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THESIS NO.:

Techno-Financial Analysis of Optimal Capacitor Placement and Design, Selection and Injection of Distributed Energy Resources (DERs) in Jomsom Distribution Feeder

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Institute of Engineering for acceptance, a thesis entitled "**Techno-Financial Analysis of Optimal Capacitor Placement and Design, Selection and Injection of Distributed Energy Resources (DERs) in Jomsom Distribution Feeder** " submitted by Dayasagar Niraula in partial fulfillment of the requirements for the degree of Master in Energy System Planning and Management.

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ABSTRACT

One of the challenging tasks of the concerned distribution authorities is to transmit the quality of power with proper reliability to the consumers. The aim of the authorities is to transmit maximum power with minimum losses and maintain a good voltage profile so that the power factor is improved and hence power transfer capability increases. Although it is almost impossible to reduce the losses to zero, power losses can be minimized. One of the ways to minimize the losses and improve the voltage profile and voltage stability is by supplying reactive power into the system, which is possibly by means of various compensating techniques such as injection of capacitor banks or Distributed Energy Resources (DERs) into the system. Usually, the voltage sags along the Radial Distribution System and is maximum at the sending end of the Distribution System and minimum at the ends of the feeder. This voltage can be improved through the injection of compensating devices or Distributed Energy Resources (DERs) taking into account both the technical and financial aspects into consideration.

This research employs the Standard IEEE 10 bus system as the test bus for validation, which is carried out by comparing the results with the published research works. Then, the same methodology is applied for Jomsom Distribution Feeder for performance improvement of the distribution system through Optimal Capacitor Placement and grid impact analysis of injection of Grid Connected Solar and Wind Power Plant in the system. The bus voltages at each node, power losses, voltage regulation, voltage profile, and total annual costs are compared for both the cases, i.e. before and after compensation through capacitor banks and injection of DERs. The total savings in annual cost is computed in both these cases. Power losses is reduced by 18.5 % and 14.5 % for Standard IEEE 10 bus system and Jomsom Distribution Feeder respectively due to Optimal Placement of Capacitor banks in the feeder. Voltage Regulation is improved from 16.25 % to 11.63 % for Standard IEEE 10 bus system and from 18.24 % to 5.54 % for Jomsom Distribution Feeder after Optimal Capacitor Placement. There is saving in $ 23,955.084 annually for Standard IEEE 10 bus system and $3,806 annually for Jomsom Distribution System, Kobang due to Optimal Capacitor Placement in Distribution System. Further injection of DERs in the distribution system feeder improves the voltage profile and helps in power loss reduction.

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LIST OF SYMBOLS AND ABBREVIATIONS

δ	:	Phase angle
AC	:	Alternating Current
ACO	:	Ant Colony Optimization
BFS	:	Backward/Forward Sweep Algorithm
DC	:	Direct Current
DERs	:	Distributed Energy Resources
DG	:	Distributed Generation
ETAP	:	Electrical Transient Analyzer Program
FACTS	:	Flexible Alternating Current Transmission System
GA	:	Genetic Algorithm
GHz	:	Giga Hertz
I	:	Current
IEEE	:	Institute of Electrical and Electronics Engineers
km	:	kilometers
Kp	:	Annual Cost per unit of power loss
kV	:	kiloVolt
kVAR	:	kiloVolt Ampere Reactive
kW	:	kiloWatts
LSI	:	Loss Sensitivity Index
MATLAB	:	MATrix LABoratory
MW	:	MegaWatts
NEA	:	Nepal Electricity Authority
P	:	Active Power
p.u.	:	per unit
PSO	:	Particle Swarm Optimization
PV	:	Photo Voltaic
Q	:	Reactive Power
R	:	Resistance

RAM	:	Random Access Memory
RDS	:	Radial Distribution System
S	:	Apparent Power
SFSOA	:	Stochastic Fractal Search Optimization Algorithm
STATCOM	:	Static Synchronous Compensator
V	:	Volt
V.R.	:	Voltage Regulation
Vr	:	Receiving End Voltage
Vs	:	Sending End Voltage
WTG	:	Wind Turbine Generator
X	:	Reactance

CHAPTER ONE: INTRODUCTION

1.1 Background

Power system comprises of the interconnected network that helps in generation, transmission and distribution of electric power to the consumers or load centres. The supply of electrical energy with the highest possible efficiency and minimum losses is of great importance and a matter of challenge for our country. Currently, the system losses of Nepal Electricity Authority (NEA) is estimated to be increased to 17.18 % from 15.27 % as compared to the last fiscal year (NEA, 2021).

The energy sources are available in different forms and conversion of the available form of energy into the electrical form of energy is called generation of electrical energy (Mehta & Mehta , 2018). Currently, the total installed capacity of power plants and projects that generate electricity is 1451.3354 MW, which is inclusive of Hydro, Solar and Thermal Power Plants (NEA, 2021).

The electrical energy generated has to be transmitted to the load centres via different conductors called transmission of electrical energy (Gupta , 2014). Till date, the maximum voltage of 400 kV has been integrated and energized to Integrated Nepal Power System (INPS). Currently, there are forty-one existing High Voltage 132 kV Transmission Lines with circuit length of about 3129.54 km. Similarly, there are five existing High Voltage 400/220 kV Transmission Lines with circuit length of about 332.60 km and there are sixteen High Voltage 66 kV Transmission Lines with circuit length of about 514.46 km (NEA, 2021).

The transmitted power to the load centre needs to be distributed to the consumers through various feeders called distribution of electrical energy. The distribution system losses of Nepal Electricity Authority (NEA) is estimated to be increased to 11.64 % from 10.28 % as compared to the last fiscal year. (NEA, 2021).

For Distribution Systems, supplying the quality of power to the consumers with high reliability and efficiency is one of the important aspects of power system. Good power factor and better voltage regulation is necessary for proper implementation of Demand Side Management. This causes minimum voltage sag and minimum losses. Therefore, if the loss is higher in Distribution System Feeders, the compensating techniques can be applied for minimization of such losses considering both the technical and financial aspects. Further, Distributed Energy Resources (DERs) like Grid Connected Solar and Wind Power Plant can further be injected in the Distribution system feeder for further performance improvement of the feeder.

1.2 Problem Statement

The energy demand increases with the increase in consumers. This causes increase in consumption of energy and line losses due to which line current also increases. This further leads to more voltage drop, poor power factor, poor voltage regulation and decrement of voltage profile. Therefore, Distribution System losses increase (El-Ela , et al., 2015). Reliable and good quality of electrical power has to be supplied to the consumers with minimum losses and high power factor. This can be done by supplying the reactive power requirement through placing the capacitor banks in the optimal location and injection of Distributed Energy Resources (DERs) like solar and wind power plant in the Distribution System Feeder.

The voltage regulation of the grid during normal operation should not deviate by more than 10 % of its nominal value (Nepal Electricity Authority, March, 2011). However, the voltage regulation of Jomsom Distribution System does not meet the NEA Grid Code Standard and there is poor voltage regulation. Therefore, application of additional techniques can help in maintaining Voltage Regulation and improve Voltage Profile, in addition to reduction in power losses.

1.3 Rationale of the Study

The distribution of electrical power from the Distribution Substations to the consumer sectors for the utilization of electrical energy with minimum loss, less voltage drop, good voltage regulation, good quality, high reliability and high power factor is a main challenge for the concerned authorities. Reduction of distribution losses, power factor improvement and voltage profile enhancement can be done through various techniques. Some of these techniques are conductor upgradation, Distribution System or feeder reconfiguration, Optimal Capacitor bank sizing and sitting, Optimal Placement of Distributed Generation Units (DGs), injection of Distributed Energy Resources (DERs) like solar energy and wind energy or by the merger of the above techniques (Kuppurajulu, et al., n.d.).

The study analyses the techno-financial aspects of optimal allocation of capacitor banks and grid impact study due to further injection of Distributed Energy Resources (DERs) in the Distribution System Feeder in terms of technical aspects such as power losses, voltage drop, voltage regulation and voltage profile and financial aspects.

Since, proper voltage regulation has to be maintained in the system as per NEA Grid Code, 2011, Jomsom Distribution System is considered as the study bus for performance improvement of the system.

1.4 Objectives

1.4.1 Main Objective

The main objective of this research work is to determine optimal location and size of capacitor banks, design or select and perform grid impact study through the injection of Distributed Energy Resources (DERs) i.e. grid connected solar and wind power plant into the Distribution System Feeders for Standard IEEE 10 Bus System and Jomsom Distribution Feeder, Kobang in terms of technical and financial aspects.

1.4.2 Specific Objectives

The specific objectives for the research work are:

- To determine the bus voltages and candidate buses for placing capacitor banks.
- To determine the optimum sizing and sitting of the Capacitor Banks across the nodes of distribution system feeders.
- To determine power losses and voltage regulation at each bus and present voltage profile of the Distribution System before and after compensation through capacitor banks.
- To design or select and inject Distributed Energy Resources (DERs) such as grid-connected solar energy and wind energy in the Distribution System Feeder.
- To perform financial analysis of distribution system feeder before and after optimal capacitor placement and DERs injection.

1.5 Assumptions and Limitations

Cost per unit of energy losses, average life expectancy, cost per kVAR of capacitor, cost per kW of wind turbine generator and cost per kW of Grid Connected solar plant is assumed in the analysis.

The limitations of this study are:

- The system does not consider no-load condition that may arise due to load rejection or disturbances in the Distribution System Feeder.
- The system does not consider the reliability assessment in the analysis.
- The system does not consider conductor replacement in the analysis, but works out on the improvement of the existing system.
- The study is limited to balanced three-phase Distribution feeder system.
- The study does not consider the load growth patterns and load models.
- The substation is considered as the infinite grid, which shows greater capability of supplying reactive power. But, voltage drop and size of capacitor may increase considering the actual scenario.

CHAPTER TWO: LITERATURE REVIEW

Distribution Systems usually consist of feeders, distributors and the service mains (Mehta & Mehta , 2018). Feeder connects the area to be supplied by the system with the substations. The distribution system may be primary or secondary. Usually, in context of Nepal, 11 kV, 6.6 kV or 3.3 kV falls under primary distribution system while 400 V or 230 V falls under secondary distribution system.

2.1 Classification of Distribution System

Distribution System is classified into Radial System, Ring Main System and Inter-connected System based on the connection schemes (Study, n.d.). Radial Distribution System (RDS) connects Substation and the feeder along the single path. Loop circuit makes loop throughout the areas to be served and finally is connected to the substation from which the feeder line starts. Interconnected system is interconnected by two or more stations in the feeder ring. (Article, n.d.)

In Nepal, almost all the distribution systems are radial in nature. There is a single path for the connection between Distributor and Substation. Another form of Distribution System is Ring Main Distribution System where feeder is in form of ring and is not common form of feeder system in case of Nepal although voltage fluctuations is minimal in such systems (Daware , n.d.). Distribution System is classified into DC and AC distribution systems based on the nature of current. AC Distribution System is the most common and widely used system used due to its simplicity and economic condition. Distribution Systems may be overhead or underground depending on the type of construction. Overhead System is economical as compared to the Underground System. However, there is more chance of faults on Overhead Systems than Underground Systems. Moreover, Overhead Systems also degrade the aesthetic beauty when compared with Underground Systems (Article, 2019).

2.2 Methods of Computation Techniques

The optimization problem is carried out that consists of objective function, constraints and decision variables. The main goal is to solve the function to minimize the objective function under the defined constraints to obtain the decision variables. There are various techniques and procedures for optimization in order to determine the best location and size of capacitor banks so that the voltage profile is improved and hence the distribution system losses are minimized. Usually, the capacitor banks are installed at the nodes of the distribution system. There are various techniques for optimization problems like analytical methods, numerical programming methods, Heuristic methods and artificial intelligence methods (Allw, et al., n.d.). Further, injection of Distributed Energy Resources (DERs) like grid connected solar and wind power plants also help in performance improvement of the Distribution System Feeder in terms of voltage profile and power loss (Khan, et al., 2019).

(El-Ela , et al., 2015) determined Loss Sensitivity Factors to determine the candidate buses for optimal sitting and sizing of capacitor banks. The load flow was carried by Backward/Forward Sweep (BFS) algorithm. The study was carried out with test bus systems as 15-bus and 34-bus Radial Distribution Systems. Ant Colony Optimization (ACO) technique was adopted for reducing the distribution system losses, power factor improvement and voltage profile improvement.

(Allw, et al., n.d.) carried out studies related to reduction in power losses on Distribution Feeders in Electrical Distribution Systems using 22-bus system and application. Considerable compensation showed the economic saving, improved performance of the system, reduction in the reactive power drawn in the system and even saving of investment costs in power plant.

(Vita , 2017) studied the best allocation for Distributed System Generation Units Sizing and Sitting using the IEEE 33-bus radial Distribution System for reducing the power losses and improving the voltage profile of the Distribution feeder. The load flow was carried out using NEPLAN 360 and proposed decision making algorithm was applied in MATLAB. The obtained results were compared with those of earlier studies carried out.

(Nguyen, et al., 2020) analysed installation of both capacitors and PV Systems in Distribution System Feeder to reduce the active power loss for Radial Sytems even by consideration of Geography Location Constraints. Study was carried out by varying the number of capacitors for the installation of PV. The analysis was carried using Stochastic Fractal Search Optimization Algorithm (SFSOA) and tested in 33 and 69 bus systems. It was concluded that PV System along with capacitor bank installation was more fruitful in Distribution System Feeder Loss Reduction.

(Khatri KC & Regmi , n.d.) computed loss of the system by load flow using sweep algorithm and then capacitor banks were placed in different candidate buses and again load flow was carried out. The analysis was conducted in 12-bus Radial Distribution System. Voltage Drop and power losses were found to be improved after compensation in the network.

(Murthy , et al., 2010) compared Conventional, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques of Radial Distribution Feeder for Distribution System Loss Reduction and improvement of Voltage Profile. The best location for placement of capacitor banks was determined by using conventional index vector method. Sizing of the capacitors were obtained by using Conventional, GA and PSO techniques. PSO was found to provide better results for distribution losses determination with compensation of capacitor banks as compared to other optimization techniques. PSO was found to give better results than GA.

(Kumar & Singh, n.d.) determined optimal sitting and sizing of Capacitors in Distribution Systems for loss reduction and voltage profile enhancement using Nelder-Mead PSO approach to IEEE 69-bus radial distribution System and was compared to PSO techniques. NM was found useful in finding the solutions fast by computation of local solutions while PSO computed by searching the global solutions instead of local solutions.

(Yu, et al., n.d.) determined optimal placement of capacitor bank in Radial Distribution System with account of Harmonic Distortion effects. PSO Algorithm was applied in IEEE 9 bus system and it was concluded that the power loss reduction and voltage profile enhancement can be implemented using PSO Algorithm on accounting harmonic effects as well.

(Dawod, 2019) implemented load flow of IEEE 33 bus test system through use of CYMDIST and selected Baghdad city Distribution network for power loss minimization and improvement of voltage profile. Hence, optimal capacitor placement was performed by means of load flow and this method showed better performance than VDLF method and PSO method.

(Paul, 2013) determined the optimal sitting and sizing of capacitor bank in distribution system by comparison of both the power loss index as well as loss sensitivity index based approach integrated with genetic algorithm for optimal capacitor allocation. This study also studied on the reason for occurrence of negative power losses in the line and presence of higher voltage on downstream nodes in case of AC Systems.

(Tahir , et al., n.d.) used Electrical Transient Analyzer Program (ETAP) for the load flow of IEEE 4 and 33 bus system and implemented GA for optimization of the distribution system for line loss reduction and improvement of voltage profile. The enhancement of power factor of the system was observed as well due to which finally the net profit was found to have increased.

(Jabari , et al., n.d.) analysed a novel sweep algorithm for optimal allocation of capacitor banks in Distribution System Feeders. Loss matrix helped in allocating the candidate locations for the installation of capacitor banks. The analysis was performed considering 33-bus standard test system and its implementation was done using MATLAB. The reduction of power loss was observed clearly in the research. The obtained results were compared with several other methods for validation of the research works.

(Mustafa, et al., 2018) used Genetic Algorithm for optimal sizing of capacitor banks to enhance low voltage and reduce losses. It presented a model simultaneously for optimal allocation of capacitor banks for the compensation of reactive power in the power system along with a specified level of dynamic rotating machine load. It also focused on the economic assessment of benefits after the installation of capacitors banks.

(Gupta, et al., 2015) used Power Loss Index Approach for Optimal placement of D-STATCOM in Radial Distribution System based on Power Loss Index Approach and found that power loss is reduced and voltage profile is improved through this technique.

Particle Swarm Optimization (PSO) is based on swarm intelligence and is a stochastic, population based algorithm, and this algorithm is metaheuristic since it seeks for broader spaces in order to determine the candidate solutions for the optimization problems. The particle moves in these spaces or search spaces as guided by the formulae needed for the required problem. This continues until optimal solution is obtained (Wikipedia, n.d.).

Usually the substation is considered as the infinite grid. This shows greater capability of supplying reactive power But, voltage drop and size of capacitor may increase considering the actual scenario while carrying out Optimal Capacitor Placement. However, this problem can be solved by injection of grid-connected solar and wind power plant in the Distribution System Feeder. It is also applicable in Electrical Distribution System for optimal location of capacitor banks for the purpose of power loss reduction, power factor and voltage profile enhancement. The financial analysis can therefore be further performed. For this, algorithm for PSO can be implemented.

Distributed Energy Resources (DERs) usually vary from 3 kW to 50 MW and are penetrated in the Distribution System for improving the performance characteristics of the Distribution System Feeder. The voltage profile of the distribution system will be improved due to the injection of DERs in the System. Power Losses will also be reduced, that enables the rise in efficiency of the Distribution System due to DERs injection in the system (Capehart, 2016).

From the above literature works, the performance of distribution systems is improved by compensation through capacitor banks, D-STATCOM, conductor upgradation or placement of Distributed Generation Units in terms of technical parameters like voltage regulation and power losses and financial parameters. In case of Jomsom Distribution Feeder, voltage regulation does not meet the NEA Grid Code Standard, 2011. Hence, the performance of Jomsom Distribution Feeder can be improved through optimal sitting and sizing of capacitor banks. Furthermore, Distributed Energy Resources (DERs) i.e. grid connected solar and wind power plant can be designed or selected according the suitability of the geographical location of the feeder, where compensation seems fruitful. Hence, impacts of injection of Distributed Energy Resources (DERs) in the distribution system feeder can be analysed.

The summary of literature works are presented in Table 2.1.

Table 2.1: Summary of Literature Works

Author(s)	Major Findings
El-Ela, Kinawy, Mouwafi & El-Sehiemy	Used Ant Colony Optimization for 15 and 34 bus RDS, carried load flow by BFS algorithm, and reduced Distribution System Losses and power factor improvement.
Allw, Almurieb, & Alamidy	Power Losses Reduction in Distribution Feeders using 22-bus system for performance improvement of the system.
Vita	Optimal allocation of Distributed Generation of IEEE 33 bus System for performance improvement of Distribution system with load flow by NEPLAN 360 and decision-making algorithm in MATLAB.

Author(s)	Major Findings
Nguyen, Dinh, Pham, & Nguyen	Analysis of installation of both capacitors and PV Systems in Distribution System Feeder so as to reduce the active power loss for Radial Systems using SFSOA in 33 and 69 bus systems.
Khatri KC & Regmi	Conducted analysis in 12-bus radial system, load flow using sweep algorithm, performance improvement in Distribution Systems.
Murthy , Raju , & Rao	Compared PSO and GA techniques for Loss Reduction and Voltage Profile Improvement
Kumar & Singh	Performance improvement in Distribution Systems through Nelder – Mead PSO approach to IEEE 69 bus RDS and compared to PSO techniques
Yu, Xiong, & Wu	Optimal capacitor bank placement in RDS in IEEE 9 bus system using PSO Algorithm, also accounting harmonic effects.
Dawod	Load flow in IEEE 33 using CYMDIST Software and performance improvement in Distribution System through VDLF and PSO Method.
Paul	Genetic Algorithm Approach on Capacitor Bank Optimal Location for performance improvement in Distribution Systems.
Tahir, Bakar, Alam , & Mazlihum	Used ETAP Software for load flow of IEEE 4-bus and 33-bus system and used GA for performance improvement in Distribution Systems.
Jabari , Sanjani , & Asadi	Novel Sweep Algorithm using MATLAB and implementation of IEEE 33 standard test bus system for performance improvement in Distribution Systems.
Mustafa, Arief, & Nappu	Genetic Algorithm for optimal sizing of capacitor banks to enhance low voltage and reduce losses of distribution systems.

Author(s)	Major Findings
Gupta, Jain, & Kumar	Power Loss Index Approach for optimal D-STATCOM Placement in Radial Distribution System for performance improvement in Distribution Systems.
Capehart	Voltage profile and power losses improvement through the injection of Distributed Generation, usually varying from 3 kW to 50 MW.
Allw, Almurieb, & Alamidy	Voltage profile and power losses improvement through the optimal location of Distributed Generation.

2.3 Load Flow Analysis

Load flow analysis is essential for proper planning and sustainable operation of power system (NPTEL, n.d.). Load flow provides the various parameters in the steady state of the system. The voltages, power, line losses are the parameters considered during the load flow of the power system. The line losses and voltage at each node can also be determined.

The stability, economic condition and reliability of power system from generation to distribution can be defined by load flow study. For satisfactory power system operation, the generation should meet the load demand and fulfill the losses. Transmission lines and transformers should not be overloaded. The generating units should operate within specified active and reactive power limits. Bus voltage should remain within the rated range.

Load flow analysis of Distribution Systems can be performed using simulation in softwares such as NEPLAN, CYMDIST, MATLAB, DigSilent, ETAP and through implementation of algorithms such as Genetic Algorithm, Ant Colony Optimization, Backward/Forward Sweep Algorithm, Particle Swarm Optimization, Nelder-Mead Particle Swarm Optimization, Novel Sweep Algorithm, etc.

The active and reactive power are converted into per unit (p.u.) system by dividing by base power. Similarly, resistance and reactance are also converted to their base values for calculation.

During load flow computation, if the buses are a and b respectively, then the active and reactive power are computed using the formula:

$$P_a = \frac{P_{eff}}{b} + P_{Loss_c}$$ Equation 1

$$Q_a = \frac{Q_{eff}}{b} + Q_{Loss_c}$$ Equation 2

Here, P_a *and* Q_a are the power along the branch c. $\frac{P_{eff}}{b}$ and $\frac{Q_{eff}}{b}$ are the effective active and reactive power respectively. P_{Loss_c} and Q_{Loss_c} are the losses along the branch c.

During load flow, current along the branch c flowing from bus a to bus b is determined using the formula as shown below:

$$I_c = \frac{S^*}{V^*} = \frac{P_a - jQ_a}{V_a < -\delta_a}$$ Equation 3

$$I_c = \frac{V_a < \delta_a - V_b < \delta_b}{R_c + jX_c}$$ Equation 4

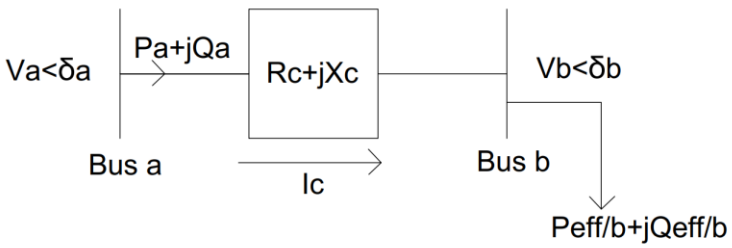

Figure 2.1: Pictorial view of power flow between two nodes of distribution system

Here, Va and Vb are the node voltages, and δ_a and δ_b are the voltage angles at buses a and b respectively. Rc and Xc are the resistance and reactance of the line connecting two buses a and b.

Power loss is calculated using the following formulae: (El-Ela , et al., 2015)

$$P_{Loss_c} = I_c^2 * Rc = \left(\frac{P^2_{\frac{eff}{b}} + Q^2_{\frac{eff}{b}}}{|V_b^2|}\right) * Rc$$ Equation 5

$$Q_{Loss_c} = I_c^2 * Xc = \left(\frac{P^2_{\frac{eff}{b}} + Q^2_{\frac{eff}{b}}}{|V_b^2|}\right) * Xc$$ Equation 6

2.4 Loss Sensitivity Index (LSI)

After carrying out load flow, two LSIs are computed for selection of candidate nodes or buses for the placement of capacitor banks optimally using the proposed algorithm. The LSIs for all buses are listed and sorted in descending order and the first half of the buses are considered as the candidate buses for the placement of capacitor.

The active power loss in the c^{th} line joining nodes a and b is calculated as:

$$Ploss_c = I_{ab}^2 R_{ab} = \frac{P_{ab}^2 + Q_{ab}^2}{V^2} * R_{ab} \qquad \text{Equation 7}$$

Loss Sensitivity Factor is calculated using the following formulae:

$$LSI_1 = \frac{\delta \mathrm{Ploss_c}}{\delta \mathrm{V_b}} = \frac{-2 * (\mathrm{P}_{\frac{\mathrm{eff}}{\mathrm{b}}}^2 + \mathrm{Q}_{\frac{\mathrm{eff}}{\mathrm{b}}}^2)}{\mathrm{V_b^3}} * \mathrm{Rc} \qquad \text{Equation 8}$$

$$LSI_2 = \frac{\delta Ploss_c}{\delta Q_{\frac{eff}{b}}} = \frac{2 * Q_{\frac{eff}{b}}}{V_b^2} * Rc \qquad \text{Equation 9}$$

(Elsheikh, Ahmed; Helmy, Yahya; Abouelseoud, Yasmine; Elsherif, Ahmed, 2014)

2.5 Particle Swarm Optimization

One of the meta-heuristic techniques used for obtaining optimal solutions, based on organism movement like fish schooling is Particle Swarm Optimization. The particles search spaces in certain velocities depending on the other particles of the group. The new velocity and position depends on the previous iterations and general formula for velocity and position is given by:

$$u_a^{b+1} = w * u_a^b + ac_1 rand_1\left(p_{bsta}^b - y_a^b\right) + ac_2 rand_2\left(g_{bsta}^b - y_a^b\right) \qquad \text{Equation 10}$$

$$y_a^{b+1} = y_a^b + u_a^{b+1} \qquad \text{Equation 11}$$

Here, u_a^b is the particle velocity a in b^{th} iteration, y_a^b is the particle position a in b^{th} iteration. Two factors rand1 and rand2 in above equations denote the random numbers that lies between 0 and 1. p_{bsta}^b denotes the best value of fitness function by particle a before iteration b. g_{bsta}^b denotes the best value of fitness function that has been achieved so far. ac_1 and ac_2 denote the acceleration factors. Hence, this technique finds the best optimal solutions using particle and velocity as the approach of solution. (Hassan, et al., 2018)

2.6 Voltage Regulation

Voltage Regulation is the difference between the voltage magnitude between the sending and receiving end. The lesser the voltage regulation, more the voltage sent from sending end is obtained at the receiving end. Voltage Regulation is one of the important factors or indicators in Distribution System to indicate the performance of the system.

The formula for Voltage Regulation is:

$$\text{Up Voltage Regulation (V.R.)} = \frac{Vs-Vr}{Vr} * 100\%$$

Equation 12

$$\text{Down Voltage Regulation (V.R.)} = \frac{Vs-Vr}{Vs} * 100\%$$

Where, Vs = Sending End Voltage and,

Vr= Receiving End Voltage

2.7 Total Energy Costs

The main objective is to maximize the saving and minimize the total energy costs as shown below:

$$\text{Min } Z = Kp*P_{Loss}+Kc*Qc_{Total}$$ Equation 13

Here, Kp is the annual cost per unit of power loss in $/kW-year, P_{Loss} is the total power loss while Qc_{Total} is the total reactive power of the capacitor and Z is the total costs.

The annual cost of the capacitor is calculated using the formula:

$$\text{Total cost of the capacitors} = \frac{Kc*Qc_{Total}}{\text{Life expectancy}}, \$/\text{year}$$ Equation 14

(El-Ela , et al., 2015)

2.8 Technical Parameters related to Solar Energy and Wind Energy

Tilt angle is the angle made by the PV module with reference to the horizontal surface. Azimuth angle is the direction shown by the compass that shows the direction of sunlight approaching the panel. Inverters convert dc current to ac current for injection of power to the grid. Performance ratio shows the ratio of measured output with reference to the expected output. Global horizontal irradiation shows the radiation received by horizontal surface from sunlight. Diffuse horizontal irradiation is the radiation received per unit area by the surface that does not arrive from direct path of the sun. The global incident in coll. plane is determined from global horizontal irradiation and diffuse horizontal irradiation in hourly values. Wind speed of a certain area shows the rate of flow of air at that area. Wind turbine is driven through the speed of the wind. This mechanical form of energy is transferred to the Wind turbine Generator (WTG) through gearbox for the production of electrical energy.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Approach

The research methodology is based on the profound analysis of technical aspects like Feeder Loss Reduction, Voltage Regulation and Voltage Profile Enhancement and financial aspects of Distribution System Feeders i.e. Standard IEEE 10 bus System and Jomsom Distribution Feeder, Kobang. The results of Standard IEEE 10 bus system is validated with previously published research papers and then the same methodology is applied for Jomsom Distribution Feeder. This employs using the method of swarm intelligence, Particle Swarm Optimization Techniques in MATLAB and load flow in ETAP through simulation, validation and comparative analysis. The financial aspects of the distribution system before and after compensation through capacitor banks and injection of Distribution Energy Resources (DERs) is compared. The impacts of Grid Connected Solar and Wind Power Plant on the Distribution System Feeder is analysed.

Primitive stage of methodology is to carry out the literature review in the concerned or related areas for carrying out the analysis. It is followed by the collection of data of Standard IEEE 10 bus system and Jomsom Distribution Feeder. Then, the load flow is performed for determining the individual bus voltages of the Distribution System and Loss Sensitivity Index (LSI) for determination of the candidate buses for the optimal placement of capacitor banks, which are used as control variables for optimization purpose. Then, load flow is run to determine the optimal capacitor locations using the proposed algorithm and is simulated in ETAP for obtaining the nodal bus voltages. The size and location of the capacitor banks across the nodes of distribution system is determined. Then, the technical parameters like power loss and voltage profile are analysed both before and after compensation.

The savings and costs associated before and after compensation of capacitor banks and injection of Distributed Energy Resources (DERs) i.e. grid connected solar and wind power plant is analysed for carrying out financial analysis.

The Solar irradiance data of Jomsom Distribution Feeder, Kobang at Dhakmar with co-ordinates of 83.88° E longitude and 29.08° N latitude is fetched from Meteonorm and the Solar Array Module is designed in PVSyst. The wind data of the corresponding location at Dhakmar is collected from NASA for the selection of Wind Turbine Generator (WTG).

Then, the impacts of injection of grid connected solar and wind power plant on the Distribution System Feeder is analysed.

Hence, both technical and financial analysis is performed in order to determine the Optimal Capacitor location and conduct grid impact study of injection of DERs into the system so that maximum power is transferred with minimum losses and good voltage profile.

3.2 Methodology

The methodology of the research is divided into different stages as discussed below in brief. The flowchart of the methodology is presented in Figure 3.1.

- Literature review

Different articles and journals were studied and analysed for understanding the current situation of distribution feeders. The idea for collection of data and information was determined from different articles. The mathematical formulation were studied and analysed. The parameters needed for the calculation and simulation were thoroughly studied and these parameters were analysed with great perseverance.

- Data Collection

The data of Standard IEEE 10 Bus System and Jomsom Distribution Feeder, Kobang was collected.

- Simulation and Algorithm

Load Flow was performed through simulation in ETAP and Optimal allocation was performed by the use of the proposed algorithm. First, load flow was run and then the candidate buses for optimal capacitor allocation was determined for optimal sizing and sitting of capacitor banks. Finally, DERs were injected in the system for grid impact study on Distribution System and then performance analysis of the system before and after injection of DERs were studied.

- Load Flow

Load flow and simulation of the system was carried out.

- Simulation

After obtaining the results, the system with optimal capacitor locations was implemented in the simulation, and then the comparison and analysis was carried out between algorithm based MATLAB and simulation based ETAP result. The analysis was carried out based on the technical aspects of the Distribution System such as Voltage Profile, Voltage Regulation, Distribution System Losses, Voltage Drop and financial aspects before and after compensation. After the detailed analysis, final result was validated and concluded based on the techno-financial parameters before and after compensation and injection of DERs in the System.

- Report Writing, Presentation and Research paper publication

The final report and presentation was prepared and the research work was published in the journal papers.

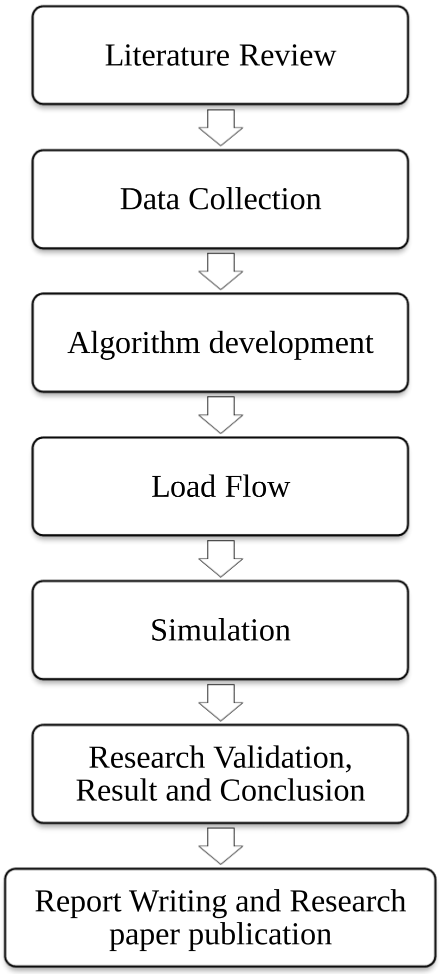

Figure 3.1: Flow diagram of Methodology

3.3 Flowchart of the proposed method

The line data and load data of the Standard IEEE 10 bus System and Jomsom Distribution Feeder, Kobang is read and then per unit values is determined. Then, the initial voltage magnitude is set for each bus. The node currents are calculated and then the bus voltages are computed. Loss Sensitivity Indices (LSIs) are calculated to determine the candidate buses for optimal placement of capacitor banks. The losses and voltage at each buses and lines are analysed for both the cases, i.e. before and after compensation through capacitor banks and injection of Distributed Energy Resources (DERs) in the system. Then, grid impact study is performed to study the impacts of injection of DERs in the Distribution System in terms of technical parameters like voltage regulation, voltage profile and power loss. The annual savings is computed after compensation through capacitor banks and injection of DERs. Hence, both the technical and financial aspects of the system after Optimal Capacitor Placement and injection of DERs are analysed.

The methodology of the proposed research work is presented in the Flowchart below in Figure 3.2.

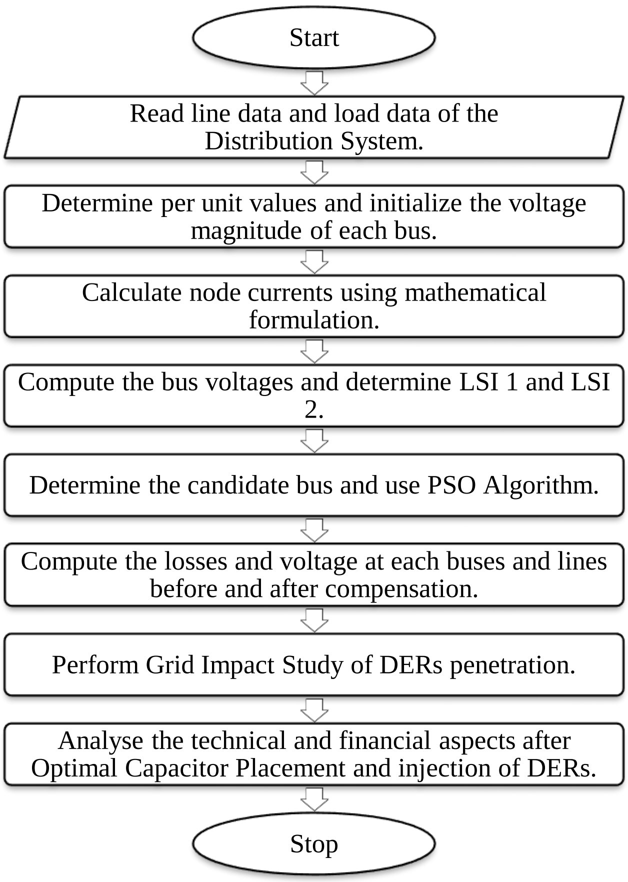

Figure 3.2: General Methodology of the Research Work

3.4 Flowchart of PSO Algorithm

The particles are initialized with random velocity vectors and position. Then, the fitness is evaluated by using fitness function. Then, pbest and gbest are found and updated. Then, the particle velocity and position is calculated and updated. Then, the termination criteria is checked. If the termination criteria is not satisfied, then the iteration again continues, while if the termination criteria is satisfied, then gbest is shown and hence optimal solution is determined.

The flowchart of Particle Swarm Optimization is presented below:

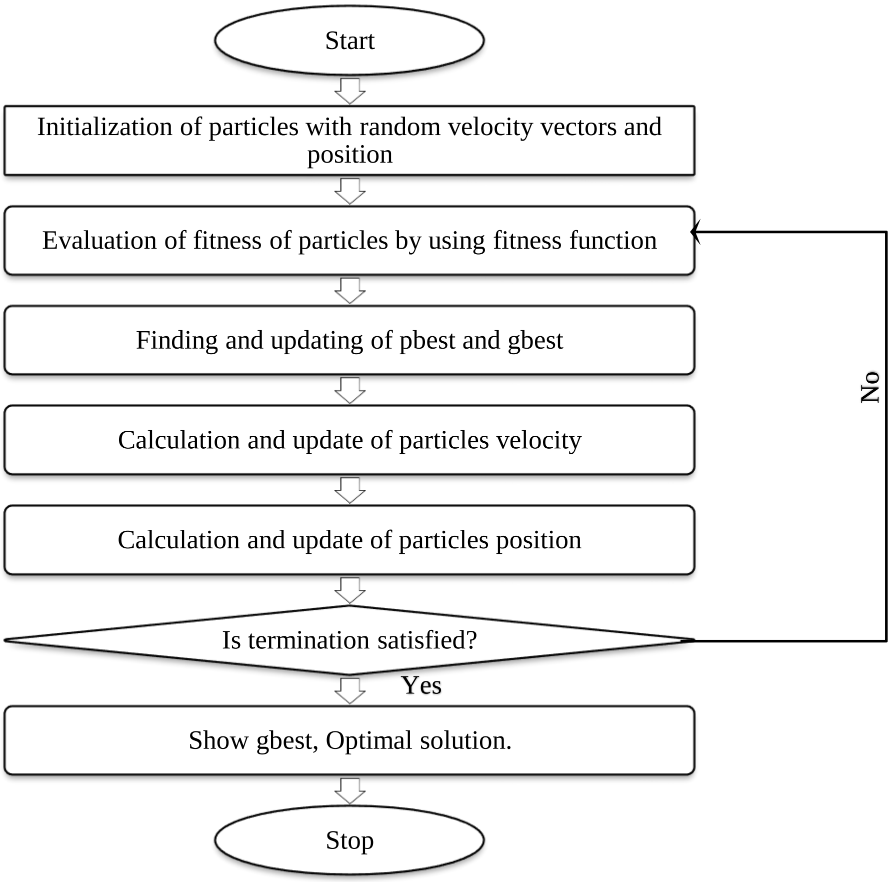

Figure 3.3: PSO Algorithm

Average life expectancy, cost per unit of energy costs, cost per kVAR of capacitors, cost per kW of wind turbine generator and cost per kW of Grid Connected solar plant are taken as the input parameters in the analysis. The line data and bus data are taken for the analysis. The base voltage and base MVA are taken to determine the per unit values of the components of the line data and bus data. The assumption for capacitor sizing is considered as per standard practices that is taken in between 150 kVAR to 1200 kVAR in steps or the difference of 150 kVAR. If the lower and upper bound value lies between 0 to 0.125, then the assumption is to use 150 kVAR capacitor. Similarly, 300 kVAR capacitor is considered for usage for value ranging from 0.125 to 0.25. If the value ranges from 0.25 to 0.375, 450 kVAR capacitor is used. 600 kVAR capacitor is used if value ranges from 0.375 to 0.5. In case the value falls between 0.5 to 0.625, 750 kVAR sized capacitor is used. Similarly, 900 kVAR is assumed for usage for value that lies in between 0.625 and 0.75. If the value falls in the range of 0.75 to 0.875, 1050 kVAR sized capacitor is assumed to be used. For the value exceeding 0.875, then 1200 kVAR sized capacitor is assumed to be used. The bus current, line loss, active and reactive power loss is calculated using the mathematical formulation. Loss Sensitivity Indices LSI 1 and LSI 2 are calculated to determine the candidate bus for placing of capacitor in the optimal location and hence are arranged in descending order and the first half of the buses are considered as the candidate buses for Optimal location of Capacitor Banks. Then, the proposed algorithm is used to determine the optimal sizing of capacitor banks. So, power loss, voltage across the nodes and voltage profile is determined both before and after compensation.

The load flow is also carried out by simulation in ETAP to make a comparative analysis between the proposed algorithm and simulation. Then, we get the locations and sizes of capacitors through the proposed algorithm that is also simulated in ETAP and the results before and after compensation is analysed in detail.

Then, the irradiance data of Jomsom Distribution Feeder at Dhakmar with latitude of 29.08° N and longitude of 83.88° E is fetched from Meteonorm and the Grid-connected Solar System Module is designed using PVSyst considering the parameters obtained from the fetched data. Similarly, the wind data in the corresponding location is obtained from NASA. The preliminary size of Wind Turbine Generator (WTG) is designed based on the available manufacturers and their technical datasheets. Then, the grid connected PV array and wind plant is injected into the system and hence the performance of the system is analysed before and after injection of DERs in both the technical and financial aspects.

3.5 Computational Tools Employed in the Analysis

The analysis is executed on Intel ® Core ™ i7-8565U CPU @1.80 GHz processor with RAM of 8 GB. The analysis is carried out by the use of algorithm in MATLAB and simulation in ETAP. The Solar Array Modules are designed using PVSyst by fetching the data from Meteonorm and the wind data are fetched from RetScreen Expert using the data extracted from NASA. The Single Line Diagrams of the Distribution System Feeders is drawn using AutoCAD.

3.6 Case Study Considered in the analysis

The line data and bus data of Standard IEEE 10 bus system is shown in Appendix- A (Kumar, n.d.) and the data of Jomsom Distribution Feeder, Kobang is shown in Appendix – B.

3.7 Documentation and presentation of the findings

The findings of the research work are presented in the form of two journal articles and formal thesis report as per requirement of the guidelines of Department of Mechanical and Aerospace Engineering, Pulchowk Campus, Institute of Engineering.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 IEEE 10 bus system

The Single Line Diagram of Standard IEEE 10 bus System with base voltage of 23 kV is shown in Figure 4.1.

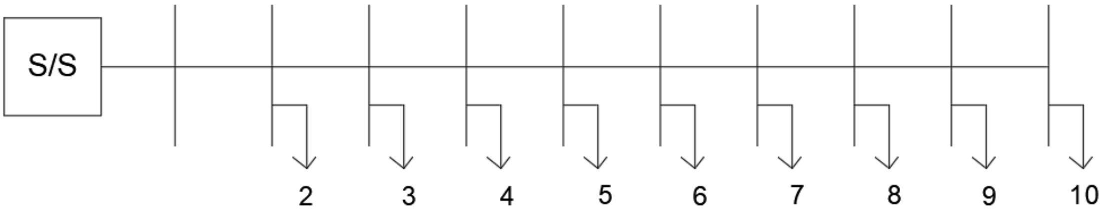

Figure 4.1: Single Line Diagram of Standard IEEE 10 bus System

4.1.1 Load Flow

The voltage across the bus without any compensation is calculated using algorithm in MATLAB and simulation is carried out in ETAP for validation and compared in Table 4.1.

Table 4.1: Comparison of Calculation of Bus Voltages of Standard IEEE 10 bus system in MATLAB and ETAP

Bus No.	Using MATLAB (Proposed Algorithm)	Using ETAP (Simulation)
1	1	1
2	0.9929	0.9931
3	0.98737	0.9878
4	0.9634	0.9647
5	0.94801	0.95
6	0.91717	0.9207
7	0.90717	0.9112
8	0.88896	0.8941
9	0.8587	0.8657
10	0.83752	0.846

The results of Load Flow Analysis of Standard IEEE 10 bus system carried out in ETAP is presented in Figure 4.2.

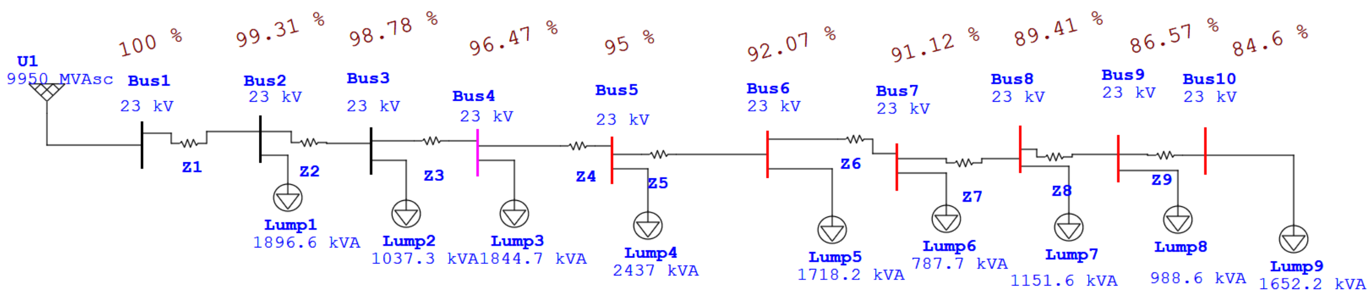

Figure 4.2: Load Flow of Standard IEEE 10 bus system in ETAP

It is found that the bus voltages decrease from the grid towards the feeder from the sending end to the receiving end as shown in Voltage Profile in Figure 4.3. The severe voltage sag is observed at the ends of the feeder. The losses increase from the starting point of the substation (sending end) to the end of the feeder (receiving end) gradually. The results from the proposed algorithm is compared with the simulation as shown in Table 4.1 and Figure 4.3. The voltage at the sending end is 1 pu and is decreased to 0.83752 pu at the receiving end that clearly shows about 16 % voltage drop.

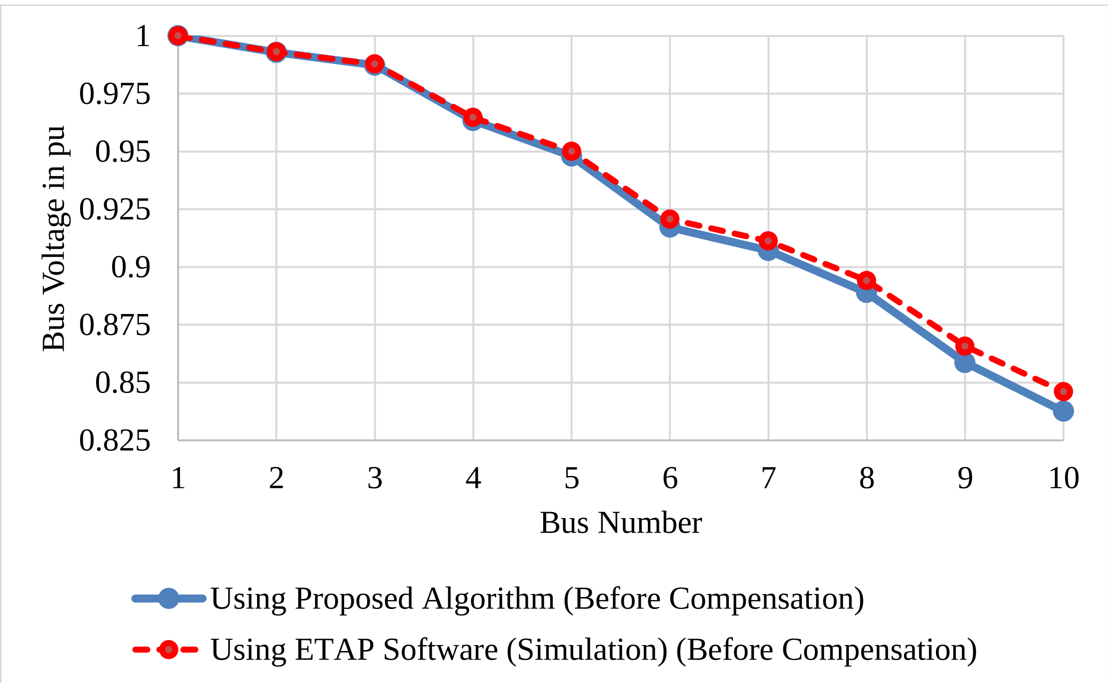

Figure 4.3: Voltage Profile of IEEE 10 bus System

4.1.2 Loss Sensitivity Factor

Two Loss Sensitivity Factors LSI 1 and LSI 2 are computed and candidate buses are chosen through this index. First half of the buses are selected as the candidate buses and hence are considered as the control variables for optimization purpose.

The Loss Sensitivity Factors (LSI 1) and (LSI 2) that we obtained are sorted in descending order and presented in Table 4.2 and Table 4.3 respectively.

Table 4.2: Loss Sensitivity Index (LSI 1)

Bus Number	LSI 1
4	-13.8E-03
6	-9.02E-03
3	-3.33E-03
5	-3.01E-03
2	-2.97E-03
9	-1.79E-03
8	-1.19E-03
7	-0.592E-03
10	-0.400E-03

Table 4.3: Loss Sensitivity Index (LSI 2)

Bus Number	LSI 2
4	9.55E-03
6	3.55E-03
3	3.29E-03
2	2.69E-03
5	1.24E-03
9	0.369E-03
8	0.252E-03
7	0.228E-03
10	0.0776E-03

Hence, first five buses Bus 2, 3, 4, 5 and 6 are the candidate buses for Optimal location of capacitor banks. The capacitors of suitable size is placed in these candidate buses which is calculated using the proposed algorithm and then load flow is carried out with the obtained sizes of capacitors further to compare, validate and analyse the results.

4.1.3 Capacitor Sizing

The following capacitor sizes is optimally placed and the assumption for capacitor sizing is considered as per standard practices that is taken in between 150 kVAR to 1200 kVAR in steps or the difference of 150 kVAR. The optimal capacitor sizes that we obtained from the candidate buses are listed below in Table 4.4.

Table 4.4: Optimal Capacitor Sizing in Standard IEEE 10-bus system

Bus Number	Size of Capacitor (kVAR)
4	1200
6	1200
3	1200
2	1200
5	1200

4.1.4 Voltage Profile before and after compensation

The bus voltages after compensation is improved when compared to that of before compensation. The optimal capacitor placement and sizing output obtained is simulated and then load flow is run. Then, the results are compared. The voltage across each node is increased after compensation when compared with that of before compensation. From Figure 4.5, it is clearly observed that the voltage profile is improved after compensation.

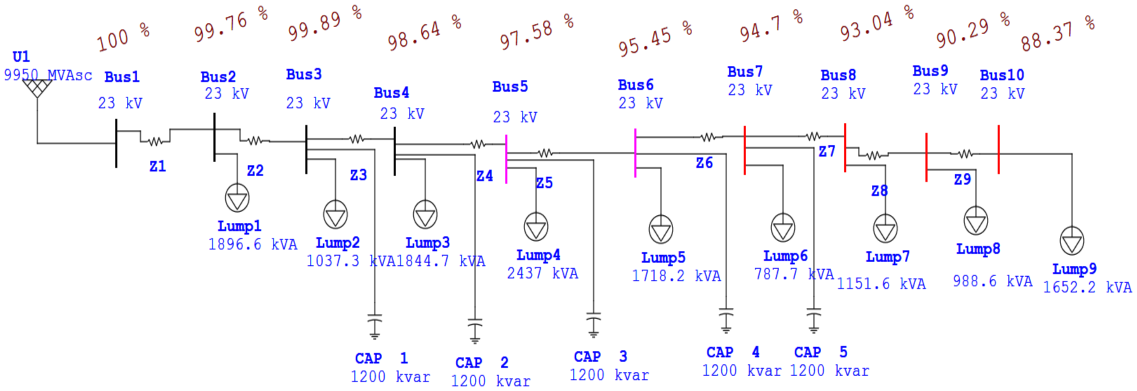

Figure 4.4: Optimal Capacitor Placement in Standard IEEE 10 bus System through ETAP

The summary of bus voltages in p.u. before and after compensation in MATLAB (Algorithm based) and in ETAP (Simulation based) is presented below in Table 4.5. It is seen that voltage after compensation is increased that causes voltage profile improvement in Distribution System.

Table 4.5: Bus Voltage Comparison before and after compensation

Bus No.	Using Proposed Algorithm (Before Compensation)	Using ETAP (Simulation) (Before Compensation)	Using Proposed Algorithm (After Compensation)	Using ETAP (Simulation) (After Compensation)
1	1	1	1	1
2	0.9929	0.9931	0.99787	0.99761
3	0.98737	0.9878	0.99773	0.99888
4	0.9634	0.9647	0.9828	0.98642
5	0.94801	0.95	0.97067	0.97582
6	0.91717	0.9207	0.9449	0.95452
7	0.90717	0.9112	0.93523	0.94702
8	0.88896	0.8941	0.91764	0.93036
9	0.8587	0.8657	0.88844	0.90285
10	0.83752	0.846	0.86801	0.88366

4.1.5 Power losses before and after compensation

We obtain the active power loss before compensation to be 783.6755 kW. Then, after placing the capacitor optimally in the candidate buses and simulating these results obtained, we obtain the power losses to be 639.3 kW as shown in Figure 4.6.

The reduction is power loss after compensation is calculated as:

Power loss reduction $= \frac{783.6755-693.3}{783.6755}$ = 18.5 %

Optimal capacitor sizing and placement led to 18.5 % decrease in power loss for Standard IEEE 10 bus system.

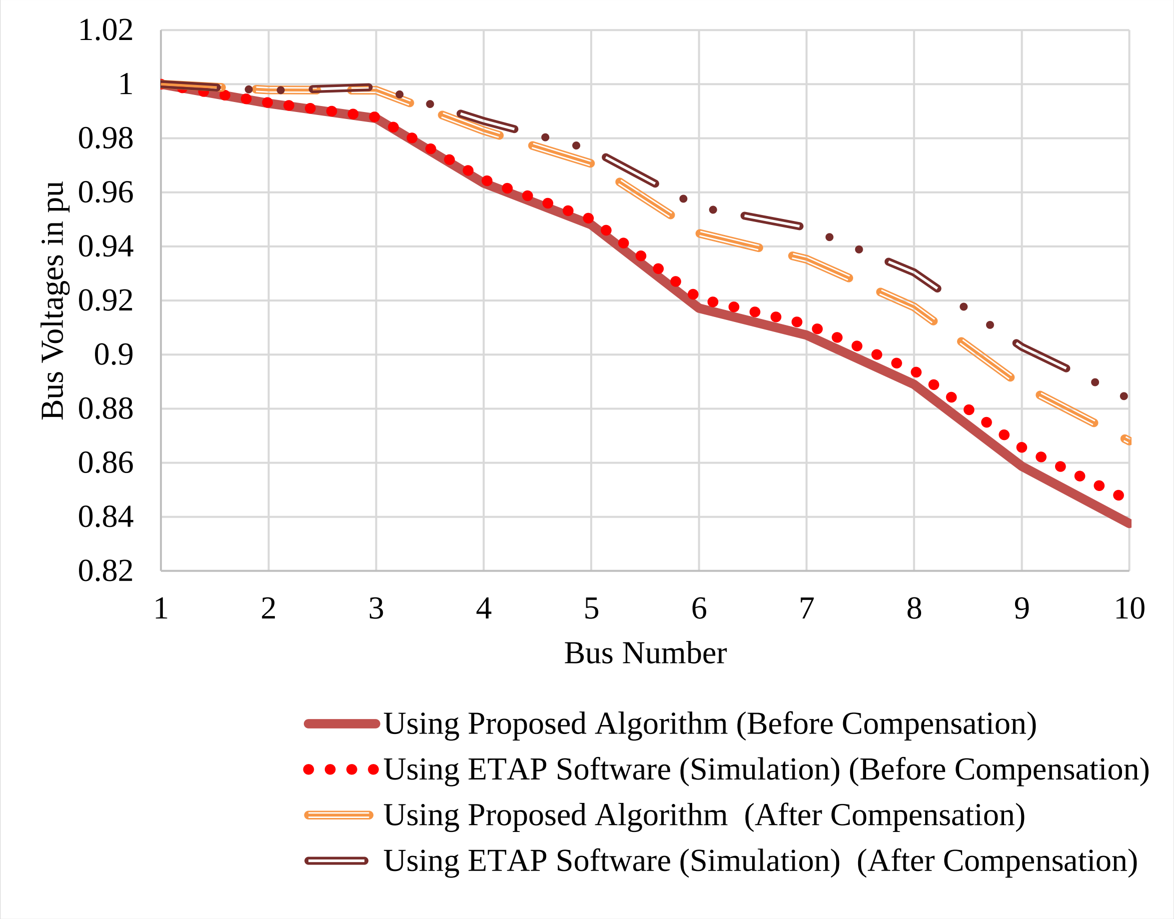

Figure 4.5: Voltage Profile of IEEE 10 bus System before and after compensation

Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Z1	12.796	-0.699	-12.758	0.827	38.3	128.1	100.0	99.8	0.24
Z2	10.920	-1.287	-10.917	1.426	3.2	139.1	99.8	99.9	0.13
Z3	9.937	-0.569	-9.797	0.795	140.1	226.2	99.9	98.6	1.25
Z4	8.017	-0.071	-7.929	0.147	87.2	76.0	98.6	97.6	1.06
Z5	6.347	-0.826	-6.185	0.967	161.3	140.5	97.6	95.5	2.13
Z6	4.604	-0.463	-4.564	0.498	40.2	35.0	95.5	94.7	0.75
Z7	3.800	0.471	-3.736	-0.435	63.5	36.0	94.7	93.0	1.67
Z8	2.617	0.376	-2.544	-0.335	73.2	41.5	93.0	90.3	2.75
Z9	1.600	0.210	-1.568	-0.191	32.3	18.3	90.3	88.4	1.92
					639.3	840.6			

Figure 4.6: Power loss after compensation in Standard IEEE 10 bus System

4.1.6 Voltage Regulation before and after compensation

Voltage regulation is simply the difference between sending end and receiving end voltage with reference to sending end voltage.

Before compensation, the bus voltage at bus 1 i.e. at sending end is 1 pu and the bus voltage at the receiving end i.e. at bus 10 is 0.83752. So, the voltage regulation before compensation is calculated as:

Voltage Regulation before compensation (V.R.) = $\frac{1-0.83752}{1} \times 100\%$ = 16.25%

After compensation, the bus voltage at bus 1 i.e. at the sending end remains unchanged while that of bus 10 at the receiving end is 0.88366. So, the voltage regulation after compensation is calculated as:

Voltage Regulation before compensation (V.R.) = $\frac{1-0.88366}{1} \times 100\%$ = 11.63%

Hence, Voltage Regulation is also improved after Optimal placement of Capacitor banks. Further improvement in voltage regulation can be achieved through injection of Distributed Energy Resources (DERs) in Distribution System Feeder.

4.1.7 Total Annual Cost Before and After Compensation

The total annual cost is calculated by multiplying the annual energy loss cost per unit with the active loss in kW. The active power loss before compensation is 783.6755 kW. We take the cost per unit of energy loss as \$168/kW (Kumar & Singh, n.d.). So, the annual cost before compensation is calculated as:

Total annual cost before compensation = \$ 783.6755 ×168 = \$ 131657.484

After compensation, the active power loss reduces to 639.3 kW. The total annual cost after compensation along with annualized capacitor cost of five banks of 1200 kVAR,

$$= \$\ 639.3 \times 168 + \frac{3000}{10} = \$\ 107702.4.$$

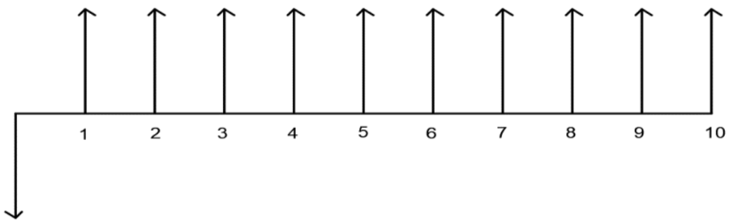

Figure 4.7: Cash Flow Diagram

Savings in annual cost = $ 131657.484 - $ 107702.4

= $ 23955.084

Hence, annual saving of $ 23955.084 is seen due to the Optimal Placement of Capacitor Banks.

4.1.8 Grid Impact Study after Injection of DERs in Standard IEEE 10 bus system

After placing the capacitor banks, Distributed Energy Resources (DERs) are injected into the system for performance analysis of the system before and after injection. 450 kW grid connected solar panel is designed for injection into Standard IEEE 10 bus system and is designed in PVSyst and 100 kW grid connected wind power plant is selected for injection into Standard IEEE 10 bus system. The performance of the Distribution System is analysed before and after injection of DERs and the impacts of DERs injection in the system is analysed in detail in terms of technical as well as financial aspects.

Consider at the receiving end of Distribution System Feeder, i.e. at bus 10, Distributed Energy Resources (DERs) is injected to analyse the system parameters before and after injection in terms of Voltage Profile and power loss. DERs of about maximum 15% of the total load is injected into the feeder near the receiving end of the radial distribution feeder. The different cases are studied for the purpose of the impact analysis of injection of DERs into the Distribution System Feeder as listed below:

(a) 450 kW Grid Connected Solar Plant

(b) 900 kW Grid Connected Solar Plant

(c) 1350 kW Grid Connected Solar Plant

(d) 1800 kW Grid Connected Solar Plant

(e) 100 kW Grid Connected Wind Plant

(f) 450 kW Grid Connected Solar Plant and 100 kW Grid Connected Wind Plant

(g) 900 kW Grid Connected Solar Plant and 100 kW Grid Connected Wind Plant

(h) 1350 kW Grid Connected Solar Plant and 100 kW Grid Connected Wind Plant

(i) 1800 kW Grid Connected Solar Plant and 100 kW Grid Connected Wind Plant

All these cases are simulated and technical and financial parameters are analysed after injection of Distributed Energy Resources (DERs) i.e. Grid Connected Solar and Wind Power Plant into the Distribution System Feeder.

4.1.8.1 Impact of DERs injection on Voltage Profile of the System

It is observed that the injection of DERs in the system causes enhancement in voltage profile of the distribution system. As the capacity of the DERs increases, the Voltage Profile of the Distribution System is increased. The voltage across each bus in each of

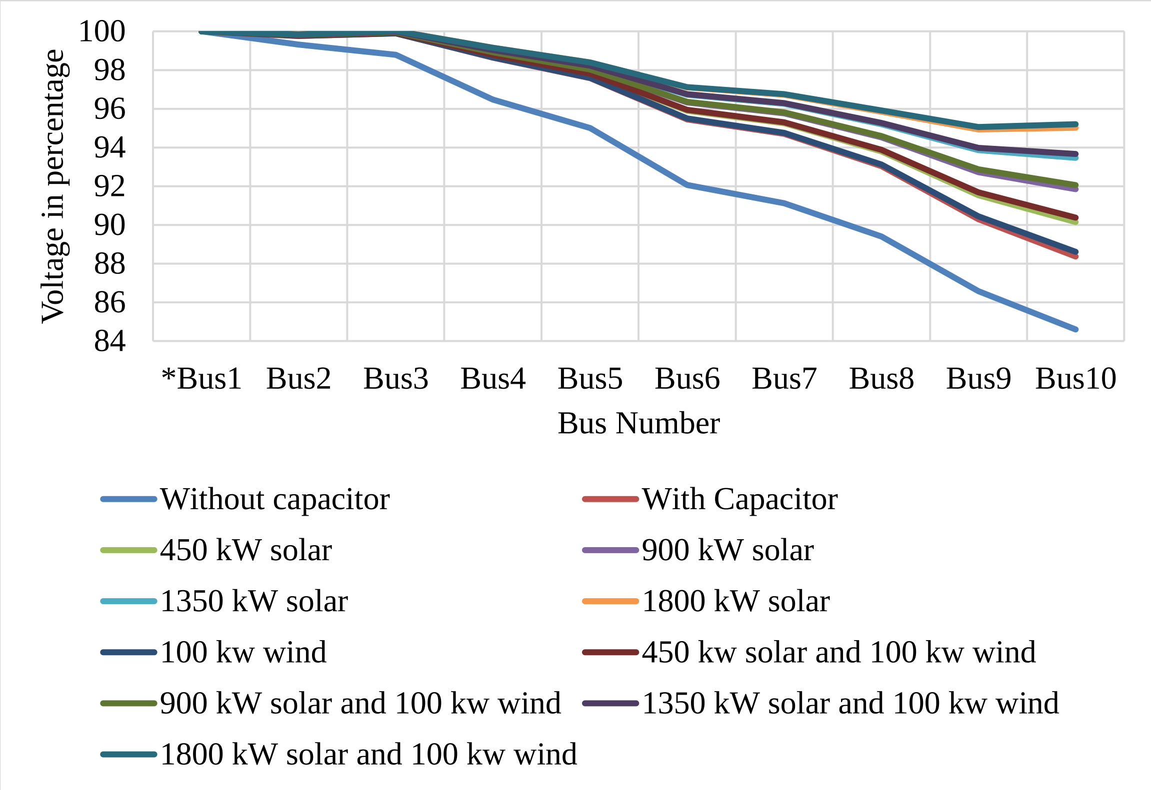

Figure 4.8: Voltage Profile of Standard IEEE 10 bus system after injection of DERs in the system

the cases is shown in Appendix-C. The graph shown in depicts voltage profile through injection of different ratings of Grid Connected Solar and Wind Power Plant for Standard IEEE 10 bus system. The graph shows that voltage profile after Optimal Capacitor Placement is increased as compared to the normal case of the Distribution System without any compensation. After injection of DERs in the system, the voltage profile is further found to be improved. Hence, the increment in voltage profile is directly proportional to the increment of capacity of DERs.

4.1.8.2 Impact of DERs injection on Voltage Regulation of the System

It is observed that the injection of DERs in the distribution system causes improvement in voltage regulation. As the capacity of the DERs increases, Voltage Regulation of the Distribution System is improved. The graph shown in Figure 4.9 depicts voltage regulation through injection of different ratings of Grid Connected Solar and Wind Power Plant. The graph shows that voltage regulation after Optimal Capacitor Placement is improved when compared to the normal case of the Distribution System without any compensation. After injection of DERs in the system, voltage regulation is found to be further improved. The improvement in voltage regulation is directly proportional to the increment of capacity of DERs.

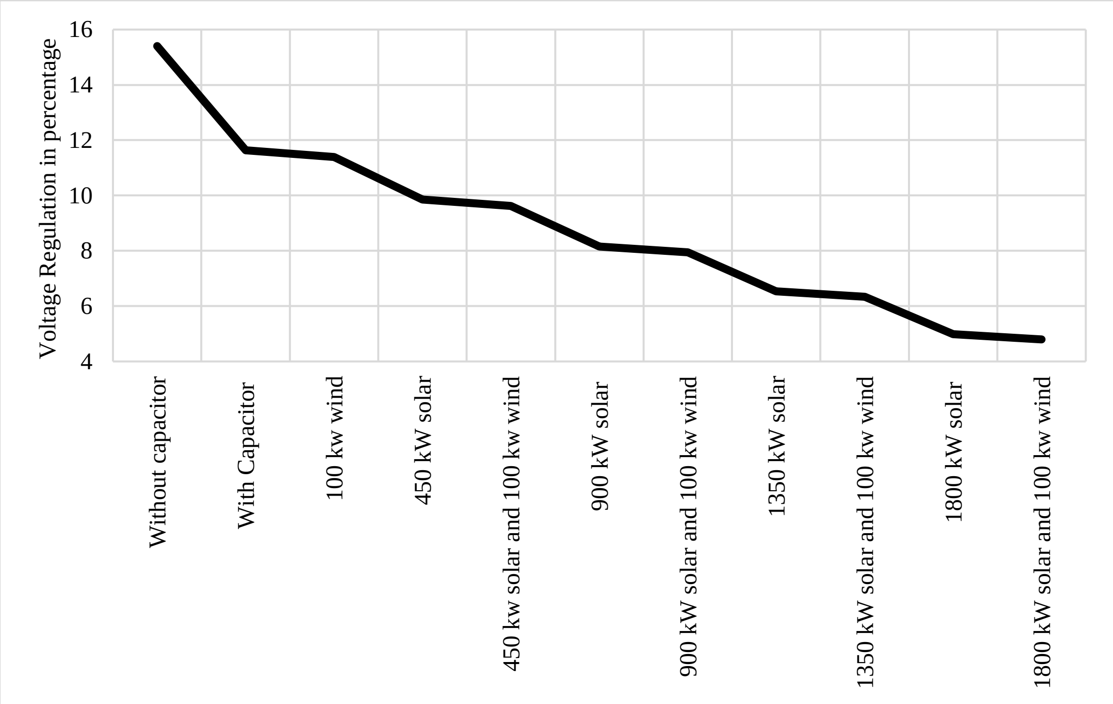

Figure 4.9: Voltage Regulation of Standard IEEE 10 bus system after injection of DERs in the system

4.1.8.3 Impact of DERs injection on Power Losses of the System

It is observed that the injection of DERs in the system causes reduction of power losses of the distribution system. As the capacity of DERs increases, power losses of the Distribution System is reduced. The graph shown in Figure 4.10 depicts power losses through injection of different ratings of Grid Connected Solar and Wind Power Plant. The graph shows that power losses after Optimal Capacitor Placement is reduced when compared to the normal case of the Distribution System without any compensation. After injection of DERs in the system, the power losses is found to be further reduced. The reduction in power losses is directly proportional to the increment of capacity of DERs.

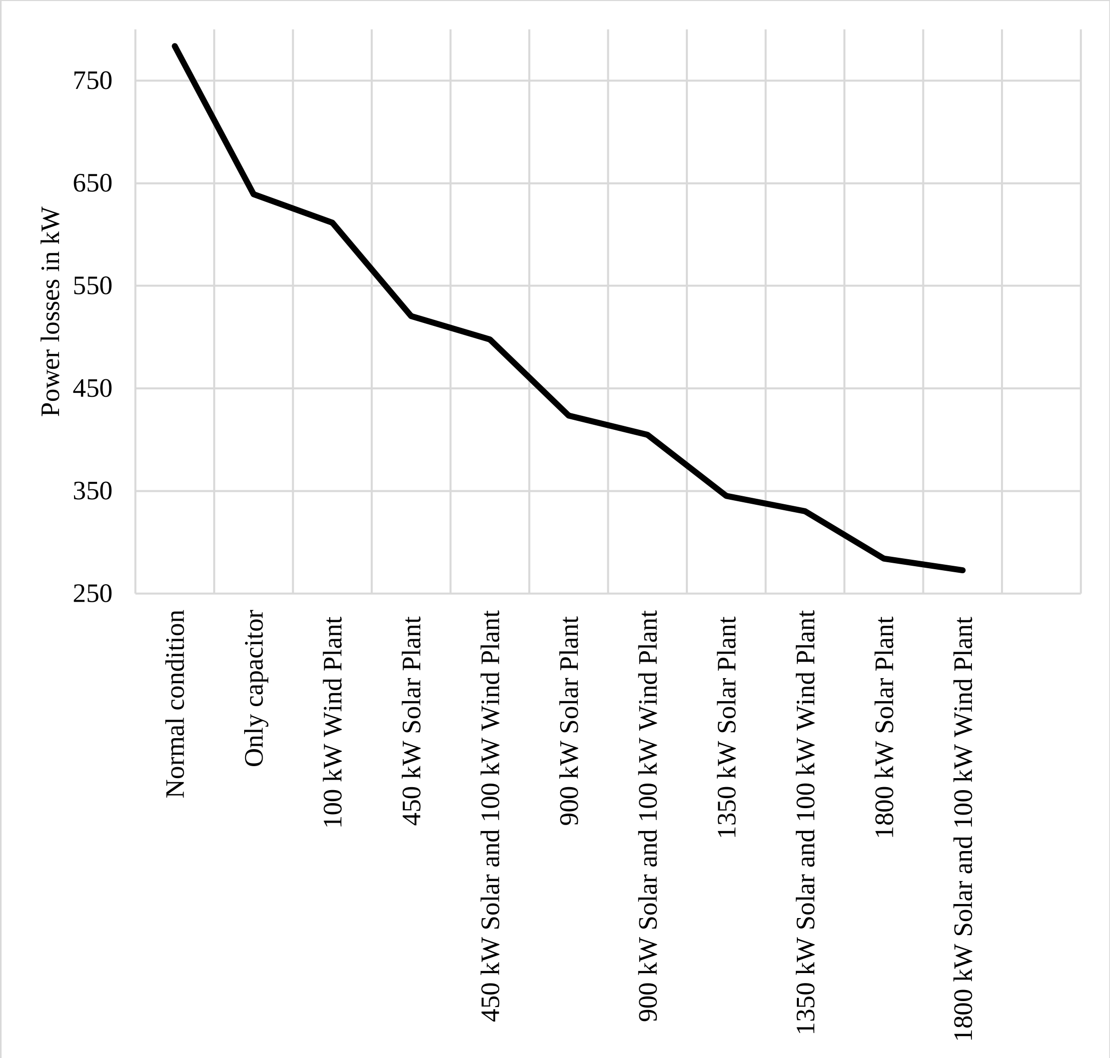

Figure 4.10: Power Losses of Standard IEEE 10 bus System after injection of DERs in the System

4.1.8.4 Impact of DERs injection on Total Annual Savings of the System

Different scenarios are considered for calculating the annual power loss and total annual savings of the system after Optimal Placement of Capacitor and further injection of Grid Connected Solar and Wind Power Plant into the Distribution System Feeder. Taking cost per kW of wind as $ 1200, solar as $ 553.84 and $ 0.5 per kVAR of capacitors, cost per unit of energy loss as $168/kW (Kumar & Singh, n.d.), the annual cost is calculated at various scenarios and is shown in Appendix-C. The total investment cost is calculated for the different selected ratings of grid connected solar and wind power plant. The energy loss cost is also calculated for each cases. Finally, the total annual savings are determined as shown in Figure 4.11. Optimum rating of DERs would be the best to minimize the total annual energy costs. It is seen that injection of 1350 kW of Grid connected solar power plant in the system gives the maximum total annual saving.

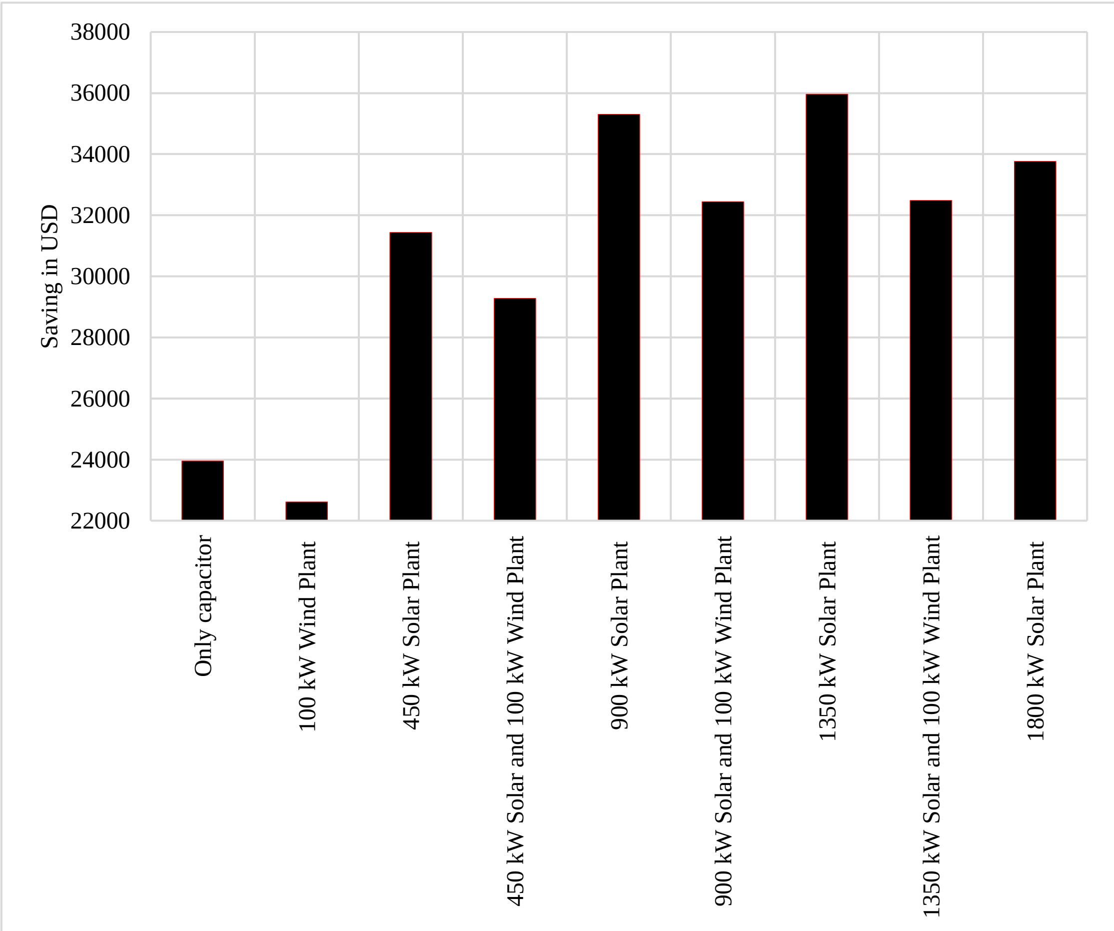

Figure 4.11: Total annual savings of Standard IEEE 10 bus system after injection of DERs in the system

4.2 Research Validation and Comparative Analysis

The result obtained after simulation is compared with the previously published research work. (Gupta, et al., 2015) calculated the total active power loss of Standard IEEE 10 bus System before and after compensation through D-STATCOM as 783.43 kW and 738.27 kW respectively using Power Loss Index Approach . This research on IEEE 10 bus system using simulation from ETAP showed that active power loss of Standard IEEE 10 bus System before and after compensation is 783.6755 kW and 693.3 kW respectively. Hence, the result of power loss before compensation are nearly same in this research work and published paper. The power loss after compensation in the published research paper is 738.27 kW using Power Loss Index Approach. However, in this research work, the active loss is reduced to 693.3 kW through Optimal Capacitor Sitting and Sizing. This shows that the proposed methodology is more reliable for desirable reduction in power losses.

Similarly, the minimum and maximum voltage obtained is 0.8375 pu and 0.8853 pu for Standard IEEE 10 bus system before and after compensation in the published paper respectively. Through this research work, we obtained the minimum and maximum voltage as 0.846 pu and 0.8837 pu for Standard IEEE 10 bus system before and after compensation. Hence, the result of voltage magnitude before compensation are nearly same in this research work and previously published papers.

This methodology is now applied for Jomsom Distribution Feeder, Kobang.

4.3 Jomsom Distribution Feeder, Kobang

Jomsom Distribution Feeder is located in Mustang district of Gandaki Province, Nepal. Distributed Energy Resources (DERs) is to be injected after Optimal capacitor placement for further improvement in performance of the distribution system feeder near the receiving ends of the system i.e. at bus 20, Dhakmar and analyse the impacts of injection of DERs in the system. It lies at a longitude of 83.88° E and latitude of 29.08° N with the elevation of about 3719 metres. The time zone of the corresponding place is UTC +5.8.

The Single Line Diagram (SLD) of Jomsom Distribution Feeder, Kobang is shown in Figure 4.12.

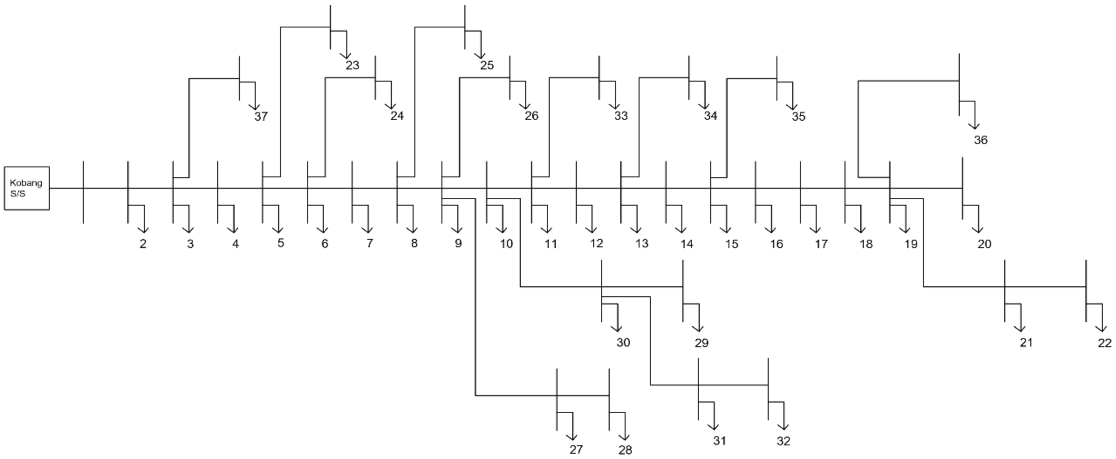

Figure 4.12: Single Line Diagram of Jomsom Distribution Feeder, Kobang

4.3.1 Load Flow

The voltage across the bus without any compensation is tabulated in Table 4.6.

Table 4.6: Bus Voltage of Jomsom Distribution Feeder, Kobang without compensation

Bus Number	Bus Voltage in Percentage
Bus 1	100
Bus 2	99.941
Bus 3	97.192
Bus 4	93.238
Bus 5	92.72
Bus 6	90.361
Bus 7	89.305
Bus 8	88.899
Bus 9	88.776
Bus 10	86.682
Bus 11	86.217
Bus 12	84.997
Bus 13	84.539
Bus 14	84.277
Bus 15	84.042
Bus 16	83.012

Bus Number	Bus Voltage in Percentage
Bus 17	82.756
Bus 18	82.722
Bus 19	82.118
Bus 20	82.083
Bus 21	81.83
Bus 22	81.76
Bus 23	92.714
Bus 24	90.086
Bus 25	88.881
Bus 26	88.712
Bus 27	88.337
Bus 28	88.267
Bus 29	86.154
Bus 30	86.202
Bus 31	86.075
Bus 32	86.029
Bus 33	85.915
Bus 34	84.528
Bus 35	84.017
Bus 36	82.031
Bus 37	97.152

The results of Load Flow Analysis of Jomsom Distribution Feeder, Kobang is presented in Figure 4.14. It is found that the bus voltages decrease from the grid towards the feeder from the sending end to the receiving end. The severe voltage sag is observed at the ends of the feeder. The voltage decreases from the starting point of the substation (sending end) to the end of the feeder (receiving end) gradually as shown in Voltage Profile in Figure 4.13.

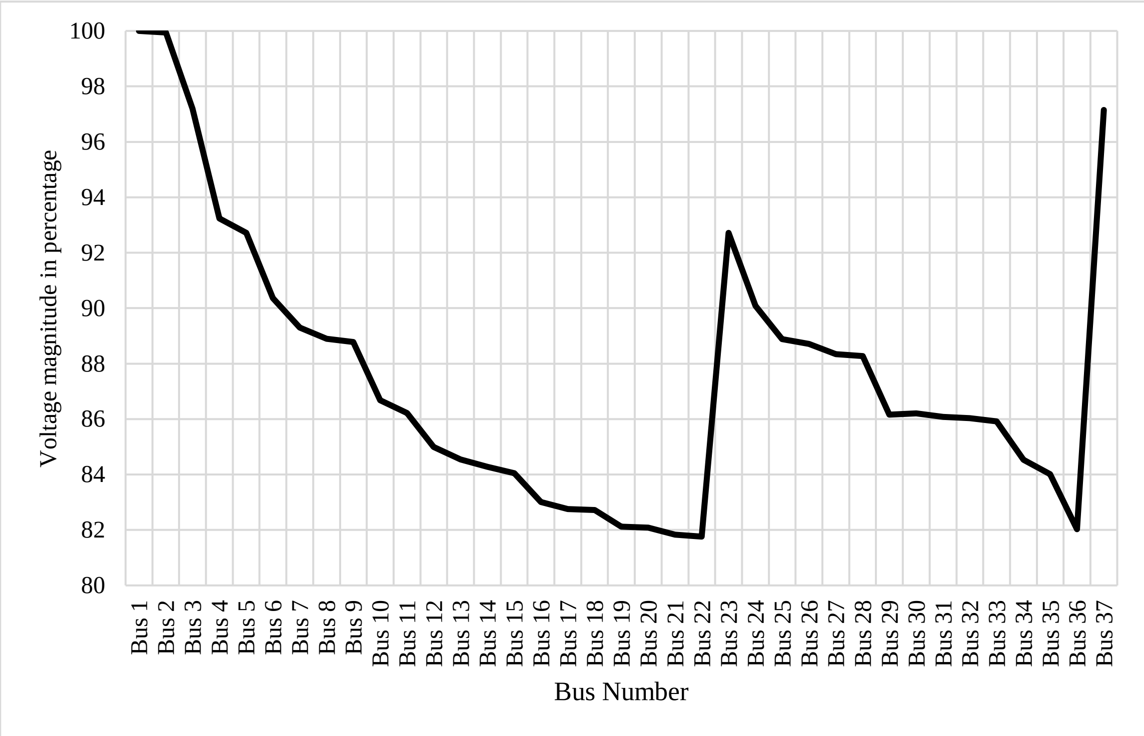

Figure 4.13: Voltage Profile of Jomsom Distribution Feeder, Kobang

4.3.2 Loss Sensitivity Factor

Two Loss Sensitivity Factors LSI 1 and LSI 2 are computed and candidate buses are chosen through this index. First half of the buses are selected as the candidate buses and considered as the control variables for optimization purpose.

The Loss Sensitivity Factors (LSI 1) and (LSI 2) that we obtain are sorted in descending order and candidate buses are selected for Optimal Placement of Capacitor banks. Buses 3,4,5,6,7,10,12,15,17,18,20,22,24,31,33,35 and 36 are the candidate buses for Optimal location of capacitor banks. The capacitors of suitable size is placed in these candidate buses which is calculated using the proposed algorithm and then load flow is carried out with the obtained sizes of capacitors.

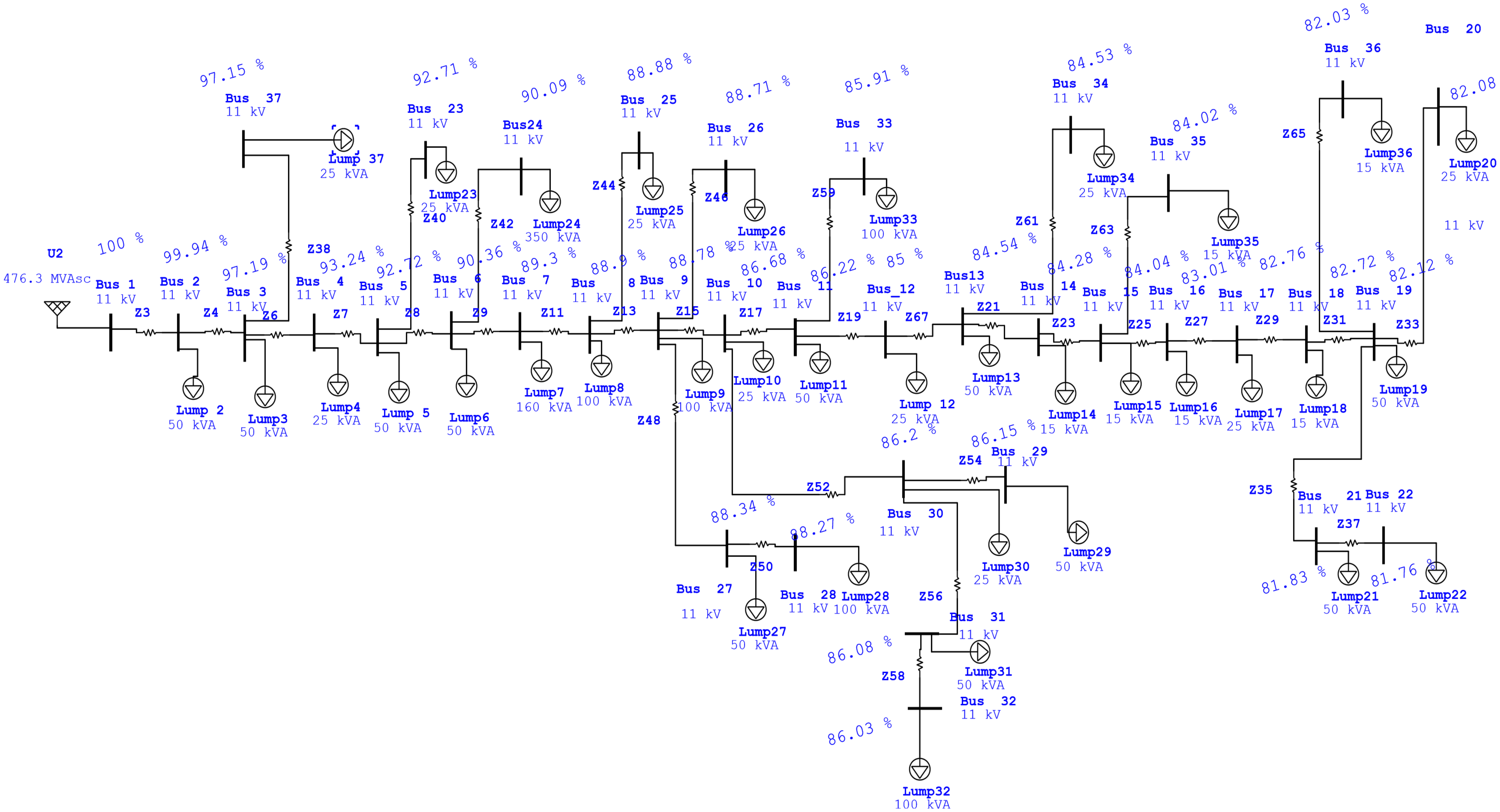

Figure 4.14: Load Flow Result of Jomsom Distribution Feeder, Kobang

4.3.3 Capacitor Sizing

The following capacitor sizes is optimally placed for Jomsom Distribution Feeder, Kobang by the algorithm. The assumption for capacitor sizing is considered as per standard practices that is taken in between 150 kVAR to 1200 kVAR in steps or the difference of 150 kVAR. The optimal capacitor sizes that we obtain in the candidate buses is listed below in Table 4.7.

Table 4.7: Optimal Capacitor Sizing in Jomsom Distribution Feeder, Kobang

Bus Number	Size of Capacitor (kVAR)
7	750
10	150
12	150
15	450

4.3.4 Voltage Profile before and after compensation

The bus voltages after compensation is improved when compared to that of before compensation. The optimal capacitor placement and sizing output obtained is then simulated and then load flow is run. The results are then compared.

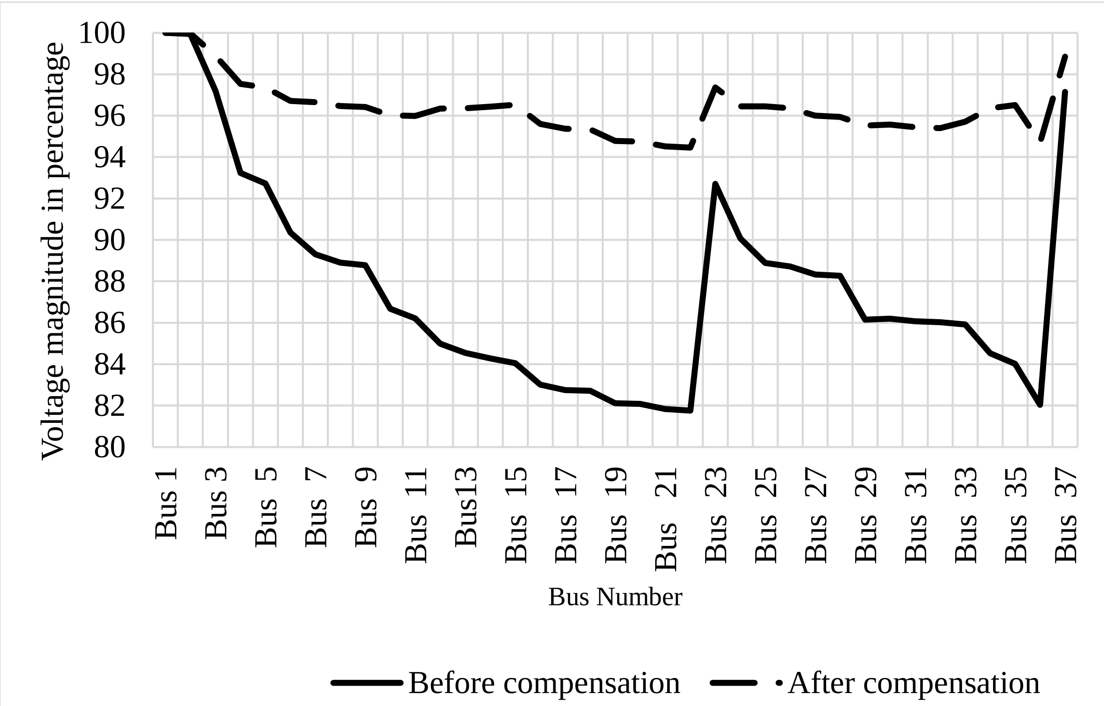

Figure 4.15: Voltage Profile of Jomsom Distribution Feeder before and after compensation

The voltage across nodes is increased after compensation when compared with that of before compensation. From Figure 4.15, it is clearly observed that the voltage profile is improved after compensation.

The summary of bus voltages before and after compensation is presented below in Table 4.8. It is seen that voltage after compensation is increased at each buses that causes voltage profile improvement in Distribution System.

Table 4.8: Bus Voltage Comparison before and after compensation

Bus Number	Bus Voltage Before Compensation in percentage	Bus Voltage After Compensation in percentage
Bus 1	100	100
Bus 2	99.941	99.976
Bus 3	97.192	98.894
Bus 4	93.238	97.533
Bus 5	92.72	97.369
Bus 6	90.361	96.715
Bus 7	89.305	96.648
Bus 8	88.899	96.466
Bus 9	88.776	96.419
Bus 10	86.682	96.017
Bus 11	86.217	95.99
Bus_12	84.997	96.335
Bus13	84.539	96.36
Bus 14	84.277	96.441
Bus 15	84.042	96.53
Bus 16	83.012	95.596
Bus 17	82.756	95.363
Bus 18	82.722	95.332
Bus 19	82.118	94.785
Bus 20	82.083	94.753
Bus 21	81.83	94.524
Bus 22	81.76	94.46
Bus 23	92.714	97.363
Bus24	90.086	96.452

Bus Number	Bus Voltage Before Compensation in percentage	Bus Voltage After Compensation in percentage
Bus 25	88.881	96.45
Bus 26	88.712	96.358
Bus 27	88.337	96.003
Bus 28	88.267	95.936
Bus 29	86.154	95.523
Bus 30	86.202	95.568
Bus 31	86.075	95.45
Bus 32	86.029	95.407
Bus 33	85.915	95.708
Bus 34	84.528	96.351
Bus 35	84.017	96.507
Bus 36	82.031	94.706
Bus 37	97.152	98.855

4.3.5 Power losses before and after compensation

The active power loss before compensation is found to be 165.3 kW. Then, after placing the capacitor optimally in the candidate buses and simulating the results obtained, we find the power losses to be 142.2 kW.

The reduction is power loss after compensation is calculated as:

Power loss reduction = $\frac{165.3-142.2}{165.3} * 100\%$ = 14 %

Optimal capacitor sizing and placement led to 14 % decrease in power loss.

4.3.6 Voltage Regulation before and after compensation

Voltage regulation is simply the difference between sending end and receiving end voltage with reference to sending end voltage.

Before compensation, the bus voltage at bus 1 i.e. at sending end is 1 pu and the bus voltage at the receiving end i.e. at bus 22 is 0.8176. So, the voltage regulation before compensation is calculated as:

Voltage Regulation before compensation (V.R.) = $\frac{1-0.8176}{1} \times 100\%$ = 18.24 %

After compensation, the bus voltage at bus 1 i.e. at the sending end remains unchanged while that of bus 22 at the receiving end is 0.9446. So, the voltage regulation after compensation is calculated as:

Voltage Regulation before compensation (V.R.) = $\frac{1-0.9446}{1} \times 100\%$ = 5.54%

Hence, Voltage Regulation is also improved after Optimal placement of Capacitor banks. Further improvement in voltage regulation can be achieved through injection of Distributed Energy Resources (DERs) in Distribution System Feeder.

4.3.7 Total Annual Cost Before and After Compensation

The total annual cost is calculated by multiplying the annual energy loss cost per unit with the active loss in kW. The active power loss before compensation is 165.3 kW. We take the cost per unit of energy loss as \$168/kW (Kumar & Singh, n.d.). So, the annual cost before compensation is calculated as:

Total annual cost before compensation = \$ 165.3 ×168 = \$ 27,770.4

After compensation, the active power loss reduces to 142.2 kW. The total annual cost after compensation along with annualized capacitor cost of four banks of ratings of total capacity 1500 kVAR.

= \$ 142.2×168 + $\frac{750}{10}$ = \$ 23,964.60.

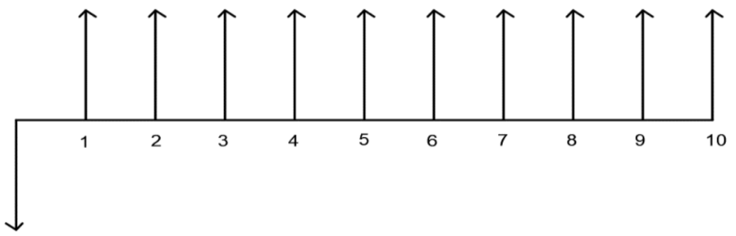

Figure 4.16: Cash Flow Diagram

Savings in annual cost = \$ 27,770.4 - \$ 23,964.60

= \$ 3,806

Hence, annual saving of \$ 3,806 is seen due to the Optimal Placement of capacitor banks.

4.3.8 Grid Impact Study after Injection of DERs in Jomsom Distribution Feeder, Kobang

Distributed Energy Resources (DERs) is injected near the receiving end of the feeder where there is severe voltage sag. Bus 20 is taken as a location for the injection of DERs at Dhakmar that lies at an altitude of almost 3713 metres and located at latitude of 29.08° N and longitude of 83.88° E. After placing the capacitor banks, Distributed Energy Resources (DERs), Grid connected solar, and wind power plants are injected into the system for performance analysis and analysis of impacts in the system before and after DERs injection. The google map of Dhakmar is shown in Figure 4.17.

Different ratings of Distributed Energy Resources (DERs), Grid connected solar and wind power plant are injected into bus 20 and impacts of injection on the grid are analysed in terms of technical parameters like voltage regulation, voltage profile, power losses and net annual savings, and financial parameters.

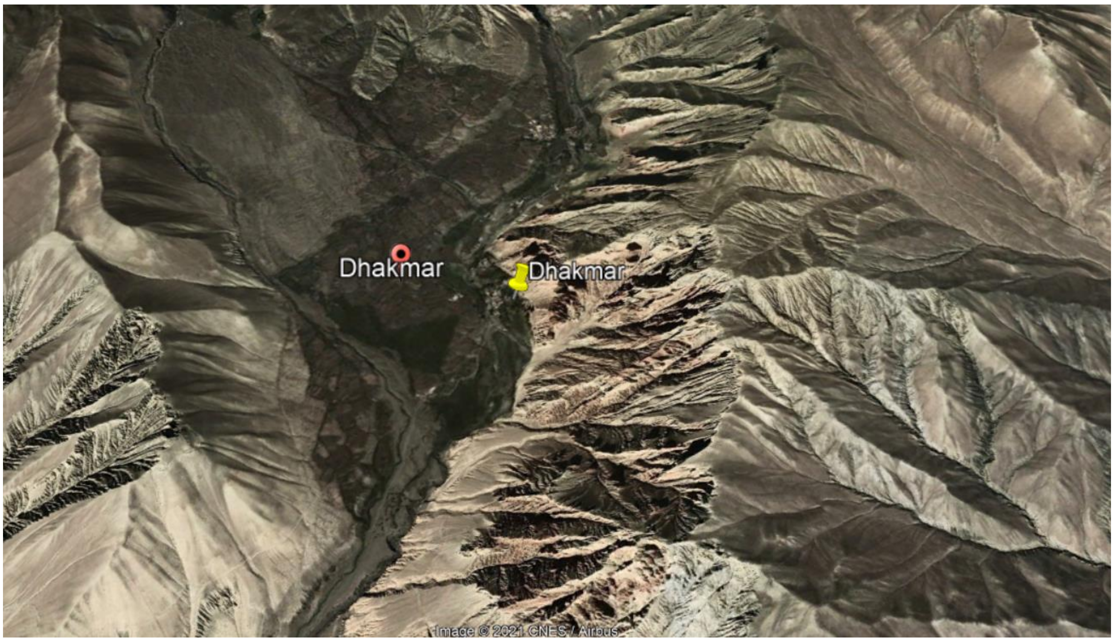

Figure 4.17: Google map showing the location of Dhakmar

4.3.8.1 Design of Grid-Connected Solar Power Plant

The Grid-connected solar power plant is designed in PVSyst with a tilt angle of approximately 30° and azimuth angle 0°. Solar arrays are designed considering the parameters like irradiance and temperature of the corresponding area.

The global horizontal radiation (GlobalHor), horizontal diffuse radiation (DiffHor), ambient temperature (T_Amb), global incident in coil plane (GlobInc) and effective global (GlobEff) for Dhakmar at latitude of 29.08° N and longitude of 83.88° E and elevation of 3719 m, for the different months is shown in Table 4.9.

Table 4.9: Solar Irradiance data of Dhakmar

	GlobalHor	DiffHor	T_Amb	GlobInc	GlobEff
	kWh/m^2	kWh/m^2	°C	kWh/m^2	kWh/m^2
January	130	38.69	-5.43	192.4	189.9
February	114.2	42.85	-3.6	146	143.4
March	184.6	58.55	0.17	214.3	210
April	219.5	64.48	4.4	223.8	218.4
May	234	79.47	8.74	216.4	210.3
June	224.8	67.03	13.02	197.3	191.5
July	188.6	78.47	13.54	169.3	164.4
August	187.3	76.65	12.7	182.4	177.2
September	179.1	59.66	11.08	196	191.8
October	187.7	44.32	4.98	241.1	237.6
November	152.3	28.5	-0.39	228.5	225.2
December	142.2	30.46	-3.97	228	224.9
Year	2144.2	669.13	4.65	2435.4	2384.7

Figure 4.18, Figure 4.19 and Figure 4.20 shows the graph of daily global radiation in $kWh/\,m^2$ in different months of the year, temperature variations in degree Celcius in different months of the year and daily temperature variations in degree Celcius in different months of the year at Dhakmar respectively. The global monthly radiations vary from 114.2 $kWh/\,m^2$ to 234 $kWh/\,m^2$. The overall global horizontal radiation for the entire year is about 2144.2 $kWh/\,m^2$ at Dhakmar. From the graph shown in Figure 4.18, the daily global radiations vary from 0.8 $kWh/\,m^2$ to 10.5 $kWh/\,m^2$. The efficiency of the panel directly depends on the temperature at which it is operated. For this regard, a thorough research of the temperature of the site is needed. The average temperature at Dhakmar varies from -5.43° to 13.54°C throughout the year. The mean temperature at Dhakmar is about 4.65°C.

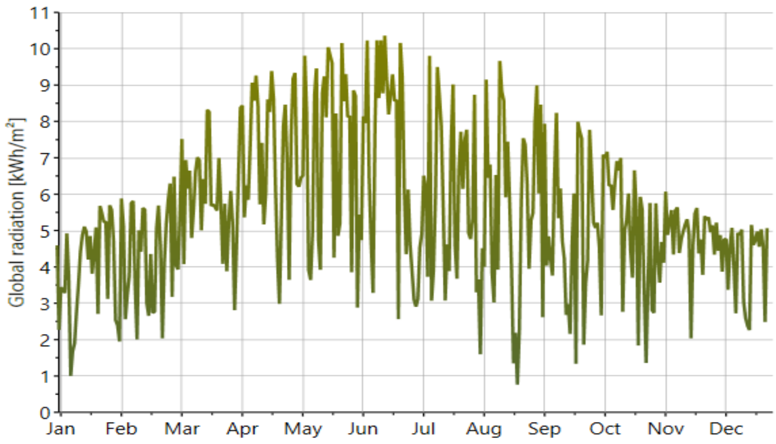

Figure 4.18: Daily global radiation at Dhakmar

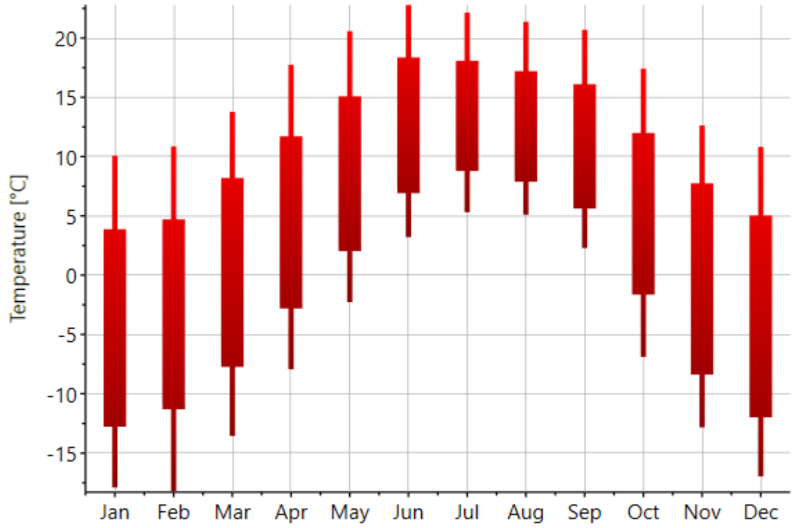

Figure 4.19: Temperature variations at Dhakmar

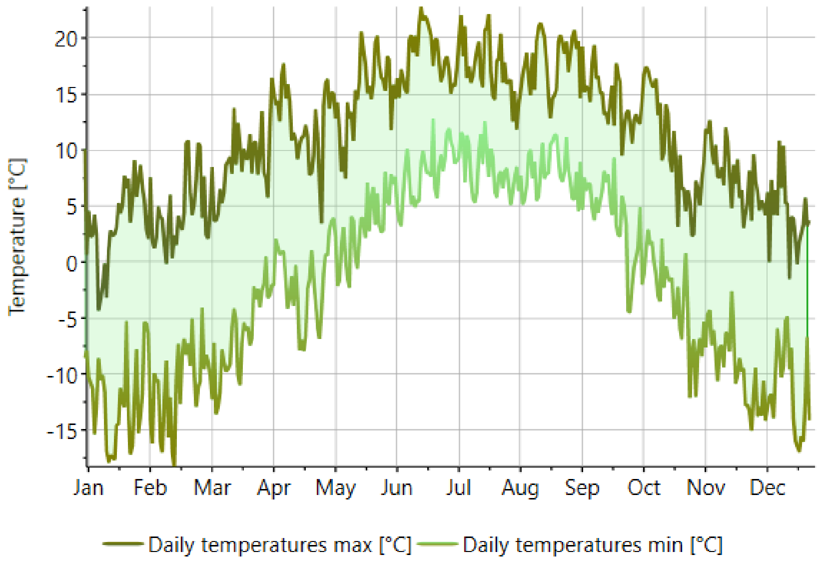

Figure 4.20: Daily temperature variations at Dhakmar

(a) For 50 kW Solar Array Design

For the design of 50 kW grid connected solar system in Dhakmar, 165 units of modules are employed with an inverter. The produced energy for Dhakmar is 110.7 MWh/year. Generic Manufacturer of Model GLCL-M6/60B-325 is used for the design purpose. 165 units of PV modules are used to obtain about 50 kW power with 11 strings*15 modules in series. One inverter of 50 kW is selected. Suitable array losses are taken into consideration for the design of the PV array modules.

(b) For 100 kW Solar Array Design

For the design of 100 kW grid connected solar system in Dhakmar, 324 units of modules are employed with an inverter. The produced energy for Dhakmar is 224.6 MWh/year. Generic Manufacturer of Model TSM-PEG14-325 is used for the design purpose. 324 units of PV modules are used to obtain about 100 kW power with 18 strings*18 modules in series. One inverter of 100 kW is selected. Suitable array losses are taken into consideration for the design of the PV array modules.

(c) For 150 kW Solar Array Design

For the design of 150 kW grid connected solar system in Dhakmar, 483 units of modules are employed with an inverter. The produced energy for Dhakmar is 329.8 MWh/year. Generic Manufacturer of Model GCL-M6/60B-325 is used for the design purpose. 483 units of PV modules are used to obtain about 150 kW power with 23 strings*21 modules in series. One inverter of 150 kW is selected. Suitable array losses are taken into consideration for the design of the PV array modules.

(d) For 200 kW Solar Array Design

For the design of 200 kW grid connected solar system in Dhakmar, 705 units of modules are employed with an inverter. The produced energy for Dhakmar is 480 MWh/year. Generic Manufacturer of Model GCL-M6/60B-325 is used for the design purpose. 705 units of PV modules are used to obtain about 200 kW power with 47 strings*15 modules in series. One inverter of 200 kW is selected. Suitable array losses are taken into consideration for the design of the PV array modules.

(e) For 250 kW Solar Array Design

For the design of 250 kW grid connected solar system in Dhakmar, 817 units of modules are employed with an inverter. The produced energy for Dhakmar is 554.7 MWh/year. Generic Manufacturer of Model GCL-M6/60B-325 is used for the design purpose. 817 units of PV modules are used to obtain about 250 kW power with 43 strings*19 modules in series. One inverter of 250 kW is selected. Suitable array losses are taken into consideration for the design of the PV array modules.

4.3.8.2 Selection of Grid-Connected Wind Power Plant

The wind speed data is fetched from NASA using RetScreen Expert for Dhakmar at latitude of 29.08° N and longitude of 83.88° E and elevation of 3713 metres. The wind speed data is taken at a distance of 10 m from the ground. The wind speed data for the different months at that corresponding place is shown in Table 4.10. Horizontal axis wind turbine is selected since for a given amount of wind, it can produce more power.

Table 4.10: Wind data of Dhakmar

Months	Wind speed (m/s)
January	4.7
February	4.5
March	4.6
April	4.4
May	4.2
June	3.6
July	3.2
August	2.8
September	3.1
October	3.7
November	4.2
December	4.4
Average	4.0

The available wind turbine generators (WTGs) in the market are researched and the suitable size needed for the proposed location is selected. The typically available WTGs selected are shown below:

(a) For 30 kW Wind Turbine Generator (WTG) Design

Aeolos Wind Turbine of rated power 30 kW is selected for Dhakmar. This employs Direct-Drive Permanent Magnet Generator. The blade type is of three glass fiber blades. The rotor blade diameter is of 15.6 m. The turbine weight is 3480 kg and temperature ranges from -20° to 50 ˚C. The design lifetime of the WTG is 20 years. (Aeolos, n.d.)

(b) For 50 kW Wind Turbine Generator (WTG) Design

Aeolos Wind Turbine of rated power 50 kW is selected for Dhakmar. This employs Direct-Drive Permanent Magnet Generator. The blade type is of three glass fiber blades. The rotor blade diameter is of 18 m. The turbine weight is 6120 kg and temperature ranges from -20° to 50 ˚C. The design lifetime of the WTG is 20 years. (Aeolos, n.d.)

(c) For 80 kW Wind Turbine Generator (WTG) Design

Enercon E-18 Wind Turbine of rated power 80 kW is selected for Dhakmar. The gear box is helical with parallel shafts. There are three rotor blades. The rotor blade diameter is of 18 m with swept area of 254.5 m^2. The generator employed is synchronous generator. The design lifetime of the WTG is 20 years. (Enercon, n.d.)

(d) For 100 kW Wind Turbine Generator (WTG) Design

Aeolos Wind Turbine of rated power 100 kW is selected for Dhakmar. This employs Direct-Drive Permanent Magnet Generator. The blade type is of three glass fiber blades. The rotor blade diameter is of 24.5 m. The turbine weight is 8350 kg and temperature ranges from -20° to 50 ˚C. The design lifetime of the WTG is 20 years. (Aeolos, n.d.)

Consider that Distributed Energy Resources (DERs) is injected in the system near to the receiving side i.e. near bus 20. Then, the system parameters are analysed before and after compensation through capacitor banks and injection of DERs in terms of technical parameters like Voltage Profile and power loss. DERs of about maximum 20 % of total load is injected in the feeder near the receiving end of the radial distribution feeder. Different cases are studied for the purpose of the impact analysis of injection of DERs into the Distribution System Feeder. The Grid connected solar power plant is varied from 50 kW to 250 kW in steps of 50 kW. The Grid connected wind turbine generator is varied from 30 kW to 100 kW. The different cases of connections of Grid connected solar plant and wind power plant into the system and their combinations are taken and performance of the system before and after their injection are analysed in terms of both technical and financial aspects.

All these cases are simulated and technical and financial parameters are analysed after injection of Distributed Energy Resources (DERs) i.e. Grid Connected Solar and Wind Power Plant into the Distribution System Feeder.

4.3.8.3 Impact of DERs injection on Voltage Profile of the System

It is observed that the injection of DERs in the system causes enhancement in voltage profile of the distribution system. As the capacity of the DERs increases, the Voltage Profile of the Distribution System is increased as shown in Appendix - D. The graph shown in Figure 4.21 depicts voltage profile through injection of different ratings of Grid Connected Solar and Wind Power Plant. The graph shows that voltage profile after Optimal Capacitor Placement is increased when compared to the normal case of the Distribution System without any compensation. After injection of DERs in the system, the voltage profile is found to be further improved. The increment in voltage profile is directly proportional to the increment of capacity of DERs.

4.3.8.4 Impact of DERs injection on Voltage Regulation of the System

It is observed that the injection of DERs in the distribution system causes enhancement in voltage regulation. As the capacity of the DERs increases, the Voltage Regulation of the Distribution System is improved. The graph shown in Figure 4.22 depicts voltage regulation through injection of different ratings of Grid Connected Solar and Wind Power Plant. The graph shows that voltage regulation after Optimal Capacitor Placement is improved when compared to the normal case of the Distribution System without any compensation. Furthermore, after injection of DERs in the system, the voltage regulation is found to be further improved. The improvement in voltage regulation is directly proportional to the increment of capacity of DERs.

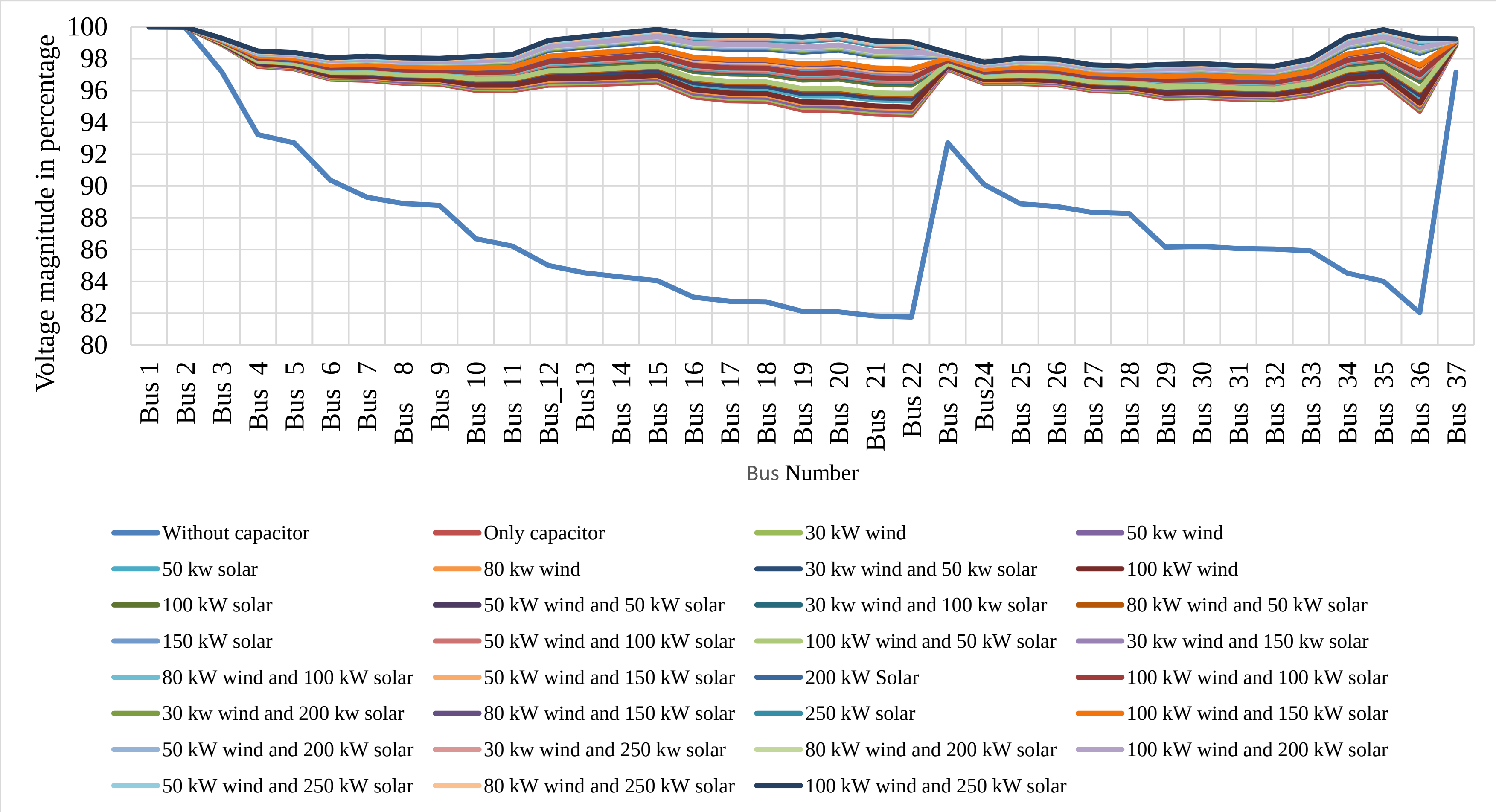

Figure 4.21: Voltage Profile of the Distribution System Feeder after injection of DERs in the system

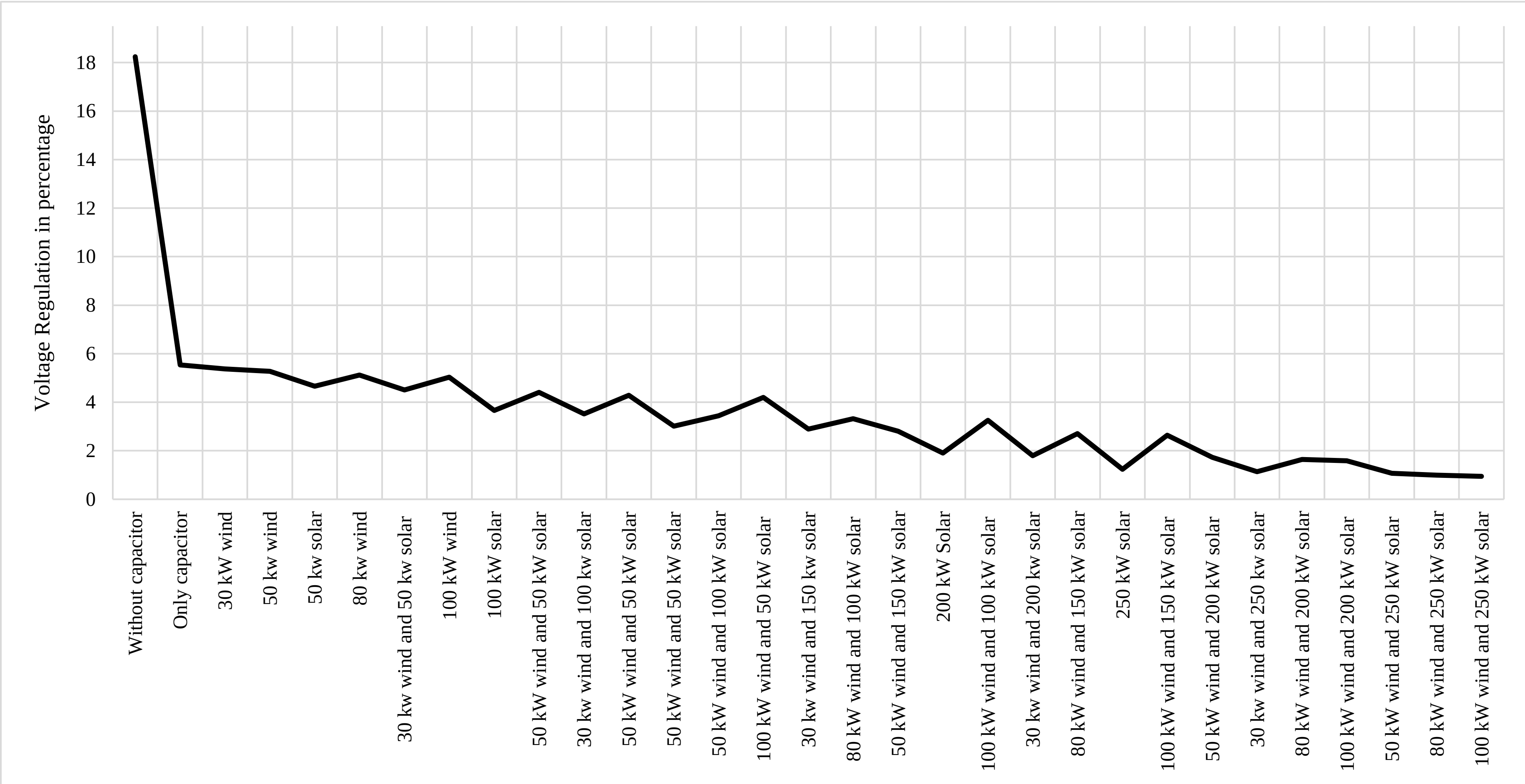

Figure 4.22: Voltage Regulation of the Distribution System Feeder after injection of DERs in the system

4.3.8.5 Impact of DERs injection on Power Losses of the System

It is observed that the injection of DERs in the system causes reduction of power losses of the distribution system. As the capacity of the DERs increases, power losses of the Distribution System is reduced. The graph shown in Figure 4.23 depicts power losses through injection of different ratings of Grid Connected Solar and Wind Power Plant. The graph shows that power losses after Optimal Capacitor Placement is reduced when compared to the normal case of the Distribution System without any compensation. After injection of DERs in the system, the power losses is further found to be reduced. The reduction in power losses is directly proportional to the increment of capacity of DERs.

4.3.8.6 Impact of DERs injection on Annual Power Loss and Total Annual Savings of the System

Different scenarios are considered for calculating the annual power loss and total annual savings of the system after Optimal Placement of Capacitor and further injection of Grid Connected Solar and Wind Power Plant into the Distribution System Feeder. Taking cost per kW of wind as $ 1200, solar as $ 553.84 and $ 0.5 per kVAR of capacitors, cost per unit of energy loss as $168/kW (Kumar & Singh, n.d.), the annual cost is calculated at various scenarios as shown in Appendix-D. The total investment cost is calculated for different selected ratings of grid connected solar and wind power plant. The energy loss cost is also calculated for each cases. Finally, the total annual savings are determined as shown in Figure 4.24. Optimum rating of DERs would be the best to minimize the total annual energy costs. It is seen that injection of 100 kW of Grid connected solar power plant in the system gives the maximum total annual saving.

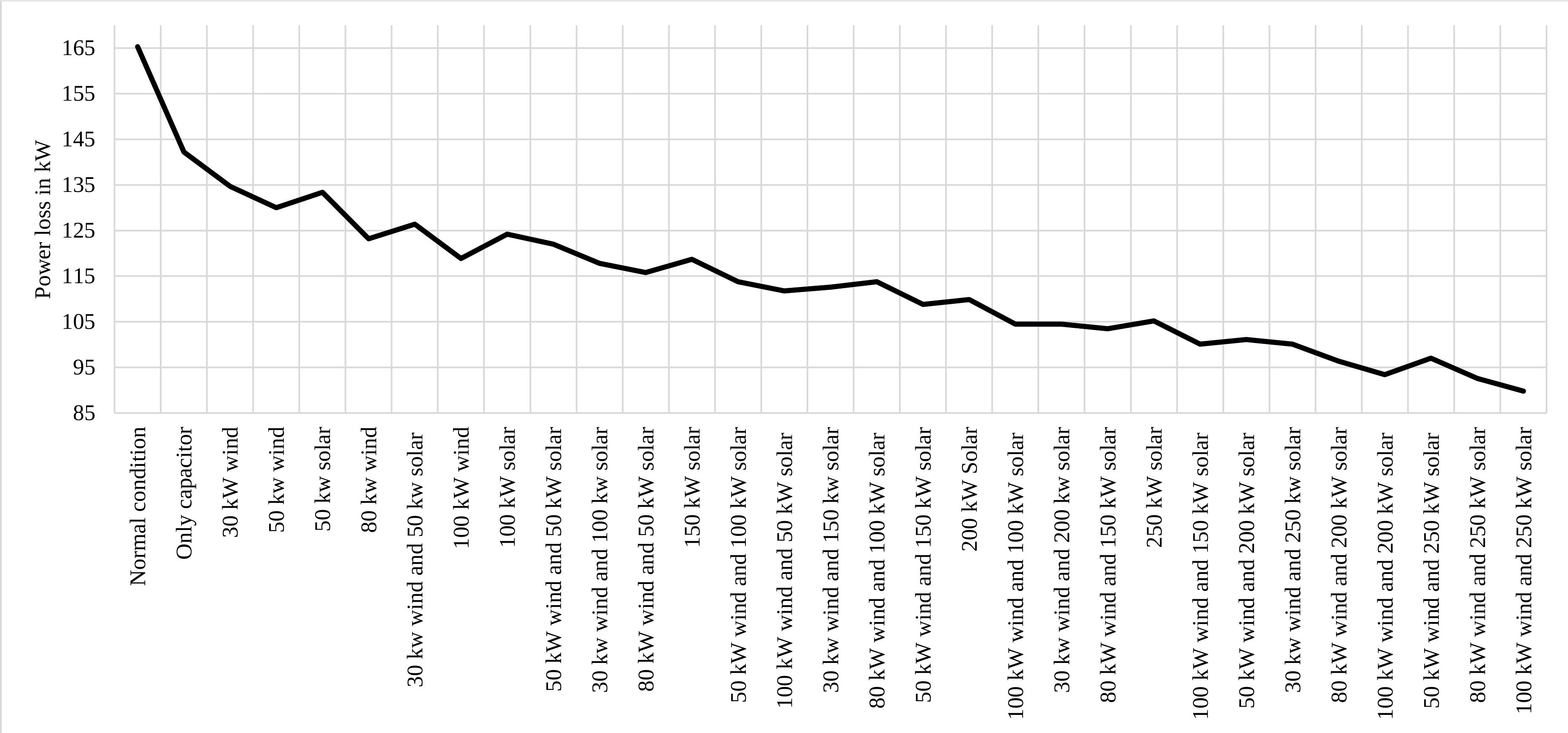

Figure 4.23: Power Losses of Kobang Distribution Feeder after injection of DERs in the System

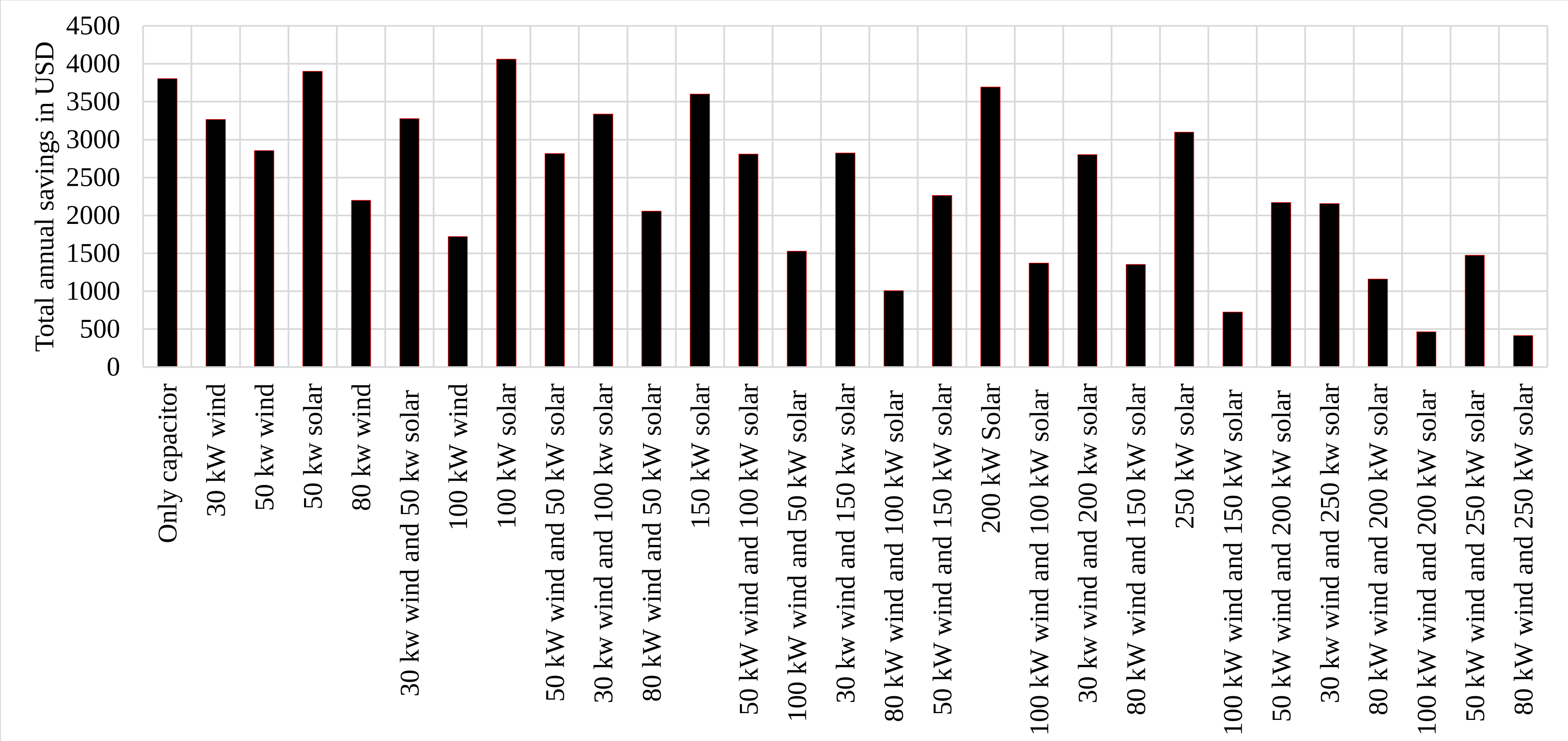

Figure 4.24: Total annual savings of Jomsom Distribution Feeder, Kobang after injection of DERs in the system

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The major cessations or findings of this analysis or research work are listed below:

- Bus voltages are determined through load flow of Standard IEEE 10 bus system and Jomsom Distribution Feeder, Kobang. Buses 2, 3, 4, 5 and 6 are selected as the candidate buses for Standard IEEE 10 bus system, while buses 3,4,5,6,7,10,12,15,17,18,20,22,24,31,33,35 and 36 are selected as the candidate buses for Jomsom Distribution Feeder, Kobang for placing the capacitor banks based on Loss Sensitivity Index (LSI).
- 1200 kVAR of capacitors are determined at each of the five candidate bus through Optimal Capacitor Placement Algorithm for Standard IEEE 10 bus system, while for Kobang Distribution Feeder, ratings of 750 kVAR, 150 kVAR, 150 kVAR and 450 kVAR are determined at buses 7, 10, 12 and 15 respectively.
- Power losses is reduced by almost 18.5 % and 14.5 % in case of Standard IEEE 10 bus system and Jomsom Distribution Feeder respectively. This causes enhancement in the performance of Distribution System. Voltage Regulation is improved from 16.25 % to 11.63 % in case of Standard IEEE 10 bus system and from 18.24 % to 5.54 % in case of Jomsom Distribution Feeder after Optimal Capacitor Placement. It is found that Voltage Profile of the Distribution System after compensation is improved.
- Design and selection of Distributed Energy Resources (DERs) is performed. Grid-connected solar power plant of different ratings is designed for Dhakmar and suitable capacity of Grid-connected wind power plant is selected for the corresponding location based on the available manufacturers. Grid Impact Study is carried out after injection of Distributed Energy Resources (DERs) in the distribution system. It is observed that Voltage Regulation and Voltage Profile is improved for Standard IEEE 10 bus System as well as Jomsom Distribution Feeder, Kobang after the injection of Distributed Energy Resources (DERs). Power losses is seen to be significantly reduced in case of Standard IEEE 10 bus System as well as Jomsom Distribution Feeder, Kobang after the injection of Distributed Energy Resources (DERs).

- There is saving in $ 23,955.084 annually in case of Standard IEEE 10 bus system and $3,806 annually in case of Jomsom Distribution System, Kobang due to Optimal Capacitor Placement in Distribution System. Total annual savings for different cases of injection of Distributed Energy Resources (DERs) in the system are compared for the analysis.

5.2 Recommendations

Further study on no-load condition that may arise due to load rejection or disturbances in the feeder can be studied in detail. Reliability Assessment of the system can further be done for Jomsom Distribution Feeder. The study can further be carried out considering load growth patterns and load models. Feeder reconfiguration can also help in reduction of losses in addition to optimally placing capacitor banks and injecting DERs in the system. The similar research works can be carried out for the feeders located in Terai Region and perform comparative analysis regarding voltage fluctuations in Hilly Region and Terai Region. The detailed analysis on harmonics of Jomsom Distribution Feeder before and after compensation and DERs injection can be further carried out. Provision of storage of solar and wind power plant can be implemented for more reliability of the system. However, storage may not be an economical option for grid connected DERs in such remote areas with unforeseen problems in repair and maintenance as well.

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APPENDIX A: IEEE 10 BUS SYSTEM DATA

The Standard IEEE 10 bus System data of Base Voltage 23 kV as mentioned in Section 3.6 is listed below:

Table A-1: Line data and load data of Standard IEEE 10 bus system

From	To	R (Ohm)	X (Ohm)	P (kW)	Q (kVAR)
1	2	0.1233	0.4127	1840	460
2	3	0.014	0.6057	980	340
3	4	0.7463	1.205	1790	446
4	5	0.6984	0.6084	1598	1840
5	6	1.9831	1.7276	1610	600
6	7	0.9053	0.7886	780	110
7	8	2.0552	1.164	1150	60
8	9	4.7943	2.716	980	130
9	10	5.3434	3.0264	1640	200

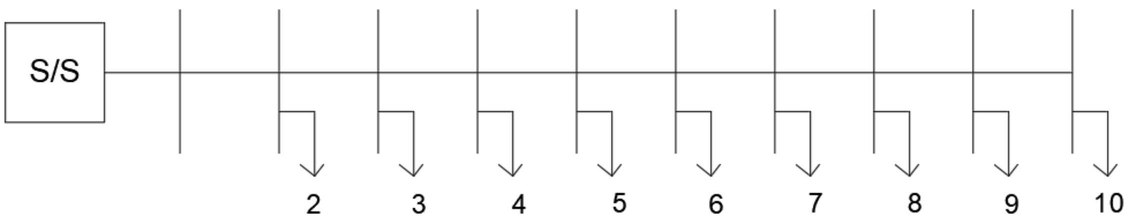

Figure A-1: Single Line Diagram of Standard IEEE 10 bus system

APPENDIX B: JOMSOM DISTRIBUTION FEEDER, JOMSOM

The line data and bus data of Jomsom Distribution Feeder, Kobang as mentioned in Section 3.6 is listed below:

Table B-1: Line data and load data of Jomsom Distribution Feeder, Kobang

From	To	R (Ohm)	X (Ohm)	P (kW)	Q (kVAR)
1	2	0.021121	0.02986	45	21.79449
2	3	1.017105	1.43791	45	21.79449
3	4	1.528675	2.161131	22.5	10.89725
4	5	0.204079	0.288513	45	21.79449
5	6	0.970748	1.372374	45	21.79449
6	7	0.561218	0.79341	144	69.74238
7	8	0.244127	0.345129	90	43.58899
8	9	0.082016	0.115948	90	43.58899
9	10	1.876488	2.652843	22.5	10.89725
10	11	0.607301	0.858558	45	21.79449
11	12	2.189739	3.095695	22.5	10.89725
12	13	0.878035	1.241303	45	21.79449
13	14	0.631713	0.893071	13.5	6.538348
14	15	0.595231	0.841495	13.5	6.538348
15	16	2.933366	4.146982	13.5	6.538348
16	17	0.77819	1.100149	22.5	10.89725
17	18	0.116578	0.164809	13.5	6.538348
18	19	2.217991	3.135637	45	21.79449
19	20	0.993241	1.404173	22.5	10.89725
19	21	2.013912	2.847124	45	21.79449
21	22	0.977606	1.382069	45	21.79449
3	37	1.230785	1.739995	22.5	10.89725
5	23	0.18049	0.255163	22.5	10.89725
6	24	0.586454	0.829086	315	152.5615
8	25	0.512393	0.724384	22.5	10.89725
9	26	1.898157	2.683478	22.5	10.89725
9	27	2.154628	3.046058	45	21.79449
27	28	0.517879	0.73214	90	43.58899

From	To	R (Ohm)	X (Ohm)	P (kW)	Q (kVAR)
10	30	1.544584	2.183622	22.5	10.89725
30	29	0.698917	0.988078	45	21.79449
30	31	0.610044	0.862436	45	21.79449
31	32	0.336566	0.475813	90	43.58899
11	33	2.185075	3.089102	90	43.58899
13	34	0.310234	0.438586	22.5	10.89725
15	35	1.181685	1.670582	13.5	6.538348
19	36	4.087073	5.77801	13.5	6.538348

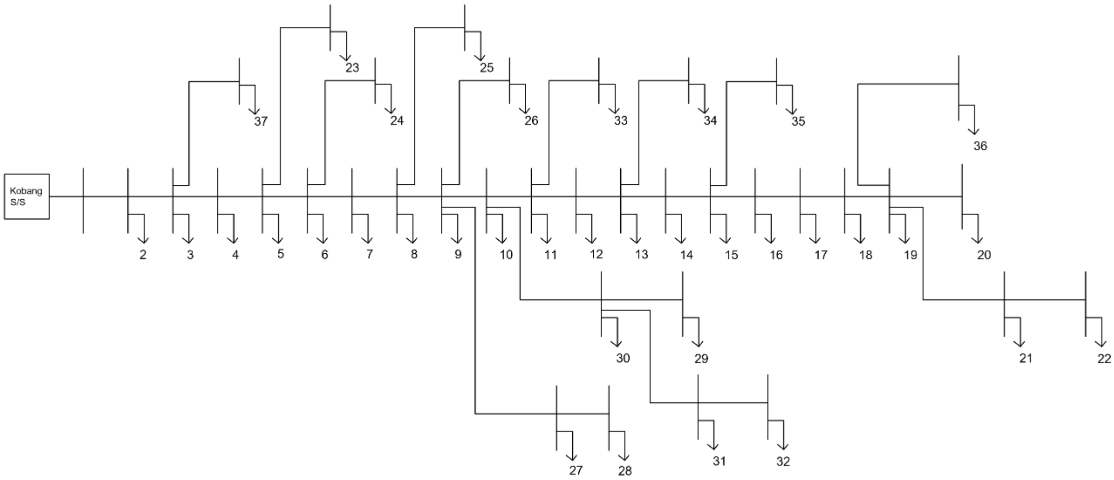

Figure B-1: Single Line Diagram of Jomsom Distribution Feeder, Kobang

APPENDIX C: STANDARD IEEE 10 BUS SYSTEM

Table C-1: Voltage Profile of Standard IEEE 10 bus system after injection of DERs in the system in percentage

	Without capacitor	With Capacitor	With 100 kW wind	With 450 kW solar	With 450 kW solar and 100 kW wind	With 900 kW solar	With 900 kW solar and 100 kW wind	With 1350 kW solar	With 1350 kW solar and 100 kw wind	With 1800 kW solar	With 1800 kW solar and 100 kW wind
Bus1	100	100	100	100	100	100	100	100	100	100	100
Bus2	99.313	99.761	99.762	99.785	99.785	99.807	99.806	99.827	99.826	99.845	99.844
Bus3	98.779	99.888	99.885	99.928	99.923	99.963	99.958	99.995	99.99	100.024	100.018
Bus4	96.472	98.642	98.647	98.783	98.786	98.914	98.914	99.035	99.034	99.148	99.145
Bus5	94.997	97.582	97.598	97.805	97.818	98.014	98.023	98.209	98.216	98.392	98.396
Bus6	92.067	95.452	95.496	95.901	95.939	96.322	96.356	96.72	96.749	97.097	97.122
Bus7	91.123	94.702	94.758	95.25	95.299	95.765	95.809	96.252	96.29	96.713	96.747
Bus8	89.408	93.036	93.126	93.798	93.879	94.518	94.591	95.2	95.266	95.849	95.909
Bus9	86.575	90.285	90.449	91.537	91.688	92.725	92.864	93.855	93.984	94.935	95.055
Bus10	84.597	88.366	88.608	90.148	90.374	91.844	92.055	93.464	93.663	95.016	95.203

Table C-2: Total Annual Savings of the Distribution System Feeder after injection of DERs in the system for Standard IEEE 10 bus System in USD

	Only capacitor	100 kW Wind Plant	450 kW Solar Plant	450 kW Solar and 100 kW Wind Plant	900 kW Solar Plant	900 kW Solar and 100 kW Wind Plant	1350 kW Solar Plant	1350 kW Solar and 100 kW Wind Plant	1800 kW Solar Plant	1800 kW Solar and 100 kW Wind Plant
kW of solar	0.00	0.00	450.00	450.00	900.00	900.00	1350.00	1350.00	1800.00	1800.0
kW of wind	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.0
kVAR of capacitor	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.0
Cost per kW of wind (USD)	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.00	1200.0
Cost per kW of solar (USD)	553.85	553.85	553.85	553.85	553.85	553.85	553.85	553.85	553.85	553.8
Total capacitor cost (USD)	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.00	3000.0
Total cost of solar	0.00	0.00	249230.77	249230.77	498461.54	498461.54	747692.31	747692.31	996923.08	996923.0
Total cost of wind	0.00	120000.00	0.00	120000.00	0.00	120000.00	0.00	120000.00	0.00	120000.0
Annual cost of solar	0.00	0.00	12461.54	12461.54	24923.08	24923.08	37384.62	37384.62	49846.15	49846.1
Annual cost of wind	0.00	6000.00	0.00	6000.00	0.00	6000.00	0.00	6000.00	0.00	6000.0
Annual cost of capacitor	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.0
Investment cost	300.00	6300.00	12761.54	18761.54	25223.08	31223.08	37684.62	43684.62	50146.15	56146.1
Energy loss before compensation	783.68	783.68	783.68	783.68	783.68	783.68	783.68	783.68	783.68	783.6
Annual Energy loss cost before compensation	131657.48	131657.48	131657.48	131657.48	131657.48	131657.48	131657.48	131657.48	131657.48	131657.4
Energy loss after compensation	639.30	611.60	520.60	497.70	423.40	404.70	345.30	330.30	284.20	272.7
Annual Energy loss cost after compensation	107402.40	102748.80	87460.80	83613.60	71131.20	67989.60	58010.40	55490.40	47745.60	45813.6
Total annual savings in cost (USD)	23955.08	22608.68	31435.15	29282.35	35303.21	32444.81	35962.47	32482.47	33765.73	29697.7

APPENDIX D: JOMSOM DISTRIBUTION FEEDER, KOBANG

Table D-1A: Voltage Profile of Jomsom Distribution Feeder, Kobang after injection of DERs in the system in percentage

	Without capacitor	Only capacitor	30 kW wind	50 kW wind	50 kW solar	80 kW wind	30 k wind and 50 kw solar	100 kW wind	100 kW solar	50 kW wind and 50 kW solar	30 kw wind and 100 kw solar	50 kW wind and 50 kW solar	50 kW wind and 50 kW solar	50 kW wind and 100 kW solar
Bus 1	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Bus 2	99.941	99.976	99.98	99.98	99.98	99.98	99.978	99.977	99.979	99.978	99.979	99.978	99.98	99.979
Bus 3	97.192	98.894	98.92	98.93	98.97	98.96	98.988	98.969	99.046	99.002	99.067	99.023	99.098	99.08
Bus 4	93.238	97.533	97.59	97.62	97.71	97.67	97.756	97.703	97.899	97.788	97.946	97.834	98.024	97.976
Bus 5	92.72	97.369	97.43	97.46	97.55	97.52	97.608	97.55	97.763	97.643	97.813	97.691	97.897	97.844
Bus 6	90.361	96.715	96.79	96.84	96.96	96.9	97.029	96.944	97.237	97.073	97.3	97.134	97.416	97.34
Bus 7	89.305	96.648	96.73	96.78	96.93	96.86	97.003	96.902	97.242	97.051	97.312	97.119	97.445	97.355
Bus 8	88.899	96.466	96.55	96.61	96.76	96.68	96.838	96.73	97.089	96.888	97.161	96.958	97.302	97.206
Bus 9	88.776	96.419	96.51	96.56	96.72	96.64	96.796	96.685	97.051	96.846	97.124	96.917	97.267	97.17
Bus 10	86.682	96.017	96.12	96.19	96.42	96.29	96.513	96.344	96.863	96.574	96.952	96.661	97.152	97.008
Bus 11	86.217	95.99	96.1	96.17	96.42	96.27	96.521	96.334	96.902	96.586	96.995	96.677	97.213	97.053
Bus_12	84.997	96.335	96.46	96.55	96.87	96.66	96.989	96.729	97.475	97.062	97.581	97.165	97.864	97.647
Bus13	84.539	96.36	96.5	96.58	96.94	96.7	97.06	96.771	97.588	97.137	97.698	97.244	98.007	97.766
Bus 14	84.277	96.441	96.58	96.67	97.05	96.79	97.173	96.862	97.731	97.252	97.843	97.361	98.171	97.913
Bus 15	84.042	96.53	96.67	96.76	97.16	96.88	97.292	96.961	97.877	97.372	97.992	97.484	98.337	98.063
Bus 16	83.012	95.596	95.75	95.85	96.35	95.98	96.49	96.063	97.203	96.577	97.327	96.698	97.753	97.404
Bus 17	82.756	95.363	95.52	95.62	96.15	95.76	96.292	95.84	97.039	96.381	97.166	96.505	97.613	97.245
Bus 18	82.722	95.332	95.49	95.59	96.12	95.73	96.266	95.81	97.018	96.355	97.145	96.48	97.595	97.224
Bus 19	82.118	94.785	94.95	95.05	95.67	95.2	95.817	95.289	96.664	95.911	96.798	96.042	97.309	96.882
Bus 20	82.083	94.753	94.92	95.03	95.67	95.18	95.827	95.267	96.716	95.922	96.853	96.057	97.389	96.938
Bus 21	81.83	94.524	94.69	94.79	95.41	94.94	95.557	95.028	96.406	95.651	96.54	95.782	97.051	96.624
Bus 22	81.76	94.46	94.63	94.73	95.34	94.88	95.494	94.965	96.343	95.588	96.478	95.719	96.989	96.561
Bus 23	92.714	97.363	97.42	97.46	97.55	97.51	97.602	97.544	97.757	97.637	97.807	97.686	97.892	97.838
Bus24	90.086	96.452	96.53	96.57	96.7	96.64	96.767	96.682	96.975	96.81	97.038	96.872	97.154	97.078
Bus 25	88.881	96.45	96.54	96.59	96.74	96.67	96.822	96.713	97.073	96.871	97.145	96.942	97.286	97.19
Bus 26	88.712	96.358	96.44	96.5	96.66	96.58	96.735	96.624	96.991	96.785	97.064	96.857	97.207	97.109
Bus 27	88.337	96.003	96.09	96.14	96.3	96.22	96.381	96.27	96.637	96.432	96.71	96.503	96.854	96.756
Bus 28	88.267	95.936	96.02	96.08	96.24	96.16	96.315	96.204	96.571	96.365	96.644	96.436	96.788	96.69
Bus 29	86.154	95.523	95.63	95.7	95.92	95.79	96.021	95.852	96.372	96.082	96.462	96.169	96.662	96.517
Bus 30	86.202	95.568	95.68	95.74	95.97	95.84	96.066	95.897	96.417	96.127	96.506	96.214	96.707	96.562
Bus 31	86.075	95.45	95.56	95.62	95.85	95.72	95.948	95.779	96.3	96.01	96.389	96.097	96.59	96.445
Bus 32	86.029	95.407	95.51	95.58	95.81	95.68	95.905	95.735	96.257	95.966	96.346	96.053	96.547	96.402
Bus 33	85.915	95.708	95.82	95.89	96.14	95.99	96.241	96.053	96.622	96.306	96.715	96.396	96.934	96.773
Bus 34	84.528	96.351	96.49	96.57	96.93	96.69	97.05	96.761	97.578	97.127	97.688	97.234	97.997	97.756
Bus 35	84.017	96.507	96.65	96.74	97.14	96.86	97.269	96.938	97.854	97.349	97.97	97.461	98.315	98.041
Bus 36	82.031	94.706	94.87	94.97	95.59	95.12	95.738	95.21	96.586	95.832	96.72	95.963	97.23	96.803
Bus 37	97.152	98.855	98.88	98.9	98.93	98.92	98.949	98.93	99.007	98.963	99.028	98.984	99.059	99.041

Table D-1B: Voltage Profile of Jomsom Distribution Feeder, Kobang after injection of DERs in the system in percentage

	100 kW wind and 50 kW solar	30 kw wind and 150 kw solar	80 kW wind and 100 kW solar	50 kW wind and 150 kW solar	200 kW Solar	100 kW wind and 100 kW solar	30 kw wind and 200 kw solar	80 kW wind and 150 kW solar	250 kW solar	100 kW wind and 150 kW solar	50 kW wind and 200 kW solar	30 kw wind and 250 kw solar	80 kW wind and 200 kW solar	100 kW wind and 200 kW solar	50 kW wind and 250 kW solar	80 kW wind and 250 kW solar	100 kW wind and 250 kW solar
Bus 1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Bus 2	99.979	99.98	99.98	99.98	99.982	99.98	99.982	99.981	99.983	99.981	99.982	99.983	99.983	99.983	99.983	99.984	99.984
Bus 3	99.035	99.118	99.099	99.13	99.187	99.111	99.205	99.148	99.24	99.159	99.216	99.257	99.232	99.242	99.268	99.283	99.292
Bus 4	97.863	98.069	98.018	98.097	98.239	98.044	98.278	98.136	98.367	98.161	98.303	98.405	98.339	98.36	98.428	98.461	98.481
Bus 5	97.722	97.944	97.889	97.974	98.128	97.917	98.17	98.016	98.266	98.042	98.197	98.306	98.234	98.257	98.33	98.365	98.387
Bus 6	97.173	97.475	97.396	97.512	97.721	97.431	97.774	97.565	97.905	97.597	97.807	97.954	97.854	97.882	97.985	98.027	98.054
Bus 7	97.162	97.51	97.417	97.551	97.792	97.455	97.85	97.608	98	97.644	97.886	98.054	97.937	97.968	98.087	98.134	98.163
Bus 8	97.002	97.369	97.27	97.412	97.666	97.31	97.726	97.471	97.884	97.508	97.763	97.94	97.815	97.848	97.975	98.022	98.052
Bus 9	96.962	97.335	97.234	97.378	97.637	97.274	97.697	97.438	97.859	97.475	97.735	97.915	97.788	97.82	97.95	97.998	98.028
Bus 10	96.715	97.235	97.085	97.287	97.646	97.133	97.719	97.359	97.944	97.403	97.764	98.011	97.827	97.865	98.052	98.109	98.143
Bus 11	96.733	97.3	97.134	97.354	97.746	97.184	97.822	97.429	98.066	97.475	97.868	98.135	97.933	97.973	98.178	98.237	98.273
Bus_12	97.229	97.962	97.738	98.023	98.531	97.795	98.616	98.108	98.932	98.159	98.668	99.009	98.74	98.784	99.057	99.122	99.16
Bus13	97.31	98.109	97.861	98.172	98.725	97.92	98.813	98.259	99.157	98.313	98.867	99.237	98.942	98.986	99.286	99.353	99.392
Bus 14	97.429	98.275	98.01	98.34	98.925	98.07	99.016	98.429	99.38	98.483	99.071	99.461	99.146	99.192	99.511	99.579	99.619
Bus 15	97.553	98.444	98.163	98.509	99.126	98.223	99.218	98.6	99.601	98.656	99.274	99.684	99.351	99.397	99.735	99.803	99.844
Bus 16	96.773	97.868	97.511	97.939	98.697	97.577	98.795	98.036	99.266	98.096	98.856	99.355	98.938	98.988	99.409	99.483	99.526
Bus 17	96.581	97.73	97.354	97.802	98.598	97.42	98.698	97.902	99.192	97.963	98.76	99.283	98.844	98.895	99.338	99.413	99.458
Bus 18	96.556	97.713	97.334	97.785	98.586	97.401	98.688	97.885	99.184	97.946	98.749	99.276	98.834	98.884	99.331	99.406	99.451
Bus 19	96.123	97.433	96.997	97.509	98.417	97.069	98.524	97.616	99.086	97.68	98.589	99.183	98.679	98.734	99.242	99.323	99.371
Bus 20	96.14	97.516	97.057	97.595	98.549	97.13	98.659	97.704	99.249	97.771	98.726	99.349	98.819	98.875	99.41	99.493	99.543
Bus 21	95.864	97.176	96.74	97.253	98.161	96.811	98.269	97.359	98.832	97.424	98.334	98.929	98.424	98.479	98.988	99.069	99.117
Bus 22	95.801	97.113	96.677	97.19	98.099	96.749	98.207	97.297	98.77	97.362	98.272	98.867	98.363	98.417	98.927	99.007	99.055
Bus 23	97.716	97.939	97.883	97.968	98.122	97.911	98.164	98.01	98.261	98.036	98.191	98.3	98.228	98.251	98.325	98.359	98.381
Bus24	96.911	97.213	97.134	97.251	97.46	97.169	97.513	97.303	97.644	97.336	97.546	97.693	97.592	97.621	97.724	97.767	97.793
Bus 25	96.986	97.353	97.254	97.395	97.649	97.293	97.709	97.455	97.868	97.492	97.747	97.924	97.799	97.831	97.958	98.006	98.036
Bus 26	96.901	97.275	97.174	97.318	97.576	97.214	97.637	97.378	97.799	97.415	97.675	97.855	97.727	97.76	97.89	97.938	97.968
Bus 27	96.547	96.922	96.821	96.965	97.224	96.861	97.285	97.025	97.447	97.063	97.323	97.503	97.376	97.408	97.538	97.587	97.616
Bus 28	96.481	96.856	96.754	96.899	97.158	96.795	97.219	96.959	97.381	96.997	97.257	97.437	97.31	97.342	97.472	97.521	97.551
Bus 29	96.224	96.745	96.595	96.797	97.158	96.643	97.231	96.869	97.456	96.914	97.276	97.523	97.339	97.377	97.565	97.622	97.656
Bus 30	96.268	96.79	96.64	96.842	97.203	96.688	97.276	96.914	97.501	96.959	97.321	97.568	97.384	97.422	97.609	97.666	97.701
Bus 31	96.151	96.673	96.523	96.725	97.086	96.571	97.159	96.797	97.384	96.842	97.204	97.451	97.267	97.305	97.493	97.55	97.584
Bus 32	96.108	96.63	96.48	96.682	97.043	96.528	97.116	96.754	97.341	96.799	97.161	97.408	97.224	97.262	97.45	97.507	97.541
Bus 33	96.453	97.021	96.855	97.075	97.467	96.905	97.543	97.15	97.788	97.196	97.59	97.858	97.655	97.695	97.901	97.96	97.995
Bus 34	97.3	98.099	97.851	98.162	98.715	97.91	98.803	98.249	99.147	98.303	98.858	99.228	98.932	98.977	99.276	99.343	99.383
Bus 35	97.531	98.421	98.14	98.487	99.103	98.201	99.195	98.578	99.578	98.633	99.252	99.662	99.328	99.375	99.712	99.781	99.822
Bus 36	96.044	97.355	96.919	97.431	98.339	96.99	98.446	97.538	99.009	97.602	98.512	99.106	98.602	98.656	99.165	99.246	99.294
Bus 37	98.997	99.079	99.06	99.091	99.148	99.072	99.166	99.109	99.202	99.12	99.177	99.219	99.193	99.203	99.229	99.244	99.253

Table D-2A: Total Annual Savings of Jomsom Distribution System Feeder, Kobang after injection of DERs in the system in USD

	Only capacitor	30 kW wind	50 kW wind	50 kW solar	80 kW wind	30 kW wind and 50 kW solar	100 kW wind	100 kW solar	50 kW wind and 50 kW solar	30 kW wind and 100 kW solar	80 kW wind and 50 kW solar	150 kW solar	50 kW wind and 100 kW solar	100 kW wind and 50 kW solar
kW of solar	0	0	0	50	0	50	0	100	50	100	50	150	100	50
kW of wind	0	30	50	0	80	30	100	0	50	30	80	0	50	100
kVAR of capacitor	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Cost per kW of wind (USD)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Cost per kW of solar (USD)	554	554	554	554	554	554	554	554	554	554	554	554	554	554
Total capacitor cost (USD)	750	750	750	750	750	750	750	750	750	750	750	750	750	750
Investment cost	75	1875	3075	1460	4875	3260	6075	2844	4460	4644	6260	4229	5844	7460
Total cost of solar	0	0	0	27692	0	27692	0	55385	27692	55385	27692	83077	55385	27692
Total cost of wind	0	36000	60000	0	96000	36000	120000	0	60000	36000	96000	0	60000	120000
Annual cost of solar	0	0	0	1385	0	1385	0	2769	1385	2769	1385	4154	2769	1385
Annual cost of wind	0	1800	3000	0	4800	1800	6000	0	3000	1800	4800	0	3000	6000
Annual cost of capacitor	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Energy loss before compensation	165	165	165	165	165	165	165	165	165	165	165	165	165	165
Annual Energy loss cost before compensation	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770
Energy loss after compensation	142	135	130	133	123	126	119	124	122	118	116	119	114	112
Annual Energy loss cost after compensation	23890	22630	21840	22411	20698	21235	19975	20866	20496	19790	19454	19942	19118	18782
Total annual savings in cost (USD)	3806	3266	2855	3900	2198	3276	1720	4061	2815	3336	2056	3600	2808	1528

Table D-2B: Total Annual Savings of Jomsom Distribution System Feeder, Kobang after injection of DERs in the system in USD

	30 kW wind and 150 kW solar	80 kW wind and 100 kW solar	50 kW wind and 150 kW solar	200 kW Solar	100 kW wind and 100 kW solar	30 kW wind and 200 kW solar	80 kW wind and 150 kW solar	250 kW solar	100 kW wind and 150 kW solar	50 kW wind and 200 kW solar	30 kW wind and 250 kW solar	80 kW wind and 200 kW solar	100 kW wind and 200 kW solar	50 kW wind and 250 kW solar	80 kW wind and 250 kW solar	100 kW wind and 250 kW solar
kW of solar	150	100	150	200	100	200	150	250	150	200	250	200	200	250	250	250
kW of wind	30	80	50	0	100	30	80	0	100	50	30	80	100	50	80	100
kVAR of capacitor	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Cost per kW of wind (USD)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
Cost per kW of solar (USD)	554	554	554	554	554	554	554	554	554	554	554	554	554	554	554	554
Total capacitor cost (USD)	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
Investment cost	6029	7644	7229	5613	8844	7413	9029	6998	10229	8613	8798	10413	11613	9998	11798	12998
Total cost of solar	83077	55385	83077	110769	55385	110769	83077	138462	83077	110769	138462	110769	110769	138462	138462	138462
Total cost of wind	36000	96000	60000	0	120000	36000	96000	0	120000	60000	36000	96000	120000	60000	96000	120000
Annual cost of solar	4154	2769	4154	5538	2769	5538	4154	6923	4154	5538	6923	5538	5538	6923	6923	6923
Annual cost of wind	1800	4800	3000	0	6000	1800	4800	0	6000	3000	1800	4800	6000	3000	4800	6000
Annual cost of capacitor	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Energy loss before compensation	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165	165
Annual Energy loss cost before compensation	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770	27770
Energy loss after compensation	113	114	109	110	105	105	104	105	100	101	100	96	93	97	93	90
Annual Energy loss cost after compensation	18917	19118	18278	18463	17556	17556	17388	17674	16817	16985	16817	16195	15691	16296	15557	15086
Total annual savings in cost (USD)	2825	1008	2263	3694	1370	2801	1354	3099	725	2172	2156	1162	466	1476	416	-314