Evaluation Of Reliability Indices and Capability Outage Table for An Organised Off-Grid Community

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Abstract- This paper analyzes the reliability of an off-grid electricity supply system for an organized community using the Redemption Camp along the Lagos-Ibadan Expressway, Nigeria, as a case study. The community, with 13,500 customers, has its distribution network divided into six zones. The study identified Zone 6 as the most critical zone, contributing 37.20% to the total system outage duration (SAIDI) but having a minimal impact (5.72%) on its own zone users. Conversely, Zone 3 had the lowest SAIDI (7.23%) but the highest customer average interruption frequency (CAIFI) of 30.19%. Outage impact: The total community outage in 2022 amounted to 911,938 kWh, equivalent to $155,029.4 annually, representing 5.08% of the system's total operation and maintenance cost. Overall, this study provides insights into the variability of reliability indices across different zones within an off-grid system. These findings can be valuable for planning and prioritizing infrastructure improvements to enhance the overall reliability and cost-effectiveness of such systems.

Indexed Terms- Reliability Indices, Off-grid system, Levelized Cost of electricity, Capability Outage probability table, Outages.

SAIFI	*System Average Interruption Frequency Index*
CAIFI	*Customer Average Interruption Frequency Index*
SAIDI	*System Average Interruption Duration Index*
CAIDI	*Customer Average Interruption Duration Index*
ASUI	*Average Service Unavailable Index*
ASAI	*Average Service Available Index*
AENS	*Average Energy Not Supplied*
ACCI	*Average Customer Curtailment Index*

I. INTRODUCTION

In developed countries, electrical power is such a basic amenity that many things cannot survive when it is down for minutes. Many processes and plants solely depend on

the grid of that supplier, and for years, that redundancy of power was placed in place for maintenance in some places while other places usually announced their maintenance periods to their consumers of power systems. This had in one way greatly contributed to developing their countries by boosting their economies, attracting investors and businessmen to locate their businesses and industries, leading to industrialization, and thereby increasing the Gross Domestic Product (GDP) and per capita income in the countries. Many electricity distributions company are only after the profit that will be generated on the investment, there by running a porous distributions network, a network which is expose to several system interruptions for a large duration of time, which in turn come back come back as losses to the investors. It is also worthy to note that user of electricity varies from residential user to industrial, in a case where the later require a constant power, it will be difficult for them to settle down with unreliable distributions, hence, they will rather site their company in a more reliable environment or select options of power supply. [2] looked into the performance study and analysis of an inclined concentrated photovoltaic-phase change material system. They investigated the performance of photovoltaic-phase change material (CPV-PCM) across -45° to 90° in an interval of 45°, with material phase changes of 50 and 200mm and concentrated ratios of 5 and 20 considered. After numerical modeling and simulations, the result showed that the

CPV-PCM inclined angle has a significant effect on the time to reach its complete state. an appreciable reduction of the mean solar cell temperature as the inclined angle moves from 0° to 90°.

[9] critically look into Yearly energy performance of a photovoltaic-phase change material (PV-PCM) system in a hot climate in the United Arab Emirate. This study was used to evaluate the savings cost of PV using a paraffin base (PCM) at high temperatures ranging from 38 to 43 degrees. Two-dimensional numerical modeling of heat transfer was used to simulate the cooling of the PV by the PCM. Economically, there was an additional 13.5 kWh/m2 energy surplus, which gives 2.2 dollars/m2 when compared to international electricity like that of Germany at 0.15 Euro/kWh.

[1] looked into Demand Side Management Strategy for Alleviating Power Shortages in Nigerian Power System: A Case Study, this paper analyse the frequency of the outages in Nigeria distributions network, which the unplanned and planed outages were taking into considerations, the maximum demand load and electricity supply from November 2017 to October 2018 data were collected for this research purposes, binary particle swarm optimizations (BPSO) was use to carry the optimizations while the modelling was carried out using Simulink, the result of this findings shows that the outages in the target area, can be improve from 63.38% or 36.62% in the existing the distribution network, to 14.08% in the proposed network also matchup the 11kv feeder to twenty-four hours from previous twelve hours power supplied.

II. RELIABILITY INDICES

The reliability of an electricity sector or system is the measure of the availability of electric power in the system; that is, for a reliable network, there is constant electric power in the community 24 hours a day, 365 days a year. For electricity to be this reliable, the probability of its availability must be 100%. For a reliable electricity network, maintainability must be apt, properly planned, and executed with high efficiency in order to reduce downtime. In this research work, the network reliability indices will be considered. The reliability indices are the quantitative assessment or analysis of the network. The community under study has about 13,500 customers which was divided into six zones and is focused on supplying all the energy demand by customers throughout the day and year. When power outages occur, they affect all the customers and last from 30 minutes to 1 hour, depending on the cause.

The operation record was obtained from the community, whose data were used to calculate the reliability indices. The data obtained were used to calculate the following eight reliability indexes: SAIFI, CAIFI, SAIDI, CAIDI, ASUI, ASAI, AENS, and ACCI. For this community.

$$SAIFI = \frac{\Sigma\lambda_i N_i}{N_T} \quad (1)$$

$$CAIFI = \frac{\Sigma\lambda_i N_i}{N_{af}} \quad (2)$$

$$SAIDI = \frac{\Sigma r_i \lambda_i N_i}{N_T} \quad (3)$$

$$CAIDI = \frac{\Sigma r_i \lambda_i N_i}{\Sigma \lambda_i N_i} \quad (4)$$

$$ASUI = \frac{\Sigma r_i N_i}{N_T.8760} \quad (5)$$

$$ASAI = \frac{N_T.8760 - \Sigma r_i N_i}{N_T.8760} \quad (6)$$

$$AENS = \frac{\sum E_{nt}}{\sum N_T} \quad (7)$$

$$ACCI = \frac{\sum E_{nt}}{\sum N_{af}} \quad (8)$$

III. CAPABILITY OUTAGE PROBABILITY TABLE (COPT)

This is one of the reliabilities that are always used to evaluate reliability of outage in a power system, this usually use binomial distribution expansion to evaluate the data. See equation

$$P_r = nC_r p^r q^{n-r} \quad (9)$$

Where;

$$nC^r = \frac{n!}{(n-r)!r!} \quad (10)$$

$$(p+q)^n = 1 \quad (11)$$

Unit 1 = 5 MW; Unit 2, 15 MW, Unit 3 = $\sum_0^{20} x$ MW (Variable Renewable Source),

Since we have 3 units (n);
Therefore;
Then, the number of combinations $= 2^n = 2^3 = 8$

Assumptions:
Logic 1 = Available; Logic 0 = Unavailable; Probability of Availability p = Average Service Availability index (ASAI); Probability of Unavailability q = Average Service Unavailability index (ASUI); and p = 0.983733; and q = 0.016267.
Kindly see table 2 for the system capability outage probability table (COPT);

IV. RESULTS DISCUSSION

After successfully obtaining numbers of results from the analysis we will be considering the eight reliability indices across the five zones of the community, kindly see table 1 for the reliability indices of the community.

Table 1. Reliability Indices of the Community.

	Zone 1	Zone2	Zone 3	Zone4	Zone5	Zone6
SAIFI	0.18519	0.11237	0.08052	0.19556	0.12489	0.41385
CAIFI	0.07	0.12261	0.180313	0.075	0.115065	0.034187
SAIDI	0.0003	0.000494	0.00069	0.000284	0.000445	0.000134
CAIDI	0.00162	0.0044	0.008569	0.001453	0.003562	0.000324
ASUI	0.01498	0.01593	0.01678	0.01695	0.01661	0.01635
ASA1	0.98502	0.98408	0.98322	0.98305	0.98339	0.98365
AENS	10.9375	10.76389	9.074074	9.625	11.67593	15.47454

A. System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Frequency Index (CAIFI)

These indices show the impact of frequent interruption on the system and customers, SAIFI shows the number of times the community electric power system gets interrupted across all six zones. This index reflects the interrupted customers (zones) against the total customers served in the network. The data in Table 1, confirmed that zone 6 has the highest SAIFI, followed by zone 4. Meaning that an outage in only zone 6 is about 37.20% of the total distributions, which is very important zone in the network unlike zone 3 of the same network which an interruption will only affect about 7.23% of the users.

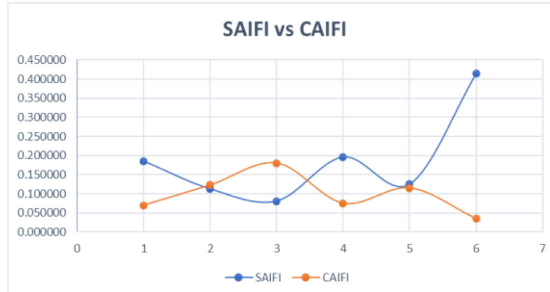

Figure 1 SAIFI vs CAIFI

CAIFI shows how much interruption each zone is exposed to; that is, it is the function of the numbers of interruptions in each zone per the customer interrupted in that zone. Without dwelling too much on it, table 1 clearly shows that zone 3 was definitely exposed to the highest number of interruptions which is about 30.19% unlike zone 6 which only 5.72% of the customers were affected. Considering figure 1, it is clearly shown that the interruptions in zone 6 have minimal effect on the customer of 5.72%, but with a significant effect of the toral utility network with 37.20%. With an inverse effect on zone 3, where the customers were exposed to highest interruptions of 30.19% but with minimal effect on the system m with 7.23%.

B. System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI)

These reliability indices show the effect of period of outage on both the system and customers, SAIDI helps to reflect the durations of the outages that affected the customers across the zones; that is, this is the function of the duration of the outages to the numbers of customers served for each zone.

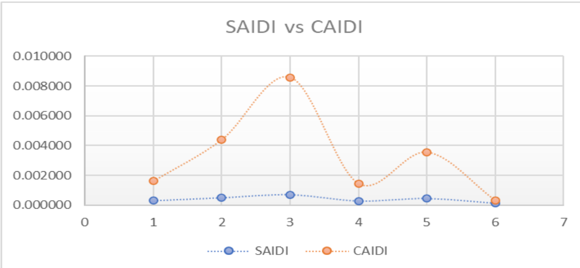

Figure 2 SAIDI VS CAIDI

From table 1. it is clearly shown that zone 3 which the highest effect on the system with about 29.40% and zone 6 which have the minimal effect on the system with 5.71%.

CAIDI shows the effect of the period of outages on the affected customers, as this is primarily the function of the durations of interruptions to the customers interrupted across each zone, which is invariably the same as the ratio of SAIDI to SAIFI of the same community and zones. For this research, zone 3 has the highest effect on the customer with 43.0%, invariable zone 6 has the lowest effect of 1.62% on the customer. Picturing the figure 2, it can be concluded that SAIDI and CAIDI have the highest effect on zone 3 and minimal effect on zone 6,

C. Average Service Unavailable Index (ASUI) and Average Service Available Index (ASAI)

These indices concentrate on the availability hours of energy to the customers, that is, ASUI is the ratio of the total customer hour of service unavailable to the total number of customer hours of service demand across the zones likewise ASAI this is the ratio of the total customer hour service available to the total number of customer hours service demand across the zones

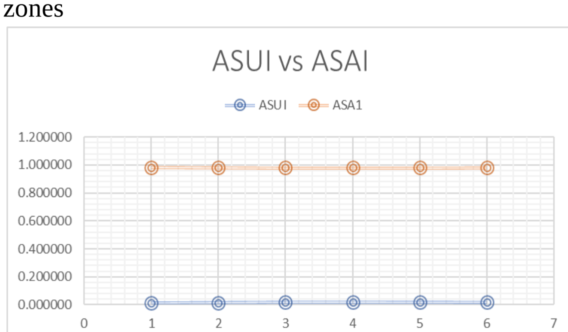

Figure 3 ASUI VS ASAI

Figure 3. clearly shows that zone 4 has the highest ASUI with 17.37% and lowest ASAI 16.65% also, zone 1 has the lowest ASUI with 15.35% and highest ASAI with 16.69%.

D. Average Energy Not Supplied (AENS) and Average Customer Curtailment Index (ACCI)

AENS helps to show the average quantity of energy not supplied to customers across the year; that is, this is the ratio of the total amount of energy not supplied to the total number of customers served in all zones. Likewise, ACCI helps to show the average quantity of energy not supplied to the affected customers across the year; that is, this is the ratio of the total amount of energy not supplied to the total number of affected customers served across all zones. Figure 4, clearly shows that zone 6 has the highest average unsupplied energy with 22.91%, this same zone has lowest ACCI of 8.35%, while zone 3 has the minimum average unsupplied energy with about 13.43% and highest ACCI of 25.18%.

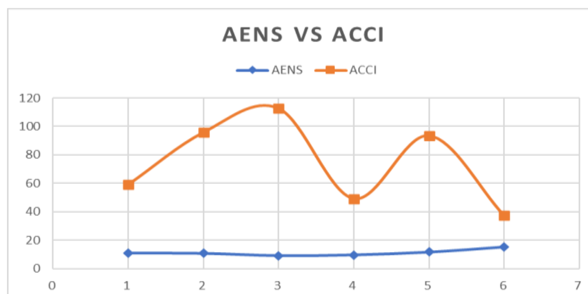

Figure 4 AENS VS ACCI

SN	Unit 1 (5 MW)	Unit 2 (15 MW)	Unit 3 (0~20) MW	Availability Capacity (MW)	Outage Capacity (MW)	Individual Probability Pr
1	0	0	0	0	20	0.000265
2	0	0	1	20	0	0.983733
3	0	1	0	15	5	0.016002
4	0	1	1	20	0	0.967731
5	1	0	0	5	15	0.0160

						02
6	1	0	1	20	0	0.9677 31
7	1	1	0	20	0	0.9677 31
8	1	1	1	20	0	0.9677 31

Table 2, Capability Outage Reliability Table

CONCLUSION

After thorough evaluation, it was deduced that the interruption in the year 2022 amount to 911,938 kWh which is $ 155,029.4 per annum in monetary value, this amount is about 5.08% of the maintenance cost, consistent outage is not good for the investors, because this will reduce the return of the investment invariably increase the payback period, many industries will not be able to rely on unreliable network for their machine. Hence, they will look for an alternative source or relocate the factory. Hence, unreliable network is not good for the both parties.

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