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Reliability Assessment of Power Distribution System of Industrial Estate: A Case Study in Balaju Industrial Estate

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Abstract

The main task of distribution system is to provide acceptable reliability, economic and quality service of electricity according to the demanded load value. To fulfill this task more accurately, the reliability assessment of the distribution system can be performed and measured using a wide variety of reliability indices. This study evaluates the reliability indices of industrial distribution network, Balaju Industrial District, and deals with the reliability of four different network configurations (Case 0-1-2-3) to increase reliability and achieve more realistic results. Using ETAP, distribution networks are designed, comparisons are made. Reliability changes achieved by network configuration have demonstrated the importance of optimal configuration planning to improve the uninterrupted and sustainable energy quality of the system. In addition, cost of electricity outage, i.e. unserved energy cost, is estimated in this paper based on industrial consumer survey for the financial analysis from the reliability point of view. Outage cost is estimated by production loss method, backup generation method and willingness to pay method. The weighted average of production loss method and backup generation method has estimated overall cost of unserved energy of BID distribution system as Rs. 28.26 per kWh, this value has been used for ECOST calculation during reliability worth analysis. The base is taken case 0 which is the existing distribution system. Cases 1, 2 and 3 are separating of two 11kV feeders by separate VCBs, adding redundant power supply and interconnections between three 11kV feeders, i.e. creating ring main, respectively. Results have concluded that all three modifications improve the reliability of the system with financial gain. As these modifications have their own importances for the reliability enhancement from the industries point of view, this paper recommends the utility office, BIDMO, for the implementation of the modifications.

Keywords

Distribution Power System Reliability, Reliability Indices, Industrial Consumer Surveys, Cost of Unserved Energy, System Modifications

1. Introduction

The main task of electrical distribution power system is to provide consumers with affordable, quality and acceptable reliable and uninterrupted energy. Industrial consumers are critical consumers as they have to suffer economic losses due to insecure and unreliable power supply. Due to power outages, manufacturing industries have different losses, such as raw materials and finished products loss, idle workers costs loss, increase in maintenance cost, penalty due to not meeting the demand, etc. So, power security and reliable supply play vital role for manufacturing industrial processes. Occurrences of faults, schedule maintenance power shutdown, no proper management of supply-demand, etc. causes power outages to consumers. Some of the industries may have backup system to cover load, partial load or full load, during grid outage. Mostly, backup system is diesel generator. But the electricity prices from the generators may be higher than the prevailing electricity tariff. According to Nepal Electricity Authority, it has managed sufficient power capacity to meet the demand of country by its own generation, IPPs' generation and power purchase from India. But NEA is facing problems in transmission system and distribution system through which power is up to consumers utilization. Upgrading and construction of these systems are ongoing but delay in work completions due to many problems, such as public disturbances, disputes in land acquisition and forest, etc. So, due to poor and old infrastructures of transmission and distribution systems, they are not capable of meeting the day-by-day increasing demand of the consumers. This has also caused unexpected power outages in Nepal. NEA is rapidly working in enhancement and reinforcement of distribution systems.

Using the statistical and reliability theory of distribution networks, reliability indices are carried out on energy sustainability. Commonly used reliability indices, including SAIDI, SAIFI, ASAI, CAIDI, EENS, EIR, etc., are used to measure system reliability. In the unlikely event of energy supply, consumers can reduce losses by anticipating and reducing the likelihood of downtime during the day ahead or the day ahead of the planning process to avoid power outages. This economic gain is achieved by keeping EENS value at a minimum, which is achieved by using required ESS in unexpected power cuts[1]. Unexpected situations that reduce system reliability adversely affect system planning, which can lead to system failures, sudden load changes and adverse environmental conditions. Energy sustainability is very important as it does not experience disruptions such as power outages and the planning is directly affecting both costs and system reliability.

In this study, reliability assessment with worth analysis of the power distribution system of Balaju Industrial District. Ten industrial estates are in operation under the government company, Industrial District Management Limited. This research is also focused on the outage cost estimation. BID has three number of underground dedicated feeders, each nearly one kilometer long from Balaju substation of NEA with 7 MVA, 4.5 MVA and 3.5 MVA approved loads serving 157 customers under BIDMO. Almost 84% are industrial consumers and remaining are commercial and non-commercials types.

Research based on estimation of cost of unserved energy by customer survey approach in Kathmandu valley was previously done[2]. In this paper, the average outage cost for the industrial customer was estimated at Rs. 38.42 per kWh which is significantly higher than electricity rates and indicated the urgent need of enhancing the supply reliability. Only 1.31% of total consumers are industrial customers which contributes nearly 38.44% of revenue collection in Nepal (NEA report, F/Y 2022/2023). So, the concerned authorities have to focus on the secure and reliable supply to productive industries which has direct positive impact in the economic growth, i.e. GDP, of country. Paper on cost of unserved energy in Karnataka, India had used analytical methodologies to estimate the outage cost for industrial and agricultural sectors[3]. According to this paper, economic loss due to power outages in industrial sector varies between 0.04% to 0.17% of total state domestic product (SDP) depending upon size of industries. Among three analytical methods, it is found that the cost of unserved energy is Rs.22.1/kWh (from production loss method), Rs.2.63/kWh (from backup generation method) and Rs.4.89/kWh (from WtP method) in Indian currency. Neto et al., 2006 had calculated the reliability indices of radial feeder connecting the distributed generation on the distribution network aiming to achieve goals like loss minimization, interruption costs reduction and voltage profile correction[4]. Alekya et al. 2011 had analyzed and compared the reliability of rural, urban and industrial distribution feeder on basis of cost benefit analysis under manual control, under partial automated control and under fully automated control[5]. Integration of renewable distributed generation units into distribution networks for reliability improvement is gaining widespread popularity. The reliability assessment of distribution system with hybrid DG systems was undertaken considering optimal restoration strategies and system uncertainties[6].

2. Methodology

The methodology of reliability assessment of distribution power system of BID includes the steps shown in Figure 1.

2.1 Industrial Consumers' Survey for Estimation of Cost of Unserved Energy

In general, the term unserved energy refers to supply interruptions or blackouts. It can be described as an estimate of the electricity that would otherwise have been used by customers but for a power cut and the cost of related to the unserved energy refers to the cost of expected energy not served. These supply interruptions may originate from various parts of the supply chain. This cost also refers to cost of alternative electricity supply during outage. Survey in

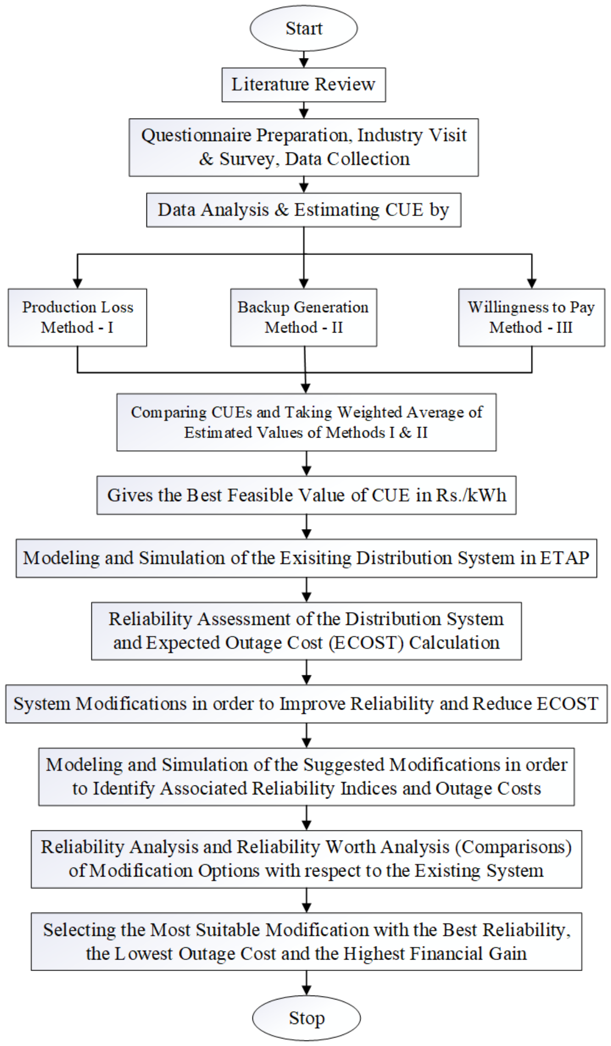

Figure 1: Flow Chart of Reliability Assessment Process

productive industries of BID is done to estimate the cost of unserved energy. Following three analytical methods are used for data collection during survey for the estimation of outage cost.

2.1.1 Production Loss Method

In this method, data collected from industries from survey are raw materials and finished products loss, cost of idle workers due outage, increment of maintenance cost, penalty for not meeting the demand, annul electricity consumed, etc. and value of production loss per hour of electricity outage is calculated for the estimation of outage cost. Calculation of production loss per unit of power outage of the i^{th} industry, unit is Rs./kWh, is given by,

$$L_i = \frac{\left(\frac{\text{production loss value in Rs.}}{\text{annual outage hours}}\right)_i}{\left(\frac{\text{annual electricity consumed from grid}}{\text{annual hours of electrcity available from grid}}\right)_i} \quad (1)$$

The weighted average of L_i in Rs./kWh is represented by L and calculated as,

$$L = \frac{\sum_i L_i U_i}{\sum U_i} \quad (2)$$

Here, U is the annual energy consumption from NEA supply and its unit is kWh.

2.1.2 Backup Generation Method

This method is applied for those industries having fully operated backup supply in case of power outage. It provides clear and transparent value of a unit of electricity by backup power supply. Collected data from survey includes capacity of backup supply, its capital cost, annual maintenance cost, fuel consumption per hour, etc. Cost of backup power generation for the i^{th} industry using j^{th} backup unit in Rs. / kWh is given by,

$$C_{ij} = \frac{(C_A + M_A + F_A)_{ij}}{(\text{total unit of electricity generated annually})_{ij}} \quad (3)$$

Where C_A, M_A *and* F_A are annual capital cost, annual maintenance cost and annual fuel cost respectively. Here, annual capital cost is the product of capital cost of backup power supply system in Rs. and capital recovery factor.

If 'r' is annual interest rate and 'n' is total life of j^{th} backup supply system in year, then capital recovery factor is given by,

$$R_j = \frac{r}{1-(1+r)^{-nj}} \quad (4)$$

The weighted average of economic cost of backup power generation in unit Rs. / kWh is calculated by,

$$C = \frac{\sum_{ij} C_{ij} U_{ij}}{\sum_{ij} U_{ij}} \quad (5)$$

Here, U is the annual energy generated by backup system, unit is kWh.

2.1.3 WtP Method

It is willingness to pay method. It gives industries' perception to pay higher tariff than prevailing electricity rates for secure and reliable electricity supply. This method is bidding process for electricity rates. In this method, current electricity price is taken as the minimum rate. During survey, questions "Are you willing to pay more per kWh?" and "What is your bid value for this?" are asked to industry. The mid-price between the highest accepted rate and the lowest rejected rate is the bid value. For example, if industry says 'Yes' to Rs.10 per kWh but no to Rs.11 kWh, the bid has taken as Rs. 10.5 kWh. All the industries may not participate in this method, i.e. may be not ready to pay higher cost of electricity than the prevailing rate.

2.1.4 Distribution System Cost of Unserved Energy and Economic Loss due to Power Outages

The weighted average value of outage costs estimated by production loss method and backup generation method gives the industrial distribution system cost of unserved energy given as below:

$$\text{CUE} = \frac{LU_l + CU_g}{\sum U_i} \quad (6)$$

Where L is CUE estimated from production loss method, U_l is Annual energy consumption of industries having production losses due to power cuts, C is CUE estimated from backup generation method, C_g Annual energy consumption of industries surveyed during method II and U_i Annual energy consumption of each responding industry. The annual expected energy not served (EENS) of distribution system is estimated from its average load and annual outage duration as given below:

$$\text{EENS} = \sum \text{Average Load} \times \text{Outage Duration} \quad (7)$$

Also, EENS is the summation of the products of average load of distribution system and unreliability of the system. The unit of EENS is MWh/year. After the estimation of cost of unserved energy and expected energy not served, then we can calculate the annual economic loss in Rs. due to power outages in distribution system given by,

$$\text{ECOST} = \text{Expected Energy Not Served} \times \text{Outage Cost} \quad (8)$$

2.2 Reliability Indices Evaluation

There are two index groups to evaluate the reliability performance of distribution system, viz., the system index and the customer load point index. The definition and evaluation of reliability indices are as follows:

1. System Average Interruption Frequency Index (SAIFI)

   It is defined as the average number of interruptions customer has experienced during study period. It is the ratio of total number of interrupted customers by total number of customers served.

$$\text{SAIFI} = \frac{\sum \lambda_i N_i}{\sum N_i} \text{ f/cust.yr.} \quad (9)$$

2. System Average Interruption Duration Index (SAIDI)

$$\text{SAIDI} = \frac{\sum U_i N_i}{\sum N_i} \text{ hr/cust.yr.} \quad (10)$$

3. Customer Average Interruption Duration Index (CAIDI)

$$\text{CAIDI} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \text{ hr/cust.int.} \quad (11)$$

4. Average Service Availability Index (ASAI)

$$\text{ASAI} = \frac{\sum N_i \times 8760 - \sum U_i N_i}{\sum \lambda_i N_i} \text{ pu} \quad (12)$$

5. Average Service Unavailability Index (ASUI)

$$\text{ASUI} = 1 - \text{ASAI pu} \quad (13)$$

6. Energy Index of Reliability (EIR)

$$\text{EIR} = \frac{\text{Total Energy Served}}{\text{Total Energy Served} + \text{EENS}} \, pu \quad (14)$$

7. Energy Index of Unreliability (EIU)

$$\text{EUI} = 1 - \text{EIR pu} \quad (15)$$

2.3 Modeling, Simulation and Data Analysis

In this paper, industrial distribution system modeling and simulation for reliability assessment is done is ETAP software and EXCEL is used for results analysis.

Series of sets of different electrical components, such as, transformers, protection devices, fuses, circuits breakers, capacitor banks, lightning arresters, cables, conductors, insulators, disconnectors, isolators, metering units, loads, etc. Real field data of these components has been taken for the modeling, simulation and data analysis.

2.4 ETAP as the Modeling Tool

ETAP is the most comprehensive analysis platform for the design, simulation, operation, and automation of generation, distribution, and industrial power systems. It creates and tests electrical power systems in a full simulation environment with access to tools for designing and adjusting all kinds of objects and structures with real-time load flow analysis, reliability analysis, short-circuit analysis, motor acceleration analysis, harmonic analysis and transient stability analysis. ETAP is developed with various features which aim to provide users with intelligent power visual monitoring, system optimizations, energy management, automation and forecasting. ETAP is a fully functional analysis tool which can be used for analyzing any of the AC/DC electrical power system.

ETAP is trustworthy, consistent and dependable tool for reliability assessment. Advanced distribution reliability assessment provides engineers with an efficient and effective tool for estimating the performance of power system. Using flexible input parameters, results can be quickly obtained for both radial and looped systems. Powerful calculation techniques allow engineers to choose the depth of system design and the associated results.

It helps to make confident decisions with reliable results. In ETAP, we can model reliability characteristics of each component, implement user-defined parameters and settings, calculate load point reliability indices, bus reliability indices, system reliability indices and reliability energy Indices, etc. It is also useful for plotting and reporting. Reporting includes graphical display of reliability results, load point and bus reliability indices, system reliability indices, EENS and ECOST sensitivity analysis, access databases of output results, export output reports to our favorite word processor, export one-line diagrams with results to third party CAD systems.

Due to all reliability assessment related features, ETAP software is chosen as the modeling tool in this thesis. Furthermore, similar other analysis like load flow analysis, short circuit analysis, transient stability analysis, etc. of distribution system of Balaju Industrial Estate can be done in the created design or model of Balaju Industrial Estate as actual in the real field.

3. Results and Discussion

3.1 Distribution System Modeling

There are 3, 11kV dedicated feeders from 132kV Balaju S/S, NEA to BID S/S – each around 1 km long underground radial feeder supplying power to 157 different consumers inside the industrial estate. This radial distribution system up to 11kV 400/5 A metering units at BID premises is owned by NEA, Balaju DCS. These feeders after entering into BID S/S is owned and operated by BIDMO. Large industries having approved load > 100 kVA have their own step-down transformers (11/0.4 kV), whereas small and cottage industries have power supply from the BIDMO owned transformers. These existing distribution system with its networks details are shown in figures 2, 3, 4, 5 and 6.

3.2 Distribution System Outage Duration

For system outage record details, data have been obtained from NEA, Kathmandu Grid Division, Balaju S/S, Balaju DCS and BIDMO S/S log sheets. Last one-year trip data are used (from 2079 Magh to 2080 Magh) for the calculation of average outage duration. Details are shown below in Table 1.

The average outage duration of the whole distribution system is found to be 100 hr./yr. During the one-year study period, NEA has cut-off power supply of BID five times during peak time of dry season. Electrical line was cut-off 3 hours per day (per time). This was like undeclared load shedding in the industrial estate.

3.3 Reliability Assessment of Different Network Configurations

Following four cases are studied.

3.3.1 Case 0: Existing Distribution System

ETAP simulation of the existing and operating distribution system of Balaju Industrail Estate is shown in Figure 7.

3.3.2 Case 1: Separating 4.5 MVA Feeder and 3.5 MVA Feeder in NEA S/S by Installing Separate VCB

There are only two VCBs, one for the 7 MVA feeder and other for 3.5 MVA and 4.5 MVA feeders in Balaju S/S, NEA. Due to having only one VCB for two feeders, problems have been faced by the respective industries. If there is fault in any one feeder in between NEA S/S and BID S/S, both feeders (one healthy and other faulted) have to be kept in shutdown during the maintenance period. If there occurs problem in the NEA VCB, both feeders suffer tripping. If we have to take NEA shutdown for the maintenance (VCB maintenance, NEA metering unit maintenance, etc.) of any one feeder, another feeder also suffers shutdown. In case of high stage faults in any one feeder, BID VCB including NEA VCB trip causing the healthy feeder electricity outage too. In this case, industries related to the healthy feeder have to face unwanted electricity interruption resulting financial losses, sometimes equipment damages also. Hence, idea of separate VCB for separate feeders has been proposed in this case for study from the reliability point of view. ETAP simulation of this case is shown in Figure 8.

3.3.3 Case 2: Adding Redundant Power Supply

In this case, redundant supply is suggested to add with an existing distribution system from 66kV Lainchour substation

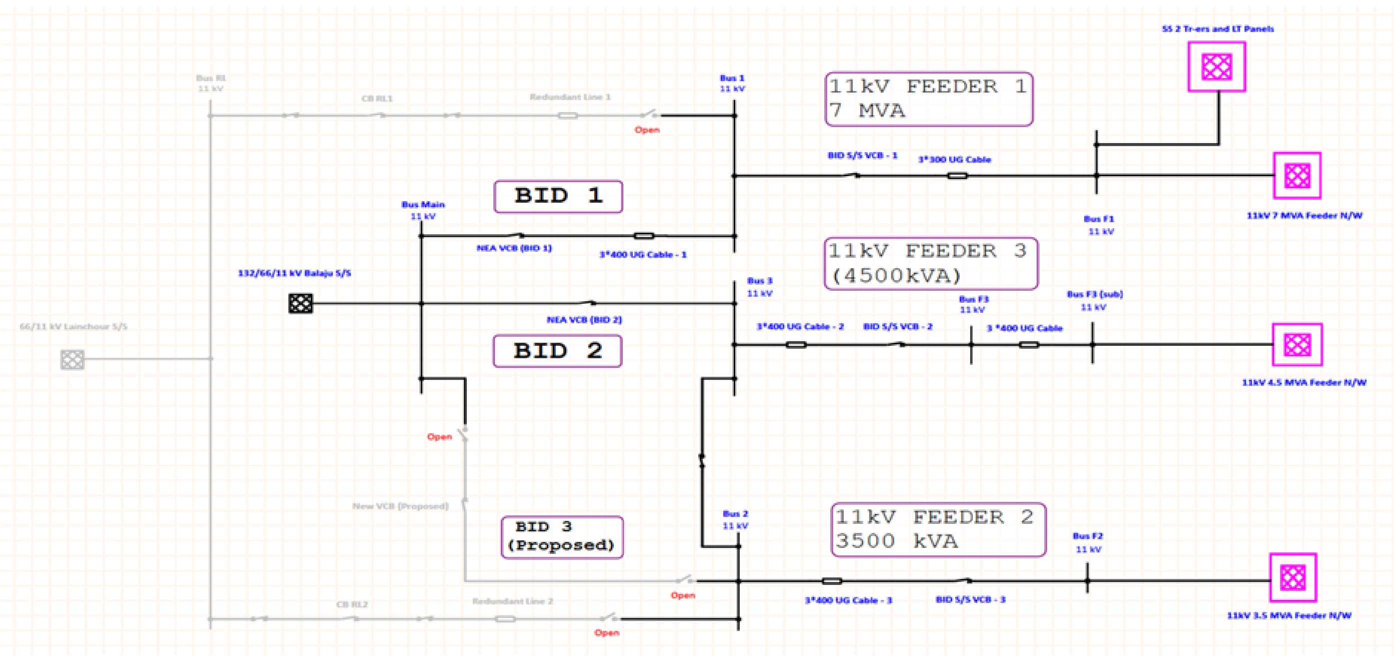

Figure 2: Existing Distribution System of BID

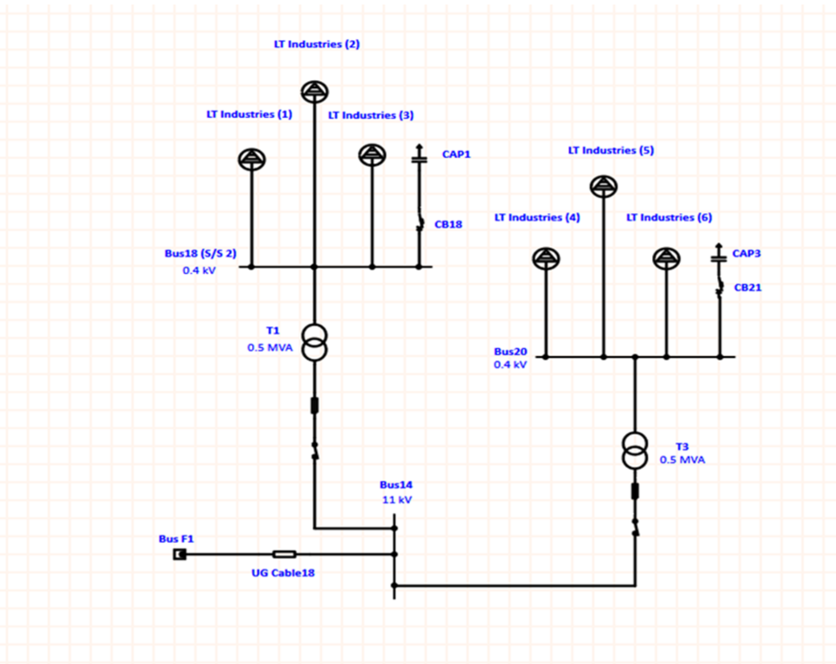

Figure 3: Composition of S/S Transformers and LT Panels Network

Table 1: Tripping and Outage Duration Details

3 BID Feeders	No. of Auto Trip Fault Types					No. of Manual Trips for Maintenance	No. of Undeclared Load Shedding in Dry Season	Electricity Outage Duration, minutes		
	Three Phase OC Protection			Earth Fault Protection						
	Low Stage: 3I >	High Stage: 3I >>	Instantaneous Stage: 3I >>>	Low Stage: Io >	High Stage: Io >>			Auto	Manual	Load Shedding
NEA S/S VCB	9	16		74	20	48	15	2228	1952	2700
BID S/S VCB	35	42		230	53	244		4315	6816	
Total:-	**44**	**58**		**304**	**73**	**292**	**15**	**6543**	**8768**	**2700**
Total Outage Duration (hrs./yr.):								**300.1833333**		
Average Outage Duration of the whole distribution System (hrs./yr.):								**100**		

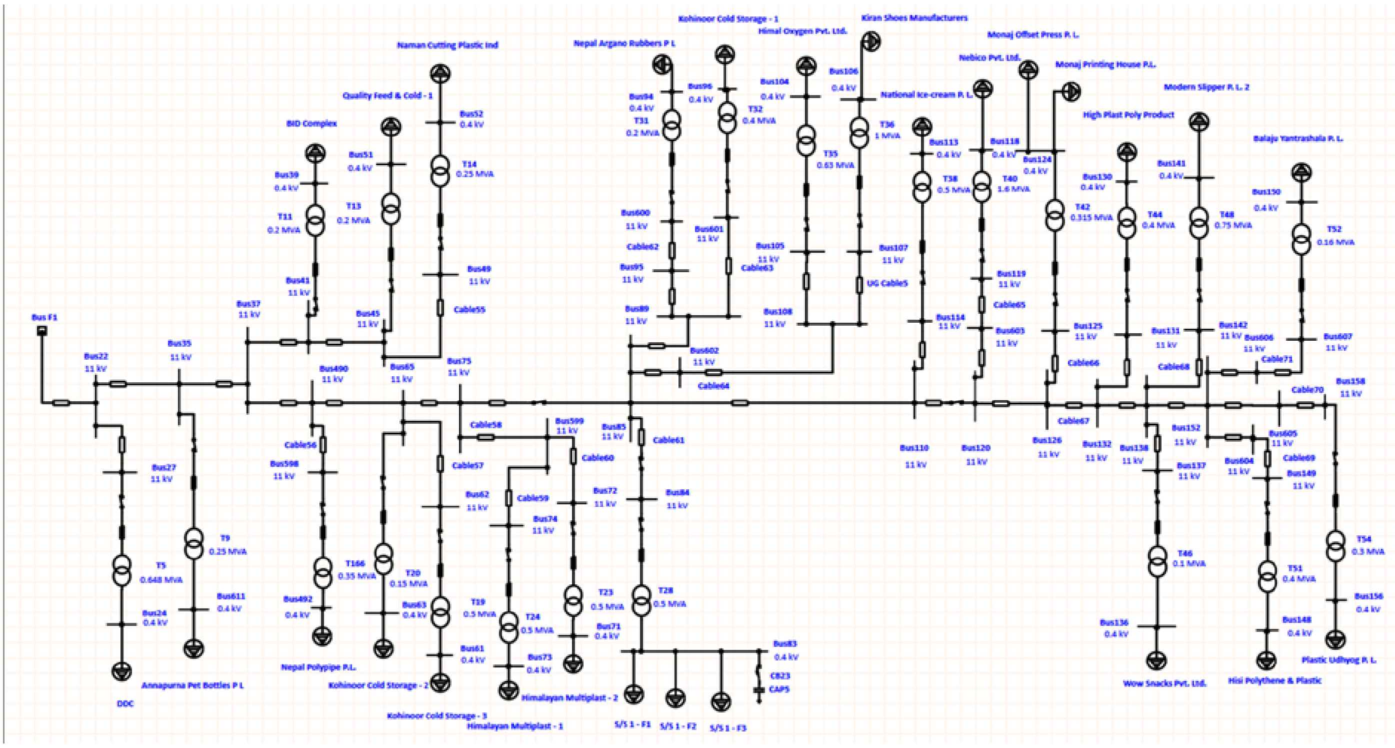

Figure 4: 11kV 7 MVA Feeder Network

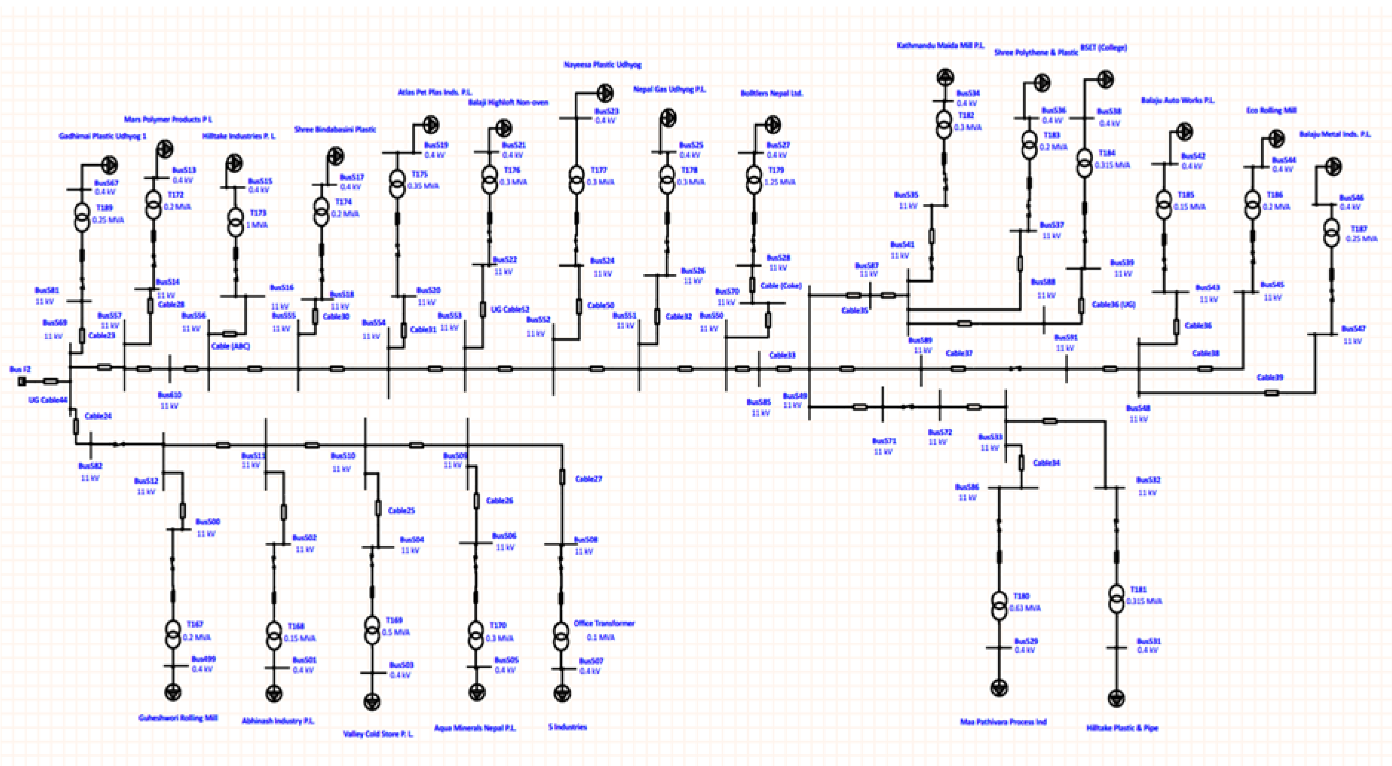

Figure 5: 11kV 3.5 MVA Feeder Network

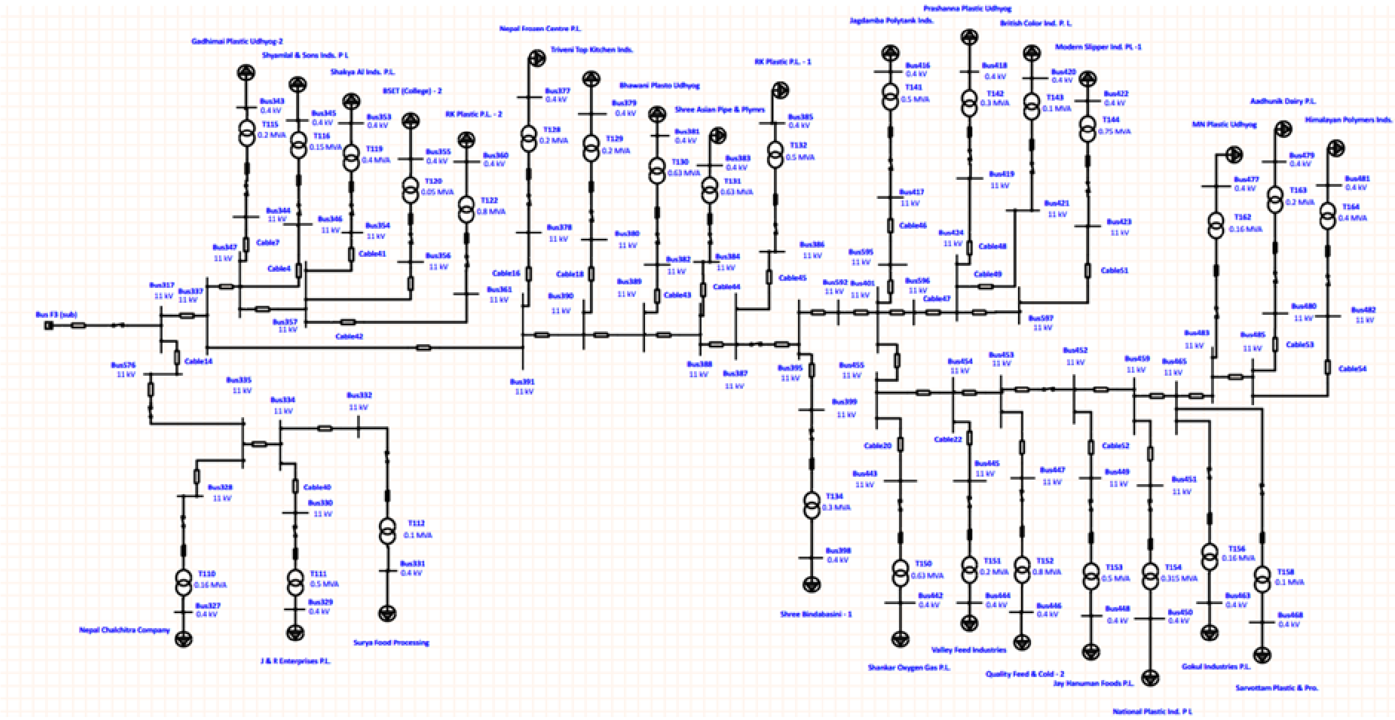

Figure 6: 11kV 4.5 MVA Feeder Network

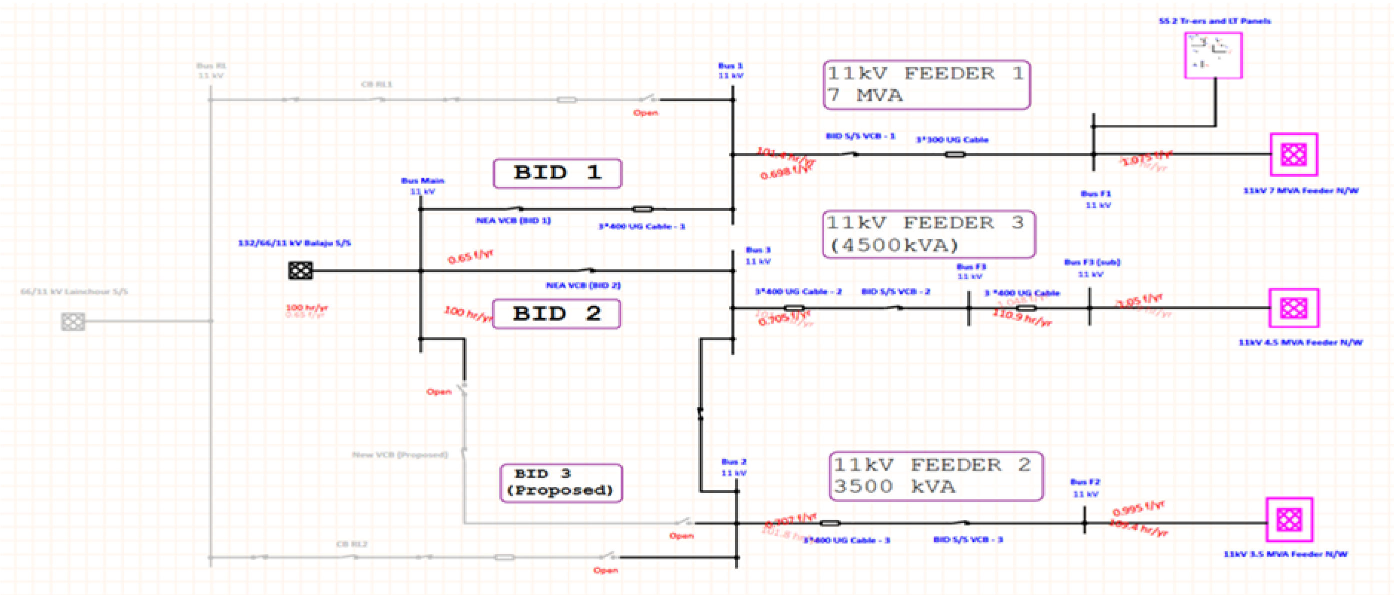

Figure 7: Simulation of Existing Distribution System

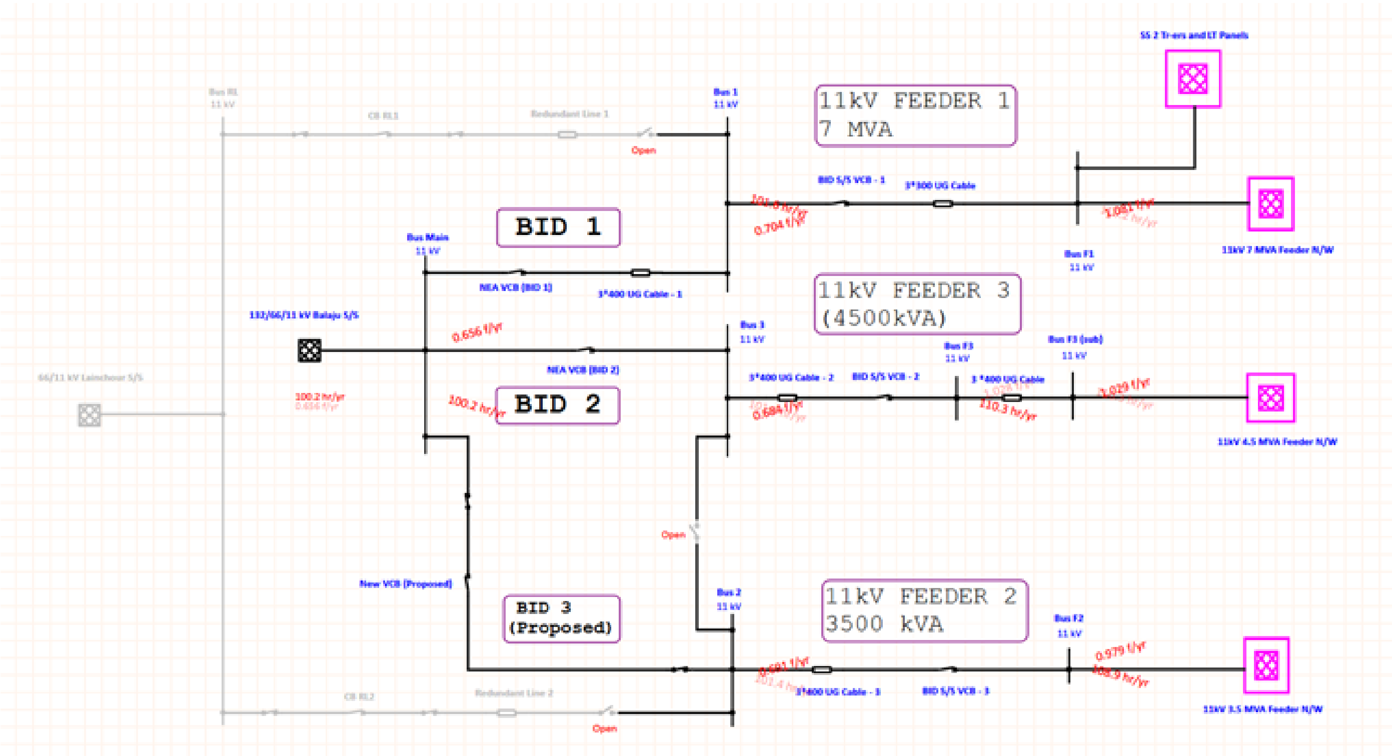

Figure 8: Modeling and Simulation of Case 1

to improve the reliability. The suggested redundant supply is able to supply whole distribution system load in case of main radial distribution system is no longer able to supply the power. ETAP simulation of this case is shown in Figure 9.

3.3.4 Case 3: Creating Ring Main Between Feeders

In general, all the feeders are not shutdown simultaneously and if happens, only for very short period. Also, faults do not occur simultaneously in all feeders. It's generally one time in one feeder. Depending upon to faults type, feeder shutdown period may be very long and the critical industries, such as, medical oxygen plants, cold storages, dairy plants, food and drinking water plants, etc. suffer. For the continuous supply of power to these critical industries, ring main between feeders is created installing isolators as one or two feeders are always in operation. In this case, power is supplied only to the critical industries considering the loading capacity of operating feeder or feeders. ETAP simulation of this case is shown in Figure 10.

3.3.5 Reliability Assessment Results

ETAP modeling and simulation results are shown in table 2.

Graphs of ASAI, EIR and EENS of all cases are shown in Figures 11, 12 and 13.

Above results show that cases 1, 2 and 3 have improved the system reliability compared to existing system (case 0). Also, EENS has decreased. It can be noticed that system EENS decreases with the increase in its reliability. Case 2 of adding redundant supply in the existing system is the most reliable network configuration compared to all cases.

3.4 Outage Cost

3.4.1 Estimation of Outage Cost

For the estimation of cost of unserved energy, questionnaire regarding to production loss methods, backup generation method and willingness to pay method is prepared and survey of productive industries in BID is done. 114 manufacturing industries participated well in the survey and collected data are used for the estimation of outage cost. Production loss method, backup generation method and willingness to pay method have estimated CUE as Rs. 27.68 per kWh, Rs. 50.93 per kWh and Rs. 11.03 per kWh respectively.

The weighted average of method-I and method-II gives the overall cost of unserved energy as Rs. 28.26 per kWh and is used for ECOST evaluation during economic losses analysis in all cases explained above.

3.4.2 Comparisons of Estimated Outage Costs

Karki et al. 2010 (Estimation of cost of unserved energy: a customer survey Approach) has estimated the average outage cost for the industrial customer Rs 38.42 per kWh is obtained using weighted average method. The outage cost was computed based on the information obtained from the survey regarding loss of raw materials, loss of profit, wages paid to idle workers, penalty for not meeting the delivery deadline, cost of standby supply, etc. Three years of outage data were obtained for two selected feeders in urban, semi-urban and semi-rural areas of Kathmandu valley.

But in case of Balaju Industrial Estate by productive industries survey method, the outage cost obtained using weighted average method is estimated as Rs. 28.26 per kWh.

The earlier estimated value of outage cost is higher by 26.45%.

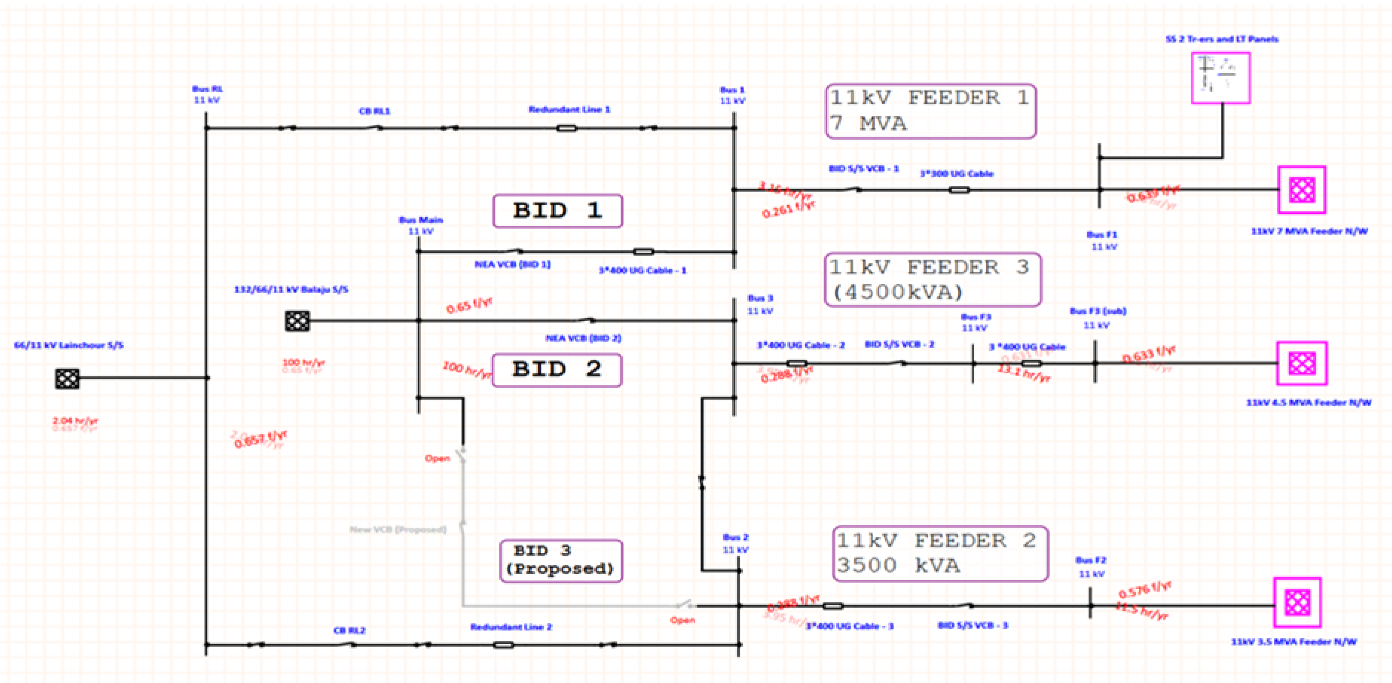

Figure 9: Modeling and Simulation of Case 2

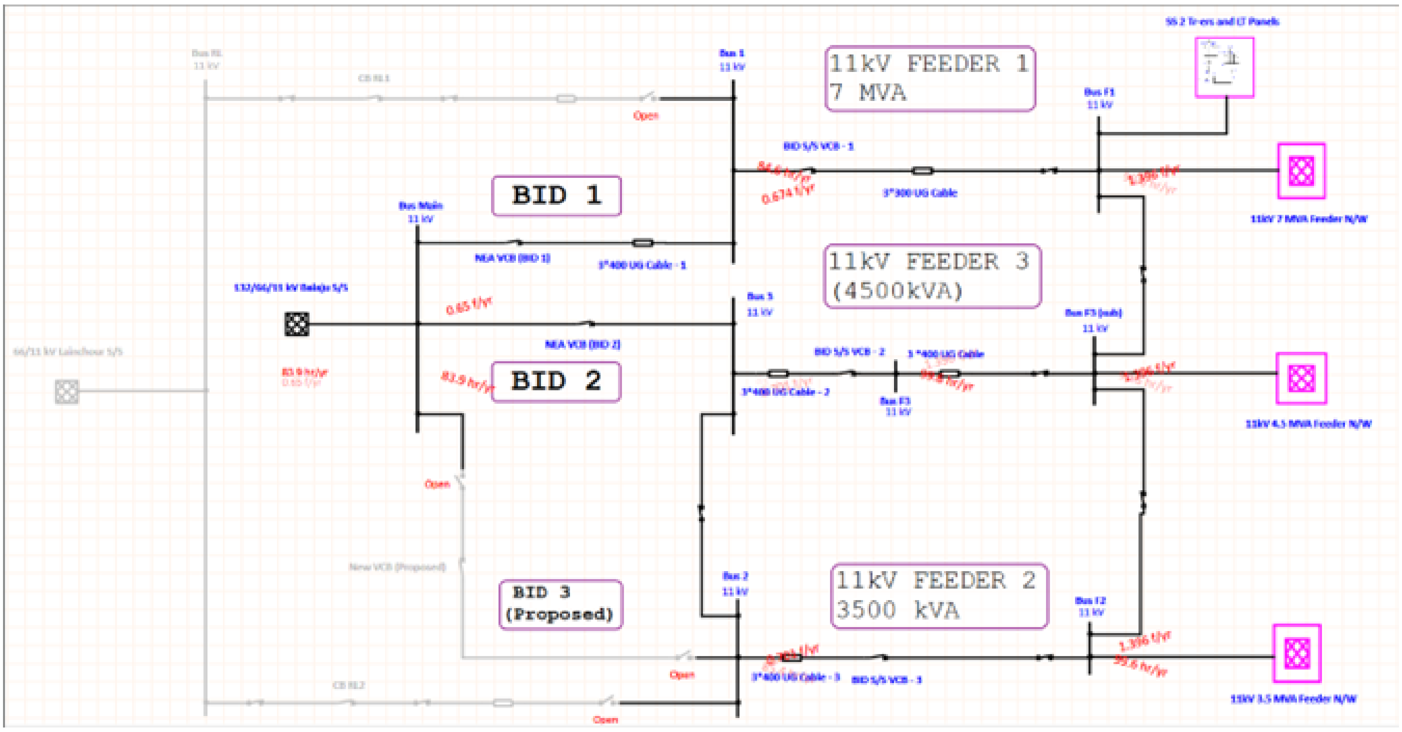

Figure 10: Modeling and Simulation of Case 3

Table 2: Results of Reliability Assessment

Cases	SAIFI (f/cus.yr)	SAIDI (hr/cus.yr)	CAIDI (hr/cust.int)	ASAI (p.u.)	ASUI (p.u.)	AENS (MWhr/cus.yr)	EENS (MWhr/yr)	EIR (p.u.)
Case 0: Grid Only	1.1224	114.9161	102.387	0.9869	0.01312	29.2704	2429.443	0.9377
Case 1: Separate VCB (BID 3)	1.1136	95.4164	85.685	0.9891	0.01089	24.3008	2016.963	0.9478
Case 2: Grid+ Redundant Supply	0.6971	16.9443	24.307	0.9981	0.00193	4.2910	356.151	0.9904
Case 3: Ring Main (Interconnections between Feeders)	1.4305	96.7756	67.651	0.9890	0.01105	25.6832	1053.011	0.9720

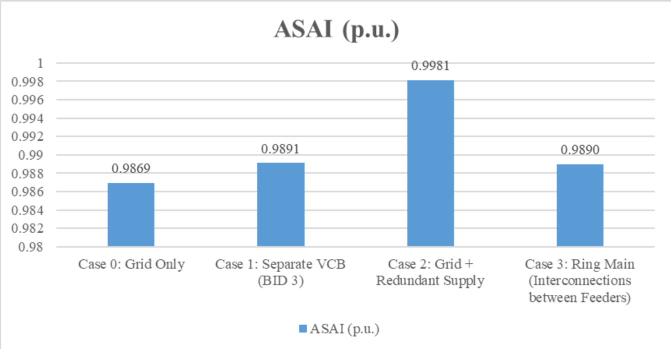

Figure 11: ASAI for All Cases

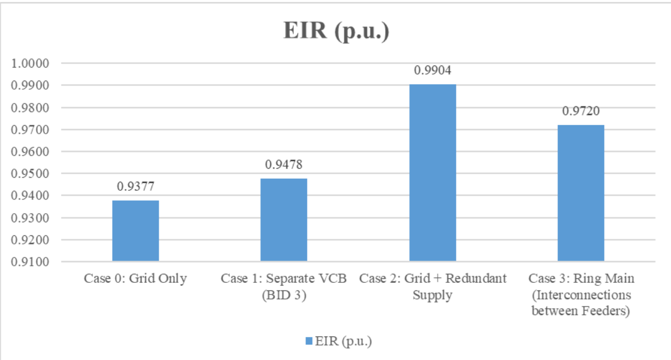

Figure 12: EIR for All Cases

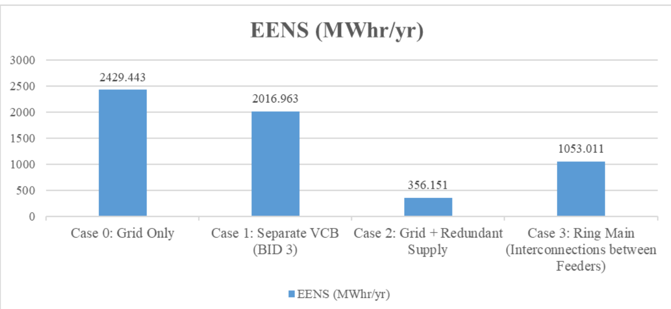

Figure 13: EENS for All Cases

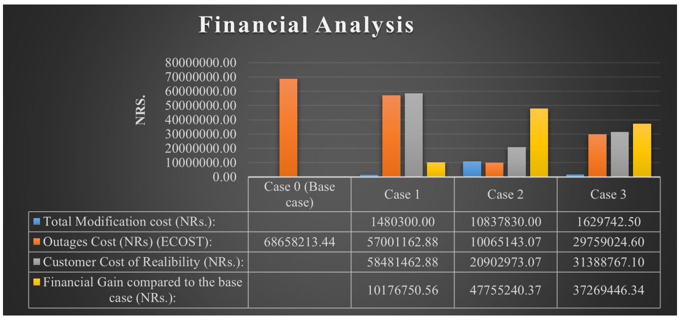

Figure 14: Results in Amount (Rs.) for all cases

Following points are to be noted worth considering.

1. At that time, Nepal had been suffering from severe power shortages and consumers had to face up to 16-hour load shedding in a day during dry season. The study has also focused on the poor infrastructure of distribution system of Kathmandu valley and indicated the urgent need of enhancing supply reliability.

2. The earlier survey was done in different areas of Kathmandu valley. But thesis survey is based on the typical industrial estate, Balaju industrial estate, owned by the Nepal Government which has improved and better electrical distribution system for industries i.e. reliable supply than outside the industrial estate.

3.4.3 Physical Possibility of System Modifications

All the suggested system reconfiguration schemes, i.e. case 1, case 2 and case 3, are practically and physically possible with investments according to the estimations. The modification costs of each case are shown in table 3.

3.5 Economic Analysis from Reliability Point of View

For the reliability worth analysis of the different cases, ECOST, NEA Income Loss and BIDMO Income Loss are calculated using the above estimated values of CUE, EENS, annual energy billing amount and annual energy served. Annual energy billing and annual energy consumption of BID are Rs. 31,42,29,554.30 and 36596869 units respectively. Calculation and analysis are given in table 4 given below.

Ten percent of NEA income loss is the BIDMO income loss as ten percent discount is given to industrial estates, undertaking of government of Nepal, by NEA only in case of payment within seven days of meter reading. Industrial estates pay electricity within prescribed time period because this rebate is also their main income source.

From the above results, it is seen that reliability indices of cases 1, 2 and 3 improve significantly compared to case 0. But it is necessary to estimate the investments to be made for network modifications for higher reliability and evaluate financial burdens, whether we have financial gain or don't have. Estimations are based on the prevailing norms. The results of economic analysis of reliability are shown in figures 14 and 15 below.

Table 3: Summary of System Modification Costs (Estimation)

S.N.	Equipment Descriptions	Estimated total cost of units including supply, installation, testing & commisioning (NRs.)		
		Case 1	Case 2	Case 3
1	11 kV Distribution Feeder		7,312,230.00	
2	400 Sq.mm XLPE Cable		551,440.00	
3	HV Circuit Breaker (Including cost of battery, its charger and Cu plate earthing)	1,480,300.00	2,917,660.00	
4	Disconnect / Isolator Switches		56,500.00	141,250.00
5	Materials and their installations for Isolators (only in case of Case 3)			1,488,492.50
	Total Modification cost (NRs.):	**1,480,300.00**	**10,837,830.00**	**1,629,742.50**

Table 4: All cases ECOSTs, income losses and reductions in ECOST

Cases	ECOST (Rs./yr)	NEA Revenue Loss (Rs./yr)	BIDMO Income Loss (Rs./yr)	NEA Revenue Loss (%)	BIDMO income Loss (%)	Percentage Reduction in ECOST
Case 0: Grid Only	68,658,213.44	21,075,418.03	2,107,541.80	6.7070	0.6707	
Case 1: Separate VCB (BID 3)	57,001,162.88	17,497,154.03	1,749,715.40	5.5683	0.5568	16.98%
Case 2: Grid + Redundant Supply	10,065,143.07	3,089,609.93	308,960.99	0.9832	0.0983	85.34%
Case 3: Ring Main (Interconnections between Feeders)	29,759,024.60	9,134,870.43	913,487.04	2.9071	0.2907	56.66%

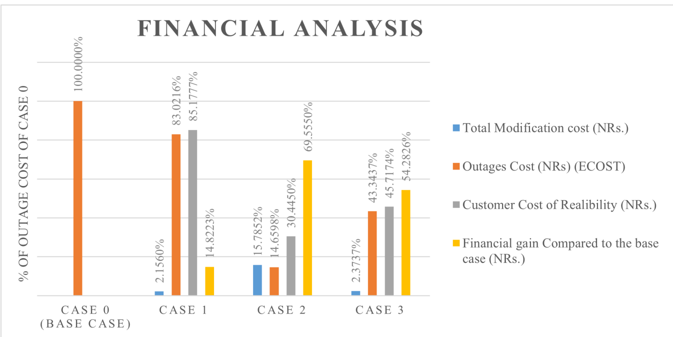

Figure 15: Results in Percentage of Outage Cost for all cases

3.5.1 Reliability Worth Analysis of Case 1

After separating 3500 kVA and 4500 kVA feeders by adding another separate VCB in NEA S/S, reliability of system is slightly improved and outage cost is reduced. This modification requires one number of VCB with its accessories. The investment is NRs. 14,80,300.00. The outage cost reduces to 83% of the base case i.e., NRs. 5,70,01,162.88 (reduced by 17%). Economic benefit (gain) in this case is NRs. 1,01,76,750.56.

3.5.2 Reliability Worth Analysis of Case 2

After adding redundant lines with the existing distribution system, reliability of system is significantly improved and outage cost is reduced. The added redundant lines have similar loading capacity as that of the existing feeders which are able to supply power in the industrial estate in case of main distribution system fails. Suggested network configuration requires double circuit 11kV overhead lines, 2 number of HV breakers, XLPE cable, isolator switches, etc. which needs an investment of NRs. 1,08,37,830.00. From the analysis, outage cost reduces to 14.66% of the base case i.e., NRs. 1,00,65,143.07 (reduced by around 85%). Economic benefit is NRs.4,77,55,240.37. This is the most suitable configuration.

3.5.3 Reliability Worth Analysis of Case 3

For creating the ring main between three 11kV feeders, installations of isolators with other required materials, such as, poles, conductors, insulator, etc., are necessary and the investment is NRs. 16,29,742.50. In this case, economic gain is NRs. 3,72,69,446.34 which is around 54% of the outage cost of case 0.

3.5.4 Importance and Comparison of the above Cases

All the three modification cases have their own importances. Case 1 for separating 3500 kVA and 4500 kVA feeder is in the favor of consumers related to the healthy feeder by remedying unwanted tripping and reducing outage duration. Case 2 of adding redundant double circuit lines is in the favor of whole industrial estate because it plays a role of emergency backup supply from the 66kV Lainchour S/S in case of failure of Balaju S/S. Case 3 is in the favor is critical industries, which require continuous supply of power, during the shortage of full power required by whole industrial estate. In each case, we observe improvement in reliability and also financial gain by comparing investments and savings. Cases 1 and 3 can be implemented very easily within short period with low cost compared to case 2.

4. Conclusion

The results obtained from the reliability assessment of distribution system of Balaju Industrial Estate seem to be very useful as suggest different ways to improve the reliability which ultimately results in financial gain to industrial consumers and respective utility offices. Results give information about planning, upgrading, designing, maintenance programming of distribution system to enhance reliability. Real data collected help to identify the weak parts of the industrial distribution system, then viable solutions are recommended to increase reliability and achieve the best performance of the system. ASAIs of all configurations, existing distribution system, separating two feeders by separate VCB, adding redundant supply and creating ring main, are 0.9869 pu, 0.9891 pu, 0.9981 pu and 0.9890 pu respectively. Adding redundant supply is the most reliable configuration. Other two modifications also have better reliability than the existing system.

In this paper, cost of unserved energy is also estimated by the three analytical methods for the reliability worth analysis and the overall cost is found Rs. 28.26 per kWh, higher than the prevailing electricity rate. Using this CUE and EENS of four different configurations, investment and return analysis is done and concluded that redundant supply with existing distribution system configuration has the highest financial gain and is the most suitable configuration.

All the suggested options for reliability enhancement have their own importances and result in improved reliability with financial gains, therefore, these modifications are recommended for implementation to the concerned utility offices, BIDMO and NEA.

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