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Reliability Assessment and Economic Impact on Utility (Case study of Adelle-Haramaya Distribution Substation)

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Abstract: High electrical power interruption is a major concern in Ethiopia. Most of the interruptions caused by the power distribution system. The paper identifies the main cause of the interruption, assesses the duration, frequency of power interruption, and indicates how much interruption influences the utility economically. To achieve the target, the steps to be completed are - secondary data like the cause of the interruption, duration, and frequency of interruption, number, and type of customer collected from the Adelle-Haramaya substation. The collected data evaluated based on IEEE guide electric power distribution reliability, compute the cost of loss in a system and identify how much the utility lost and this task done by E-TAP software. Distribution reliability indices assessment of Adelle_Haramaya the distribution system is, SAIFI, SAIDI, and ENS. The result of reliability indices against the benchmark is SAIFI, SAIDI and EENS are 15.5986 f/customer. Year, 379.4565 hr. /Customer. A year and 2,986.195MWh /year. The most annual outage duration and average interruption rate is Grawa feeder among other feeders which are 827.9941 hours/yr and 33.5360 f/yr respectively. This interruption shows, Adelle-Haramaya Distribution system is unable to satisfy the customers. The Adelle- Haramaya distribution system is lost 3,578,121.6 ETB or 63,263.7644 $ and it has a great impact on the economy what the utility expects to get. In fact, the assessment is done, what the utility is expected to lose. Regarding, Customer side's costs such as residential, commercial, and industry the customer survey method is recommended. Finally, the paper suggests three mitigation techniques in order to tackle the problem, providing reliable and good quality of continuous power to customers such as Design, security strategy, and Adequacy solution.

Keywords: Reliability Indices, Power distribution system, Utility, IEEE, E-TAP Software.

1. Introduction

A frequent power interruption a series of power problems for industries and the cities. Identify how much the utility lost due to the frequent interruption is put pressure on the utility used to improve the existing system. Assessment should do nationally to identify how the utility is lost economically due to interruption concerning the initial investment. Since the paper presents Adelle-Haramaya distribution system reliability assessment and pointing out lost economically in the utility. Suggesting the mitigation method is to address the problem is an essential issue to enhance the standard living of the population. [1] The paper describes the existed IEEE 13 bus radial distribution system which is converted to a ring and mesh network to identify the reliability indices. In the end, the renewable energy source integrated to ring and mesh networks to determine the performance of the networks. Another paper by [2] explains the evaluation of existing systems of Debre Tabor Town by distribution reliability indices and gives recommendations based on the performance evaluation. [3] The author of this paper presents some effective and simple measures to improve electric power distribution service continuity. The main goal is to evaluate the development and performance of the distribution networks through the study of characteristics and the analysis of service quality indicators. [4] The authors attempt to identify the cause of power interruption and the customer's dissatisfaction. Additionally, the author discusses design, maintenance, reliability, and operation finally distributed generation (DG) suggest by the researcher to ensure reliability improvement and it's used to increase the reliability worth. The paper [5] Presents, the comparison and performance of some reliability indices by an increment of load in an equal and unequal mode in every node. This is done by 33-node of the distribution network. The technique helps to find out a healthy mode of increment. So, the result shows a multiplying factor is suitable for the increment of load at various nodes. Finally, another paper [6] presents the distribution processing approach of the reliability index assessment of the distribution system. To achieve the target the paper proposed an unbalanced task partition approach to achieve better efficiency. This paper presents the main cause of power interruption, evaluate the existing system by IEEE guideline distribution reliability indices by using E-TAP software, determine how much the utility lost, and suggest mitigation technique to improve the existing system.

2. Material and Methods

2.1. Description of Study Areas

Haramaya (Alemaya) is an east town in east-central Ethiopia, which is located in the East Hararge Zone in the Oromiya Region; the town has a latitude and longitude of $9^0$24′N42^0 01′E with an elevation of 2047 meters above sea level. Haramaya city is the home to Haramaya University (formerly Alemaya University). Adelle is the main road to Harer and Dire Dawa. The center along that road is connected to Haramaya. Adelle- Haramaya substation has been supplied from the national grid. With the growth of cities, Haramaya University, which is a higher institution in

Ethiopia and high demand for electric power, supplying continuous electric power is the pressing task of the electric utility.

2.2. Reliability Assessment of Distribution Systems

The distribution system network of Adelle-Haramaya is feed 66KV from Harar Substation. This Adelle-Haramaya Substation has two power transformers which is step down to a corresponding voltage level. Each 15KV and 33KV voltage step down to 380V to end customers' which is shown in fig 1.

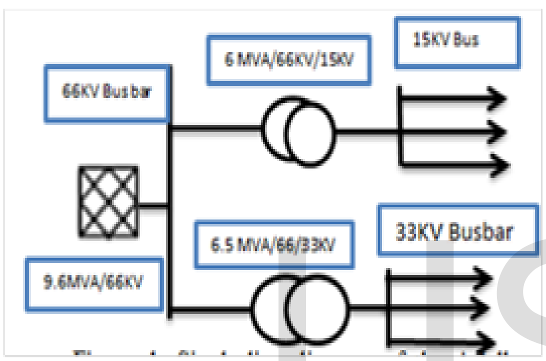

Fig.1. Single line diagram of the Adelle-Haramaya Distribution system.

2.3. The Reliability Indices

Distribution reliability primarily relates to equipment outages and customer interruption. In normal operating conditions, all equipment (except stand by) is energized schedule and unscheduled events disrupt normal operating condition and can lead to outage and interruptions [7].

To evaluate the reliability of distributed systems, two considerations are concerned, that is, the customer and the load based reliability indices. Improving customers' service reliability is always a major object. The customer's annual power supply duration, outage duration, failure rate, and degree of outage affection have all affected the distribution system reliability (Lin W, 2000). The distribution network is also the most important factor to influence the reliability of the distribution system. Generally, the reliability indices of the distribution system can be listed as follows [8]. The reliability of the power supply is assessed using known reliability indices. The indices for distribution system analysis include customer-oriented indices and load or energy-oriented indices as defined in the IEEE standard 1366 [9]. [10] [7].

2.3.1. Customer-Based Reliability Indices

The most widely used reliability indices are average that weights each customer equally. Customer-based indices are popular with regulating authority. Since a small residential customer has just as much as important as a large customer. They have limitations, but generally considered a good aggregate measure of reliability and are often used as reliability benchmark and improved targeting [7].

System Average Interruption Frequency Index (SAIFI) =

$$\frac{\sum Total\ Number\ of\ Customer\ Interruption}{Total\ Number\ of\ \ Customer\ Served}\ \frac{Intr.}{yr.cust.} \quad (1)$$

Where: SAIFI between 1 and 2.

System Average Interruption Duration Index (SAIDI) =

$$\frac{Customer\ Interruption\ Duration}{Total\ Number\ of\ \ Customer\ Served}\ \frac{hr}{yr.cust} \quad (2)$$

Where: - SAIDI between 1.5 and 3

Customer Average Interruption Duration Index (CAIDI) =

$$\frac{\sum Customer\ Interruption\ Duration}{Total\ Number\ of\ Customer\ Interruption}\ \frac{hr}{yr.cust} \quad (3)$$

Where: - CAIDI between 90 and 150 min

Customer Average Interruption frequency Index (CAIFI) =

$$\frac{\sum Total\ Number\ of\ Customer\ Interruption}{Customer\ experiences\ one\ or\ more\ Interruption}\ \frac{intr.}{yr.cust.} \quad (4)$$

2.3.2. Load Based Reliability Indices

Two of the oldest distribution reliability indices weight customers based on connected KVA instead of weighting each customer equally.

Average System Interruption Frequency Index (ASIFI) =

$$\frac{Connected\ KVA\ Interrupted}{Total\ Connected\ KVA\ \ Served} \quad (5)$$

Average System Interruption Duration Index (ASIDI) =

$$\frac{Connected\ KVA\ \ Hours\ \ Interrupted}{Total\ Connected\ \ KVA\ \ Served} \quad (6)$$

Energy is Not supplied Index (ENS) = $\sum_i^n Piri\ \frac{kwhr}{yr}$ (7)

Average Energy Not supplied Index (AENS) =

$$\frac{\sum_i^n Piri}{Ni} \quad \frac{kwhr}{yr.cust.} \quad (8)$$

Where: P - expressed in KW

Power - Outage Cost Utility: - The cost of energy not supplied due to interruption Adelle-Haramaya is computed by using equation below:-

$$(Cost\ of\ Energy\ =\ Power\ (KW)\ *Time\ (hr)\ *\ Tariff\ for\ /(KWhr) \quad (9)\ )\ [11]$$

For the, domestic and general customers category due to lack of demand metering, the current tariff comprising Energy charge (KWhr) is maintained. To promote energy conservation while ensuring tariff structure simplicity, the following three blocks energy tariff structure is suggested.

1st block, 0-50 KWh =0.40 Cents/KWhr

2nd block, 51- 150 KWh=0.90 Cents /KWhr

3rdblock above, 150 KWh = 1.40Birr/KWhr [12]

2.4. Data Collection of Distribution System

Data collection is done by secondary data collection of load interruption, frequency interruption, number, and type of customer of the existing Adelle-Haramaya distribution system.

The following input data of Adelle-Haramaya Distribution system is used to calculate reliability indices:-

TABLE 1
. DETAIL ONE YEAR (2018-2019) LOAD FLOW DATA OF 33 KV BUS BAR ADELLE- HARAMAYA SUBSTATION

Name of feeder	Max Load ((A)/MW)	Min Load ((A/MW)	MWhr	MVAR
Feeder (33KW)	157.57/3.909	46.219/1.165	2131.07	561.857
Haaqa (L1)	47.3571/0.798	17/0.272	361.571	41.5714
Grawa (L2)	49/1.238	17.148/0.421	703.7142	248.785
Harer water (L4)	75.785/1.867	22.5/0.496	754.785	178.7885

- Loading of Feeders
- Power interruptions (KVA)
- Frequency of interruption
- Duration of interruption in hours

Table 1 is shows the detailed loading of 33K V bus bar. Since 33KV bus bar this is fed from 66KV bus bar by step down. 33KV bus bar feeders are Haaqa (L1), Grawa (L2), and Harer Water (L4). From this feeder 33KV feeder and Harer Water (L4) since it is an industrial load type which is the highest loading among other feeders. The average loading expressed in terms of a maximum current, megawatt, and minimum current, megawatt.

TABLE 2
THE FAULT DATA FOR ONE YEAR (2018-2019) ON 33KV BUS BAR

Name of feeders	Time	TSC	PSC	T EF	PEF
Haaqa (L1)	F=7.14	F=0.78	F=2.48	F=0.85	F=3.785
	T=7.751	T=0.007	T=14	T=0.013	T=24.77
Grawa (L2)	F=9.5	F=3.642	F=4.571	F=1.35	F=3.214
	T=7.102	T=0.054	T=22.62	T=0.014	T=20.02
Harer water (L4)	F=1.714	F=0.928	F=1.214	F=1	T=1.142
	T=1.784	T=0.010	T=19.67	T=0.012	T34.97

Table 2 describes that faulty data for one year and four months of the feeders. Where TSC, PSC, TEF, PEF, F, and T are stands for Temporary Short Circuitry, Permanent, Short circuit, Temporary Earth Fault, Permanent Earth fault, Frequency, and Time respectively. Among the feeders, the most faulted feeder is Grawa (L2) in terms of frequency and time due to loading. Grawa (L2) is the highest outage compare with other feeders. Permanent short circuit (PSC) and the earth is high when compared to temporarily short circuit and earth fault.

TABLE 2
DETAIL ONE YEAR (2018-2019) LOAD FLOW DATA OF 15 KV BUS BAR ADELLE- HARAMAYA SUBSTATION

Name of feeder	Max Load ((A)/MW)	Min Load ((A/MW)	MWhr	MVAR
Feeder (15KW)	55.21/2.87	11.57/0.545	-	-
HU (L2)	33.21/1.626	7.857/0.387	-	-
Bate finkile (L1)	8.071/0.3667	7.857/0.387	-	-
Harer water (L4)	28.8571/-	4.07/0.211	-	-

TABLE 4
THE FAULT DATA FOR ONE YEAR (2018-2019) ON 15KV BUS BAR.

Name of feeders	Time	TSC	PSC	T EF	PEF
Bate finkile (L1)	F=10.28	F=4.925	F=6.857	F=0.85	F=1.857
	T=6.102	T=0.062	T=26.39	T=0.008	T=11.71
HU (L2)	F=2.357	F=7.928	F=4.071	F=0.928	F=0.5714
	T=1.314	T=0.07	T=6.1372	T=0.012	T=0.32
Harer water (L4)	F=18.42	F=2.785	F=4.5	F=3.5	F=3.428
	T=11.20	T=0.042	T=16.35	T=0.057	T=15.98

Tables 3 indicate the maximum and minimum loading of 15KV side distribution feeders. The feeders are Haramya University (L2), Bate Finkile (L1), and Haramaya City (L4). Among this feeder 15KV and Haramaya University has the highest loading based on, one year and four month's data.

Table 4 shows that the fault data for one year and four-month data of feeders. Where TSC, PSC, TEF, PEF, F, and T are stands for temporary short circuit, permanent, short circuit, temporary earth fault, permanent earth fault, frequency, and time respectively. Among the feeders, Haramaya city (L4) is faulted feeder when we compared to others feeder. Permanent short circuit and earth fault are high for all feeders when we compare to temporarily short circuit and earth fault.

Discussion and Simulation Results

A distribution system of Adelle-Haramaya Substation, which is incoming 66KV fed from the Harare III substation. This 66KV is stepping down to 33KV/6.5MVA and 15KV/6MVA respectively. Each bus bar (they are 33KV and 15KV) has three feeders respectively, which is shown in Fig. 2.

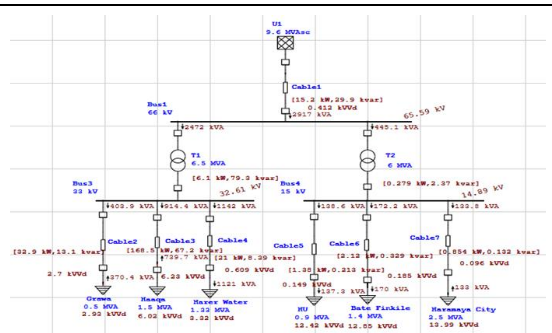

Fig .2. Load flow of Adelle-Haramaya Substation

Load flow analysis was done by the method of the Newton Raphson method and the maximum number of iterations is 99.999. The precision of the solution is 0.000100 and the system frequency is 50HZ. Since the simulation load flow is used in this paper to know the loading of each feeder and the component which is shown in fig .2.

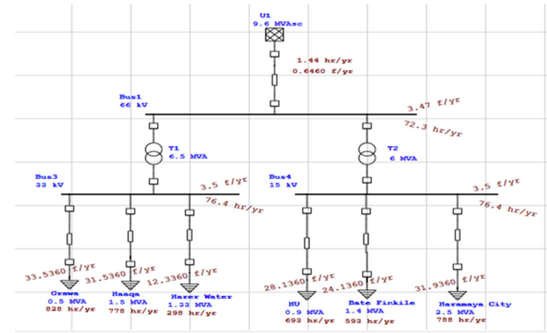

Fig.3. Reliability indices of the Adelle-Haramaya Distribution System

Fig.3. diagram simulation results show Average Interruption Rate and Average Outage Duration. Regarding simulation result 1.44 f/yr and 0.6460 hr/yr which is the lowest Average Interruption Rate and Average Outage Duration in a year respectively, which is an incoming feeder from the national grid to the Adelle-Haramaya Distribution System. According to the input data, the Grawa is the most interrupted feeder among other feeders. Due to that, the result shows the most outage feeders are Grawa feeder which is 33.5360 failures/year, and the maximum time Average Outage Duration is 828 hr/yr. Since Haramaya University (HU) is one of the biggest institutions powered from this substation and Average Interruption Rate is 28.1360 f /yr and Average Outage Duration is 693hr/yr.

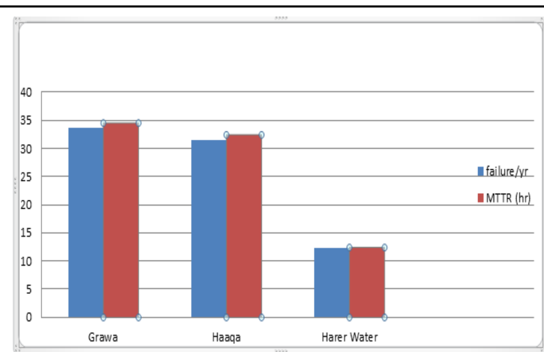

Fig .4. 33KV Bus bar of Active failure rate and Meant Time to Repair

The graph shows a 33KV bus bar of Active failure rate and Mean Time to Repair. Since, 33KV bus bar having three feeders, they are grave, Haaqa, and Harer Water. Among these feeders, Grawa is the most failure rate in a year, and the meantime to repair an hour is close to the Haaqa. The Grawa feeders during the practical inspection, it is interrupted daily 3 to 4 times. The lowest interrupted feeder among these feeders is a Harar Water feeder and the meantime to repair is lowest.

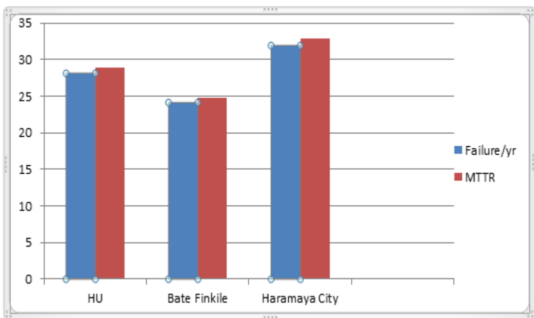

Fig 5. 15KV Bus bar of Active failure rate and Mean Time to Repair

TABLE 6

LOAD POINT OUTPUT REPORT OF ONE YEAR.

Name of feeders	Average Interruption Rate (f/yr)	Average Output Duration (hr)	Annual Output Duration (hr/yr)	EEN (MWh
Haramaya University (HU)	28.1360	24.63	692.9941	98.31
Bate finkile	24.1360	24.57	592.9941	104.7
Haramaya city	31.9360	24.67	787.9941	107.4
Grawa	33.5360	24.69	827.9941	373.1
Haaqa	31.5360	24.67	777.9941	897.9
Harer water	12.3360	24.16	297.9940	354.9

According to Fig 5, 15KV bus bar consists of three feeders which are Haramaya University, Bate Finkile, and Haramaya City. Among the feeders, Haramaya city is the most interrupted feeders and in fact, Haramaya Institute of Technology is one of the institutes from Haramaya University it is connected with Bate finkile feeders, due to that most of the time the institution is interrupted and the utility lost economically by these feeders. Bate finkile feeders are one of the lowest interruptions that take place among other feeders and the meantime to repair hours from the interruption is the different for all feeders.

TABLE 7

SUMMERY SYSTEM INDEX

System Index	Value
SAIFI (System Average Interruption Frequency Index)	15.5986 f/customer.yr.
SAIDI (System Average Interruption Duration Index)	379.4565hr/customer.yr.
EENS (Expected Energy Not Supplied)	1049.579 MWhr/yr.
CAIDI (Customer Average Interruption Duration Index)	24.326hr/customer. Inte
ASUI (Average Service Unavailability Index)	0.04332pu
ASAI (Average Service Availability Index)	0.9567pu
AENS (Average Energy Not Supplied)	174.9298MWhr/Custon

Table 6 describes the load output report data for each feeder in terms of Average Interruption Rate, Average Outage Duration, Annual Outage Duration, and Expected Energy Not Supplied. Among the feeders, the lowest ENS is Haramaya University which has to have the value is a 98.3133 MWhr / Yr and the feeder having the highest EENS value is a 897.9225 MWhr / Yr, the name of the feeder is Haaqa. Since expected energy is not supplied to the consumer it has an economic impact on the utility. So, the paper identifies the expected energy not supplied to the consumer in term's cost and puts pressure on the utility combat problem and suggesting the technique to address the issue.

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Table 7 shows the general reliability index of Adelle-Haramaya Substation. Regarding the reliability index, the existing reliability index is high when compared to the benchmark. The benchmark value for the first three indexes is SAIFI 1 and 2, SAIDI 1.5 and 3, and CAIDI 90 and 150 minutes. So that the existing system values for SAIFI 15.5986 f/customer year, SAIDI 379.4565 hr/Customer. A year and CAIDI 24.32 hr/Customer

TABLE 9

LOSS OF UTILITY IN TERMS OF COST SUMMARY OF EACH FEEDER, SYSTEM AND BUS

No.	Name of feeder	EENS (MWhr/yr.)	EENS (KWhr/yr.)	Cost (ETB)
1.	Haramaya University (HU)	98.3133	98,313.3	88,481.97
2.	Bater finkile	104.7132	104,713.2	94,241.88
3.	Haramaya city	107.4983	107,498.3	96,745.47
4.	Haaqa	897.9225	897,922.5	1,257,091.5
5.	Harer water	354.9908	354,990.8	496,98.12
6.	Grawa	373.1779	373,177.9	522,449.06
7.	System	1049.579	1,049,579	1,469,410.6
Total		2986.195	2,986,195	3,578,121.6

Interruptions. Form comparatives against the benchmark the utility have a lot of responsibility to minimize the gap against the benchmark.

In table 8 different country's reliability indices comparison showed. Some of the countries like Australia and Germany are within a range of benchmarks. Ethiopia, particularly Adelle- Haramaya distribution system, the value is very high when compared to the benchmark. So, a lot of tasks and mitigation techniques should be applied to the distribution system to address the problem. This gap is pressuring that the utility to take responsibility.

According to table 9 the Utility lost 3,578,121.6 ETB. for one year from Adelle-Haramaya Distribution System. This amount of money the utility lost due to power interruption. Most of the feeders, particularly the Grawa feeder, four times interrupted per day. But, the cost of system and bus feeders higher than among other feeders. The cost is computed by using the normal tariff scale of Ethiopian Electric Utility. This is a great economic impact on the utility. The utility expected to supply continuous and reliable power to customers to get profit. But, when we compare to initial investment cost to generate electrical power and distribute electric power to demand , running costs during supply electric power to consumer it should be assess as national level and particularly in the distribution system side to bring utility economical. So further research is suggested on the Ethiopian Electric utility (Distribution side) as compare as Ethiopian Electric Power investment. To answer the question assessment will be done as a nation. In fact our investment is hydropower. Generally Outage or interruption cost can be classified into direct and indirect cost. 1) direct cost are cost which is related with power interruption such as, loss of industrial production, spoiled food or raw material, hospital (loss of life) and university. 2) Indirect cost is related to impact which is raised from response to the power interruption. Such as, short term (Black out which is leads to crime and political devastation) and long term (related economic). Up to date, the customer survey method commonly used in utility. [13].

3. Conclusion

The reliability indices assessment of Adelle-Haramaya distribution system simulation results is SAIFI 15.5986 f/customer year, SAIDI 379.4565 hour/customer year, and EENS 1049.579 MWhr/year. The most annual outage duration and average interruption rate is Grawa feeder among other feeders which are 827.9941 hr/yr and 33.5360 f/yr respectively. This shows that the utility unable to supply a huge amount of power to the customers. The utility lost yearly from energy in terms of cost is 63,263.7644 $ or 3,578,121.6 ETB. This amount of money, which is lost by the utility, which is expected to get from the customers. Regarding to customer side cost such as, residential, commercial and industry the customer survey method is recommended. To address the above problem and

TABLE 8

SUMMARY OF COMPARISON OF RELIABILITY INDICES FOR DIFFERENT COUNTRY

Country	SAIFI (f/customer.yr.)	SAIDI (hr/customer.yr.)	Frequency (
United States	1.3	1	60
Australia	0.9	1.2	60
France	1.0	1.03	60
Germany	0.5	0.383	60
Italy	2.2	0.967	60
Spain	2.2	1.73	60
UK	0.8	1.5	60
Ethiopia	20	25	50
Adele Haramaya (Ethiopia)	15.5986	379.4565	50

providing continuous, reliable, and good quality power to the customers the paper suggests three mitigation techniques. They are (i) Design solution is done by enhancing the existing system of distribution cable and transformer. For the design, distribution system all material and equipment should meet international and national standards. (ii) Security Strategy Solution implements by improving operation, maintenance, and automation. Due to increasing dependency on electricity and sensitivity of loads in all customer sectors (residential, commercial, and industrial) the utility is expected to strive to maximize reliability to ensure that the customer requirement is satisfied economically. (iii) Adequacy solution is the incorporation of existing distribution with renewable energy. Increasing load demand in comparison with the present generation, load shading, and power interruption, integration with renewable energy is the best solution. To meet the demand and tackle the problem, the optimal site place has a great concern. Finally, the paper selects Adequacy's solution to address the root cause of the problem and supply continuity, reliability, and quality of power economically to the customer for further work.

4. Abbreviations

DG = Distribution Generation

ETB = Ethiopian Birr

E-TAP = Electrical Transient Analysis Program

IEEE = International Electrical and Electronics Engineering.

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