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A Case Study of Pokhara Industrial Estate to Estimate Cost of EENS and Perform Reliability Worth Analysis

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Abstract

Estimation of cost of unserved energy and reliability worth analysis of industrial distribution feeder provides clear concept on value of lost load and its impact on cost of production of manufacturing industries. It provides the useful input tools for electricity planner and policy maker to take serious about ways to reducing outage costs and its impact to customers. In this paper, distribution system modification options are suggested to improve reliability of PID feeder of Pokhara DCS to reduce economic losses of customers and utility due to power outages. Due to unreliable electricity supply with unplanned interruption industrial consumer losses their revenue which reflects losses in national economy as a whole. Cost of EENS is estimated by three different analytical methods depending on customer status of stand by generation system and their perception of willingness to pay/accept higher tariff for improved supply. Results obtained from different methods were analyzed and weighted average of results estimated the cost of EENS of feeder as NRs.41.46/kWh. The estimated economic loss due to power outages in Pokhara Industrial Estate is NRs. 4,81,238.74 per outage and their losses depend upon the customer category and size of industries. In this paper, reliability assessment of PID feeder also conducted to identify the existing reliability indices of distribution system and financial risk associated with existing reliability indices. After estimation of cost of EENS in initial phase of study, distribution system modification options and their reliability worth were computed and compared. Paper concluded optimal modification option is addition of 11 kV overhead redundant line from common grid substation which yields better financial gain and improved reliability of system.

Keywords

Cost of EENS, Reliability indices, Outage cost, Modification Option

1. Introduction

Secure and reliable supply of electricity plays a vital role in economic growth of country. Power security and reliable supply is an important input for many industrial processes in manufacturing industries for industrial automation and computerization in modernized service sector. Due to natural phenomenon like wind, lightning, freezing rain, iced-up lines, wildlife, snow, trees/bushes and lack of proper knowledge and planning between supply and demand pattern power outage problems arises in the system. Electricity customers suffer from various types of power outages like, instantaneous tripping of protective devices, scheduled maintenance outage, long time interruption due to fault etc. During power outages industrial customer losses their processing raw materials which incur large portion loss in annual production damages. No and insufficient backup system of industries with unexpected power outage and unreliable electricity services from utility are the main problem of industrial customer no having a 24-hour electricity supply. From the last five years Nepal is completely load shedding free but customers are suffering from unplanned short and long duration power outages. According to Nepal Electricity Authority, utility has sufficient power supply capacity to meet the demand from NEA own and its subsidiary companies, IPP's generation and import from India through cross broader transmission link. But up-gradations of transmission and distribution infrastructure are ongoing. So, power demand is increasing day to day but customer uses power supply through old transmission and distribution networks. This is another reason of unexpected power outages in Nepal. Karki et al.[1] had used the consumer survey method based on preparatory action approach, WtP and WtA methods for the estimation of cost of unnerved energy .

Small and cottage industries have lack of capital investment to install standby backup system during business planning in establishment phase. Also, they have no technical knowledge regarding the power outage cost. Contribution of manufacturing industries in GDP gradually declined from 9% in 2000/01 to 5.39% in 2017/18 in Nepal[2]. For general and pilot survey, this research is focused on outage cost in case of Pokhara Industrial Estate which is a largest customer under Pokhara DCS but customers of PIE suffer from high rate of sustained and momentary electricity interruptions. At present, industries from PIE accounts for approx.NRs.500 million revenue collection to government of Nepal annually and 3000 direct employees are working. PIE occupies 500 Ropani land. Bose et al.[3] had proposed three different analytical methodologies to estimate cost of unserved energy (CUE) for industrial and agricultural sector. Electricity outage cost was estimated in between US $26 to US $400 billion in the world largest economy [4]. From the research outage cost contribution by industrial and commercial customer is 98% and remaining 2% is only by residential customer. Only 1.3% of industrial customer contributes nearly 42% of revenue collection in Nepal[5]. Omer et al.[6] has modified distribution system to improve reliability and reduced outage cost and also, done reliability worth analysis for optimal modification. Distribution system automation with optimal placement of switches reduces the interruption cost and returned the high reliability worth [7]. Billinton et.al.[8] had conducted customer survey to estimate the cost of unserved energy incurred by residential customer of developing countries and extend reliability worth analysis of distribution feeder by customer survey approach for developing countries.

2. Methodology

2.1 Cost of EENS

In general, cost of EENS refers to cost of alternative energy sources to provide electrical energy. It would be either loss or investment on alternative sources of energy supplies. Whereas, cost of reliability represents involvement of cost while maintaining reliability by investing for more generation, demand-side management, network assets etc. Cost of EENS is estimated by following analytical methods.

2.1.1 Direct Assessment Method I

This method is applied for those customers do not have standby system. During survey information were took from respondents including the accounts of value of production loss, cost of ideal worker, increase in O&M cost and opportunity lost and penalty for not meeting the market demand in dateline due to power outages. Cost of EENS estimated as follows;

$$Li = \frac{Pi/Oi}{Ui/Ai} \tag{1}$$

Where, Li is production loss per unit of power outage by the ith consumer.

$$L = \frac{\sum_i Li * Ui}{\sum_i Ui} \tag{2}$$

Where, L is weighted loss of production loss per unit of power outage from the grid, expressed in Rs/kWh; P is annual production opportunity loss in Rs; A is annual hour of electricity available from the grid; O is annual hour of electricity not available from the grid; U is annual electricity consumption from the grid in kWh and i is the number of valid consumers. It is important to note that net value lost by a consumer due to power outage is uncertain. This method unable to find the accounting for scrap and adopting the production loss minimization technique adopted in industries. So, industrial customer power outage cost is based on reported value of gross production loss attributed to disrupted power supply.

2.1.2 Indirect Assessment Method II

This is widely used method to provide useful information on clear and transparent value of a unit of electricity. In this study, this method of cost of EENS computation technique is applied for customer those have standby supply facility during power interruptions. Economic cost of backup power generation for the ith consumer using jth backup unit is computed as follows;

$$Cij = \frac{KijRj + Mij + Fij}{Uij} \tag{3}$$

$$Rj = \frac{r}{1-(1+r)^{-nj}} \tag{4}$$

Further, by weighted average of economic cost of electricity generated by each backup generation by *i*th consumer is given as;

$$Ci = \frac{\sum_j Cij}{\sum_j Uij} \quad (5)$$

$$C = \frac{\sum_i CiUi}{\sum_{ij} Uij} \quad (6)$$

Where, C is annual cost of backup power generation in Rs./kWh, K is capital cost of backup power generation in current prices in Rs., U is the electrical unit generation by backup generation in kWh, R is capital recovery factor, M is annual operation and maintenance cost in Rs., F is the annual fuel cost of backup generation in Rs., r is annual rate of interest, n is total life of the backup device in year, i is number of valid cases and j is number of backup unit.

2.1.3 Willingness to Pay Survey

WtP is the particular amount to fix the power output problem they face is a factor estimate of the CUE for an industrialist. Despite of above methods WtP is calculated even when there are no data on alternative cost of supply. The marginal value of improved supply produced by the WtP estimates applies only to those who are willing to pay for improvement. WtP method of CUE estimation current price is taken as minimum acceptable figure. Respondent were asked for straight forward question "what is your maximum WtP?". The bidding is started from higher WtP rate for feasibility than lower starting price being first. Bid values which are taken as mid-point between highest price accepted and lowest price rejected.

Distribution Feeder Cost of EENS

Feeder cost of EENS is calculated by weighted average of method I and II as;

$$CUE_{feeder} = \frac{L * U_l + C * Uc}{\sum_i Ui} \quad (7)$$

Where, L is CUE calculated from direct method; U_l is annual energy consumption of customer those have production lost due to electricity outages; C is CUE calculated from indirect method; Uc annual energy consumption of customer those have stand by generators; Ui annual energy consumption of each customer. In general, Expected Outage Cost of feeder is estimated as;

$$ECOST = EENS * CUE_{feeder}$$

The annual expected energy unserved is found from its average load and annual outage duration.

$$EENS = \sum averageload * Outageduration$$

From reliability assessment of feeder total energy not supplied by system is;

$$EENS = \sum_s LsUs \frac{kWh}{year} MWhr/Customer.yr \quad (8)$$

Where, Ls and Us are average load and unreliability of distribution system.

2.2 Reliability Worth Assessment

A real industrial distribution feeder (PID feeder of Pokhara DC) has taken for study as model. Reliability assessment and cost benefit analysis of this feeder with modification has been evaluated as in flow chart below. Distribution system consists of series set of

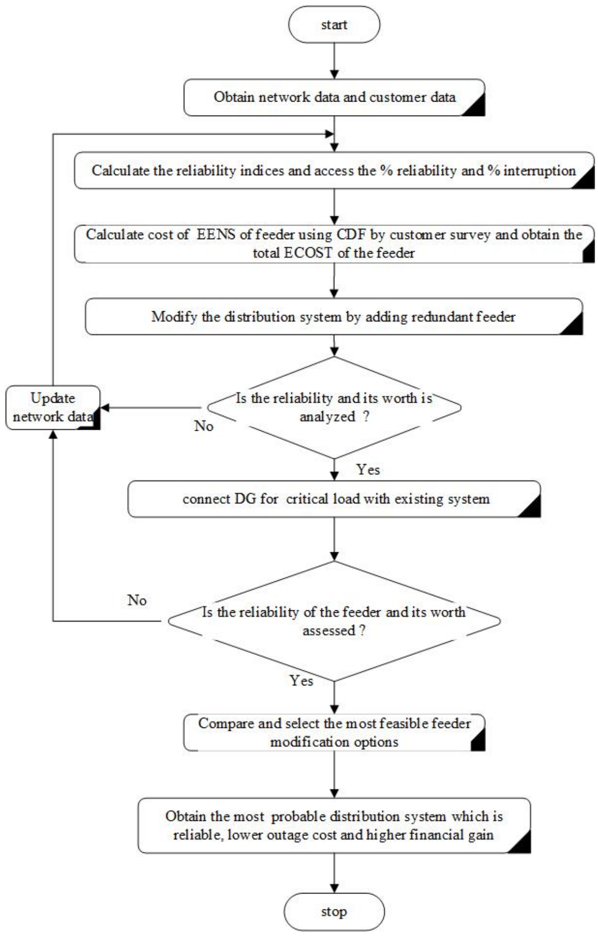

Figure 1: Flow Chart of Reliability Worth Analysis

components including protection devices, circuits breaker, cables, conductor, insulator, disconnecting s/w, sectionalizer, load etc. as in sample feeder shown in Figure 2. Cut set method is used for reliability evaluation. All the load points are considered as cut set. Failure and repair rate of each and every line component is taken from IEEE std 493-1990. ETAP simulation used to test reliability indices. Reliability indices of feeder are estimated as follows;

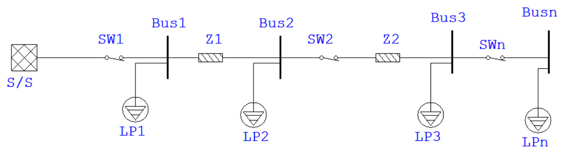

Figure 2: Sample Model of Distribution System

$$\lambda_{LPi} = \sum_{i=1}^{m} U_j \lambda_i ; U_{LPi} = \sum_{i=1}^{m} U_i ; r_{LPi} = \frac{U_{LPi}}{\lambda_{LPi}} \quad (9)$$

Where m is number of contingencies in section that cause failure of supply up to load point LPi; λ_j, γ_j, U_j are failure rate, repair rate and annual unavailability of contingency j; λ_{LP_i}, γ_{LP_i}, U_{LP_i} represents respective reliability rates up to load point i; λ_s, γ_s, U_s are failure rate, repair rate annual unavailability of system (whole feeder). Feeder performances are evaluated by using these indices as follows;

1. System Average Interruption Frequency Index

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} f/customer.yr \quad (10)$$

2. System Average Interruption Duration Index

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} hr/customer.yr \quad (11)$$

3. Customer Average Interruption Duration Index

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} hour/cust.interruption \quad (12)$$

4. Average Service Availability Index

$$ASAI = \frac{\sum N_i * 8760 - \sum U_i N_i}{\sum \lambda_i N_i} p.u \quad (13)$$

5. Average Service Unavailability Index

$$ASUI = 1 - ASAI = \frac{\sum UiNi}{N_i * 8760} p.u \quad (14)$$

3. Results and Discussion

3.1 Estimation of Cost of Expected Energy Not Served

Initially, customer were categorized according to NAICS as shown in Table 1 and questionnaire has prepared. Then customers belonging to 11 categories were surveyed. After that, data has been analyzed and CUE is estimated. These estimates are based on primary data collected from 68 manufacturing industries those gave positive response out of 78 which are usable and stood. Production loss method has estimated cost of EENS as Rs.55.11/kWh and back up generation method estimated Rs.40.7/kWh. Whereas, WtP survey estimated Rs.11.26/kWh flat tariff which indicates 59% of customer willing to pay 17.29 % higher tariff for improved supply. Weighted average of production loss method and backup generation method has estimated overall cost of EENS of distribution feeder as Rs.41.46/kWh, as presented in Table 2. This value has been used for ECOST calculation during reliability worth analysis of distribution feeder in next phase. Per outage cost estimated by use of data from survey are summarized in Table 3.

Table 1: North American Industrial Classification System

NAICS	Industry Category
311	Food Manufacturing product
312	Beverages and Tobacco Manufacturing
315	Clothing Manufacturing
316	Leather and Allied Product Manufacturing
323	Printing and Related Support Activities
325	Chemical Manufacturing
326	Plastic and Rubber Product manufacturing
332	Fabricated Metal Product Manufacturing
335	Electrical Equipment Manufacturing
337	Furniture and Related Products
339	Miscellaneous Manufacturing

Outage records and backup responses

Most of customers were unable to give the exact record of outage time and frequency but they expressed the frequent unexpected outage experiences. So, feeder outage data details were taken from Pokhara substation SCADA record as well as PID utility office for PID internal outage. From all this records expected outage time is estimated approximately 110 hours for last F/Y 2020/021. Trip record and detail is presented in Table 4. Based on the responses, 29.42 % of customers have full back-up

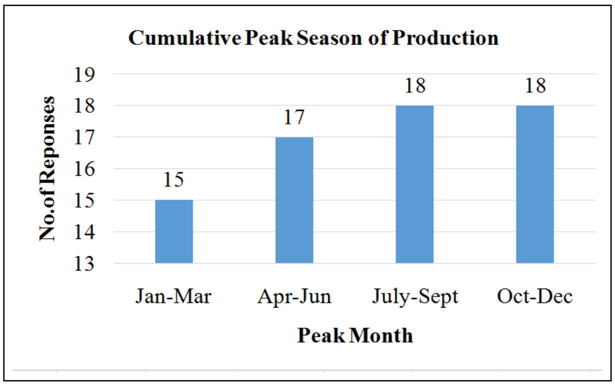

Figure 3: Peak Operating Season of Customers

system and 13.24% of customers have partial load back-up system of stand by diesel generator sets whereas, 57.35% of customer have no stand by back-up system. Customers who don't have backup system asked for ability to makeup lost production without addition of manpower. Most of the customers express inability to makeup lost production for unexpected, without prior informed momentary outages. None of the customer have surplus stand by capacity. Peak operating season of customer and worst outage month is as shown in Figure 3.

Table 2: Cost of EENS Estimation (Rs./kWh

NACIS Code	Method I	Method II	WtP
311	335.9	41.21	11.25
312	46.2	36.16	12
315	173.22	0	0
316	624.22	0	0
323	531.96	36.46	10.5
325	430.16	0	0
326	777.25	63.22	11.25
332	165.47	35.89	11.2
335	1805.42	0	11.04
337	1247.93	0	12
339	292.55	55	11.5
WA	55.11	40.7	11.26
kWh/yr	278199	4978633	Grid
WA of I & II	41.463		

3.2 Reliability Worth Analysis of Distribution Feeder

After the calculation of cost of expected energy not served from three analytical method above, overall economic loss due to unreliable supply of electricity is obtained. For reliability improvement and outage cost reduction following distribution feeder suggested modification options indices are tested in ETAP simulation.

3.2.1 Case Study

PID feeder is 5 km long, extended from 132 kV Kudahar S/S of Pokahara supplying power to Pokhara indusrial area. This feeder is own and operate by NEA from 132 kV Kudahar S/S to HT metering unit at PIE premises. After entering the feeder into PIE area distribution system owns and operated by Pokhara Industrial Estate itself. Pokhara Industrial Estate is a government organization established for management, supervision and promotion of industries. Distribution system consists of 25 distribution transformer, 51 buses, 30 number of load points having peak load of 2.5 MVA. Simulated diagram of PID feeder with modification is shown in Figure 4. Summary of reliability indices results are presented in Table 5. Modification case wise reliability indices are plotted as shown in Figures 5, 6, 7, 8.

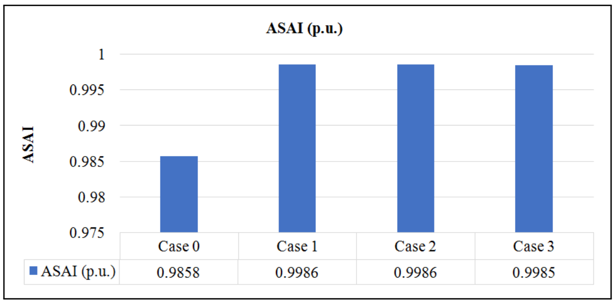

Figure 5: Graph of ASAI

3.2.2 Financial Analysis

From reliability assessment of existing distribution network (case 0), poor reliability indices were found which lead to high EENS, ASAI and large ECOST. It is seen that reliability indicators of case 1, case 2 and case 3 have significant improvement but financial risk and burden associated after implementation of these are unknown. So, cost estimate of suggested modifications and their comparison with base case is evaluated. Rate analysis and their estimate is based on current norms of Government of Nepal and current market price of equipment's. Summary of cost estimate and reliability worth analysis is presented in Table 6 and Figure 9.

Considering existing distribution system (case 0)

Main reliability indices like EENS and ECOST has obtained as 428.83 MWh/yr and Rs.1,77,81,484.87 Rs./yr respectively with availability of the feeder is

Table 3: Average Industrial Customer Supply Outage Cost, Rs./Outage

NAICS Code	Raw materials and finished products loss (Rs.)	Salary to idled worker (Rs.)	Increase in maintenance cost (Rs.)	Loss in opportunity cost, penalty (Rs.)	Cost of stand by (Rs.)	Total
311	58900.00	7493.75	7050.00	26500.00	44664.20	144607.95
312	0.00	0.00	1000.00	0.00	2466.46	3466.46
315	1500.00	674.28	0.00	0.00	0.00	2174.28
316	0.00	428.37	0.00	0.00	0.00	428.37
323	10537.00	752.16	2500.00	0.00	3374.04	17163.21
325	0.00	71.39	0.00	0.00	0.00	71.39
326	149680.00	4167.93	5860.29	2687.50	1593.32	163989.04
332	1650.00	7352.28	2025.00	1075.00	6587.69	18689.98
335	39700.00	1543.70	697.45	10000.00	0.00	51941.15
337	0.00	2776.44	360.00	6500.00	0.00	9636.44
339	54800.00	758.89	1650.00	10100.00	1761.58	69070.48
Total sum	316767.00	26019.21	21142.74	56862.50	60447.30	481238.74

Table 4: Feeder Outage and Tripping Detail

11 kV PID Feeder	Auto (EF Ie>)	Manual (Maintenance)
No. of Trip	126	237
Trip duration, min	2884	3637
Total outage duration(hour/yr)		110

Table 5: Summary of ETAP Results for All Cases

CASE	SAIFI (f /yr. Cus.)	SAIDI (hr/ cus.yr)	CAIDI (hr/ cust.int)	ASAI (p.u.)	EENS (MW. hr/yr)
0	1.269	124.39	98.027	0.9858	428.83
1	0.476	12.69	26.563	0.9986	42.781
2	0.475	12.51	26.314	0.9986	42.316
3	0.482	12.88	26.73	0.9985	43.611

0.9858 p.u. From these reliability indices expected revenue loss of NEA is 6.458% from PID and 0.645% annual income loss of Pokhara Industrial Estate Management Office (PIDMO) from electricity sales. The revenue loss of NEA and income loss of PIDMO indices calculation are based on;

- Annual billing (kWh charge only) from NEA to PIE (F/Y:2076/077) is Rs.5,41,18,650.00.
- PIE will receive 10% rebate from NEA in case of timely payment of electricity bill.

Adding a redundant distribution line (case 1)

In this case similar redundant line is suggested to add with existing line from common substation to bus no. 47 to improve the reliability of the distribution system with outage cost reduction. The suggested redundant line is able to supply power to whole load in case of main radial distribution feeder is no longer able to supply the power. In this case, reliability improved to 0.9986 p.u., EENS reduced to 42.781 MWh/yr. Similarly, improvements in other indices are presented in Table 5. In this modification customer reliability indices like SAIFI, SAIDI and CAIDI are much more favorable than original system (case 0).

Redundant line extension from separate substation (i,e Lekhanath substation) is also exercised in study. Lekhanath substation is near about 10 km far from PIE. Due to increase in length of feeder number of system component's increased which reduced the reliability of system by 1.79 % with other indices being poor than that of redundant line extension from Kudahar substation and problem of voltage drop is seen. In reality, redundant line extension from Lekhanath will have to face problem of right of way.

Suggested redundant line extension from Kudahar substation requires 1 km 11 kV overhead line, 2 numbers of HV breaker for sending end and receiving end, XLPE cable, synchronizer with ATS panel and other electrical accessories. The total modification cost is NRs.81,10,813.93 as indicated in Table 6. From the cost analysis outage cost reduces to 90.02 % from the base case. Furthermore, customer cost of reliability (modification cost added to outage cost) is NRs.98,84,732.98 which is less than outage cost of original distribution system. Finally, financial gain from implementing the suggested modification

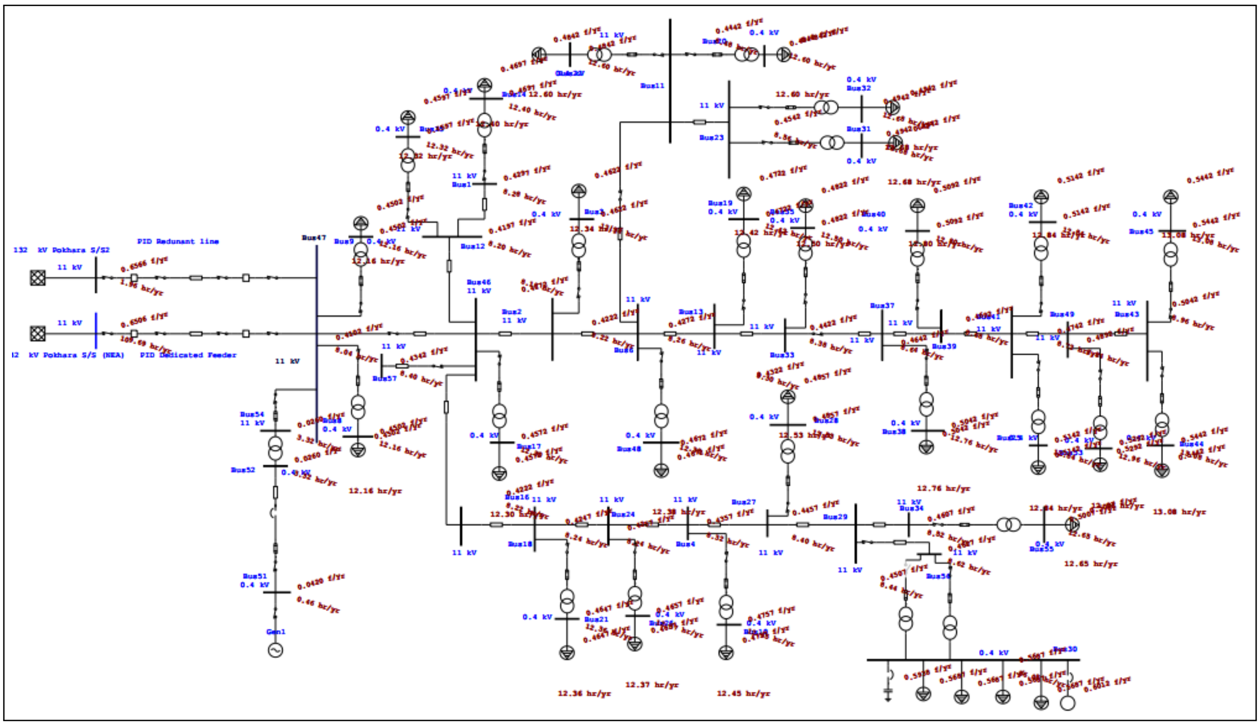

Figure 4: Simulated View of Feeder with Modification

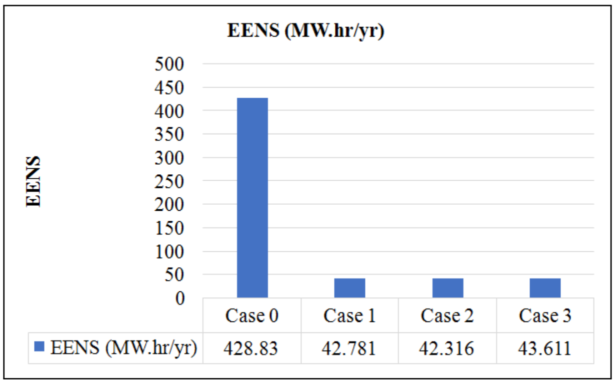

Figure 6: Graph of EENS

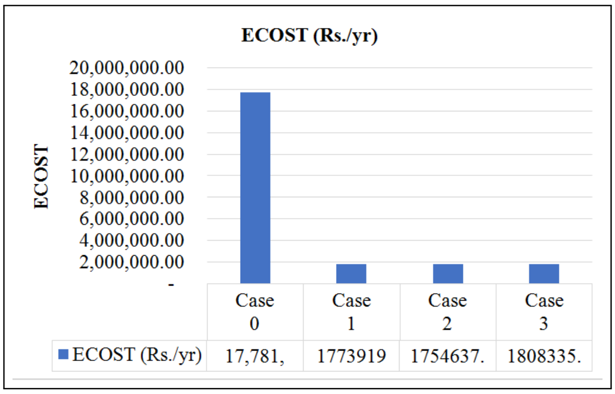

Figure 7: Graph of ECOST

options is NRs.78,96,751.89. Which is much more favorable than other modification options. Therefore, this suggested modification is recommended since it improves the reliability of the system and yields a significantly lower outage cost.

DG connection with grid line (Case 2)

In this modification, 1 MW diesel generator is suggested to connect with existing line to supply the power to critical plants(like Oxygen plants are more critical and sensitive for human being during second variant of COVID-19 pandemic, NEA officials have discussed for this option) in case of grid failure. This modification required 1.5 MVA DG unit, 1.6 MVA power transformer with other connection accessories. Due to high capital cost of DG unit and power transformer total modification cost is estimated as NRs.2,72,98,369.82. Therefore, implementing the suggested modification option will lead to financial loss of NRs.1,12,71,522.72 indicated -ve sign in Table 6 and downward bar in Figure 9. However, reliability indices are slightly better than case 1. Therefore, although this modification improves the reliability of system, it is not recommended yields financial loss.

Connecting 1 MW DG and adding redundant line

Modification suggests to connect 1.5 MVA DG set for critical load and adding a redundant line with original system. This modification requires all components of case 1 and case 2 altogether. The estimated cost of

Table 6: Summary of Estimated Modification Cost, Customer Cost of Reliability and the Financial Gains Compared to the Base Case

S.N	Equipment Description	Estimated total cost of units (NRs.)			
		Case 0	Case 1	Case 2	Case 3
1	1.5 MVA Diesel Generator		0	19,616,800.00	19,616,800.00
2	11 kV Distribution Feeder		1,367,213.49	166,481.09	1,533,694.58
3	240 Sq.mm XLPE Cable		1,084,800.00	420,360.00	1,505,160.00
4	1.6 MVA Power Transformer		-	5,056,750.00	5,056,750.00
5	630 sq.mm unarmored cable		-	374,538.50	374,538.50
6	HV Circuit breaker with ATS		5,550,560.00	1,157,120.00	6,707,680.00
7	Low Voltage Circuit Breakers		0	402,539.90	402,539.90
8	Disconnect Switchs		108,240.44	81,180.33	189,420.77
9	Drop Out Fuses		0	22,600.00	22,600.00
10	Total Modification Cost(NRs.)		8110813.93	27298369.82	35409183.75
11	Outages Cost (NRs.)(ECOST)	17,781,484.87	1,773,919.05	1754637.767	1808335.09
12	Customer Cost of Reliability(NRs.)		9,884,732.98	29,053,007.59	37,217,518.84
13	Financial Gain Compared to Base Case (NRs.)		7,896,751.89	- 11,271,522.72	- 19,436,033.97

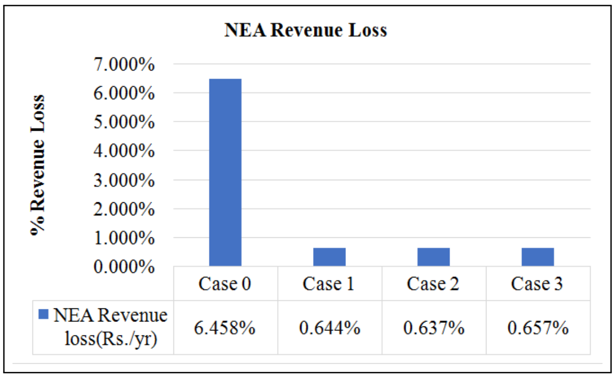

Figure 8: Graph of % of NEA Revenue Loss

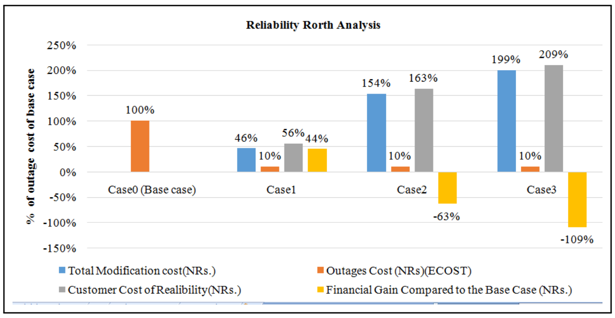

Figure 9: Graph for Reliability Worth Analysis of Modification Cases

modification is as indicated in Table 6. Reliability indices of this modification are not favorable than case 1 and 2. Therefore, it is not recommended for implementation because it yields financial loss.

4. Conclusion

Three method of cost of EENS calculation provides useful information to policy planner while determination of tariff. Production loss method estimated maximum level of customer outage cost, which can be interpreted as upper bound value on electricity tariff. Backup power generation method estimates indirect electricity rate gives lower bound on tariff with customer will to pay at marginal cost. WtP survey shows 59 % of customers are willing to pay in an average of 17.29 % higher tariff for improved supply. The estimated of cost of EENS is Rs.41.46/kWh which is significantly higher than current electricity prices. So, cost of EENS of PID feeder requires urgent need of reliability improvement of distribution system by feeder modification and reconfiguration. Reliability worth analysis of distribution system modification options provide important evaluation which reflects the overall benefits for utility and customers. The estimated cost of each modification option found customer cost of reliability and financial gain after implementing it. Research concluded that adding a redundant line with existing system from common grid substation yields better reliability with lower outage cost and financial gain of 44% with 90% reduction in EENS compared to base case, which is recommended for implementation.

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