



# Efficiency Improvement on a Distribution Feeder: A Case Study

Megha Nath Dhakal<sup>1,\*</sup>, Rudra Ghimire<sup>1,\*\*</sup>

*Department of Mechanical Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal.*

Corresponding Email: megh11521@gmail.com, ghimire.rudra@gmail.com

## **Abstract:**

Electricity is a necessary requirement for accelerating the economic development of any country and is considered an important input to improve quality of life. Electricity supply to consumer end is possible by the combine function of power generation, transmission and distribution instantly. One of the most chronic areas of power loss in power system is power distribution feeder. Loss in feeders are identified mainly due to overloaded conductors and transformers, long distance feeder, unbalance load on transformer, low power factor load, uses of energy inefficient load, hooking etc. The distribution losses which are more predominant can be categorized as technical losses and non-technical losses. The main target of the study is to improve the technical and overall efficiency of a distribution feeder. A high loss feeder is selected for efficiency study. Direct method of loss calculation is used to calculate total losses of the feeder and indirect method is used to find the technical losses on the feeder in existing condition. Technical losses of existing feeder and improvement on same distribution system through technical loss reduction options is analyzed by implementing the conductor replacement, rerouting and optimum capacitor placement (OCP) methods using electrical transient analyzer program (ETAP) simulation. Technical efficiency and overall efficiency for the different non-technical loss values are calculated and analyzed. Implementation of results will improve financial health of the power distribution company and provide reliable electricity supply to the consumers. In addition, it provides further inputs to energy planners and managers for a number of remedial measures to loss reduction and improvement of overall efficiency of the power distribution system.

**Keywords:** Rerouting, Technical and Commercial (T&C), Optimum Capacitor Placement (OCP), Technical Loss, Efficiency

## **1 Introduction**

Electricity is a necessary requirement for accelerating the economic development of any country and is considered an important input to improve quality of life. Presently, in Nepal, the electricity demand has far outgrown the supply, leading to load curtailment and increased dependence on imports from India in recent times. About 63% of the population in Nepal has access to electricity but the supply quality is unreliable and inadequate [1]. The government has recognized the immediate need for reinforcement and upgrade of outdated distribution systems crucial to deliver the required energy to the customers even if the generation and transmission lines are in place. In this regard, the need for immediate distribution network enhancement is included in the government's action plan to address energy crisis and provide universal access to reliable and efficient electricity for all by 2030 [2]. Major sections of the existing distribution network were constructed decades ago and despite significant increase in electricity demand and the number of consumers, minimal reinforcement of the distribution network has been carried out. The efficiency improvement study will enhance the distribution capacity and improve reliability and quality of

electric supply by reducing distribution system overloads and technical and non-technical losses.

For an electric utility Distribution Companies (DISCOMs) the distribution losses which are more predominant can be categorized as Technical Losses and non-Technical Losses. There are two methods of determining the energy losses: The **Direct method** involves placement of energy meters at all locations starting from the input point of the feeder to the individual consumers. The difference between input energy and sum of all consumers over a specific duration is accounted as distribution loss of the network. This calls for elaborate and accurate metering and collection of simultaneous data. The **Indirect method** essentially involves energy metering at critical locations in the system such as substation and feeders, compiling the network information, such as length of the line/feeders, conductor size, DTR details, capacitor details etc., conducting load flow studies (all electrical parameters) on peak load durations as well as normal load durations, application of suitable software to assess the system losses. This software can also be used for system simulation, identifying improvements and network optimization.

Any illegal consumption of electrical energy, which is not correctly metered, billed and revenue collected, causes non-technical losses to the utilities. Some of the measures to reduce non-technical losses in distribution system includes accurate metering, appropriate range of meter with reference to connected load, installation of electronic meters, intensive inspections, energy audit as a tool to pinpoint areas of high losses, eradication of theft etc. Technical losses can be minimized by: Re-routing and re-conducting such feeders and lines where the losses / voltage drops are higher, power factor improvement by incorporating capacitors at load end, opting for lower resistance All Aluminum Alloy Conductors (AAAC) in place of conventional Aluminum Cored Steel Reinforced (ACSR) lines, optimum loading of transformers in the system, minimizing losses due to weak links in distribution network such as jumpers, loose contacts, and old brittle conductors, Relocating transformers and substations near to load centers etc.

Nepal Electricity Authority (NEA) is the vertically integrated national utility, which owns and operates generation, transmission and distribution facilities. System efficiency improvements and loss reductions will improve NEA's financial health, while customers will benefit from a reliable and improved quality of electricity supply and reduced dependence on diesel generators to meet their daily electricity needs. Customer services are provided with around 33,000 km of 11 kV distribution lines. NEA has about 2.96 million customers, which are categorizes in commercial, industrial, domestic (or residential), etc. [3]. This study covers the analysis the technical losses of one feeder of Lahan Distribution Centre of NEA by performing the audit activities with available data, field survey and time for study.

## **2 Literature Review**

Distribution losses consist of two components namely the technical losses (TL) and commercial or non-technical losses (NTL) [4]. Traditionally, total distribution energy losses have been estimated by means of energy balances that consist of subtracting the total energy consumed (metered and billed) by customers from the total energy generated or delivered to distribution substations and feeders. Since total energy losses account for technical and non-technical (commercial) losses, then further analysis is required to estimate them individually [5]. Ideally losses in the distribution system should be around 3 to 6%. However, in developing countries distribution loss is around 20% [6].

In our integrated Nepalese power system, we have the information about the total system losses (technical and non-technical) but there is a great contradiction in the actual figure of the technical and non-technical components of the losses. The technical losses in generation, transmission and distribution level of the power system have been evaluated to be 0.653%, 3.952% and 6.979 %of the total energy input to the system [7]. Cumulative loss of the distribution services in NEA has been found 16.83% [8] and remaining losses from the total loss of 23% was found losses on the transmission system [3].

In India, T&D loss percentage is presently calculated on the basis of 11KV feeders. In the power distribution utility, the factors contributing to high technical and commercial losses are different for different category of consumers like agricultural, domestic, commercial, industrial etc. [9]. India's energy efficiency is the fifth lowest in the world, but there is the potential for substantial energy savings. The industrial sector consumes 30% of the total commercial energy available in India, 70% of which is in energy-intensive sectors [10]. Study of 11 kV rural feeder emanating from Jaipur Discom, Jamwa Ramgarh 33 kV feeder having 230 Buses has been electrical modeled using Mi-Power Software. The load flow study has been performed to assess the feeder loss, loading of 11 kV lines, DTRs and voltage at various points of feeder. From the study it is found that 11 kV Feeder kW losses are reduced from 17.57% to 10.42% and kVAr losses are reduced by 40.66% [11]. A practical distribution system is taken (Patna city, Bihar, India) and a complete analysis on loss reduction is carried out on the system. The whole Patna city's distribution system is modeled using ETAP software. Simulation results have shown that the implementation of these projects leads to a significant improvement in voltage profile, and reduction in the active and the reactive power loss. Total percentage loss 7 % is reduced to 4 % after implementing necessary changes [12].

Iraq medium voltage distribution system 11kv, and low voltage distribution system 0.4 kV generally is radial distribution system, the voltage of the buses of the radial distribution system decreased proportional with distance from main supply. The optimal capacitor placement on radial distribution systems in rural area using ETAP is presented and simulation results shows the low voltage problem in distribution system can be reduced to reach 99% of the rated voltage and power loss decreased significantly [13]. Nigeria had 38% losses, which was considered very high. The measured and test distribution

network is the Akure township which feeds a total 55,000 consumers, which are connected under seven 11 kV delivery points. Technical loss was found 15% and conclude that long feeder length and high loads are the main causes of distribution power loss [14]. In Iran, it was observed that the distribution loss levels of studied section were brought down considerably from 23.17% before the implementation of the schemes to 3.85% after implementation within a period of one year [15].

Network reconfiguration is a very imperative approach to save the electrical energy. Reconfiguration is applied for service restoration under faulty conditions, load balancing to relieve overload on networks and improve voltage profile, planning outages for maintenance and loss minimization [16]. Further, the life span of switchgear could be another limiting factor prohibiting frequent reconfigurations, although this might be improved if solid state switches are massively deployed [17].

The application of capacitors to electric power systems can be used for the control of power flow, stability improvement, voltage profile management, power factor correction, and power and energy loss reduction [16]. The optimum value of the capacitor depending upon the any of the criterion chosen does not guarantee that relative parameter in the system configuration under consideration will improve simultaneously [18]. Therefore, it can be concluded from the test results that the main advantages of power factor improvement are reduction in kVA demand, which results in reduced per unit power cost. Using capacitors to supply reactive power reduces the amount of current in the line, so a line of a given capacity can carry more loads [19]. Mathematically, the capacitor placement problem (CPP) can be formulated as a nonlinear mixed-integer optimization problem where the objective function consists of minimizing the power losses and investment costs [20]. Shunt Capacitor supplies constant reactive power independent of load. The main challenges in capacitor placement are: selection of an appropriate number of capacitor units, allocation of capacitors, and sizing of capacitors to achieve a required result [16].

The non-technical loss problem is faced not just by the developing countries instead it also includes the developed countries like the United States of America. Taking United States as an example for the problem of NTLs, the total annual revenue is estimated to range from 0.5% to 3.5%. Bangladesh, India, Iran, and Pakistan comes under the category of developing countries, where the percentage of NTL is average, and it ranges from 10% to 15%, whereas the United States of America and the

United Kingdom falls under the category of developed countries [21].

### 3 Research Methodology

The flowchart for the efficiency improvement on the distribution feeder is shown in figure 1.

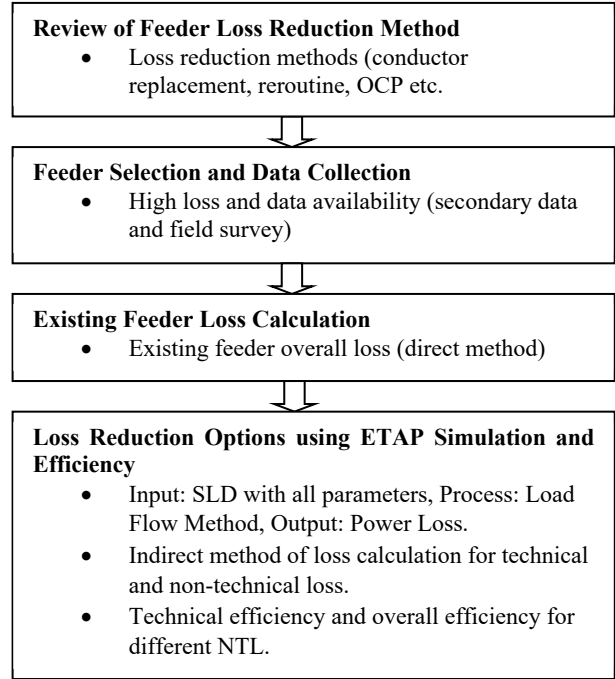


Figure 1: Flow Chart for Efficiency Improvement on Distribution Feeder

#### 3.1 Review of Feeder Loss Reduction Methods

Power Loss of the distribution feeder is given by the equation.

$$\text{Power loss} = I^2R \tag{1}$$

This equation shows higher the voltage, lesser the current and lesser the power loss. Resistance of line is directly proportional to the length of the line. Newton–Raphson method begins with initial guesses of all unknown variables (voltage magnitude and angles at Load Buses and voltage angles at Generator Buses). Next, a Taylor Series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{2}$$

Where  $\Delta P$  and  $\Delta Q$  are called the mismatch equations:

$$\Delta P_i = -P_i + \sum_{k=1}^N |V_i| |V_k| (G_{ik} \cos\theta_{ik} + B_{ik} \sin\theta_{ik}) \tag{3}$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^N |V_i| |V_k| (G_{ik} \sin \theta_{ik} - B_{ik} \cos \theta_{ik}) \quad (4)$$

And J is a matrix of partial derivatives known as a Jacobian:

$$J = \begin{bmatrix} \frac{\partial \Delta P}{\partial \theta} & \frac{\partial \Delta P}{\partial |V|} \\ \frac{\partial \Delta Q}{\partial \theta} & \frac{\partial \Delta Q}{\partial |V|} \end{bmatrix} \quad (5)$$

The linearized system of equations is solved to determine the next guess ( $m + 1$ ) of voltage magnitude and angles based on:

$$\theta^{m+1} = \theta^m + \Delta \theta \quad (6)$$

$$|V|^{m+1} = |V|^m + \Delta |V| \quad (7)$$

The process continues until a stopping condition is met. A common stopping condition is to terminate if the norm of the mismatch equations is below a specified tolerance. One common method is the decoupled NR power flow. In this approach approximations are used to decouple the real and reactive power equations.

To improve our power factor from a certain low value to desired value the correction limits is to be decided and the corresponding size of the capacitor can be calculated as follow:

$$kW = kVA * \cos \varphi \quad (8)$$

$$\% \text{ Loss Reduction} = \left[ 1 - \left( \frac{PF_1}{PF_2} \right)^2 \right] \quad (9)$$

$$VAr = P * (\tan \varphi_1 - \tan \varphi_2) \quad (10)$$

Here, P is the active power at the respective node,  $\varphi_1$  is initial power factor angle and  $\varphi_2$  is improved power factor angle at the same node. The vector sum of the active power and reactive power make up the total (or apparent) power used.

$$\text{Overall Efficiency} = \text{Technical Efficiency} * (1 - \text{NTL}\%) \quad (11)$$

If energy measured in sending end terminal meter of the feeder is referred to as Energy input ( $E_i$ ) and the sum of total billed energy of consumer is ( $E_c$ ), then the total T&C loss will be the difference of total Input energy and total billed consumer energy. These losses are the sum of total technical and non-technical losses.

$$\left( T\&C \text{ Loss } \% = \frac{E_i - E_c}{E_i} * 100\% \right) \quad (12)$$

Energy audits segregate the T&C loss into technical loss and non-technical loss components. Energy audits can be determined only after determining energy accounting. Technical loss is found from load flow studies and

$$\text{Non - technical loss} = \text{TC loss} - \text{Technical loss} \quad (13)$$

### 3.2 Feeder Selection and Data Collection

Selection of a distribution feeder for the efficiency study was based on the existing loss level, length of the feeder, availability of data and feeder capacity. Conductor type and size, transformers rating and load, load centre, consumer consumption units, energy supply from substation etc are taken as a secondary data provided from distribution centre. Whereas site condition of load centre and route and their line length were taken from the field survey using GPS tracking device

### 3.3 Losses on the Distribution Feeder

Total loss of the feeder was calculated by direct method of loss calculation in which difference of sending end energy meter and total energy consumption is calculated using secondary data available from distribution centre. Indirect method of loss calculation is used in which details parameters of feeder components like conductors, transformers, loads, transformers etc. are taken in to consideration to calculate the technical loss in feeder.

### 3.4 Technical and Overall Efficiency Calculations

Technical efficiency of the feeder is calculated dividing the output power by input power obtained from simulation result. Overall efficiency depends on the technical and non technical loss of the system. Technical loss is obtained from simulation result for all loss reduction options. Different non technical loss values are considered for the calculation of overall efficiency.

## 4 Results and Discussion

### 4.1 Technical Losses of Existing Feeder

The existing network contains 56 DTR with capacity 25, 50, 100, 150, 160, 200 and 250 kVA ratings. Eight load centre sections in which maximum line length of 34.32 km. Most of the conductors used in feeder were Rabbit ACSR. SLD contains 110 buses, one power grid, 56 DTRs or loads.

Loss report generated by ETAP simulation for the existing feeder shows the 11 kV Lahan feeder has 22% technical loss on peak load. The total T&C loss of the Lahan feeder is found 38.59% by manual calculation using the sending end and receiving secondary data.

Therefore, Non-Technical loss = 38 – 22 = 16 %

Existing Feeder Efficiency = 100-38= 62 %

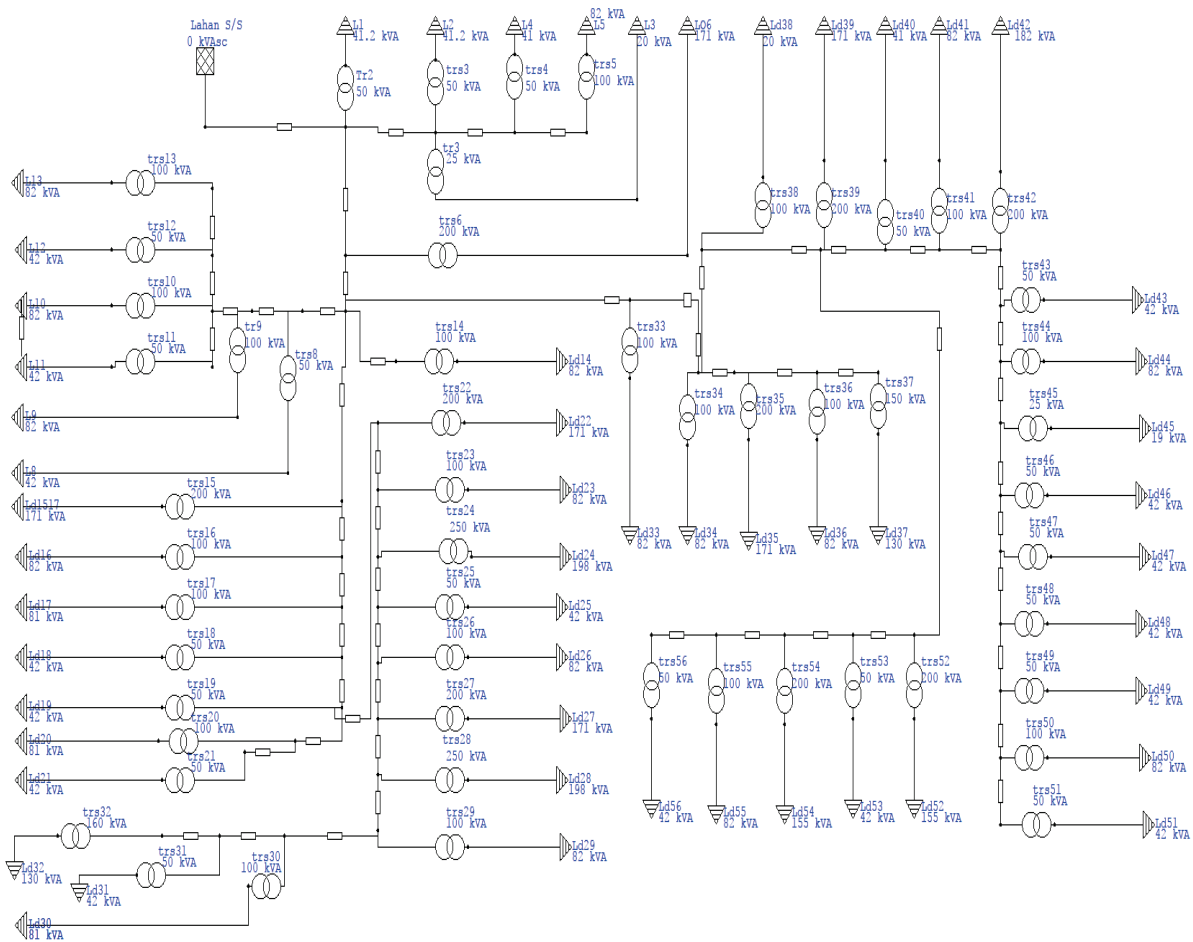


Figure 2: Single Line Diagram (SLD) of distribution feeder

Results show that, Technical Losses on existing feeder is higher than non-technical losses. Potential areas for the reduction of technical losses were identified and simulated using ETAP.

### 4.2 Technical Loss Reduction Techniques

Options studied for technical loss reduction are: Loss reduction using conductor replacement (Rep), Loss reduction using rerouting of conductors (Rer), Loss reduction using Optimum Capacitor Placement (OCP), Loss reduction using conductor replacement and rerouting, Loss reduction using conductor replacement, rerouting and OCP. Technical loss from the simulation results for all five options and existing system is shown in figure 3.

#### 4.2.1 Loss reduction using conductor replacement

Rabbit Conductors in the initial sections of feeder are replaced by Dog conductors. After the replacement of conductors having total length of 15.85 km in six sections, loss generated by simulation become 20.98% which is

reduced from the existing system loss 22.09%. Since the loss is reduced by 1.11%, it is considered as technically feasible option for the technical loss reduction.

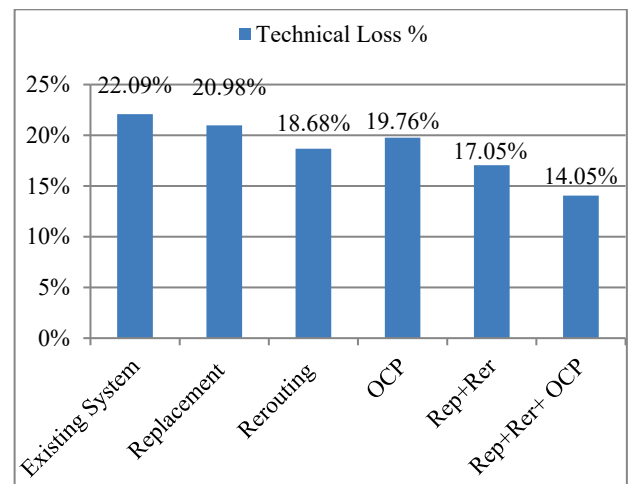


Figure 3: Technical losses in existing system and loss reduction options.

#### 4.2.2 Loss reduction using rerouting of conductors

The simulation was run by changing the connection for three locations saving the total 14.38 km distance of feeder results significant reduction on line losses. As the result system loss is reduced to 18.68% which is less by 3.41% than existing loss level. Thus, overall efficiency of system is increased and becomes 65.41% from the existing efficiency of 62%.

#### 4.2.3 Loss reduction using Optimum Capacitor Placement

The target for power factor improvement on the system was 0.98. Size and number of capacitors are chosen for automatic switching operation. Total of 2300 kVAr is required for peak load on the distribution feeder. Nine capacitor bank supplies the reactive power on the system. After implementation of capacitor, loss is reduced from existing system loss 22.09% to 19.76%. Thus, efficiency of system is increased to 64.33 % from the existing overall efficiency of 62%.

#### 4.2.4 Loss reduction using conductor replacement and rerouting

Conductor replacement (15.85 km) and rerouting (reduced 14.38 km length) result 17.88% technical losses on peak load. Thus, the implementation of this option improves the efficiency by 4.21 %. Efficiency of feeder is increased to 66.2% after implementation of conductor replacement and rerouting initiatives.

#### 4.2.5 Losses after conductor Replacement, Rerouting and Capacitor Placement

After implementing the conductor replacement and rerouting works subsequently OCP results for loss reduction was again tested using software module. OCP of the feeder was carried out by choosing the eight buses for different load centre. Installation of 1850 kVAr rating capacitors in eight load centers results technical loss of 14.05% reducing the 8% loss from existing system. Efficiency of the system improved to 70%.

### 4.3 Efficiency of Existing and Improved System

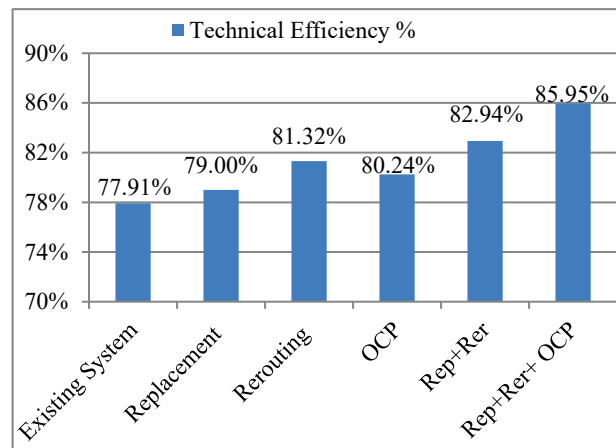
In this study, only the technical efficiency is considered to improve by technical loss reduction activities. Taking the non technical loss as a constant, overall efficiency is calculated. Non-technical loss reduction activities could result further improvement on overall efficiency of system. Figure 4 shows the technical efficiency of existing and improved system.

### 4.4 Non Technical Loss Reduction Analysis

A comparative study for the overall efficiency of the system using the different NTL values is shown on table 1.

**Table 1: Overall Efficiency (OE) % for different Non - technical Loss levels**

Descriptions	Tech. Effic.	OE NTL =0%	OE NTL= 3.5%	OE NTL =10%
Existing System	77.91	77.91	75.19	70.12
Replacement	79	79	76.24	71.1
Rerouting	81.32	81.32	78.47	73.19
OCP	80.24	80.24	77.43	72.22
Replacement + Rerouting	82.94	82.94	80.03	74.64
Replace + Reroute + OCP	85.95	85.95	82.94	77.36



**Figure 4: Bar Chart for existing and improved system efficiency**

## 5 Conclusions

Technical and non-Technical Loss (T & C) of a distribution feeder using secondary data is found 38 %. Technical loss for the existing feeder was 22%. Loss reduction using conductor replacement in high ampere carrying six sections (total 15.85 km) of feeder reduces losses by 1.11% and technical efficiency reached 79% from existing efficiency level 77.91%. Loss reduction using conductor rerouting in three lowest possible erection distances (saving total 14.38 km length) of feeder reduces technical losses by 3.41% and technical efficiency reached 81.32% from existing efficiency level 77.91%. Loss reduction using conductor replacement and rerouting in existing system of feeder reduces technical losses by

4% and technical efficiency reached 82.94% from existing efficiency level 77.91%. Loss reduction using optimum capacitor placement in nine load centre of existing system (total 2300 kVAr capacity) of feeder reduces technical losses by 2.33% and technical efficiency reached 80.24% from existing efficiency level 77.91%. Loss reduction using conductor replacement, rerouting and OCP in existing system (option I, II and total 1850 kVAr capacitor in eight load centre) of feeder reduces technical losses by 8% and technical efficiency reached 85.95% from existing efficiency level 77.91%. Considering NTL up to 10%, overall efficiency of the system could reach up to 77.36%.

From the above discussions it is found that there are various factors responsible for Technical and Non-Technical losses which need to be eliminated. The approaches taken over the years in Nepal has created an inefficient distribution system contributing to very high overall losses and poor quality and reliability of power supply to consumers. It has led tremendous consumes dissatisfaction as well as it has affected the financial performance of the utilities. As it is extremely difficult to eliminate all the causes simultaneously in our country, strategically measures should be taken to reduce or marginalize the major causes of losses. In the ongoing power sector reforms, the focus has rightly been shifted to upgrading the distribution system and improving its efficiency to reduce overall losses. Ultimately, this may contribute in the process of overall national development.

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