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# Techno-economic analysis of impact on the distribution feeder with capacitor placement as per NEA's regulations and optimum scenario

Santosh Prasad Pant [a], Shree Raj Shakya [b]

[a,b] *Department of Mechanical and Aerospace Engineering, Pulchowk Campus, IOE*
[a]spp3444@gmail.com

**Abstract**

With the aim of distribution loss reduction, Nepal Electricity Authority has brought regulation to install the capacitor with size equivalent to approx. 30% of the load demand. This paper compares the techno-economical impact of the placement of the capacitor as per NEA's regulations and the other case for the optimal placement and sizing with the cost minimization function of genetic algorithm. Melamchi feeder taken into account, the base case minimum voltage and loss was obtained as 0.704pu and 17.67% respectively. The minimum voltage with the capacitor placement as per NEA's regulation and Optimal capacitor placement (OCP) are 0.75pu and 0.802pu with loss 15.13% and 10.37% respectively. Moreover, IRR are 18.02% and 24.30% respectively. The techno-economical results indicates that the optimal placement of the capacitor is the better alternative than the placement mentioned by NEA's regulations

**Keywords**

OCP, genetic algorithm, NEA's regulation with capacitor

## 1. Introduction

The distribution system, being near to the consumers is often prioritized in case of quality power supply. The components of the qualitative power supply include the regulation of the system voltage along with the loss minimization. Also, the system has an huge investment to benefit cost as compared to the transmission and distribution systems. So, the further investments need to be made considering the technical improvements and financial aspects associated with it.

Along the various methods of the enhancement of the distribution system, the addition of capacitor is an effective method. In general case, the distribution feeders need to carry the reactive load to the end consumer. This power requirement cause increase in the current at the line sections of feeder which in turn increases the system loss and cause voltage drop.

In context of Nepal, Nepal Electricity Authority (NEA) is the major utility distributor.The voltage at the distribution feeders (11kV) are stepped-down to the required level (0.23/0.4kV) through the utility and privately owned distribution transformers. The private consumers get supply from either of these transformers and contributes in over 55% of the energy consumption [1, 2]. Acknowledging the importance of the reactive power management in the distribution system, NEA has recently issued a regulation stating that the private consumers should install the capacitor with size 30% of the load demand.

In this paper, the technical impacts of this regulation is analyzed and is compared with the scenario of optimal capacitor placement . The technical impacts of system voltage and loss has been analysed. Also, a comparison is made based on the financial analysis, about the suitability of the the installation.

The optimal capacitor size and placement in radial distribution systems have been carried out in the article [3] taking into account the parameters: capacitor cost, voltage, angle, and load variations. When completing the load flow with the inequality constraints of the aforementioned parameters, the system loss minimization was taken into account. The findings show where the capacitors should be placed specifically to minimize energy system losses. The papers [4–12] presents various optimization techniques including generic algorithm and particle swarm optimization for the reduction of the distribution system loss.

Another study [13] used the Electrical Transient Analyzer Program's (ETAP) optimum capacitor module to accomplish the best capacitor placement for the IEEE 118 bus system. The selection of optimal size and location of the capacitor has been performed with objective function of minimization of cost of annual loss and annualized investment cost.The load flow equations are the equality constraints; and voltage deviation and reactive power constraint as the inequality constraints.

In this study a distribution feeder: Melamchi feeder is simulated in the ETAP software and the optimal placement and sizing of the capacitor is carried out with the genetic algorithm.

## 2. Materials and Methods

The methods and techniques followed in the course of the study are presented in this section.

### 2.1 System Modeling

The 11kV Melamchi feeder has been modeled in ETAP software. The voltage at the feeder source, i.e. substation is considered as 1pu. The line parameters are considered for the network from the ACSR standard data sheet. For the load , the current measured by the Melamchi DC for the NEA transformers is considered. The load for the private transformers are taken from the private transformer's TOD billing data. The overall load is then scaled for the time of feeder peak.

### 2.2 NEA's Capacitor placement

As per the regulation of NEA, the capacitor banks needs to be installed by the private consumers above 5kVA load demand with size equivalent to 30% of the demand. As mentioned, these private consumers get supply from both utility transformers or their own private transformers(for large consumers). In case of the private consumers with their own transformer, the capacitor of the size 30% of the load demand of the consumer is placed. While in the case of the NEA transformers, there can be a large number of private consumers with up to 5kVA load demand is present. So, the size of capacitor is obtained from the summation of the load demands connected to the specific utility's transformer.

### 2.3 Optimal Capacitor sizing and placement

Figure1 is a presentation of the genetic algorithm's objective function together with its accompanying equality and inequality constraints:

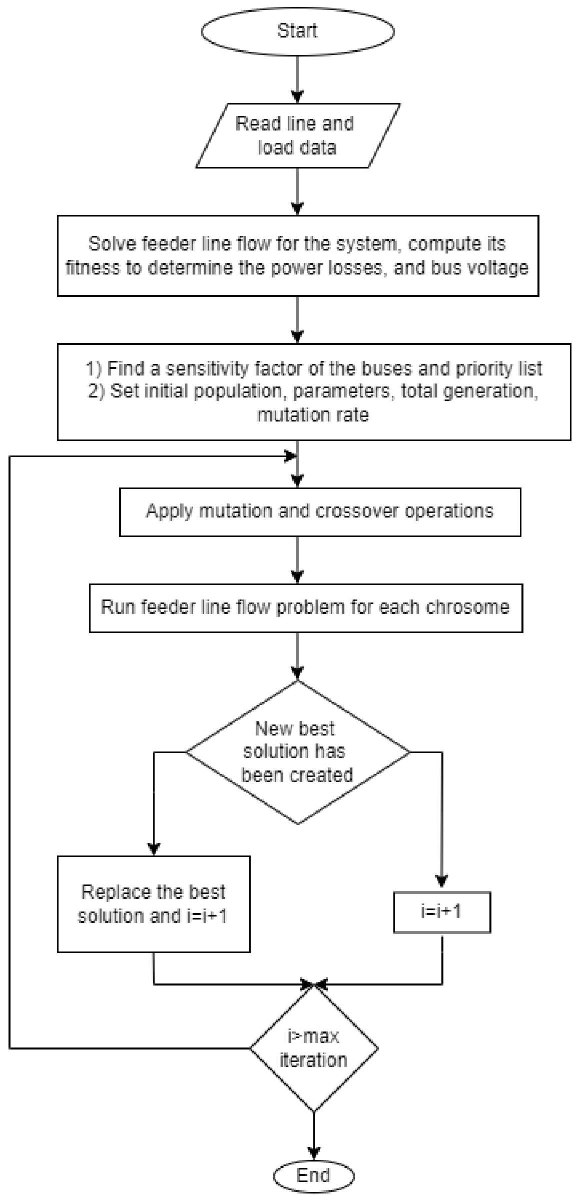


**Figure 1:** GA Methodology

Objective Function: The system's cost can be expressed mathematically as follows:
Minimization function=

$$\sum_{i=1}^{Nbus}(x_1C_{0i}+Q_{ci}C_{1i}+B_iC_{2i}T+C_2\sum_{i=1}^{Nbus}(T_1P_L^1)) \quad (1)$$

where,

$Nbus$ Candidate bus number
$x_i$ 0/1,1 means the capacitor installed at bus i

$C_{0i}$ Initial investment cost for installation
$C_{li}$ cost of cap bank per kVAR
$Q_{ci}$ Size of cap bank in kVAR
$B_i$ No. of cap banks
$C_{2i}$ Operation cost of bank per year per bank,
$T$ Project period (years)
$C_2$ Cost of kWh loss in \$/kWh
$L$ Load levels: maximum, average and minimum
$T_1$ Time duration (hr) of load level 1
$P_{Li}$ Loss at load level l Constraints

The equality constraints are:

$$\begin{aligned} P_i(V,\delta) - P_{Gi} + P_{Di} = 0 \\ Q_i(V,\delta) - Q_{Gi} + Q_{Di} = 0 \end{aligned} \tag{2}$$

The inequality constraints considered for the genetic algorithm is:

$$\begin{aligned} V_{i_{min}} \leq V_i \leq V_{i_{max}} \\ Q_{j_{min}} \leq Q_j \leq Q_{j_{max}} \end{aligned} \tag{3}$$

Where, i is the no. of buses and j is the no.of the source of reactive power. The flowchart for for the methodology of GA is shown in Figure 1. The iteration is performed with mutation and crossover of each individuals with the convergence in the minimization of the objective function.

## 3. Results and Discussion

### 3.1 IEEE-33 bus radial distribution system

The IEEE-33 bus radial bus system is simulated and the voltage and the loss status of the system is determined. From the Figure 2, it was evident that the minimum voltage is observed at Bus18 with value 0.903pu. The system loss is 212.93kW active and 144.35kvar reactive loss.

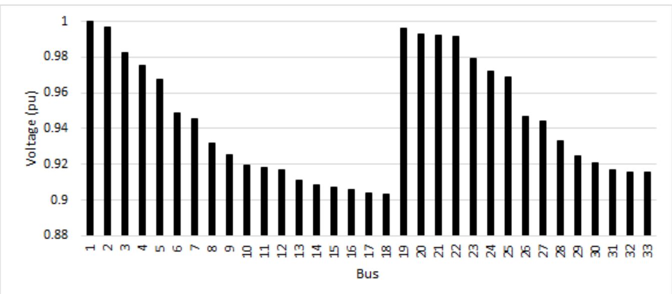


**Figure 2:** Voltage profile of 33kV bus

With the ETAP software, the optimal placement and location of the capacitor was determined. The results shows that for the 33kV system, a total of 1650kvar is to be installed. The optimal location are at Bus3, Bus6 and Bus10 with sizes 580kvar, 550kvar and 520kvar respectively. With this the voltage at the 18th bus would improve to 0.927pu and overall active and reactive loss decreases to 163.28kW and 112.24kvar respectively.

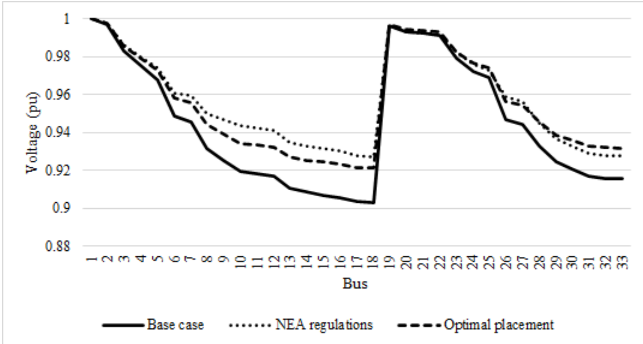


**Figure 3:** Comparison of voltage profile for 33kV bus

For the capacitor placement as per NEA's regulation guideline, the capacitors are placed at each of the 32 bus beyond Bus1. A total of 1363kvar are required at these locations. The results shows that the overall system voltage improves and the loss decreases. The minimum voltage at Bus18 improves to 0.921pu with the active loss decreasing to 154.43kW and reactive loss to 104.91kvar.

The voltage profile of the system for the original case, with optimal capacitor placement and capacitor placement as per NEA's guidelines is shown in Figure3.

### 3.2 Utility Feeder

The similar siumulation is also carried out in case of the distribution Feeder of NEA. The feeder has peak load demand of 2.97MVA with the total length of 88km composed of Dog, Rabbit and Weasel conductors. There are altogether 99 transformers with 81 of them belonging to the utility consumers and remaining 18 owned by the private consumers. The major of those private consumers are crushers near the Indrawati river.

The nodal voltages of the Melamchi feeder are shown in Figure 4. The results shows that the bus voltages along the feeder drops up to 0.704pu at Bhirkharka in the peak load case. The cause for such drop in the voltage is due to the higher line loading and longer radial length. The loss of the overall system in the peak is evaluated to be 542kW and 344kvar active and reactive loss respectively. So, the loss is 17.67% at the peak conditions considered.

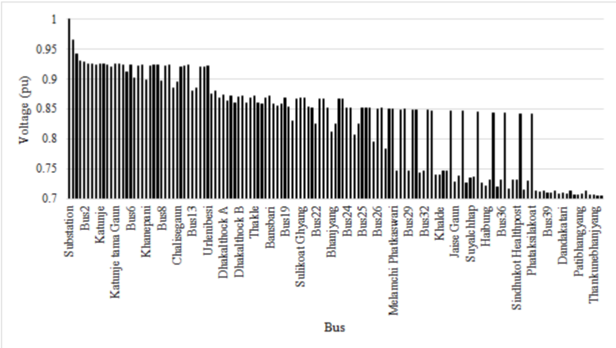


**Figure 4:** Bus voltages for Melamchi feeder

The optimal placement of the capacitors are determined. As per the results the 1,230kvar, 475kVAR and 175kvar are to be placed at the locations: Koiralatar, Gurunggaun and Yakikrit namuna basti respectively. The minimum voltage at Bhirkharka increases to 0.802pu with the placement of the capacitor. Moreover, the overall system active and reactive loss decreases to 292kW and 263kvar respectively, i.e. 10.37% as shown in Figure 5.

Considering the regulations of the NEA, the voltage profile as shown in Figure 5 was obained. The system minium voltage at Bhirkharka increases to 0.75pu. Also, the active and reactive loss from the existing system drops down to 449.9kW and 102.78kvar respectively i.e. to 15.13%.

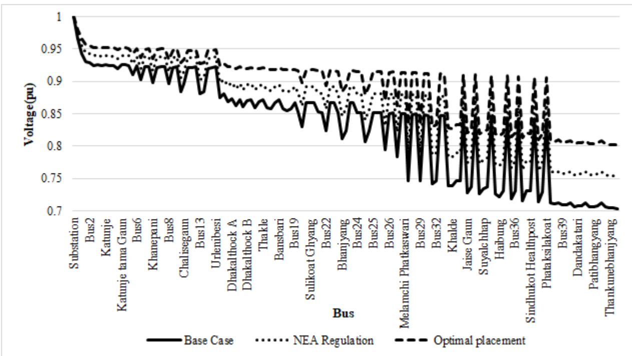


**Figure 5:** Comparison of bus voltages for Melamchi feeder in different cases

So, in case of the Melamchi feeder the result shows that with the optimal capacitor placement, the system voltage has improved with lower value of the system loss as compared to that with NEA regulations. Also for the 33-bus radial system the loss is lower with the placement of optimal sized capacitor at the optimal locations. So, technically, the optimal location of capacitor is better as compared to the placement of capacitor with NEA's guideline. This needs to be confirmed from the financial analysis too.

### 3.3 Financial Analysis

The financial analysis was performed with the comparison of the placement of capacitor as per NEA's regulations and with optimal placement and sizing. The IRR and payback period for the placement of the capacitor as per the regulation and optimal locations were evaluated to be 18.02% & 5.27years and 24.30% & 4.34years respectively. So, from the financial analysis, it can be inferred the optimal placement of capacitor is more financially justifiable as compared to the NEA's regulation for capacitor placement.

## 4. Conclusion

From the results, it can be concluded that the system yields the better results with the placement of the capacitor at the optimal location and with optimal size than the regulations of the NEA. The size of the capacitor determined from the optimal capacitor placement are: 1,230kvar, 475kVAR and 175kvar at Koiralatar, Gurunggaun and Yakikrit namuna basti respectively. The system voltage and loss initially at 0.704pu & 17.67% at peak changes to 0.75pu & 15.13% and 0.802pu & 10.37% for the system with the NEA's placement of capacitor and optimal sizing & placement of capacitor respectively. The financial analysis indicates that the optimal placement is more beneficial financially than the other case with IRR 24.30% over 18.02% respectively.

The future recommendations for the extension of the project can be performed with the detail analysis of the size of the capacitor that can be assigned to the distribution feeder depending upon the consumer category with the size which will be more beneficial than the NEA's regulations.

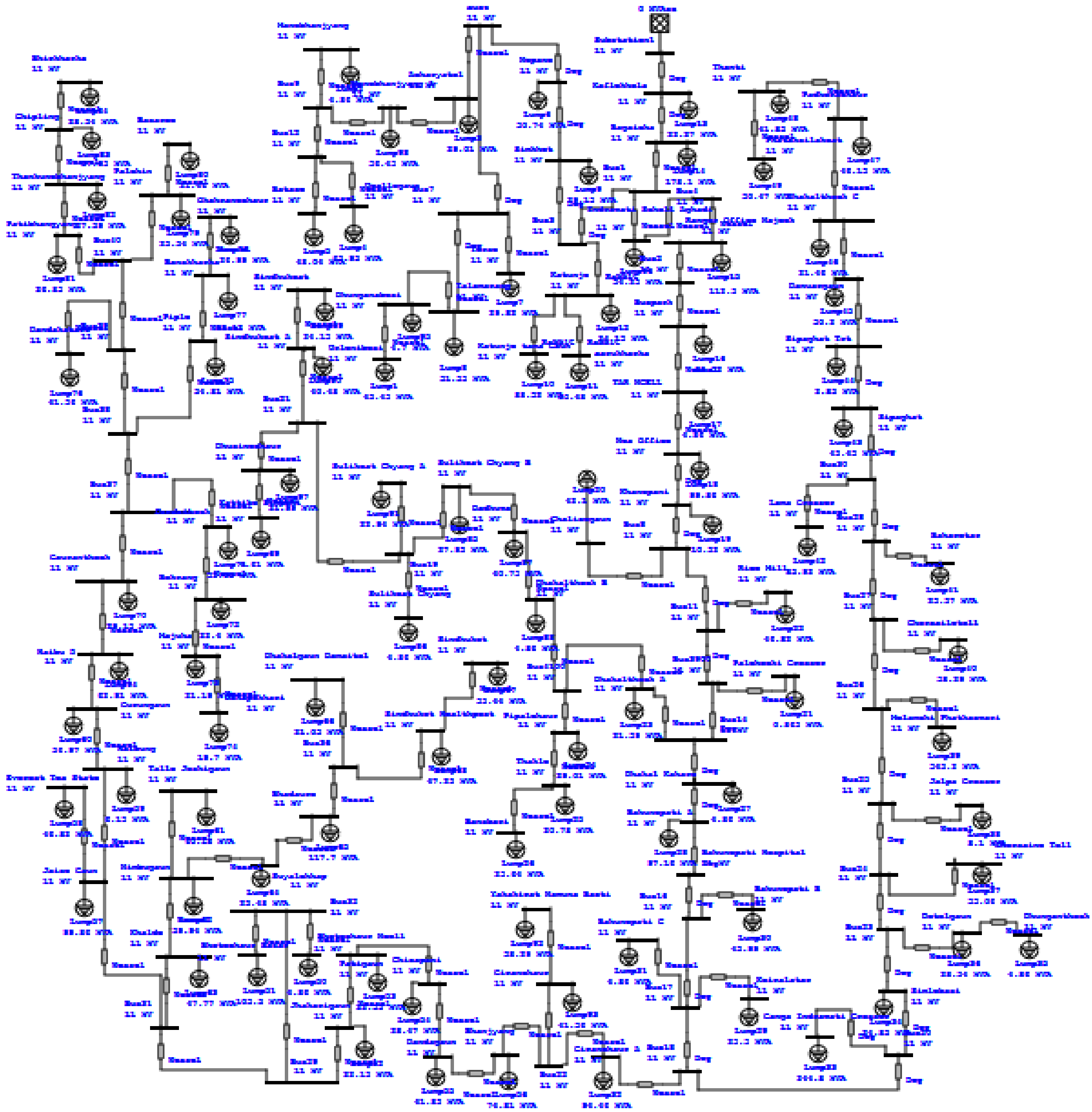

**Figure 6:** SLD of Melamchi Feeder

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