetic algorithm (GA) (Rojas et al., 2008). The GA is a local search technique used to find approximate solution to the optimization and search problems (Delkhooni et al., 2017). Mimicking the process of natural evolution along with mutation and crossover, a solution of good characteristics is carefully chosen then and carried to the next sequence of iterations. GA like some other optimization techniques uses probabilistic transition rules and is good for the situations with less information about the problem. Though the method is time consuming as compared to the similar other techniques (Santos et al., 2004) the ETAP software will be used which has the feature to set precision to speed ratio. The optimization will be carried out with the maximum precision under normal time.

(Levitin et al., 2000)performed a study on the optimal allocation of the capacitor in the distribution system with the genetic algorithm and a fast energy loss computation technique for the consumers having different load pattern. From the capacitor placement with the results of the genetic algorithm, the benefits were analyzed in the terms of the energy saving with the energy calculated from the feeder curve pattern of the different variety of the consumers. The result showed a significant reduction of the loss in the system along with the release of a large amount of the reactive power loading in the system.

Similarly, presented a research on the optimum placement of the capacitor employing a sequential linear programming method. It required a mixed integer linear programming problem (MILP) to be solved for each iteration along with Branch and Bound method and two genetic algorithm procedures. With the analysis of the Italian network, it was inferred that with the smaller test cases, Branch and bound method is more efficient than genetic algorithms as the later method produced the result with the larger number of the simplex iterations leading to long computational times. So, the introduced hybrid method uses the initial population as output from the branch and bound method and uses it as the input for the genetic algorithm.

2.5 Modeling, Load Flow, OCP with ETAP

The modeling of the INPS system will be realized in ETAP. A case study with the load flow of the INPS was studied. The study models the system with the transmission lines parameters based on the line length, type of conductor used and the line capacity. The data of generators was based upon the design capacity of the power and its power factor. All the loads were transferred to the side with the higher voltage for the simplicity of the study (Ghimire & Paudyal, 2019). However, the study was carried out irrespective of the system peak and all the generations was assumed to run at their generation capacity. So, the load flow will be carried out in this research considering the load and generation for the month of Bhadra.

A study was carried out with the different types of load: constant power, constant current and constant impedance. It showed that the load flow solution for the constant power load required a smaller number of iterations for the convergence than the other models (Indulkar & Ramalingam, 2008).For the load model in this research, a constant power load of ETAP will used, in which the power consumption remains same irrespective of the change in the terminal voltage.

Various papers show the significance of ETAP for the analysis purpose and make a use of it. A research performed the load flow of the some of the interconnected 132 kV grid substations of Pakistan along with the short circuit analysis as well as the reliability analysis of the system (Nisar et al., 2015). Similarly, a paper covenants with the necessity of performing load flow for the understanding of power flow in the utility system. The authors also evaluated the proper size of detection equipment and protection relays highlighting their necessity in solving problems. The study was carried out for the Ghazaouet 220/63/30 kV substation located in the West Tlemcen Wilaya of Algeria consisting of 8 power transformers, 83 circuit breakers, 7 high voltage lines, 32 isolators, 33 current transformers, 7 potential transformers and 15 load areas and ensured that the major causes for the loss being voltage drop and use of the optimal size and location of capacitors to solve the problem (Zeggai & Benhamida, 2019).

Various other research presents the optimum capacitor placement with the usage of OCP module in ETAP. A research accomplished a simulation for an electrical model of a 1240 MW combined cycle power plant, developed on the ETAP software with Load Flow Analysis (LFA), voltage stability and Short Circuit Analysis (SCA) being performed. The authors evaluated the effect of power grid voltage instability on the system buses if the power plant. Using the algorithm of Newton-Raphson, the terminal buses which are functioning at under were identified and the improvement on their voltages were carried out with respect to the functions of voltage constraints. Along with it the tap changers which can be operated on-load and compensation of the reactive power compensation are carried out for the improvement in voltage. The most suitable (optimal) position was determined for the placement and number of the capacitor banks by providing the sizes using OCP module of ETAP. Moreover, the results obtained from the SCA are contrasted with the real case values of the short circuit current being experienced at the substations. It was concluded that the results obtained from the ETAP was found to be favorable for all power system studies (Ullah et al., 2017).

Similarly, another paper presented the assessment of the Kaduna 132/33 kV station performing the power flow analysis to determine its operating condition at the normal conditions. ETAP was employed in the modeling and performing LFA using the Single Line Diagram (SLD) with the real case data collected from the substation. The existing loss in the system network was compensated with the placement of the capacitor bank using the OCP module. From the results of OCP, eight capacitor banks were placed in the eight of the candidate buses. The results showed that the bus voltages previously in the range between 90.244%-94.716% was improved to 96.847-99.11% consequently reducing the active component of loss by about 22% (Airoboman et al., 2019). Similarly, the conditions of the voltage and loss before and after the capacitor placement will be studied in this research then from the energy savings the financial analysis will be carried out.

2.6 Financial Analysis

To know whether the practical implementation of a study is financially feasible, the financial analysis of the overall scenario needs to be carried out. Moreover, to attract investors for the expansion of a project in the future, it is significant to perform a feasibility analysis from a monetary objective. A paper illustrates a complete quantifiable analysis of the project profitability with Net Present Value (NPV), Internal Rate of Return (IRR), Return on Equity (ROE), Return on Assets (ROA) and an assessment of the affect of these factors on the profitability of the project with the value of Weighted Average of Cost Capital (WACC) for a mini battery manufacturing plant of Indonesia (Sutopo et al., 2013). This paper will calculate the NPV and IRR and will calculate the economical voltage for the connection of the capacitor based upon the Benefit Cost Ratio (BCR) and discounted payback period.

The capital cost will be the cost of the optimum sized capacitor installation at the optimum locations and the return will be made on the energy savings with the installation of the capacitor. Similar to the study (Poudel & Kumar Mishra, 2020), the project lifetime will be considered to be 20 years with the energy cost Rs. 10/kWh. So, with the analysis of the financial parameters: NPV, IRR, BCR and discounted payback period the financial feasibility of the study will be determined.

CHAPTER THREE: METHODOLOGY

For the optimum capacitor placement, the modelling of the system needs to be done from the data collected, followed by the load flow of the system. The effect of the capacitor placement at different voltage levels is studied. The study also includes the analysis of the change in power transfer capacity of the transmission line after the optimum use of the capacitor for the substations of KGD. To check the feasibility of the study, financial analysis is to be performed to know the feasibility of the study on the monetary point of view. The methodology proposed is presented in Figure 3.1 and some of the major process is described herewith.

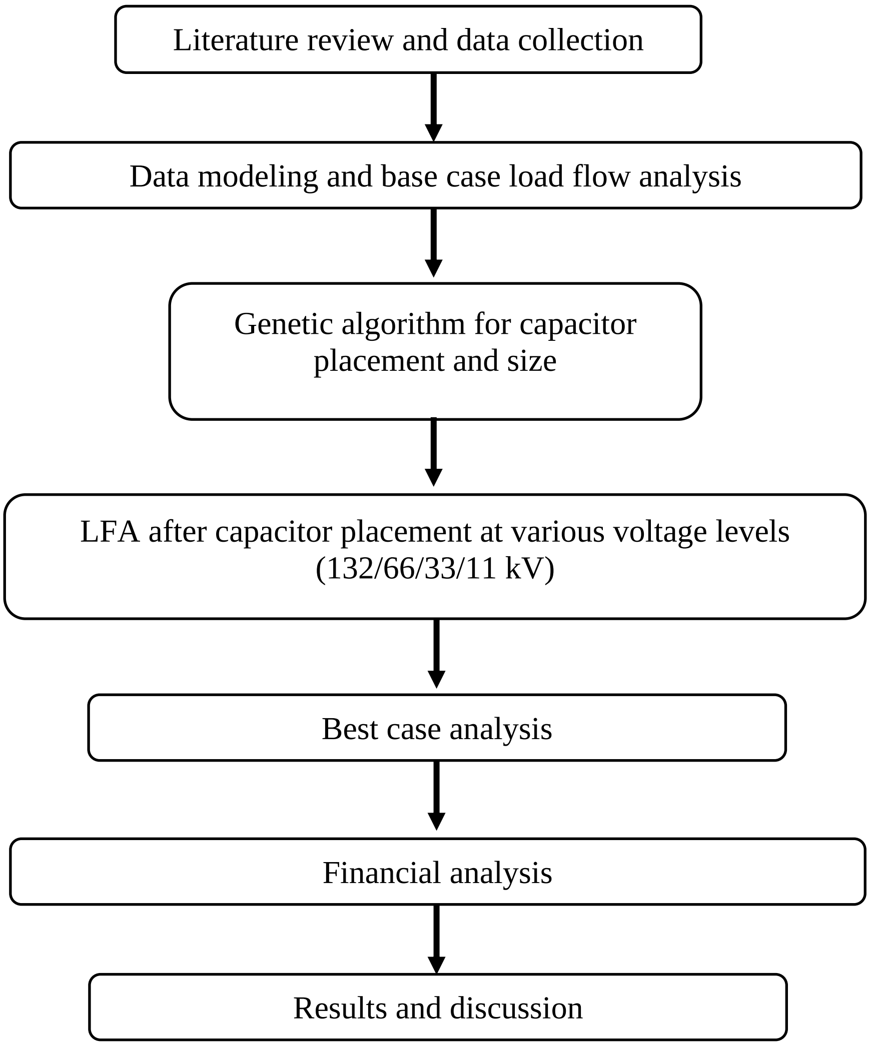

Figure 3.1 Flowchart of methodology

3.1 Data Collection

The data required for the study is collected from numerous sources. The major data sources include the NEA Annual Book and Transmission/Project Management Directorate Annual Book of FY 2076/77. During the modeling of the system the Single Line Diagram (SLD) the reference for substation connections, conductor size and configuration, Hydropower Plant (HP) connection and generation capacity is considered from the INPS layout available those publications. The load data is reflected from the data provided from the various Grid Divisions/Branches. For the analysis, the both the generation and load data are considered from the month of Bhadra of year 2077.

3.2 System Modelling

The INPS is simulated in the ETAP 16.0 software. In the modeling of the INPS, the load model the constant kVA load is assumed. The power factor of the load is assumed to be 0.9 (average pf of each SS). The transmission line parameters are computed as per the conductor reference provided in the IS 398-1976 standard. The substation bus in India is considered as the infinite bus importing only the required amount of power to set the bus voltage in Nepal near to 1 pu

3.3 Load Flow Analysis

The Load Flow Analysis (LFA) in the ETAP provides a variety of selection for the load flow methodology including, Adaptive Newton-Raphson, Newton-Raphson, Gauss-Seidel and Fast Decoupled Power Flow. The Adaptive Newton-Raphson method in the ETAP is used in the Load Flow. This improved method presents a smaller set of steps for iterations until a possible condition of divergence is met. Those set of minor rises in the values can help to meet a solution of the load flow in case of some of the systems where the failure of the Newton-Raphson method might have occurred. The results from the test of method concluded that the method, with significant series capacitance effects (i.e., negative series reactance), can improve the convergence for distribution and transmission systems.

One disadvantage with this method is reduction in the calculation speed due to the incremental steps considered for the solution. The default value of 99 iterations and a precision of 0.0001 is set for the load flow.

3.4 Optimum Capacitor Placement

The OCP module in ETAP allows us to identify the optimal location for the placement capacitors to provide voltage support and correction in the power factor minimizing capital and maintenance cost. The sophisticated user interface provides the suppleness for the control of the entire process of the placement of capacitor, allowing the users to view the results quickly. The best location and size of the capacitor banks is obtained automatically from the precise calculation approach. Moreover, the report regarding the increment in the power transfer capacity of the line branch and the energy saved with the capacitor placement in the overall planning period can be obtained.

The candidate bus was selected with the lower voltage level and the bus having higher value of the reactive consumption. The installation, operating and maintenance as well as the energy cost per kW was provided as the input for the optimum sizing of the capacitor. Thus, the result obtained will also have sound economical return.

The objective of OCP is to minimize the total cost associated with the system. This cost includes the purchase cost of the capacitor, the cost associated with its installation and operation. The operation cost also includes the maintenance cost required annually for the system installed and also the depreciation in cost along with the time. Moreover, the cost includes the cost of the real power losses that remains in the system with the addition of the capacitor in the system. This cost can be represented mathematically reprented in the objective function as:

Minimization function:

$$\sum_{i=1}^{Nbus}(x_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T + C2 \sum_{i=1}^{Nbus}(T_l P_L^1) \tag{3.1}$$

where,

- Nbus= No of bus candidate
- x_i – 0/1,0 means no cap installed at bus i
- C_{0i} – Installation cost
- C_{1i} – per kVAR cost of capacitor bank
- Q_{ci}– Capacitor bank size in kVAR
- B_i – Number of capacitor banks
- C_{2i} – Operating cost of per bank, per year

- T – Planning period (years)
- C_2 – Cost of each kWh loss in NRs. /kWh
- L – Load levels, maximum, average and minimum
- T_l – Time duration, in hours, of load level 1
- P_{Li}– Total system loss at load level l constraints

The main objective for the placement of capacitor is to meet the load flow constraints. Furthermore, the magnitudes of the voltage of all the load (PQ) buses should be within the acceptable range of lower and upper values. Also, the power factor (pf) of the load connected bus should be larger than the required minimal value with the maximum value equal to unity. The equality constraints are:

$$P_i(V,\delta) - P_{Gi} - P_{Di} = 0 \tag{3.2}$$

$$Q_i(V,\delta) - Q_{Gi} - Q_{Di} = 0 \tag{3.3}$$

The inequality constraints considered for the genetic algorithm is:

$$V_{i_{min}} \leq V_i \leq V_{i_{max}} \tag{3.4}$$

$$Q_{j_{min}} \leq Q_j \leq Q_{j_{max}} \tag{3.5}$$

Where, i is the number of buses and j is the number of the reactive power sources. The voltage considered in this case is: $0.9\, pu \leq V_i \leq 1.1\, pu$

The voltage constraint will be combined while enhancement of the bus voltages. After the placement of the capacitor, the bus voltages must lie within these constraints.

The OCP module provides information concerning the amount of the capacitor banks essential for reactive compensation causing enhancement of the voltage in the specified candidate buses and the overall system along with the optimal location for the placement.

3.5 Economic Analysis

The Internal Rate of Return (IRR), Net Present value (NPV), Benefit to Cost Ratio (BCR) and Discounted Payback Period was also calculated to analyze the economic aspects of the practical implementation of the study. The economic analysis was performed considering the project lifetime period of 20 years and with the inflation rate of 10% per annum.

Net Present Value (NPV): It is used to compute the today's value of the annual of payments of future years. With the positive value of NPV it can be inferred that the project is likely to provide positive returns and is attractive. In brief, it means that the discounted value of all future cash flows at present related to that project or investment will be positive.

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \tag{3.6}$$

where,

R_t = net cash inflows-outflows during a single period t

i = discount rate

t = number of time periods

Internal Rate of Returns (IRR): It is the yearly percentage growth that an investment is likely to produce, thus can be used in an estimation of the profitability of the potential investments. It can be calculated by setting NPV equal to zero. Any project that exceeds the Required Rate of Return (RRR) is determined to be acceptable and for the comparison of the cases the scenario with the highest IRR is more financially feasible.

$$0 = NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} - R_0 \tag{3.7}$$

where,

R_t = net cash inflows-outflows during a single period t

R_0 = Total initial investment cost

i = discount rate

t = number of time periods

Benefit Cost Ratio (BCR): It provides the inclusive association between the costs and the benefits associated with the project and can be articulated in the quantitative or monetary terms. If the BCR of an investment is greater than 1, it can be expected that the project delivers a positive return on capital cost to its investors and vice-versa.

$$BCR = \frac{\sum_{t=0}^{n} \frac{R_b}{(1+i)^t}}{\sum_{t=0}^{n} \frac{R_c}{(1+i)^t}} \tag{3.8}$$

where,

R_b = benefit net cash inflows during a single period t

R_c = cost net cash outflows during a single period t

i = discount rate

t = number of time periods

Discounted Payback Period: It gives the quantitative value in terms of years for a project to break even, from undertaking the initial expenditure, by discounting future cash flows and considering the time value of money. The lower the value of the period, the sooner the project will generate the cash covering the initial cost. The project with the lower value of discounted payback period will be more appropriate.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Test with standard IEEE 9 Bus system

The methodology is tested for the standard IEEE 9 bus of transmission system. The standard bus system consists of 9 buses with 3 generators, 3 loads and 3 transformers and 9 line/ transformer branches. The load, generation and line data for the system is tabulated in Annex D.

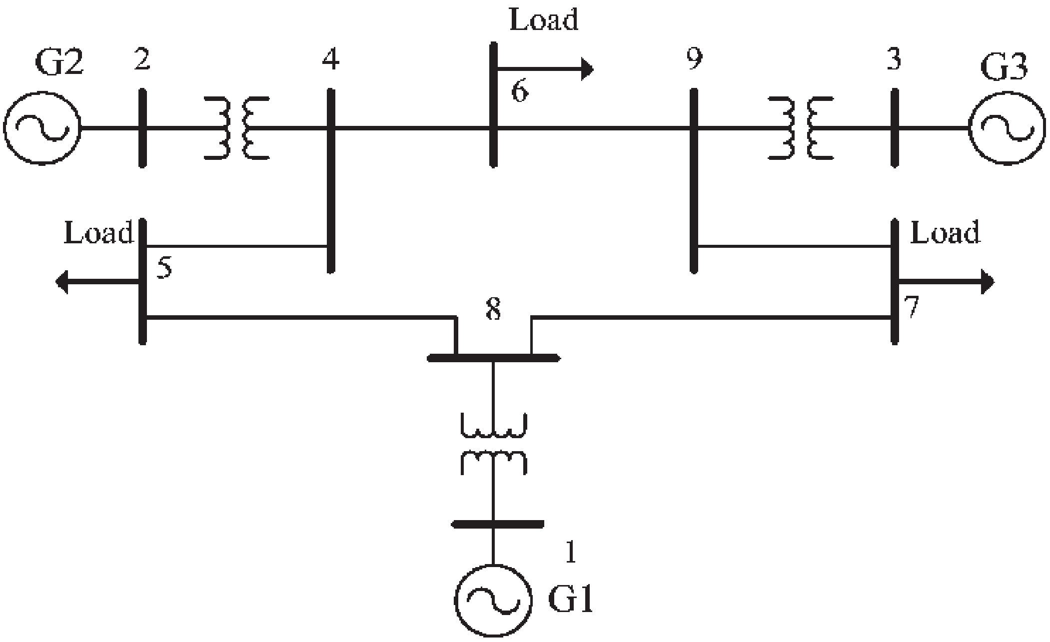

Figure 4.1 Model of the standard IEEE 9 bus system

The load flow analysis of the IEEE- 9 bus transmission system is performed with the adaptive Newton-Raphson method and the results are compared with the standard results of IEEE.

Table 4.1 Summary of load flow of standard IEEE 9 bus system

S.N.	Description	IEEE 9 bus- base case
1.	Generation-MW	319.34
2.	Generation-MVAR	22.64
3.	Loss-MW	4.66
4.	Loss-MVAR	-92.21
5.	No. of SS below 1 pu voltage	1
6.	Loss %	1.46%
7.	Average Load Factor	0.64
8.	Annual Energy Dispatched (GWh)	1,790.33
9.	Annual Energy Loss (GWh)	26.13

From the results it can be determined that the voltage of the buses obtained after the load flow using adaptive Newton Raphson method is identical to the standard for most of the buses and almost equal for the other.

Table 4.2 Comparison of the voltage results of load flow with standard of IEEE

S.N.	Bus	Standard voltage (pu)	Voltage obtained (pu)	Difference (%)
1.	Bus 1	1.04	1.0400	0.000
2.	Bus 2	1.025	1.0250	0.000
3.	Bus 3	1.025	1.0250	0.000
4.	Bus 4	1.026	1.0258	0.019
5.	Bus 5	0.996	0.9957	0.030
6.	Bus 6	1.013	1.0127	0.030
7.	Bus 7	1.026	1.0257	0.029
8.	Bus 8	1.016	1.0159	0.010
9.	Bus 9	1.032	1.0323	-0.029

The results of the power flow in the branch are presented in Table. The result illustrates that the most voltage drop occurs in the section Bus 4 - Bus 5 and the most KW loss occurs in the section Bus7 – Bus 5.

Table 4.3 Branch results of IEEE 9 bus form LFA

S. N.	From Bus	To Bus	MW Flow	MVAR Flow	Voltage drop (%)	Losses (kW)
1.	Bus 5	Bus 4	40.460	38.642	3.01	255.4
2.	Bus 6	Bus 4	30.453	16.556	1.31	165.6
3.	Bus 7	Bus 5	84.301	11.253	3.00	2298.8
4.	Bus 9	Bus 6	60.842	-18.099	1.97	1355
5.	Bus 9	Bus 8	24.066	24.295	1.65	87.84
6.	Bus 8	Bus 7	75.909	10.683	0.99	475.4
7.	Bus 4	Bus 1	71.337	26.963	1.42	3.1
8.	Bus 2	Bus 7	162.984	-9.269	0.07	15.8
9.	Bus 3	Bus 9	84.996	-14.981	0.73	4.1

The optimum capacitor placement is simulated for the standard bus system. Since the minimum voltage of the system is on bus 5 with the minimum voltage of 0.996 pu, it is selected as the candidate bus. However, the maximum and the minimum voltage range were adjusted for 1.1 pu > V > 1 pu, so that the voltage of all the bus exceed 1 pu. From the simulation, the optimal size of the capacitor to be placed is 26 MVAR. The load flow is performed with the optimal placement of the capacitor bank and the summary of results is presented herewith in Table 4.4.

Table 4.4 Summary of LFA results with optimum placement of capacitor

S.N.	Description	IEEE 9 bus with capacitor placement
1.	Generation (MW)	320.13
2.	Generation (MVAR)	-3.87
3.	Loss (MW)	3.87
4.	Loss (MVAR)	-94.60
5.	No. of SS below 1 pu voltage	0
6.	Loss %	1.37%
7.	Average load factor	0.64
8.	Annual energy dispatched (GWh)	1,794.78
9.	Annual energy loss (GWh)	24.50

From the results, it can be seen that the loss of the system decreases from 1.46% to 1.37% with the addition of the capacitor. Assuming the average load factor of 0.64, the annual energy savings is calculated to be 1.63 GWh. Moreover, the voltage at 7 of the buses have increased with the major increment in the bus with the capacitor placed.

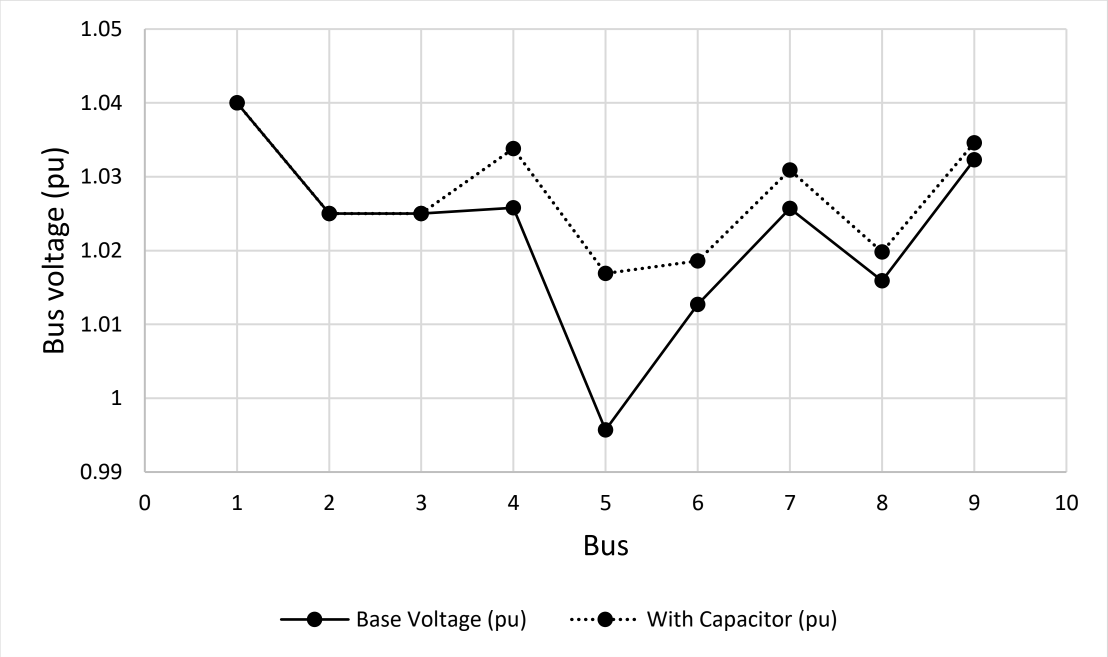

Figure 4.2 Voltage comparison of the buses before and after capacitor placement

4.2 Collection of data

The data was collected from the various sources including the journals and annual books of NEA. Since the study was related to the load flow and the placement of the capacitor in the grid substations, the data regarding the configuration of the interconnected substations, the previously placed capacitors and the general scenario of loading can be obtained from the annual book published by the Transmission and

Project Management Directorate for the fiscal year 2076/77. Similarly, the necessary values for the peak generations of the grid connected NEA owned hydro powers was obtained from the year book of the Generation Directorate and for the IPPs was extracted from the annual reports of the particular hydropower. With the obtained data the model was drawn and simulated in the software.

4.3 Formulation of model

The load flow of the existing INPS system was carried out considering the overall system peak of Bhadra month in the ETAP software. The model was drawn as per mentioned in the subheading 3.2. Moreover, with the load flow analysis using Newton-Raphson and the optimum capacitor placement with the OCP module were performed and the obtained results are described under the following sub-headings.

4.4 Load flow analysis

During the season, while most of the generating units are operating almost at their full capacity, the voltage in the 11kV of the grid substations were still below the standard. Those substations include most of the substations of the Lumbini province and some of the substations of the Kathmandu valley and Sudurpaschim province. Moreover, the system suffers around 4.16 percent of power loss. The total generation for the system is 1367.30 MW of which 56.93 MW of loss is prevalent in the transmission lines and as the copper loss of the substation transformers. The calculated value for the percentage loss is a bit lower than the loss as mentioned by the Transmission and Project Monitoring Directorate because the loss result excludes the non-technical loss and the iron-loss in the substation transformers.

Since, the load flow was performed at the system peak, to calculate the energy the load factor needs to be determined from the annual energy dispatched. So, from the data published by NEA, the annual energy dispatched and system peak are 7,894.47 GWh and 1,407.94 MW respectively. So, Load Factor = 7894.47 × 1000 MWh / (1407.94 MW × 365 × 24 hr) = 0.64 and the reduction in the peak loss needs to be multiplied with this factor and annual hours to find the annual energy savings. Thus, there is an energy loss of about 319.19 GWh in the system from the overall dispatched energy of 7,665.54 GWh.

Table 4.5 Summary of result for load flow at system peak

S.N.	Description	Base case
1.	Generation (MW)	1,367.30
2.	Generation (MVAR)	279.045
3.	Loss (MW)	56.933
4.	Loss (MVAR)	67.62
5.	No. of SS below 0.9 pu voltage	11
6.	Loss %	4.16%
7.	Average load factor	0.64
8.	Annual energy dispatched (GWh)	7,665.64
9.	Annual energy loss (GWh)	319.19

The bus where the voltage is lower below 0.9 pu and the part with the higher demand are then selected as the candidate bus for the optimum capacitor placement. Most of the substations below 0.9 pu are located in Lumbini and Sudurpaschim due to the requirement of the substation to feed from the power source located at a longer distance and two of the substations of Kathmandu Valley: K3 and Bhaktapur. In most of the substations suffering lower voltage conditions, the power demand is higher than 25 MVA. So, as the load is high in most of those substations, the voltage drop is also high.

4.5 Placement of optimum capacitor

The capacitors are placed using the genetic algorithm selecting the best among the candidate bus. The rating of the capacitors in the multiple of 2.5 MVAR was considered and the optimal location as determined by Optimum Capacitor Placement (OCP) module in the ETAP. It was determined that the following size of capacitors when placed at the corresponding substations would be the optimum location and size of the capacitors as listed in Table 4.6. It is illustrated that there is still 25 MVAR of capacitor required at the Butwal Grid substation due to the high-power demand from the substation and a unit of 10 MVAR at K3, Lamki and Mahendranagar substation as well as 12.5 MVAR at Bhaktapur and Lamahi substation.

Table 4.6 Optimum size of capacitors to be placed in the optimum substations

S.N.	Substation	Capacitor size (MVAR)
1.	Bhaktapur	12.5
2.	Butwal	2×12.5
3.	K3	10
4.	Lamahi	12.5
5.	Lamki	10
6.	Mahendranagar	10

When the load flow study was performed after the placement of capacitor banks in the above-mentioned substations, it was evaluated that the loss decreased from 4.16% to 3.96% and the system suffers about 303.17 GWh of annual energy loss, lower than the previous energy loss by about 16.02 GWh. The summary of result after the optimum placement of capacitors for the system peak is provided in Table 4.7.

Table 4.7 Summary of results of load flow for the scenario after the optimum placement of the capacitors

S.N.	Description	With Capacitor
1.	Generation (MW)	1,364.44
2.	Generation (MVAR)	161.15
3.	Loss (MW)	54.08
4.	Loss (MVAR)	47.29
5.	No. of SS below 0.9 pu voltage	-
6.	Loss %	3.96%
7.	Average Load Factor	0.64
8.	Annual Energy Dispatched (GWh)	7,649.62
9.	Annual Energy Loss (GWh)	303.17

The voltage profile of the substations throughout the country is studied. The alteration in the voltage profile of the substation before and after the capacitor placement is shown in Figure 4.3. The voltage of the substations has improved drastically and most of its effect can be seen in the substations at Lumbini and Sudurpaschim province and mode through analysis for the substations in KGD is performed.

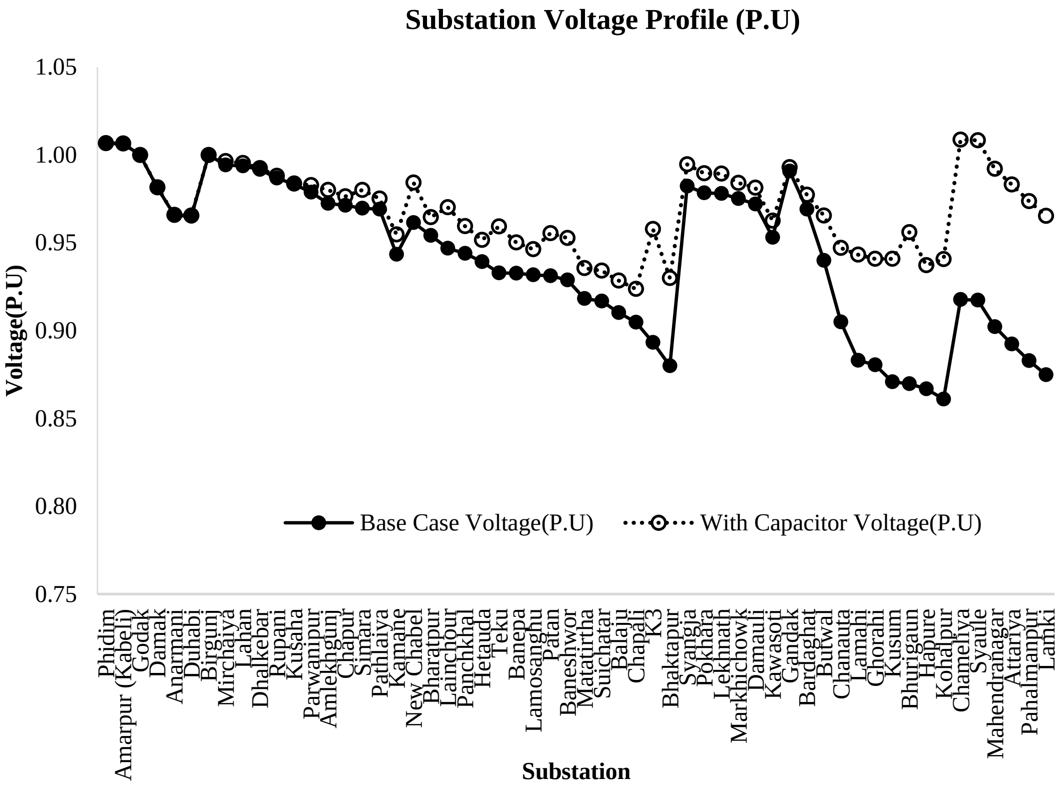

Figure 4.3 Alteration of voltage profile in the grid substations of INPS at the base case and with capacitor placement

The voltage at the 132 kV grid substation ranges from 116.16 kV to 122.98 kV at the peak loading condition. With the placement of 12.5 MVAR and 10 MVAR capacitor banks at the Bhaktapur and K3 substations respectively, the voltage increased to the range of 121.93 kV to 124.91 kV.

Along with the increment of the voltage the 132kV system, there is the voltage improvement in the sub-coordinate 66 kV substations as well. The voltage initially ranged in between 58.95 kV - 63.46 kV increased to the range of 63.22 kV – 64.96 kV. The result showed that the K3 substation has the lowest voltage among the 66 kV substations of the Kathmandu grid and it increased from 58.95 kV to 63.22 kV. The figure attached herewith provides the scenario of the rest of the grid substation throughout the country. The voltage of the substations increased up to 7.24% in the 66kV substations.

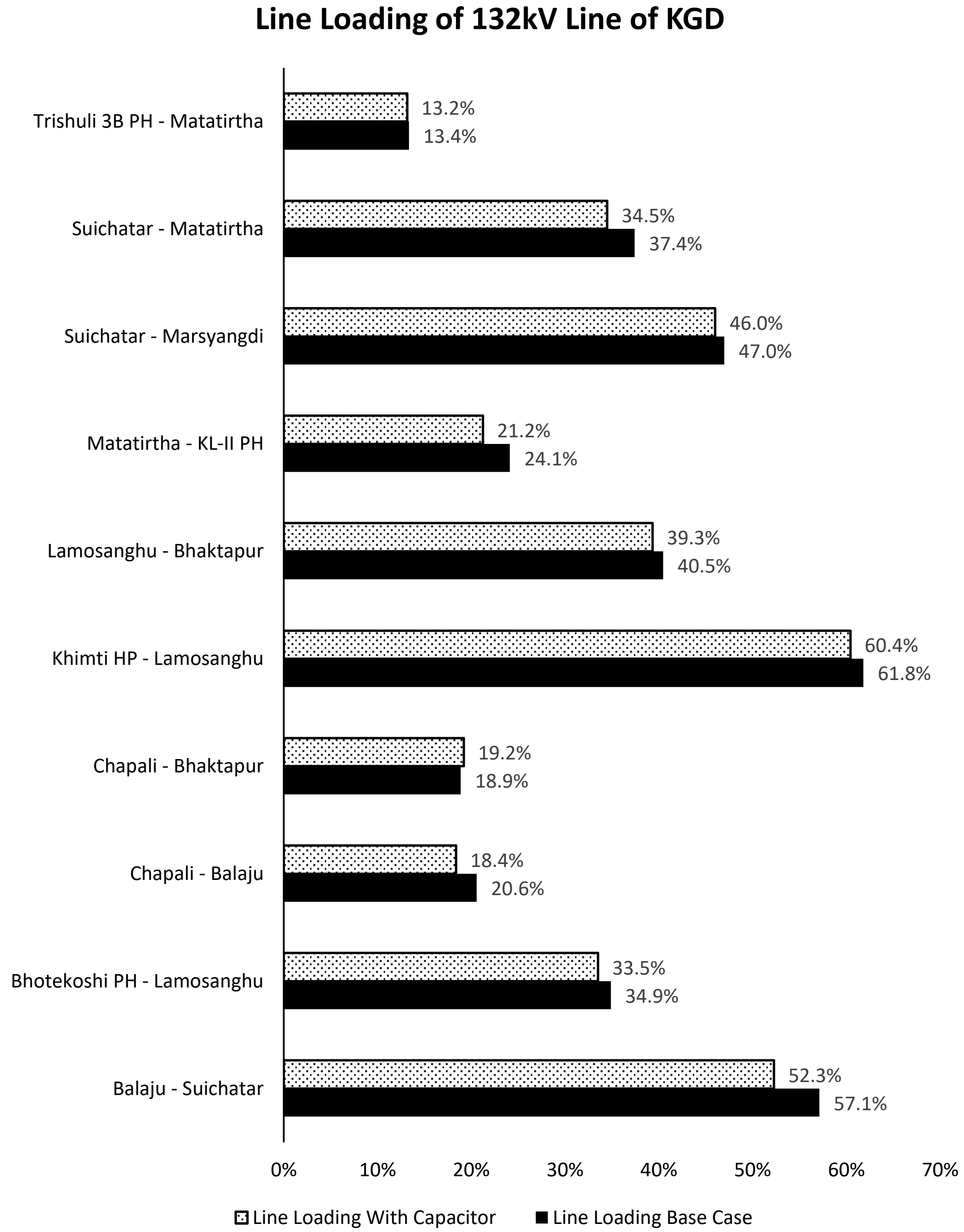

Figure 4.4 Line loadings before and after the capacitor placement for 132kV lines of KGD

The comparison of the loadings of the line before and after the placement of capacitor for the 132 kV lines is presented in the Figure 4.4. It can be inferred that the loadings of the lines decrease in most of the line sections with the placement of the capacitor in two of the substations however with the transfer of the reactive power from the Bhaktapur substation to the nearby substations, the line loading has increased in those sections. In general, the line loading in between most of the substations has decreased and the overall power transfer capacity of the KGD has increased. Most increase was found in the line section of Balaju – Suichatar. With the capacitor placed in the K3 substation, the reactive power required for the K3 and Teku substations are supplied from the capacitor and the power flow through the interconnected lines has decreased. Similarly, with the capacitor placed in the Bhaktapur substation the overall power sent from the Lamosanghu substation will decrease causing the overall reduction in the loadings.

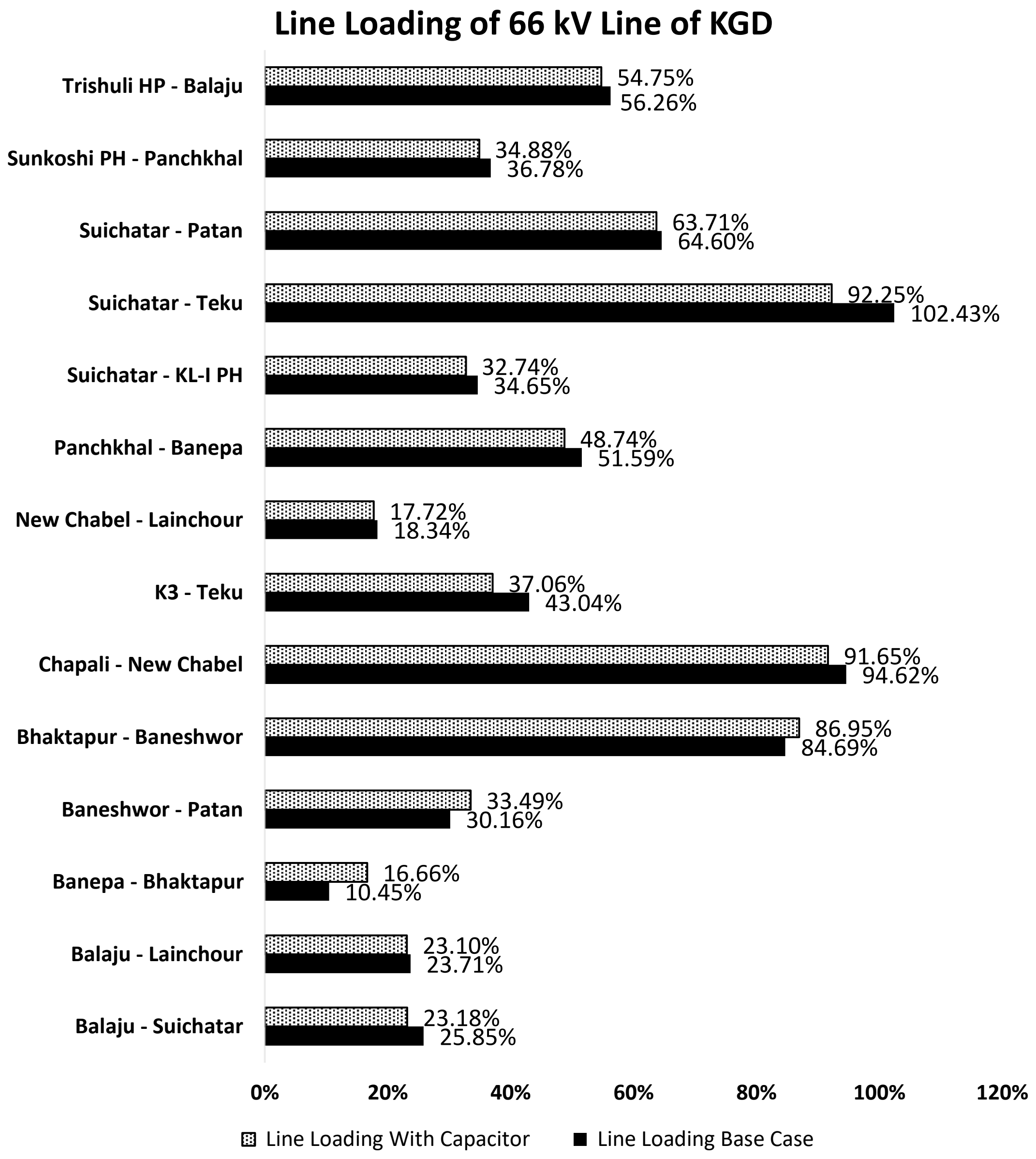

Figure 4.5 Line loadings before and after the capacitor placement for 66 kV lines of KGD

In case of 66 kV transmission lines, the impact of Capacitor bank placement can be significantly seen in Suichatar – Teku line, resulting around 10 percentages of decrease in the line loading as in Figure 4.5. Similarly, the line loading of Chapali-New Chabahil and Suichatar-Balaju 66 kV line have also improved by good margins due to the placement of the Capacitor at K3 and Bhaktapur substations. In some of the 66kV line sections the loading has increased due to the capacitor placed in Bhaktapur substations. The improvement of the substation voltage of the Suichatar and Chapali S/S due to the reactive power compensations has allowed lesser amount of reactive power to carry the same amount of active power through these lines resulting further improvement in the line loading.

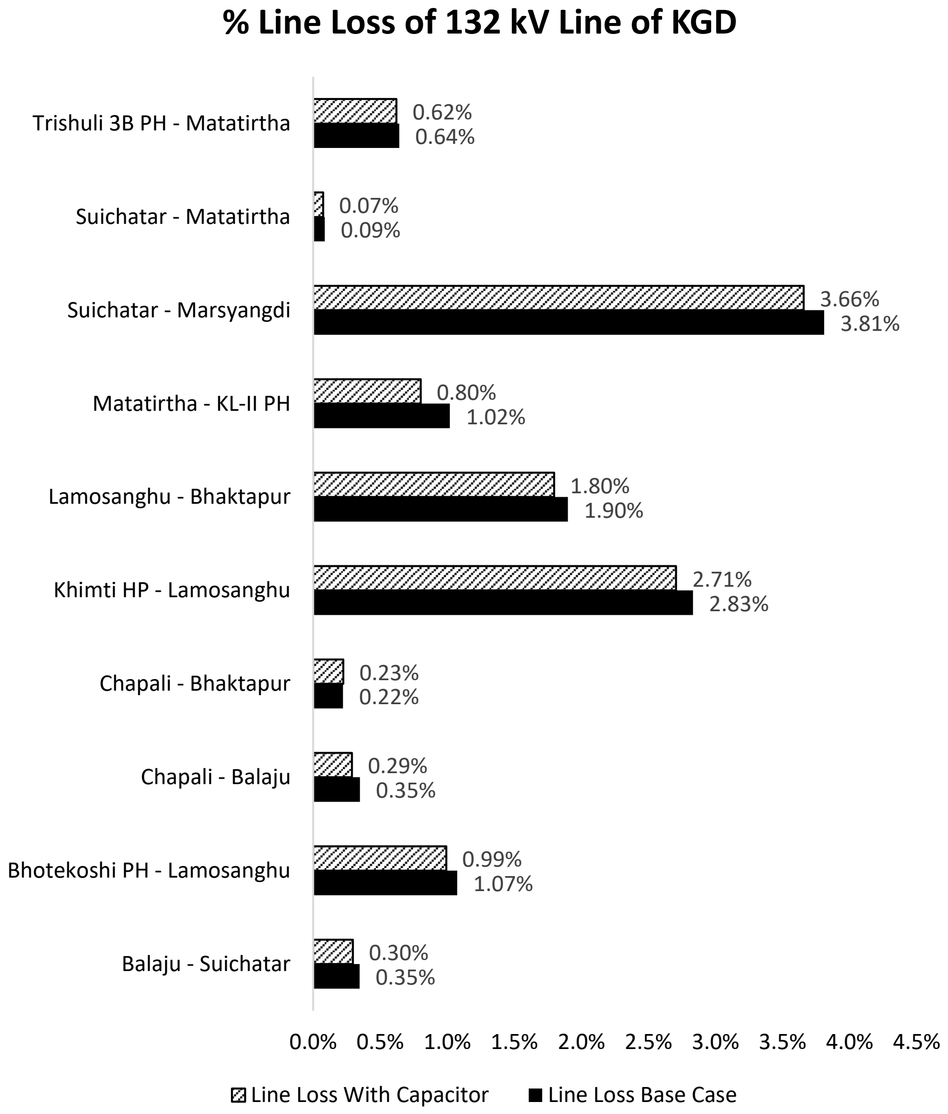

Figure 4.6 Line loss before and after the capacitor placement for 132kV lines of KGD

As the line loss is proportional to the loading, the loss also decreased in all of the 132kV line sections, except the line between Chapali and Bhaktapur due to the increase in flow of reactive power from Bhaktapur to the Chapali Gid. Major percentage loss was prevalent in Suichatar-Marsyangdi line at the system peak due to the long length and transfer of higher amount of the power and similar is the cause for the loss in Khimti - Lamosanghu line. So, there is an overall decrease in the line loss due to the placement of the capacitor in the 132kV Lines as seen in the Figure 4.6.

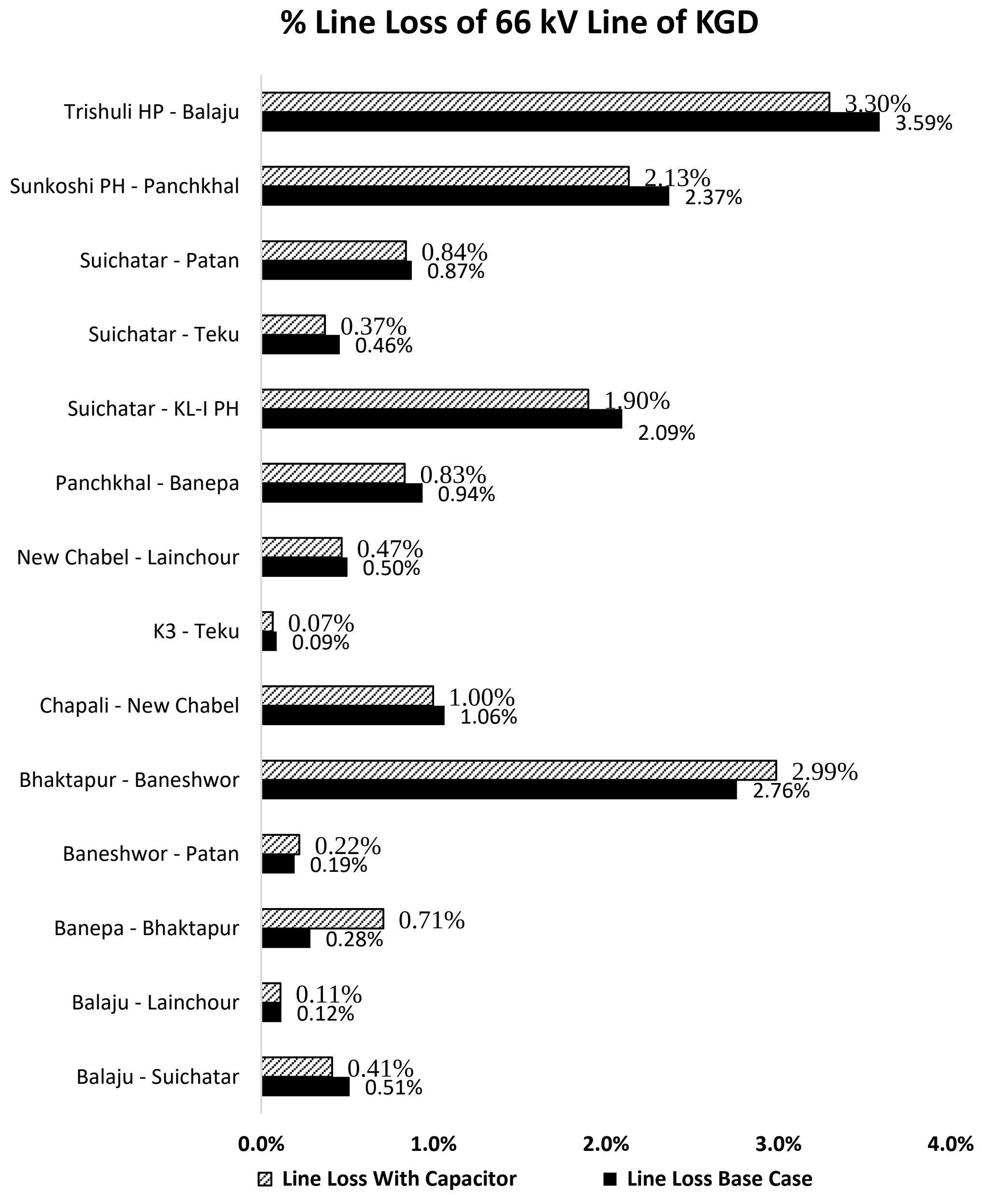

Figure 4.7 Line loss before and after the capacitor placement for 66 kV lines of KGD

Similarly, the decrease in the line loss can also be seen in the 66kV transmission line too. There is a significant reduction in the loss of the overall lines. However, along with the loading, the loss has increases in the line connecting the substations Bhaktapur, Baneshwor and Patan due to the increase in the flow of the reactive power as illustrated in Figure 4.7.

Hence, with the optimum placement of the capacitors, the overall loading of the transmission line decreases causing an increase in the power transfer capacity of the lines with reduction in the overall line loss.

4.6 Financial Analysis

From the results of the technical analysis, it was well perceived that there would be a significant reduction in the loss and the loadings with the increased voltage level supporting the technical feasibility. Similarly, the financially viability of the implementation also needs to be analyzed. So, the financial parameters: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit Cost Ratio (BCR), and the discounted payback period with the implementation was studied and the results are presented herewith.

4.6.1 Results

The financial analysis for the study is carried out considering the annual inflation of 10% p.a. The total cost associated with the installation of the capacitor in the 6 substations was found to be NRs. 4,51,20,000. With the annual savings of 16.02 GWh of energy, and NRs. 10 per unit cost of the energy the total savings each year would be NRs. 1,60,20,000. The total capital cost of the project will be dispersed in 3 years at 20%, 60% and 20% and the revenue due to savings in the first three years will be 0%, 20%, 100% respectively. The operation and the maintenance cost of the implementation is considered to be about 0.1% of the capital cost/year and starts from the year of complete implementation.

From the annual cash flow table as shown in Annex B, it was calculated that the NPV, IRR, BCR and discounted payback period of NRs. 6,98,57,166, 19.691.93 and 5.97 years respectively.

Table 4.8 Summary of the financial analysis

S.N.	Parameters	Value
1.	Capital Investment (NRs.)	4,51,20,000
2.	Annual Energy Savings (GWh)	16.02
3.	Energy Cost (NRs. /kWhr)	10.00
4.	Annual cost Savings (NRs.)	1,60,20,000
5.	NPV (NRs.)	6,98,57,166
6.	IRR	19.69%
7.	BCR	1.93
8.	Discounted Payback Period (years)	5.97

4.7 Most Suitable Voltage

Moreover, the analysis for the most techno-economically suitable voltage for the placement of the capacitor was performed which will provide a clear insight on the selection of the most suitable voltage for the placement of the capacitor. The comparison of the technical parameters with the capacitor placed at varying voltage levels of the optimum sized and located capacitors at the suitable voltage level is shown in Table 4.9.

Table 4.9 Summary of technical parameters for capacitor placed at various voltage levels

S. N.	Description	With capacitor placement			
		11kV	33kV	66kV	132kV
1.	Generation (MW)	1,364.44	1,364.42	1,364.29	1,364.48
2.	Generation (MVAR)	161.15	161.18	159.24	161.48
3.	Loss (MW)	54.08	54.10	53.92	54.11
4.	Loss (MVAR)	47.29	47.31	47.46	47.75
5.	No. of SS below 0.9 pu voltage	-	-	-	-
6.	Loss (%)	3.96	3.96%	3.95	3.97
7.	Annual Energy Dispatched (GWh)	7,649.62	7,649.48	7,648.76	7,649.80
8.	Annual Energy Loss (GWh)	303.17	303.26	302.30	303.35
9.	Annual Energy savings (GWh)	16.02	15.92	16.89	15.84

From the technical analysis, the results shows that the overall system loss during the peak, with the capacitor placed at the varying voltage level is almost identical varying only by 0.01% from 3.96% and almost identical annual energy savings. From the minute perspective, the energy savings with the capacitor placed at the 66kV is higher than at the other voltage levels with the lowest at 132kV.

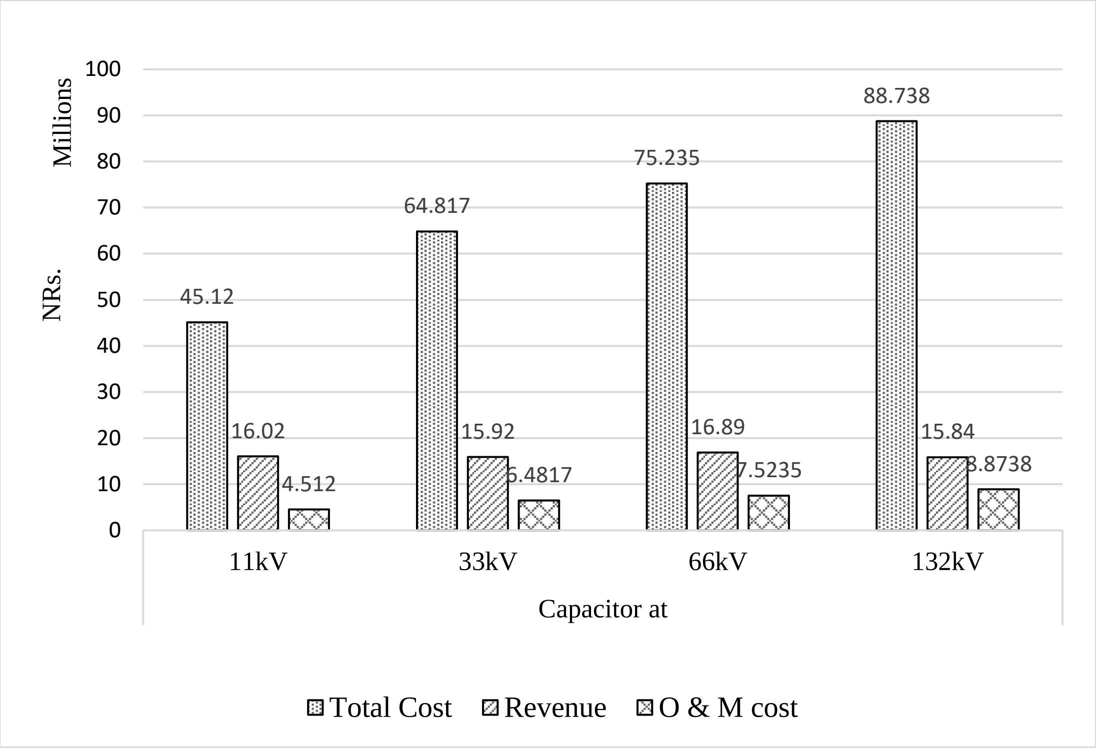

Figure 4.8 Capital cost, annual revenue and operating cost with capacitor at different voltage levels

The cost associated with the implementation like the capital cost, operation and maintenance cost and the annual revenue generated for the implementation is presented in the Figure 4.6. Similarly, the results of the financial analysis is presented in Table 4.10 and discussed herewith.

Table 4.10 Summary of the financial parameters for capacitors placed at various voltage levels

S. N.	Description	With capacitor placement			
		11kV	33kV	66kV	132kV
1.	NPV (NRs.)	69,827,166	36,237,313	27,710,584	-4,181,492
2.	IRR (%)	19.69	7.65	5.16	-0.71
3.	BCR	1.93	1.34	1.22	0.97

S. N.	Description	With capacitor placement			
		11kV	33kV	66kV	132kV
4.	Payback Period (Years)	5.97	9.73	11.56	>20

From the financial analysis, it can be inferred that the capacitor placed at the voltage of 11kV is more feasible among the alternatives with the highest value of IRR, NPV and BCR as well as with the lower discounted period. While the IRR of capacitor placement at 66kV is positive and have BCR greater than one, the installation of capacitor at 132kV is financially unfeasible with negative value of IRR and BCR less than unity.

So, from the techno-economic analysis it was clear that the most suitable voltage level for the optimum placement of the capacitor is 11kV. From the technical perspective, though the scenario is almost identical for all the cases but from the financial perspective due to the higher cost of the capacitor for installation at the higher voltages the installation is comparatively not suitable.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

The various conclusions and recommendations have been obtained from study.

5.1 Conclusions

Following conclusions have been drawn from study:

- The grid substations in Nepal are below the standard voltage level during the wet peak. With the total capacity of 80 MVAR capacitor placed across the 6 grid substations throughout the country, all the substations reached within the standard voltage level. The system loss in the transmission decreased from 4.16% to 3.96% with the annual energy savings of 16.02 GWh.
- With the detail technical analysis of the transmission lines in the Kathmandu Grid Division it was determined that with the addition of the capacitor in the Bhaktapur and K3 substations, the loadings in the overall transmission lines decreased thus there is an increase in the power transfer capacity of the transmission lines. The voltage in the substations improved by up to 7.24%. Moreover, with the decrease in the loading, the line loss also decreased by a significant amount.
- From the economic analysis with the proposed changes, it was evaluated that the IRR, NPV, BCR and discounted payback periods are 19.69%, NRs. 6,98,57,166, 1.93 and 5.97 years respectively.
- The effects of the capacitor placed at the varying level of voltage, on the system voltage and loss is almost similar. But considering the financial aspects, the installation at 11kV is more suitable and financially feasible.

5.2 Recommendations

Following recommendations have been made from the study:

- An elaborate study can be done considering the variations of system loss along with the seasonal peak and an extended and detail study can be made for the effect on the transient characteristics due to the capacitor switching.
- The study can be augmented for the substations at 33kV along with the grid substations and place the optimum sized capacitors in those substations too.

- The plans and research can be made for the placement of the capacitor considering the load and generation forecast of 5 to 10 years in the future and realize the size and location of the capacitors for effective planning.

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ANNEX A: INPUT SYSTEM DATA

Table A.1: Generation from NEA, IPPS and import data

S.N.	Generation / Import Name	Generation (MW)
1.	Bagmati	17.1
2.	Bhotekoshi PH	36
3.	Chameliya	35.595
4.	Chilime	21.933
5.	Devighat	14
6.	Gandak	1.264
7.	Indrawati	9
8.	IPP to Godak	56.266
9.	IPP to Phidim	36.915
10.	Jhimruk	9.187
11	Kaligandaki	140
12.	Khimti HP	59.672
13.	KL-I PH	50.004
14.	Mai	25.976
15.	Marsyangdi	37.934
16.	Midle Marsyangdi	69.883
17	Modi HP	34.2
18.	Puwa Khola	5.985
19.	Raxaul	70.83
20.	Sunkoshi PH	9.259
21.	Tanakpur	80
22.	Trishuli	19.8
23.	Trishuli 3A	33.192
24.	Upper Marsyangdi	39.897

Table A.2: Load demand of the grid substations

S.N.	Substation Name	MVA	MW	MVAR
1.	Amarpur (Kabeli)	1.50	1.35	0.65
2.	Amlekhgunj	0.48	0.43	0.21
3.	Anarmani	49.61	44.65	21.63
4.	Attariya	17.35	15.62	7.56
5	Balaju	29.72	26.75	12.95
6.	Banepa	11.29	10.16	4.92
7.	Baneshwor	27.55	24.80	12.01
8.	Bardaghat	14.63	13.17	6.38
9.	Bhaktapur	31.79	28.61	13.86
10	Bharatpur	69.88	62.89	30.46
11.	Bhurigaun	1.54	1.39	0.67
12.	Birgunj	52.93	47.64	23.07
13.	Butwal	150.67	135.60	65.67
14.	Chanauta	38.09	34.28	16.60
15.	Chapali	33.91	30.52	14.78
16.	Chapur	42.70	38.43	18.61
17.	Damak	19.49	17.54	8.50
18.	Damauli	13.26	11.93	5.78
19.	Dhalkebar	44.75	40.28	19.51
20.	Duhabi	174.50	157.05	76.06
21.	Gandak	20.18	18.16	8.79
22.	Ghorahi	12.17	10.96	5.31
23.	Godak	3.65	3.29	1.59
24.	Hapure	9.77	8.80	4.26
25.	Hetauda	18.30	16.47	7.98
26.	K3	29.32	26.39	12.78
27.	Kamane	21.37	19.23	9.32
28.	Kawasoti	21.49	19.34	9.37
29.	Kohalpur	61.62	55.45	26.86
30.	Kusum	0.10	0.09	0.05

S.N.	Substation Name	MVA	MW	MVAR
31.	Lahan	26.03	23.43	11.35
32.	Lainchour	32.00	27.20	16.86
33.	Lamahi	25.72	23.15	11.21
34.	Lamki	10.92	9.83	4.76
35.	Lamosanghu	17.49	15.74	7.62
36.	Lekhnath	12.47	10.60	6.57
37.	Mahendranagar	21.77	19.59	9.49
38.	Markhichowk	6.26	5.63	2.73
39.	Matatirtha	8.23	7.41	3.59
40.	Mirchaiya	9.13	8.22	3.98
41.	New Chabel	33.91	30.52	14.78
42.	Pahalmanpur	5.78	5.20	2.52
43.	Parwanipur	43.21	38.89	18.83
44.	Patan	41.90	37.71	18.26
45.	Pathlaiya	8.59	7.73	3.75
46.	Phidim	1.00	0.90	0.44
47.	Pokhara	34.07	30.66	14.85
48.	Purbi Chitwan	0.10	0.09	0.04
49.	Rupani	19.41	17.47	8.46
50.	Simara	15.43	13.89	6.73
51.	Suichatar	20.52	18.46	8.94
52.	Syangja	6.12	5.50	2.67
53.	Syaule	7.03	6.33	3.06
54.	Teku	23.90	21.51	10.42
55.	Tingla	0.10	0.09	0.05

Table A.3 Line Parameters of the INPS Data

S. N.	From	To	Line Impedance								
			Positive			Negative			Zero		
			R1	X	Y	R1	X	Y	R1	X	Y
1.	Attariya	Mahendranagar	2.04	6.80	206.09	2.04	6.81	206.09	7.18	45.21	59.53
2.	Kohalpur	Bhurigaun	2.75	9.19	278.50	2.75	9.20	278.50	9.70	61.10	80.45
3.	KL-I PH	Bagmati PH	0.73	1.56	10.93	0.73	1.56	10.93	1.29	5.91	4.78
4.	Bhotekoshi PH	Lamosanghu	3.38	12.09	81.07	3.38	12.09	81.07	7.72	44.21	37.76
5.	Parwanipur	Raxaul	1.74	6.24	41.84	1.74	6.24	41.84	3.98	22.82	19.49
6.	Trishuli 3B PH	Matatirtha	1.97	8.63	267.36	1.97	8.64	267.36	8.69	58.46	77.23
7.	Purbi Chitwan	Bharatpur	4.76	13.93	91.53	4.76	13.93	91.53	9.66	50.19	42.63
8.	Trishuli HP	Balaju	3.97	5.86	161.53	3.97	5.86	161.53	8.00	35.99	46.66
9.	Chilime	Trishuli HP	7.14	15.87	101.99	7.14	15.87	101.99	12.60	56.28	47.50
10.	Devighat PH	Trishuli HP	0.83	1.86	11.92	0.83	1.86	11.92	1.47	6.58	5.55
11	Okhaltar	Devighat PH	3.63	5.36	147.61	3.63	5.35	147.61	7.31	32.89	42.64
12.	Okhaltar	Chapali	0.08	0.49	15.60	0.08	0.49	15.60	0.47	3.40	4.51
13.	Suichatar	KL-I PH	2.64	5.58	161.53	2.64	5.57	161.53	6.70	35.70	46.66
14.	Hetauda	Purbi Chitwan	4.76	13.93	91.53	4.76	13.93	91.53	9.66	50.19	42.63
15.	Khimti HP	Dhalkebar	6.15	28.63	196.13	6.15	28.65	196.13	16.65	106.28	91.35
16.	Mai PH	Godak	0.61	2.02	61.27	0.61	2.02	61.27	2.13	13.44	17.70
17.	Godak	Puwa HP	1.65	3.11	27.58	1.65	3.11	27.58	2.94	14.03	11.39
18.	Kusum	Kohalpur	2.64	8.83	267.36	2.64	8.83	267.36	9.31	58.66	77.23
19.	Suichatar	Teku	0.23	0.75	22.84	0.23	0.75	22.84	0.80	5.01	6.60
20.	Kamane	Hetauda	0.44	1.47	44.56	0.44	1.47	44.56	1.55	9.78	12.87
21.	K3	Teku	0.08	0.49	15.60	0.08	0.49	15.60	0.47	3.40	4.51
22.	Suichatar	Patan	0.59	1.25	36.21	0.59	1.25	36.21	1.50	8.00	10.46
23.	Baneshwor	Patan	0.71	1.13	7.06	0.71	1.13	7.06	1.09	3.93	3.29
24.	Balaju	Suichatar	0.55	1.95	13.08	0.55	1.95	13.08	1.25	7.13	6.09
25.	Balaju	Suichatar	0.64	1.35	38.99	0.64	1.34	38.99	1.62	8.62	11.26
26.	Balaju	Lainchour	0.27	0.80	5.23	0.27	0.80	5.23	0.55	2.87	2.44
27.	New Chabel	Lainchour	0.39	2.59	18.31	0.39	2.59	18.31	1.37	9.84	8.53
28.	Chapali	New Chabel	0.69	1.01	27.85	0.69	1.01	27.85	1.38	6.21	8.05
29.	Chapali	Bhaktapur	0.66	2.21	66.84	0.66	2.21	66.84	2.33	14.66	19.31
30.	Bhaktapur	Baneshwor	3.42	5.43	34.00	3.42	5.43	34.00	5.24	18.90	15.83
31.	Hapure	Kusum	2.40	8.58	57.53	2.40	8.58	57.53	5.48	31.37	26.80
32.	Banepa	Bhaktapur	2.89	4.60	28.77	2.89	4.60	28.77	4.43	15.99	13.40
33.	Panchkhal	Banepa	2.10	3.34	20.92	2.10	3.34	20.92	3.22	11.63	9.74
34.	Indrawati PH	Panchkhal	3.81	11.15	73.22	3.81	11.14	73.22	7.73	40.15	34.10
35	Sunkoshi PH	Panchkhal	7.63	12.12	75.84	7.63	12.12	75.84	11.69	42.17	35.32
36.	Lamosanghu	Bhaktapur	2.64	8.83	267.36	2.64	8.83	267.36	9.31	58.66	77.23
37.	Suichatar	Matatirtha	0.11	0.37	11.14	0.11	0.37	11.14	0.39	2.44	3.22
38.	Matatirtha	KL-II PH	1.98	6.62	200.52	1.98	6.62	200.52	6.98	43.99	57.92
39.	KL-II PH	Hetauda	0.44	1.47	44.56	0.44	1.47	44.56	1.55	9.78	12.87
40.	Pathlaiya	Kamane	2.04	6.80	206.09	2.04	6.81	206.09	7.18	45.21	59.53
41.	KL-I PH	Hetauda	1.46	3.08	89.12	1.46	3.07	89.12	3.70	19.70	25.74

S. N.	From	To	Line Impedance								
			Positive			Negative			Zero		
			R1	X	Y	R1	X	Y	R1	X	Y
42.	KL-III PH	Hetauda	0.88	2.94	89.12	0.88	2.94	89.12	3.10	19.55	25.74
43.	Parwanipur	Pathlaiya	0.94	3.13	94.69	0.94	3.13	94.69	3.30	20.77	27.35
44.	Chanauta	Lamahi	2.81	9.38	284.07	2.81	9.38	284.07	9.89	62.32	82.06
45.	Lamahi	Kusum	2.59	8.64	261.79	2.59	8.65	261.79	9.12	57.43	75.62
46.	Mahendranagar	Tanakpur	1.42	5.07	34.00	1.42	5.07	34.00	3.24	18.54	15.83
47.	Butwal	Chanauta	2.48	8.27	250.65	2.48	8.28	250.65	8.73	54.99	72.41
48.	Ghorahi	Lamahi	1.38	4.60	139.25	1.38	4.60	139.25	4.85	30.55	40.23
49.	Bardaghat	Butwal	2.37	7.91	239.51	2.37	7.91	239.51	8.34	52.55	69.19
50.	Bardaghat	Gandak	0.95	2.63	77.98	0.95	2.63	77.98	2.91	17.16	22.53
51.	Gandak	Ramnagar	0.34	1.00	6.54	0.34	1.00	6.54	0.69	3.59	3.05
52.	Bardaghat	Kawasoti	4.62	13.53	88.91	4.62	13.53	88.91	9.38	48.76	41.41
53.	Hetauda	Amlekhgunj	0.55	1.11	34.76	0.55	1.10	34.76	1.39	7.63	9.35
54.	Amlekhgunj	Simara	0.55	1.11	34.76	0.55	1.10	34.76	1.39	7.63	9.35
55.	Birgunj	Parwanipur	0.55	1.11	34.76	0.55	1.10	34.76	1.39	7.63	9.35
56.	Jhimruk	Lamahi	2.75	9.19	278.50	2.75	9.20	278.50	9.70	61.10	80.45
57.	Syaule132	Attariya	14.28	51.10	342.57	14.28	51.09	342.57	32.62	186.81	159.56
58.	Chapur	Pathlaiya	1.76	5.88	178.24	1.76	5.89	178.24	6.21	39.10	51.49
59.	Chapur	Dhalkebar	3.85	12.87	389.90	3.85	12.88	389.90	13.58	85.54	112.63
60.	Dhalkebar	Muzaffarpur	2.31	7.72	233.94	2.31	7.73	233.94	8.15	51.32	67.58
61	Mirchaiya	Dhalkebar	1.82	6.07	183.81	1.82	6.07	183.81	6.40	40.33	53.10
62.	Rupani	Lahan	1.49	4.96	150.39	1.49	4.97	150.39	5.24	32.99	43.44
63.	Tingla	Mirchaiya	0.91	1.84	57.94	0.91	1.84	57.94	2.32	12.71	15.59
64.	Modi HP	Pokhara	4.03	14.43	96.76	4.03	14.43	96.76	9.21	52.76	45.07
65.	Lahan	Mirchaiya	1.49	4.96	150.39	1.49	4.97	150.39	5.24	32.99	43.44
66.	Kusaha	Kattaiya	1.42	5.07	34.00	1.42	5.07	34.00	3.24	18.54	15.83
67.	Kusaha	Rupani	1.76	5.88	178.24	1.76	5.89	178.24	6.21	39.10	51.49
68.	Chameliya	Syaule	0.11	0.39	2.62	0.11	0.39	2.62	0.25	1.43	1.22
69.	Duhabi	Kusaha	1.38	4.60	139.25	1.38	4.60	139.25	4.85	30.55	40.23
70.	Damak	Duhabi	5.23	18.73	125.52	5.23	18.72	125.52	11.95	68.45	58.46
71.	Anarmani	Damak	2.94	10.53	70.61	2.94	10.53	70.61	6.72	38.50	32.89
72.	Phidim	Godak	2.37	7.91	239.51	2.37	7.91	239.51	8.34	52.55	69.19
73.	Amarpur (Kabeli)	Phidim	0.77	2.57	77.98	0.77	2.58	77.98	2.72	17.11	22.53
74.	Godak	Damak	1.93	6.44	194.95	1.93	6.44	194.95	6.79	42.77	56.32
75.	Kaligandaki	Butwal	2.26	8.71	267.36	2.26	8.69	267.36	8.98	58.56	77.23
76.	Lekhnath	Pokhara	1.91	2.99	18.31	1.91	2.99	18.31	2.89	10.23	8.53
77.	Lekhnath	Damauli	8.24	18.32	117.68	8.24	18.32	117.68	14.54	64.94	54.81
78.	Pahalmanpur	Attariya	2.09	6.99	211.66	2.09	6.99	211.66	7.37	46.44	61.14
79.	Syangja	Kaligandaki	1.69	6.53	200.52	1.69	6.52	200.52	6.73	43.92	57.92

S. N.	From	To	Line Impedance								
			Positive			Negative			Zero		
			R1	X	Y	R1	X	Y	R1	X	Y
80.	Markhichowk	Damauli	0.99	3.31	100.26	0.99	3.31	100.26	3.49	22.00	28.96
81.	Marsyangdi	Bharatpur	2.38	9.63	65.38	2.38	9.63	65.38	5.88	35.53	30.45
82.	Marsyangdi	Markhichowk	2.18	7.80	52.30	2.18	7.80	52.30	4.98	28.52	24.36
83.	Lamki	Pahalmanpur	1.93	6.44	194.95	1.93	6.44	194.95	6.79	42.77	56.32
84.	Bharatpur	Kawasoti	4.90	14.33	94.14	4.90	14.33	94.14	9.94	51.62	43.85
85.	Lekhnath	Syangja	1.79	6.89	211.66	1.79	6.88	211.66	7.11	46.36	61.14
86.	Bhurigaun	Lamki	1.82	6.07	183.81	1.82	6.07	183.81	6.40	40.33	53.10
87.	Damauli	Bharatpur	7.14	15.87	101.99	7.14	15.87	101.99	12.60	56.28	47.50
88.	Suichatar	Marsyangdi	7.98	32.35	219.66	7.98	32.34	219.66	19.74	119.36	102.31
89.	Mid. Marsyangdi PH	Markhichowk	4.36	15.60	104.60	4.36	15.60	104.60	9.96	57.04	48.72
90.	Mid. Marsyangdi PH	Markhichowk	1.96	7.02	47.07	1.96	7.02	47.07	4.48	25.67	21.92
91.	Upp. Marsyangdi	Mid. Marsyangdi PH	2.40	8.58	57.53	2.40	8.58	57.53	5.48	31.37	26.80
92.	Chapali	Balaju	0.61	2.02	61.27	0.61	2.02	61.27	2.13	13.44	17.70
93.	Khimti HP	Lamosanghu	5.23	18.73	125.52	5.23	18.72	125.52	11.95	68.45	58.46

Table A.4 Capacitor placed at the base case (existing capacitor in grid substations)

S.N.	Substation	Voltage Level (kV)	Capacitor Bank (MVAR)
A	**Kathmandu Grid Division**		
1.	Balaju	11	25
2.	Siuchatar	11	20
3.	New Chabel	11	25
4.	New Patan	11	20
5.	Baneswor	11	25
B	**Hetauda Grid Division**		
6.	Hetauda	11	10
7.	Bharatpur	33	12.5
		11	15
8.	Birgunj	33	15
		11	15
9.	Parwanipur	66	30
		11	20
10.	Simra	11	5
11.	Pathlaiya	11	10
C	**Dhalkebar Grid Branch**		
12.	Chandranigahpur	33	12.5
13.	Mirchaiya	33	10
14.	Dhalkebar	33	24
15.	Lahan	132	10
		132	30
		33	20
D	**Duhabi Grid Branch**		
16.	Duhabi	33	55
17.	Anarmani	33	15
18.	Damak	33	10
E	**Butwal Grid Division**		
19.	Butwal	33	40
G	**Attaria Grid Branch**		
20.	Kohalpur	132	20

ANNEX B: ETAP MODEL

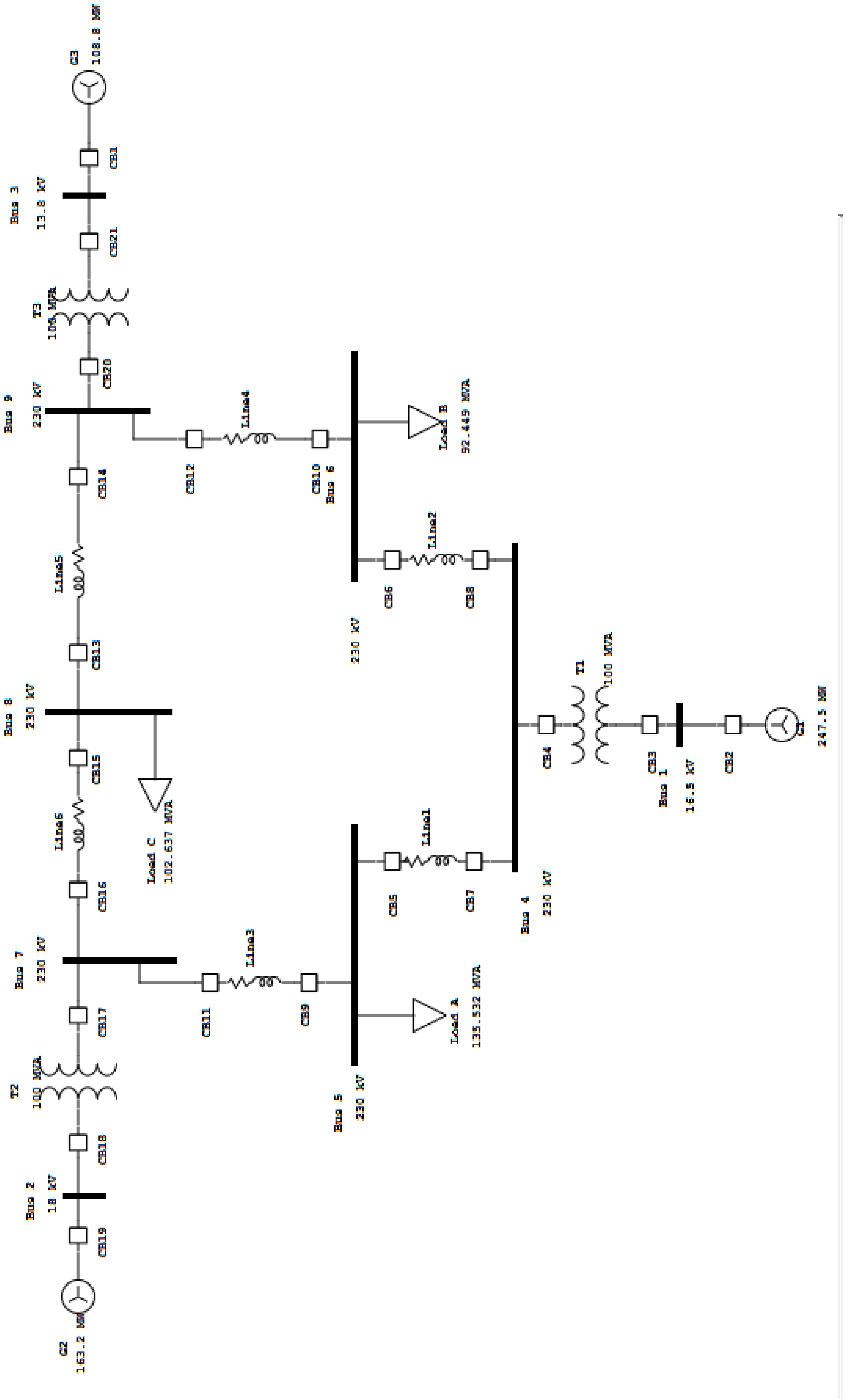

Figure B.1 ETAP simulation model of the IEEE 9 bus system

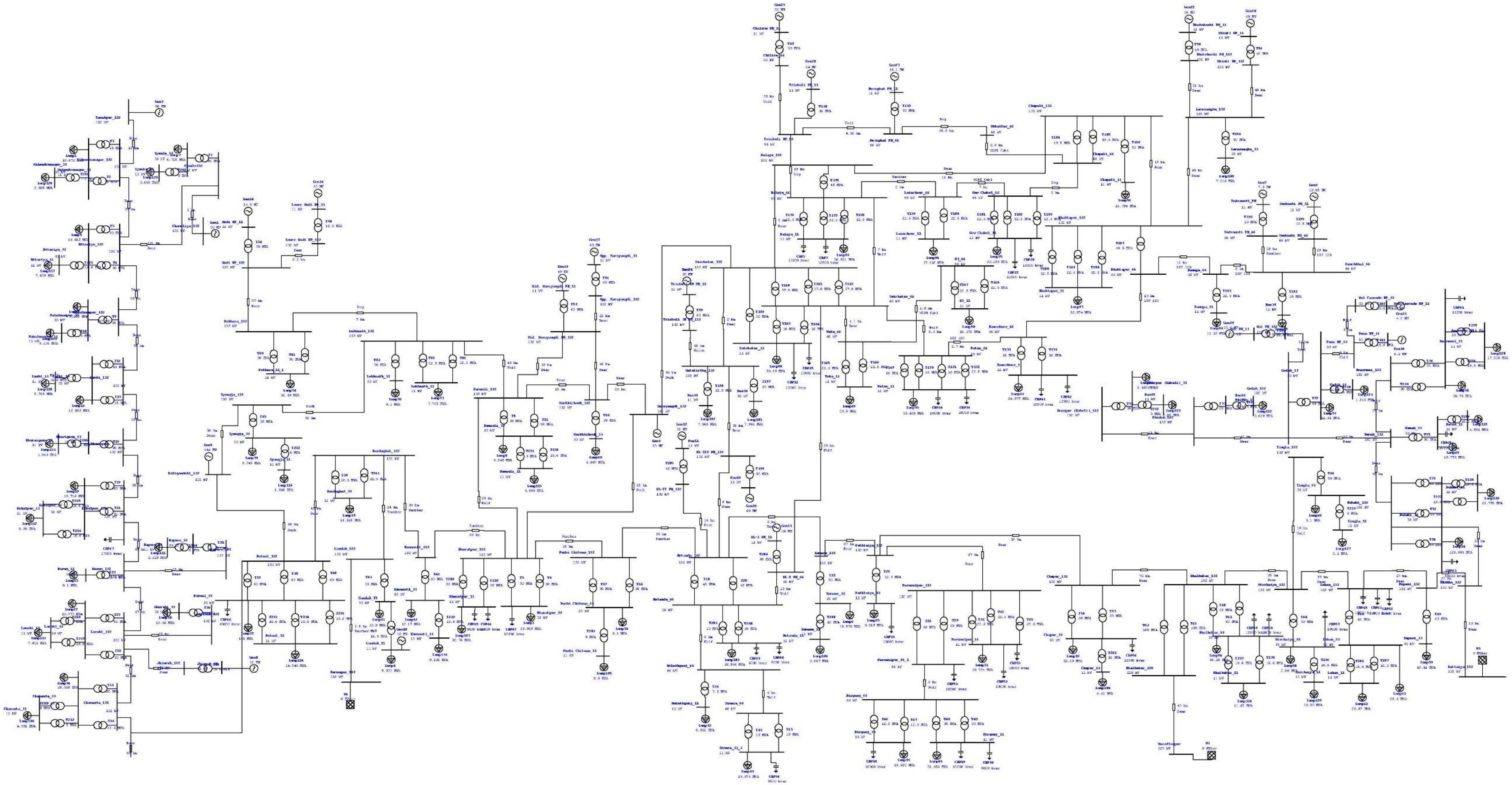

Figure B.2 ETAP model of INPS for the existing system

ANNEX C: FINANCIAL ANALYSIS

Table C.1 Financial analysis with capacitor placed at 11kV

Total Economic Cost of the project (NRs.)	45,120,000
Incremental Return (NRs.)	16,020,000
Economic Cost of O & M (NRs.)	4,512,000

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
0	9,024,000	-	9,024,000	-	(9,024,000)	9,024,000	-	(9,024,000)	(9,024,000)
1	27,072,000	1,804,800	28,876,800	3,204,000	(25,672,800)	26,251,636	2,912,727	(23,338,909)	(32,362,909)
2	9,024,000	2,707,200	11,731,200	16,020,000	4,288,800	9,695,207	13,239,669	3,544,463	(28,818,446)
3	-	3,609,600	3,609,600	17,622,000	14,012,400	2,711,946	13,239,669	10,527,724	(18,290,723)
4	-	4,512,000	4,512,000	18,423,000	13,911,000	3,081,757	12,583,157	9,501,400	(8,789,323)
5	-	4,512,000	4,512,000	19,224,000	14,712,000	2,801,597	11,936,592	9,134,995	345,672
6	-	4,512,000	4,512,000	19,224,000	14,712,000	2,546,906	10,851,447	8,304,540	8,650,212
7	-	4,512,000	4,512,000	19,224,000	14,712,000	2,315,369	9,864,952	7,549,582	16,199,795
8	-	4,512,000	4,512,000	19,224,000	14,712,000	2,104,881	8,968,138	6,863,257	23,063,051
9	-	4,512,000	4,512,000	19,224,000	14,712,000	1,913,528	8,152,853	6,239,324	29,302,375
10	-	4,512,000	4,512,000	19,224,000	14,712,000	1,739,571	7,411,684	5,672,113	34,974,488

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
11	-	4,512,000	4,512,000	19,224,000	14,712,000	1,581,428	6,737,895	5,156,466	40,130,954
12	-	4,512,000	4,512,000	19,224,000	14,712,000	1,437,662	6,125,359	4,687,697	44,818,651
13	-	4,512,000	4,512,000	19,224,000	14,712,000	1,306,966	5,568,508	4,261,542	49,080,193
14	-	4,512,000	4,512,000	19,224,000	14,712,000	1,188,151	5,062,280	3,874,129	52,954,323
15	-	4,512,000	4,512,000	19,224,000	14,712,000	1,080,137	4,602,073	3,521,936	56,476,259
16	-	4,512,000	4,512,000	19,224,000	14,712,000	981,943	4,183,703	3,201,760	59,678,019
17	-	4,512,000	4,512,000	19,224,000	14,712,000	892,675	3,803,366	2,910,691	62,588,709
18	-	4,512,000	4,512,000	19,224,000	14,712,000	811,523	3,457,605	2,646,083	65,234,792
19	-	4,512,000	4,512,000	19,224,000	14,712,000	737,748	3,143,278	2,405,530	67,640,321
20	-	4,512,000	4,512,000	19,224,000	14,712,000	670,680	2,857,525	2,186,845	69,827,166
Total						74,875,312	144,702,479	69,827,166	5.96216

NPV (NRs.)	69,82,71,66
BCR	1.93
IRR	19.69%
Payback Period (Years)	5.97

Table C.2 Financial analysis with capacitor placed at 33kV

Total Economic Cost of the project (NRs.)	64,817,000
Incremental Return (NRs.)	15,920,000
Economic Cost of O & M (NRs.)	6,481,700

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Discount Factor	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
0	12,963,400	-	12,963,400	-	(12,963,400)	1.00	12,963,400	-	(12,963,400)	(12,963,400)
1	38,890,200	2,592,680	41,482,880	3,184,000	(38,298,880)	0.91	37,711,709	2,894,545	(34,817,164)	(47,780,564)
2	12,963,400	3,889,020	16,852,420	15,920,000	(932,420)	0.83	13,927,620	13,157,025	(770,595)	(48,551,159)
3	-	5,185,360	5,185,360	17,512,000	12,326,640	0.75	3,895,838	13,157,025	9,261,187	(39,289,972)
4	-	6,481,700	6,481,700	18,308,000	11,826,300	0.68	4,427,088	12,504,610	8,077,522	(31,212,450)
5	-	6,481,700	6,481,700	19,104,000	12,622,300	0.62	4,024,626	11,862,081	7,837,455	(23,374,994)
6	-	6,481,700	6,481,700	19,104,000	12,622,300	0.56	3,658,751	10,783,710	7,124,959	(16,250,035)
7	-	6,481,700	6,481,700	19,104,000	12,622,300	0.51	3,326,137	9,803,373	6,477,236	(9,772,799)
8	-	6,481,700	6,481,700	19,104,000	12,622,300	0.47	3,023,761	8,912,157	5,888,396	(3,884,403)
9	-	6,481,700	6,481,700	19,104,000	12,622,300	0.42	2,748,874	8,101,961	5,353,087	1,468,684
10	-	6,481,700	6,481,700	19,104,000	12,622,300	0.39	2,498,976	7,365,419	4,866,443	6,335,127

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Discount Factor	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
11	-	6,481,700	6,481,700	19,104,000	12,622,300	0.35	2,271,796	6,695,835	4,424,039	10,759,166
12	-	6,481,700	6,481,700	19,104,000	12,622,300	0.32	2,065,269	6,087,123	4,021,854	14,781,020
13	-	6,481,700	6,481,700	19,104,000	12,622,300	0.29	1,877,518	5,533,748	3,656,231	18,437,251
14	-	6,481,700	6,481,700	19,104,000	12,622,300	0.26	1,706,834	5,030,680	3,323,846	21,761,097
15	-	6,481,700	6,481,700	19,104,000	12,622,300	0.24	1,551,667	4,573,346	3,021,678	24,782,775
16	-	6,481,700	6,481,700	19,104,000	12,622,300	0.22	1,410,607	4,157,587	2,746,980	27,529,755
17	-	6,481,700	6,481,700	19,104,000	12,622,300	0.20	1,282,370	3,779,625	2,497,255	30,027,010
18	-	6,481,700	6,481,700	19,104,000	12,622,300	0.18	1,165,791	3,436,022	2,270,232	32,297,242
19	-	6,481,700	6,481,700	19,104,000	12,622,300	0.16	1,059,810	3,123,657	2,063,847	34,361,089
20	-	6,481,700	6,481,700	19,104,000	12,622,300	0.15	963,463	2,839,688	1,876,224	36,237,313
	Total						107,561,904	143,799,217	36,237,313	9.72564

NPV (NRs.)	3,62,37,313
BCR	1.34
IRR	7.65%
Payback Period (Years)	9.73

Table C.3 Financial Analysis with capacitor placed at 66kV

Total Economic Cost of the project (NRs.)	75,235,000
Incremental Return (NRs.)	16,890,000
Economic Cost of O & M (NRs.)	7,523,500

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
0	15,047,000	-	15,047,000	-	(15,047,000)	15,047,000	-	(15,047,000)	(15,047,000)
1	45,141,000	3,009,400	48,150,400	3,378,000	(44,772,400)	43,773,091	3,070,909	(40,702,182)	(55,749,182)
2	15,047,000	4,514,100	19,561,100	16,890,000	(2,671,100)	16,166,198	13,958,678	(2,207,521)	(57,956,702)
3	-	6,018,800	6,018,800	18,579,000	12,560,200	4,522,014	13,958,678	9,436,664	(48,520,038)
4	-	7,523,500	7,523,500	19,423,500	11,900,000	5,138,652	13,266,512	8,127,860	(40,392,178)
5	-	7,523,500	7,523,500	20,268,000	12,744,500	4,671,502	12,584,833	7,913,332	(32,478,846)
6	-	7,523,500	7,523,500	20,268,000	12,744,500	4,246,820	11,440,758	7,193,938	(25,284,908)
7	-	7,523,500	7,523,500	20,268,000	12,744,500	3,860,745	10,400,689	6,539,944	(18,744,965)
8	-	7,523,500	7,523,500	20,268,000	12,744,500	3,509,768	9,455,172	5,945,403	(12,799,561)
9	-	7,523,500	7,523,500	20,268,000	12,744,500	3,190,698	8,595,611	5,404,912	(7,394,649)
10	-	7,523,500	7,523,500	20,268,000	12,744,500	2,900,635	7,814,191	4,913,556	(2,481,093)
11	-	7,523,500	7,523,500	20,268,000	12,744,500	2,636,941	7,103,810	4,466,870	1,985,777

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
12	-	7,523,500	7,523,500	20,268,000	12,744,500	2,397,219	6,458,009	4,060,790	6,046,567
13	-	7,523,500	7,523,500	20,268,000	12,744,500	2,179,290	5,870,918	3,691,628	9,738,195
14	-	7,523,500	7,523,500	20,268,000	12,744,500	1,981,173	5,337,198	3,356,025	13,094,220
15	-	7,523,500	7,523,500	20,268,000	12,744,500	1,801,066	4,851,998	3,050,932	16,145,152
16	-	7,523,500	7,523,500	20,268,000	12,744,500	1,637,333	4,410,907	2,773,575	18,918,726
17	-	7,523,500	7,523,500	20,268,000	12,744,500	1,488,484	4,009,916	2,521,431	21,440,158
18	-	7,523,500	7,523,500	20,268,000	12,744,500	1,353,168	3,645,378	2,292,210	23,732,368
19	-	7,523,500	7,523,500	20,268,000	12,744,500	1,230,152	3,313,980	2,083,828	25,816,196
20	-	7,523,500	7,523,500	20,268,000	12,744,500	1,118,320	3,012,709	1,894,389	27,710,584
	Total					124,850,268	152,560,853	27,710,584	11.55544

NPV (NRs.)	2,77,10,584.45
BCR	1.22
IRR	5.16%
Payback Period (years)	11.56

Table C.4 Financial Analysis with capacitor placed at 132kV

Total Economic Cost of the project (NRs.)	88,738,000
Incremental Return (NRs.)	15,840,000
Economic Cost of O & M (NRs.)	8,873,800

Year	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
0	17,747,600	-	17,747,600	-	(17,747,600)	17,747,600	-	(17,747,600)	(17,747,600)
1	53,242,800	3,549,520	56,792,320	3,168,000	(53,624,320)	51,629,382	2,880,000	(48,749,382)	(66,496,982)
2	17,747,600	5,324,280	23,071,880	15,840,000	(7,231,880)	19,067,669	13,090,909	(5,976,760)	(72,473,742)
3	-	7,099,040	7,099,040	17,424,000	10,324,960	5,333,614	13,090,909	7,757,295	(64,716,447)
4	-	8,873,800	8,873,800	18,216,000	9,342,200	6,060,925	12,441,773	6,380,848	(58,335,599)
5	-	8,873,800	8,873,800	19,008,000	10,134,200	5,509,932	11,802,473	6,292,541	(52,043,058)
6	-	8,873,800	8,873,800	19,008,000	10,134,200	5,009,029	10,729,520	5,720,492	(46,322,566)
7	-	8,873,800	8,873,800	19,008,000	10,134,200	4,553,663	9,754,110	5,200,447	(41,122,119)
8	-	8,873,800	8,873,800	19,008,000	10,134,200	4,139,693	8,867,372	4,727,679	(36,394,440)
9	-	8,873,800	8,873,800	19,008,000	10,134,200	3,763,357	8,061,248	4,297,890	(32,096,550)
10	-	8,873,800	8,873,800	19,008,000	10,134,200	3,421,234	7,328,407	3,907,173	(28,189,377)
11	-	8,873,800	8,873,800	19,008,000	10,134,200	3,110,213	6,662,188	3,551,975	(24,637,402)

Ye ar	Capital Cost	O & M Cost	Total Cost	Incremental Return	Net Return	Present Value of Cost	Present Value of Benefit	NPV	Payback Period
12	-	8,873,800	8,873,800	19,008,000	10,134,200	2,827,466	6,056,535	3,229,068	(21,408,333)
13	-	8,873,800	8,873,800	19,008,000	10,134,200	2,570,424	5,505,941	2,935,517	(18,472,817)
14	-	8,873,800	8,873,800	19,008,000	10,134,200	2,336,749	5,005,400	2,668,652	(15,804,165)
15	-	8,873,800	8,873,800	19,008,000	10,134,200	2,124,317	4,550,364	2,426,047	(13,378,118)
16	-	8,873,800	8,873,800	19,008,000	10,134,200	1,931,197	4,136,695	2,205,497	(11,172,621)
17	-	8,873,800	8,873,800	19,008,000	10,134,200	1,755,634	3,760,631	2,004,997	(9,167,623)
18	-	8,873,800	8,873,800	19,008,000	10,134,200	1,596,031	3,418,756	1,822,725	(7,344,898)
19	-	8,873,800	8,873,800	19,008,000	10,134,200	1,450,937	3,107,960	1,657,023	(5,687,876)
20	-	8,873,800	8,873,800	19,008,000	10,134,200	1,319,034	2,825,418	1,506,384	(4,181,492)
	Total					147,258,100	143,076,608	(4,181,492)	>20

NPV (NRs.)	-41,81,491
BCR	0.97
IRR	-0.71%
Payback Period (years)	>20

Table C.5 Considerations made for the financial analysis

Inflation 10 %

Cost & Benefit Distribution (%)			
Year	Capital Cost Imbursement	O & M Cost	Benefit
0	20	0	0
1	60	40	20
2	20	60	100
3	0	80	110
4	0	100	115
5 and more	0	100	120

ANNEX D: IEEE 9 BUS SYSTEM STANDARD DATA

Table D.1 Generation data of IEEE 9 bus system

S. N.	ID	Connected Bus	MW	MVA	PF
1.	Generation G1	Bus 1	247.5	247.5	1
2.	Generation G2	Bus 2	163	192	0.85
3.	Generation G3	Bus 3	108.8	128	0.85

Table D.2 Load data of IEEE 9 bus system

S. N.	Load	Load	
		MVA	PF
1.	Load A	135.532	0.9285
2.	Load B	92.449	0.9487
3.	Load C	102.637	0.9439

Table D.3 Line and transformer parameters of IEEE 9 bus system

S. N.	Bus to Bus	Series Z [pu]		Shunt Y [pu]
		R	X	B
1.	Transformer 1-4	0	0.0576	-
2.	Transformer 3-9	0	0.0586	-
3.	Transformer 2-7	0	0.0625	-
4.	Line 4-5	0.01	0.085	0.176
5.	Line 4-6	0.017	0.082	0.158
6.	Line 5-7	0.032	0.161	0.306
7.	Line 6-9	0.039	0.17	0.358
8.	Line 7-8	0.085	0.072	0.149
9.	Line 8-9	0.0119	0.1008	0.209