Electric Power Distribution Network Performance Assessment Based on Reliability Indices

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Abstract – *This paper assessed the performance of a selected 33 kV electric power distribution network within the Western region of Ghana which is one of the ten geographical regions of the country. Reliability indices were computed for the performance assessment of the electric power distribution line outages. A total of 2929 outages were recorded for the selected electric power distribution line routes within the region. The historical outage data used for the performance assessment was obtained from the regional office of the Electricity Company of Ghana (ECG). The ECG regional office is in-charge of operation and maintenance of all electric power distribution networks within the Western region of Ghana. The performance assessment was carried out by computing the mean-time-to-failure (MTTF), mean-time-to-repair (MTTR) and other reliability indices.*

Key Words: **Electric power distribution network, Reliability indices, Mean-time-to-failure (MTTF), Mean-time-to-repair (MTTR), Availability (A), Unavailability (U), Failure rate (λ), Repair time (r) and Outage frequency (f).**

1. INTRODUCTION

The definition of a power system includes a generating, a transmission and distribution systems. The basic function of a power system is to supply its customers with electrical energy as economically and as reliably as possible [1, 2]. Electric power distribution networks are responsible for delivering the electrical energy from the bulk power systems to the end users. Issues such as radial operating status, aging infrastructures, poor design, operation practices and high exposure to environmental conditions have caused electric power distribution networks to be addressed as the main contributor to the customer reliability problems. Generally, about 90 percent of the customer reliability problems do originate from the electric power distribution networks. Therefore, the challenge for electric utilities, especially in the competitive electricity market, is to identify and evaluate potential reliability reinforcement schemes and then determine and prioritise those appropriate for implementation [3]. A core mission of an electric power distribution network is to deliver electrical energy from the supplying points to the end users without any interruption. The electric power distribution network segment has been the weakest link between the source of supply and the customer load points. The greatest problem encountered in the area of electric power distribution network operation and maintenance is how to reduce the number of outages experienced by customers [4]. The electric power distribution network is an important part of the electric power system, the proportion of investment accounts for about 40% of the entire power grid investment, especially the urban distribution network [5]. The many associated unplanned outages affect everyone namely, households, businesses, industries and so on. Electric power distribution networks constitute the greatest risk to the interruption of power supply. It has been reported in many technical publications that 80% of all customer interruptions are due to failures in the electric power distribution networks [6]. Electric power distribution networks are highly complex and contain a large number of connections and components. These components account for almost 40% of all power systems infrastructure [7].

2. RELATED WORKS

[8] carried out a study on 11 kV distribution network of Ado-Ekiti in Nigeria. The condition of all relevant equipment for power distribution at the 11 kV level was assessed. Power availability was also considered by collecting necessary data that had to do with energy supplied, faults and other outages. The study revealed that the distribution lines were in a rather poor state with as many as 25% of the poles not meeting a condition of "goodness", 33% of cross-arms being broken or unsatisfactory, about 10% of the insulators defective and almost 40% of the span not complying with standards. The analysis of the performance of the medium voltage (MV) electric power distribution network operated by Cameroon's AES-SONEL company was carried out in [9]. The results indicated that losses were very high as result of improper distribution of generated energy to consumers as well as long outage durations due to long time spent in

searching for faults to be restored. Real-time diagnosis of faults on AESSONEL's electric power distribution network was proposed to curtail unnecessary outage durations. The reliability indices were determined for industrial and urban feeders to assess their performances in [10]. The results of the reliability analysis of the two electric power distribution feeders was compared to benchmark the performance and operation of the power distribution network. The result indicated that interruptions have a negative impact on economy due to associated cost of interruptions. The analysis of the outages on the selected 33 kV feeders of the electric power distribution network in Maiduguri, Borno state, Nigeria was carried out by [11]. The analysis was based on monthly outage data collected for a period of about two years (2008 to 2009). The type, number and duration of the outages were identified. The result indicates the outages are mainly due to ageing of equipment, lighting, vandalisation and poor maintenance culture. [12] assessed the performance of 33 kV Kaduna electricity distribution feeders by computing the reliability indices using analytical method based on historical outage data. The results showed that the closer the value of MTTF is to MTBF, the longer the service hours and the shorter the outage durations. Therefore, by minimising the value of MTTR, the service hours can be increased thereby increasing overall system performance. More recently, [13] used the analytical method of electric power distribution reliability analysis in assessing the reliability of Ekpoma electric power distribution network of Edo State in Nigeria. They concluded that majority of service interruptions that affect customers were caused by problems in the electric power distribution network. A system modelling and simulation study was carried out on one of Bhutan's electric power distribution systems which consisted of 33 kV and 11 kV using analytical technique. The reliability assessment was done on both 11 kV and 33 kV system to assess the performance of the present electric power distribution system and also predictive reliability analysis for the future system considering load growth and system expansion in [14]. [15] quantified and predicted the impact of adding new components to an electric power distribution system using analytical technique. Reliability analysis was conducted for each component such as Miniature Circuit Breaker (MCB), Moulded Case Circuit Breaker (MCCB) and other different components by calculating failure and repair rates individually on yearly basis by [16]. These calculations were done for electric power distribution system at Balanagar facility which consisted of three phase and single phase loads. Customer and load-oriented indices of the overall electric power distribution system were predicted from load details, failure rates and unavailability for each feeder line using cut set method.

3. TYPES OF FAULTS IN ELECTRIC POWER DISTRIBUTION NETWORKS

An important objective of electric power distribution network is to maintain a very high level of continuity of service, and when abnormal conditions occur, to minimize the outage times. It is practically impossible to avoid consequences of natural events, physical accidents, equipment failure or mis-operation which results in the loss of power or voltage dips in the electric distribution power network. A power system fault is defined as any failure which interferes with the normal current flow. A fault occurs when there is a discrepancy between the reference value and the measured value for any given network parameter. A fault occurring anywhere within the electric power distribution network could lead to a local or system wide outage. The fault phenomenon affects network's reliability, security, and energy quality, and can be considered stochastic. When faults occur in the electric power network, they usually provide significant changes in the system quantities like over-current, over or under-power, power factor, impedance, frequency and power or current direction.

Different events such as lightning, insulation breakdown and trees falling across lines are common causes of faults in electric power distribution networks. Power system faults in general, may be classified as temporary or permanent. Temporary faults in overhead lines are usually caused by lightning. In this case, system service can be automatically restored after approximately 20 fundamental frequency cycles, with the circuit breakers opened, to allow deionization. However, permanent faults are associated with different events, like trees falling across lines. For these situations, system restoration is maintenance crew dependent. Facility maintenance crew must search and repair the fault. Natural events can cause short circuits, thus, faults which can either be single phase to ground or phase to phase or phase to phase to ground or a three phase fault. Most faults in an electric power distribution networks are single-phase to ground faults caused by lightning induced transient high voltages and from falling trees. In the overhead lines, tree contact caused by wind is a major cause for faults. The appropriate percentages of occurrences of various line faults and the contribution of fault incidents by each component in a power system to its failure are given in Table 1 and Table 2 respectively [17, 18, 19].

Table 1 Types of Faults and their Occurrence Rates

S/N	Type of Fault	Occurrence Rate (%)
1	Single line to ground fault	70 - 80
2	Line-Line to ground fault	10 - 17
3	Line-Line fault	8 - 10
4	Three phase	2 - 3

Table 2 Types of Components and their Rates of Contribution to Electric Power Distribution System Failure

S/N	Type of Component	Fault Incident Rate (%)
1	Cables	10
2	Switch gears	15
3	Transformers	12
4	Current and Voltage Transformers (CTs and VTs)	2
6	Control Equipment	3
7	Miscellaneous	8

4. RELIABILITY PERFORMANCE ASSESEMENT

Modern day society would like electrical energy to be continuously available on demand. However, it is not technically or economically feasible to plan, design, construct and operate a power system that has zero likelihood of failure. A basic objective, therefore, is to satisfy the system load requirements as economically as possible and with a reasonable assurance of continuity and quality. Reliability describes the ability of a system

or component to perform its required functions under stated conditions for a specified period of time [0, t]. No failure is allowed for the entire time interval. It is a function of failure probabilities and operating time interval.

Reliability assessment is very important in today's deregulated utility environment. Customers are demanding high level of service and desire the lowest possible cost. In order for utilities to remain competitive, they need to maintain high level of reliability while keeping the capital as well as operation and maintenance cost at the barest minimum [20]. The concept of power-system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There are two aspects of system reliability namely, system adequacy and system security as shown in Figure 1.

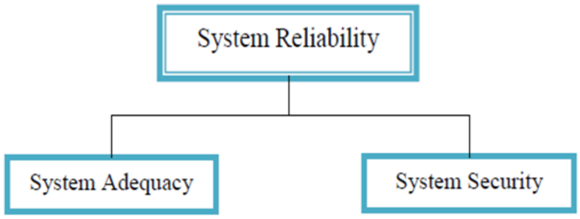

Figure 1 Aspects of System Reliability

Adequacy refers to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. Security refers to the ability of the system to respond to disturbances arising within that system. Most of the probabilistic techniques presently available for power-system reliability evaluation are in the domain of adequacy assessment [21]. To evaluate the reliability of a system, a mathematical or graphical model of the system is used and designed to reflect its reliability characteristics. The models can be either analytical or simulation. Analytical models represent the system by a set of exact or approximate mathematical models and evaluate the reliability based on this mathematical representation of each state. The Markov model is one of the popular analytical techniques to evaluate the reliability of the power system. All transition rates between the states are assumed, making it possible to evaluate the steady-state probability of the states. The Markov chain is also one of the best models that can represent the dynamic behavior of the system, but it is also very complicated to construct the transition matrix for a large number of components [22].

Even though availability and reliability are used interchangeably, they are not the same in concept and values. The reliability basically represents the probability that a component or a system will perform its designed function without any failure under the normal working environmental conditions. The reliability does not reflect or contain any time to repair the failed component. It mainly reflects how long the system is expected to work during a specific time before it fails. The availability, on the other hand, is the probability that the component or the system is working as expected during its operational cycle. It shows how long the system had been working. Availability depends on both the expected time to fail and time to repair the component or the system. For continuously operating systems such as power systems, it is more informative to study the availability of the components and system to address the quality of service provided to the customers. The term "reliability" is used in this study as a general word that represents all aspects of the study (e.g., availability, unavailability, failure frequency, duration) rather than a quantity or a value. The life span of power system equipment may be divided into three namely, infant mortality, useful life, and wear out period. The useful life period is typically where the reliability evaluation is conducted. The electric power transmission lines under study are assumed to be repairable components with a time to repair or to restore service. Most components in power systems are repairable or replaceable. If a component is repaired, it is assumed that it will perform its function as new component with the same failure rate. The time it takes for each component to fail is called the mean- time- to- failure (MTTF). Similarly, the time to restore service or to repair the faulty component is called the mean-time-to-repair (MTTR) [2, 23]. Assume that a system can be represented by a two-state model so that the system is either in the up (or in) state or the down (or out) state at a given time. Thus, the mean-time-to-failure (MTTF) of the system can be estimated using Equation (1) according to [22, 23] as follows:

$$MTTF = \frac{\sum_{i=1}^{n} m_i}{n} \qquad (1)$$

Where,
m_i = observed time to failure for the i^{th} cycle
n = total number of cycles

According to [12, 13], to estimate the mean-time-to-repair (MTTR), Equation (2) is used which is expressed as:

$$MTTR = \frac{\sum_{i=1}^{n} r_i}{n} \qquad (2)$$

Where,
r_i = observed time to repair the i^{th} cycle
n = total number of cycles

Availability (A), unavailability (U), failure rate (λ), repair time (r) and outage frequency (f) are calculated based on i^{th} operating duration (T_{ui}), i^{th} outage duration (T_{di}) and number of outages, (N) according to [8] as follows:

$$A = \frac{\sum_{i=1}^{N} T_{ui}}{\sum_{i=1}^{N} (T_{ui} + T_{di})} \qquad (3)$$

$$U = \frac{\sum_{i=1}^{N} T_{di}}{\sum_{i=1}^{N} (T_{ui} + T_{di})} \qquad (4)$$

$$\lambda = \frac{N}{\sum_{i=1}^{N} (T_{ui})} \qquad (5)$$

$$r = \frac{\sum_{i=1}^{N} T_{Tdi}}{N} \qquad (6)$$

$$f = \frac{N}{\sum_{i=1}^{N} (T_{ui} + T_{di})} \qquad (7)$$

5. MATHERIALS AND METHODS

5.1 Data Collection

The historical outage data used for the analyses was obtained from the regional office of the Electricity Company of Ghana (ECG). The regional office is in-charge of operation and maintenance of all electric power distribution networks within Western region of Ghana. The outage data is for a selected electric power distribution line routes within the region. The monthly distribution line outages for the year 2016 are as given in Table 3 and Table 4 respectively.

5.2 Determination of Reliabilities Indices

Reliability of electric power distribution network is defined as the ability to deliver uninterrupted service to customers. Electric power distribution system reliability indices can be presented in many ways to reflect its performance. To assess the reliability of a distribution network, two different approaches are normally used; namely, historical assessment and predictive assessment. Historical assessment involves the collection and analyses of distribution system outage and customer interruption data [24]. Historical assessment generally is described as assessing the past performance of the electric power distribution network by consistently logging the frequency, duration, and causes of system component failures and customer interruptions. The historical data is very useful when analyzed to ascertain what went wrong in the past and therefore correct it, and also as input to predict future service reliability [25]. Assessment of past performance is necessary in the sense that it helps to identify weak areas of the network and the need for reinforcement [26]. The predictive reliability assessment also helps to predict the reliability performance of the electric power distribution network after any expansion and quantify the impact of adding new components to the network according to [27].

The reliability assessment is normally used to evaluate performance of electric power distribution system network. The reliability of a power system can be determined by different reliability indices which includes, system average interruption frequency index, system average interruption duration index, customer average interruption frequency index, customer average interruption duration index etc., according to [10]. The reliability indices were determined using Equation (1) through to Equation (6). The results are as given in Table 5. A graph of the year 2016 outages of the various electric power distribution line routes was plotted as given in Chart -1. The graphs of the various reliability indices of the various electric power distribution line routes are also given in Chart - 2 through to Chart - 8.

6. DISCUSSION OF RESULTS

A graph of the year 2016 outages of the various electric power distribution line routes is plotted as shown in Figure 6. As depicted, Asanko distribution line route experienced the highest number of outages of 432 for the year 2016. Followed closely are Wassa Akronpong and Jejetreso of 340 and 298 outages respectively. This high number of outages is as result of the fact that appreciable lengths of these distribution line routes are passing through light forests. The outage rates went up appreciably during the rainy season. Tree branches falling onto the electric power distribution lines frequently accounts for this high number of outages. Harbour No. 1 distribution line route experienced the least number of 3 outages within the year 2016. This could be as a result of the fact that a number of factories are sited along the distribution line route, and the electric power supply route is of the ring type.

Chart - 2 and Chart - 3 shows the MTTF and MTTR of the various electric power distribution line routes for the year 2016. Whilst Harbour No. 1 distribution line route had the highest MTTF value of 2919.33 hours as given in Chart -2, the highest MTTR value of 5.80 hours was obtained for the Nyinahin distribution line route in Chart - 3. The 2919.33 MTTF exhibited by the Harbour No. 1 distribution line route was as result of the least number of outages experienced on that distribution line route. Whilst all the distribution line routes exhibited above average availabilities, the least availability value of 0.8452 was recorded for the Asanko distribution line route as given in Chart - 4. This is due to the fact that a lot of outages occurred on that particular distribution line route. The same Asanko electric power distribution line route recorded the highest unavailability value of 0.1548 which is followed closely by Agona power distribution line route of 0.081as shown in Chart - 5. The highest failure rate of 0.0583 failures per annum was recorded for the Asanko electric power distribution line route. Harbour No. 1 distribution line route recorded the least failure rate per annum of 0.0003 as given in Chart - 6. The highest repair times of 5.8 hours and 4.8 hours were recorded for the Nyinahin and Agona electric power distribution line routes respectively; whilst the least repair time of 0.29 hours was obtained for Chirano distribution line route as indicated in Chart - 7. Outage frequency rates of 0.0493 and 0.0003 being the maximum and the minimum were recorded for Asanko and Harbour No.1 distribution line routes respectively as given in Chart - 8. This is as result of the highest and the least number of outages recorded for those two distribution line routes.

The model developed for the assessment of the electric power distribution line route outages based on the historical outage data is given by:

$$Y = -0.5703x^2 + 18.46x - 8.71$$

$$R^2 = 0.1424$$

Where,
Y = total outages,
x = time, in months
R^2 = Coefficient of determination.

The parameter Y (the total number of outages) gives an indication of the total outages that were recorded for the various line routes of the electric power distribution network within a year. The parameter Y can also be used to predict the performance of the electric power distribution network into the future. R^2 shows the extent of the relationship between the total number of outages recorded on the electric power distribution line routes and the outage durations. The model is a quadratic function whose order may increase as more outages are recorded on the various electric distribution line routes.

7. CONCLUSIONS

A quadratic model equation had been developed for the assessment of the performance of the selected electric power distribution line routes in the Western region of Ghana. Asanko distribution line route experienced the highest number of outages of 432 for the year 2016. Followed closely are Wassa Akropong and Jejetreso of 340 and 298 outages respectively. Harbour No. 1 distribution line route recorded the highest MTTF value of 2919.33 hours, and the highest MTTR value of 5.80 hours was obtained for the Nyinahin distribution line route. The highest failure rate of 0.0583 failures per annum was recorded for the Asanko electric power distribution line route. Harbour No. 1 distribution line route recorded the least failure rate per annum of 0.0003. It was also observed from the analyses that, the terrain through which a particular electric power distribution line route passes through had direct impact on the outage rate and duration. Those electric power distribution line routes passing through light forests encountered more outages as compared to those distribution line routes passing through ordinary bushes.

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Table 3 Monthly Electric Power Distribution Line Outage Data for the Year 2016

S/N	Distribution Line Route	Voltage Level (kV)	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1	AGONA	33	19	16	14	8	x	15	8	3	11	5	14	37	150
2	APOWA No.1	33	x	x	2	2	x	1	x	2	4	5	x	x	16
3	APOWA No. 2	33	2	8	2				2	1					15
4	DIAMOND CEMENT	33	x	4	2	2	x	3	1	1	1	5	3	3	25
5	HARBOUR No.1	33	x	3	x	x	x	x	x	x	x	x	x	x	3
6	HARBOUR No. 2	33	x	2	x	x	x	2	3	2	x	3	2	3	17
7	AXIM	33	8	11	11	9	x	17	4	4	5	5	11	12	97
8	EIKWE	33	4	1	5	8	x	6		7	3	5	13	8	60
9	HALF ASSINI	33	13	10	11	18	x	16	9	6	6	9	9	25	132
10	NKROFUK	33	12	9	18	16	x	9	7	5	9	14	10	21	130
11	BONSA	33	8	9	11	9	x	8	5	8	4	2	9	5	78
12	ABOSO No.1	33	x	1	1	1	x	1	x	1	2	3	3	x	13
13	ABOSO No. 2	33	2	1		2	x	1		4	1	4	2	2	19
14	ASANKO	33	38	37	43	33	30	36	35	36	34	38	37	35	432
15	WASSA AKROPONG	33	16	49	55	21	27	22	10	15	21	17	49	38	340
16	BAWDIE No.1	33	23	23	25	31	26	13	3	4	5	5	26	25	209
17	BAWDIE No.2	33	7	3	9	24	4	3		3	1	5	10	8	77
18	HIMAN	33	2	1	1	x	5	3	1	1	1	1	2	6	24
19	PRESTEA TN	33	1	3	6	4	5	6	1	1	3	1	x	3	34
20	BONDAYE	33	6	4	10	4	6	5	5	3	6	4	5	3	61
21	JEJETRESO	33	21	34	38	40	25	19	20	21	22	18	23	17	298
22	JUABOSO	33	16	23	20	20	22	8	8	3	12	8	18	11	169
23	DWINASE	33	7	9	15	11	7	6	1	5	6	8	8	12	95
24	NEW OBUASI	33	10	9	16	18	15	10	10	7	6	14	23		138
25	CHIRANO	33	2	x	5	2	3	1	x	2	1	3	2	x	21
26	AWASO	33	x	3	3	x	3	1	x	2	x	1	3	2	18
27	BIBIANI	33	4	2	6	11	12	13	3	7	5	x	14	14	91
28	TAK-INCHA No. 1	33	6	8	1	3	5	8	5	5	4	10	11	12	78
29	TAK-INCHA No.2	33	5	1	2	1	10	9	8	5	10	9	8	11	79
30	NYINAHIN	33	x	2	x	1	2	x	x	x	1	x	1	3	10

Table 4 Electric Power Distribution Lines' Outage Data for the Year 2016

S/N	Distribution Line Route	Voltage Level (Kv)	Line Route Length (km)	Total Number of Outages	Desired Annual Operating Hours	Total Outage Duration (Hours)	Actual Operation Duration (Hours)
1	AGONA	33	28	150	8760	702	8058
2	APOWA No.1	33	8	16	8760	34	8726
3	APOWA No. 2	33	9	15	8760	26	8734
4	DIAMOND CEMENT	33	14	25	8760	18	8742
5	HARBOUR No.1	33	5	3	8760	2	8758
6	HARBOUR No. 2	33	6	17	8760	9	8751
7	AXIM	33	24	97	8760	125	8635
8	EIKWE	33	18	60	8760	34	8726
9	HALF ASSINI	33	45	132	8760	125	8635
10	NKROFUK	33	6	130	8760	113	8647
11	BONSA	33	21	78	8760	32	8728
12	ABOSO No.1	33	3	13	8760	21	8739
13	ABOSO No. 2	33	2	19	8760	26	8734
14	ASANKO	33	60	432	8760	1356	7404
15	WASSA AKROPONG	33	27	340	8760	235	8525
16	BAWDIE No.1	33	15	209	8760	403	8357
17	BAWDIE No.2	33	6	77	8760	98	8662
18	HIMAN	33	12	24	8760	11	8749
19	PRESTEA TN	33	11	34	8760	37	8723
20	BONDAYE	33	9	61	8760	44	8716
21	JEJETRESO	33	17	298	8760	276	8484
22	JUABOSO	33	65	169	8760	56	8704
23	DWINASE	33	3	95	8760	32	8728
24	NEW OBUASI	33	6	138	8760	76	8684
25	CHIRANO	33	18	21	8760	6	8754
26	AWASO	33	22	18	8760	8	8752
27	BIBIANI	33	27	91	8760	53	8707
28	TAK-INCHA No. 1	33	18	78	8760	54	8706
29	TAK-INCHA No.2	33	22	79	8760	35	8725
30	NYINAHIN	33	11	10	8760	58	8702

Table 5 Electric Power Distribution Network Reliability Indices for the Year 2016

S/N	Distribution Line Route	MTTF	MTTR	Availability (A)	Unavailability (U)	Failure rate (λ)	Repair time (r)	Outage frequency (f)
1	AGONA	53.72	4.68	0.9199	0.0801	0.0186	4.68	0.0171
2	APOWA No.1	545.4	2.13	0.9961	0.0039	0.0018	2.13	0.0018
3	APOWA No. 2	582.3	1.73	0.9970	0.0030	0.0017	1.73	0.0017
4	DIAMOND CEMENT	349.7	0.72	0.9979	0.0021	0.0029	0.72	0.0029
5	HARBOUR No.1	2919.3	0.67	0.9998	0.0002	0.0003	0.67	0.0003
6	HARBOUR No. 2	514.8	0.53	0.9990	0.0010	0.0019	0.53	0.0019
7	AXIM	89.0	1.29	0.9857	0.0143	0.0112	1.29	0.0111
8	EIKWE	145.4	0.57	0.9961	0.0039	0.0069	0.57	0.0068
9	HALF ASSINI	65.4	0.95	0.9857	0.0143	0.0153	0.95	0.0151
10	NKROFUL	66.5	0.87	0.9871	0.0129	0.0150	0.87	0.0148
11	BONSA	111.9	0.41	0.9963	0.0037	0.0089	0.41	0.0089
12	ABOSO No.1	672.2	1.62	0.9976	0.0024	0.0015	1.62	0.0015
13	ABOSO No. 2	459.7	1.37	0.9970	0.0030	0.0022	1.37	0.0022
14	ASANKO	17.1	3.14	0.8452	0.1548	0.0583	3.14	0.0493
15	WASSA AKROPONG	25.1	0.69	0.9732	0.0268	0.0399	0.69	0.0388
16	BAWDIE No.1	40.0	1.93	0.9540	0.0460	0.0250	1.93	0.0239
17	BAWDIE No.2	112.5	1.27	0.9888	0.0112	0.0089	1.27	0.0088
18	HIMAN	364.5	0.46	0.9987	0.0013	0.0027	0.46	0.0027
19	PRESTEA TN	256.6	1.09	0.9958	0.0042	0.0039	1.09	0.0039
20	BONDAYE	142.9	0.72	0.9950	0.0050	0.0070	0.72	0.0070
21	JEJETRESO	28.5	0.93	0.9685	0.0315	0.0351	0.93	0.0340
22	JUABOSO	51.5	0.33	0.9936	0.0064	0.0194	0.33	0.0193
23	DWINASE	91.9	0.34	0.9963	0.0037	0.0109	0.34	0.0108
24	NEW OBUASI	62.9	0.55	0.9913	0.0087	0.0159	0.55	0.0158
25	CHIRANO	416.9	0.29	0.9993	0.0007	0.0024	0.29	0.0024
26	AWASO	486.2	0.44	0.9991	0.0009	0.0021	0.44	0.0021
27	BIBIANI	95.7	0.58	0.9939	0.0061	0.0105	0.58	0.0104
28	TAK-INCHA No. 1	111.6	0.69	0.9938	0.0062	0.0090	0.69	0.0089
29	TAK-INCHA No.2	110.4	0.44	0.9960	0.0040	0.0091	0.44	0.0090
30	NYINAHIN	870.2	5.80	0.9934	0.0066	0.0011	5.80	0.0011

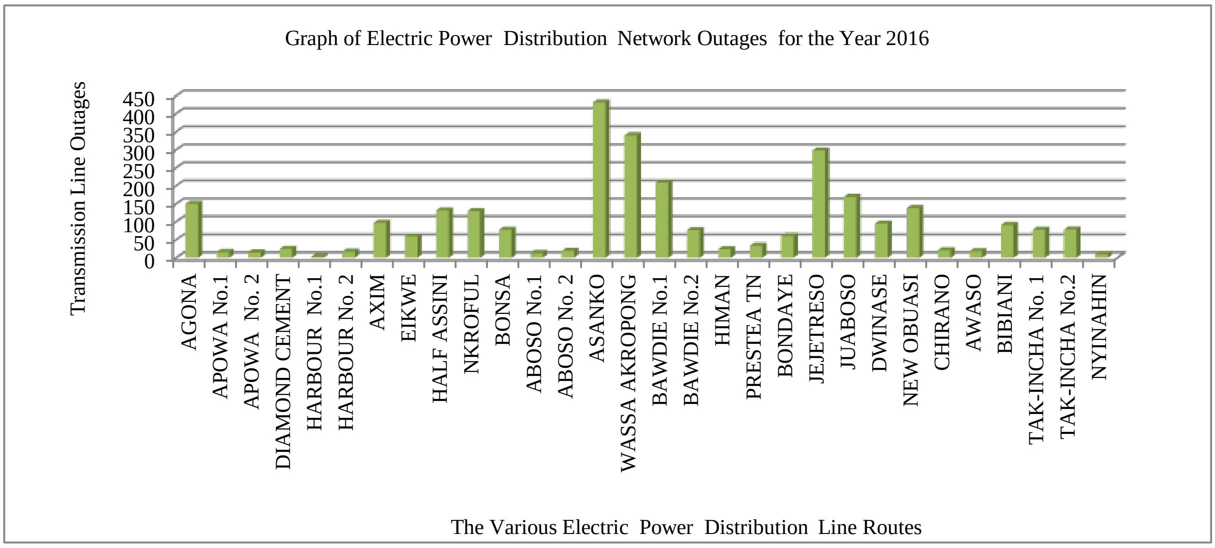

Chart – 1: Electric Power Distribution Network Outage Levels

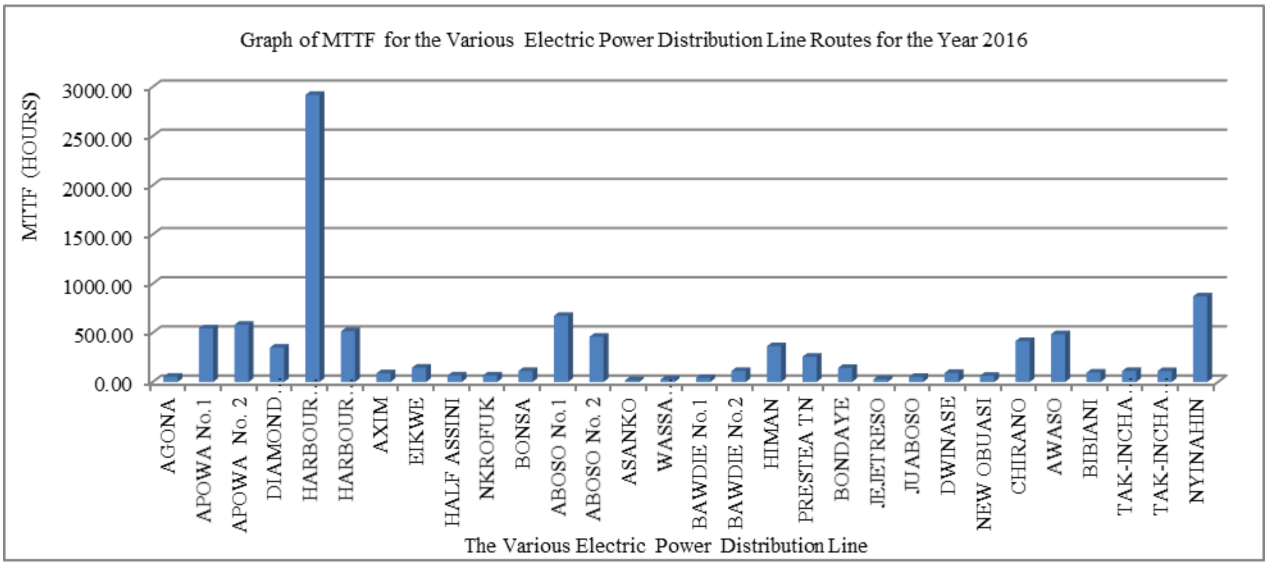

Chart – 2: Graph of MTTF for the Various Electric Power Distribution Line Routes

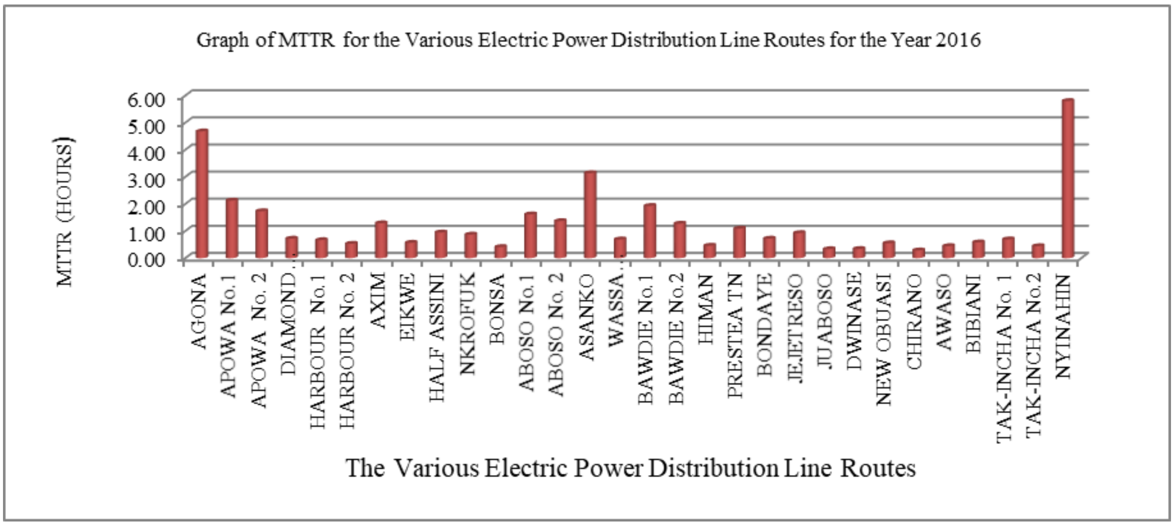

Chart – 3: Graph of MTTR for the Various Electric Power Distribution Line Routes

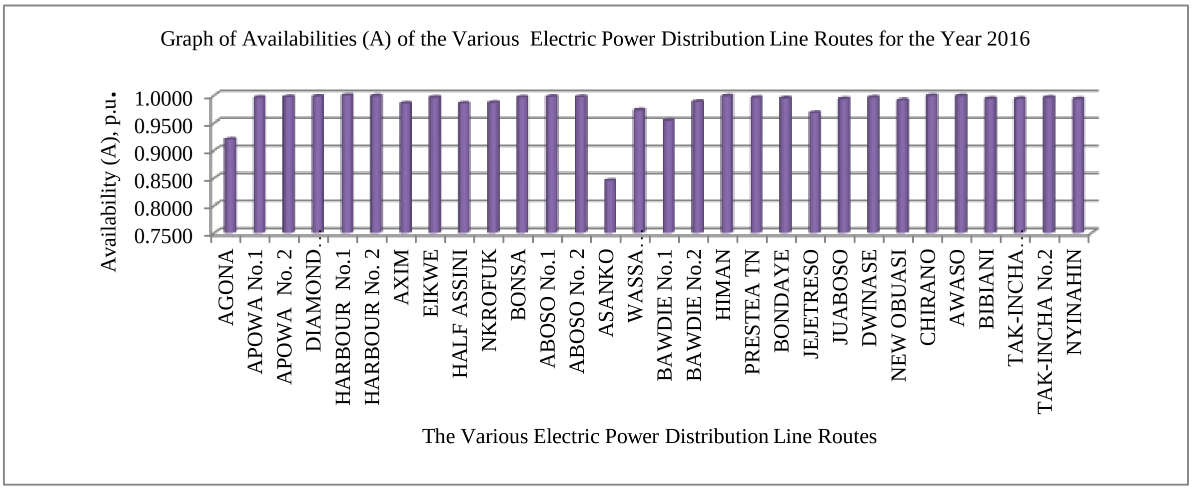

Chart – 4: Graph of Availabilities (A) for the Various Electric Power Distribution Line Routes

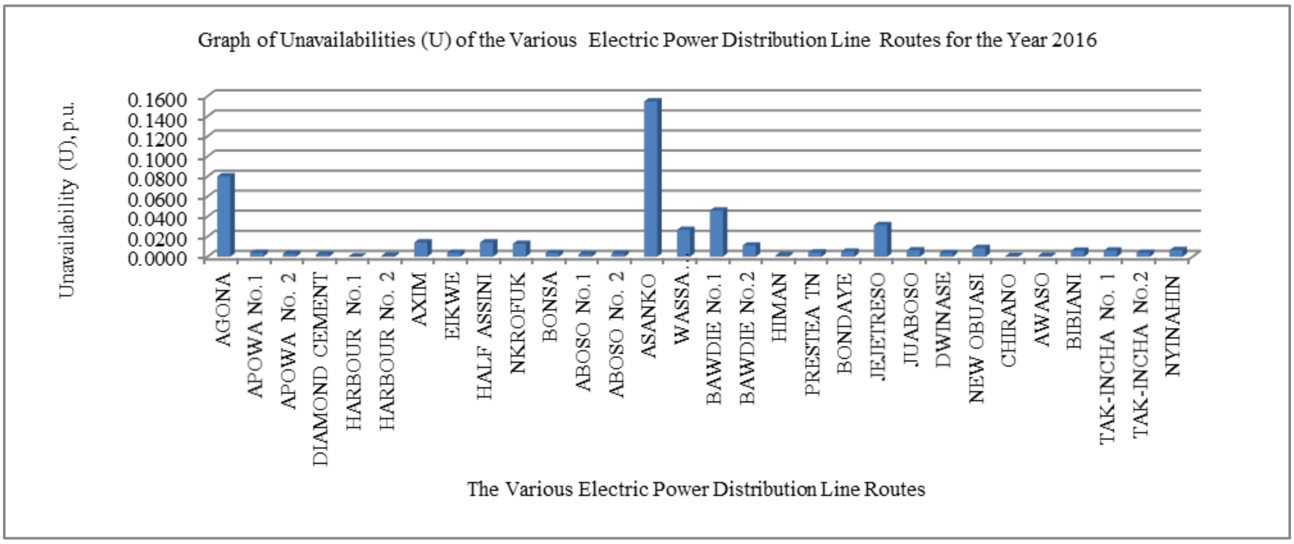

Chart – 5: Graph of Unavailabilities (U) for the Various Electric Power Distribution Line Routes

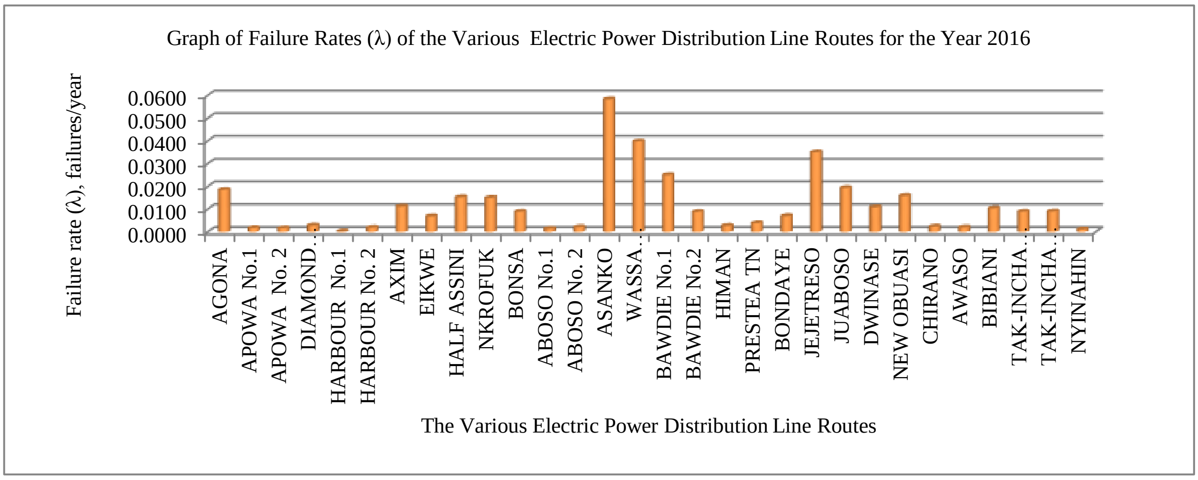

Chart – 6: Graph of Failure Rates (λ) for the Various Electric Power Distribution Line Routes

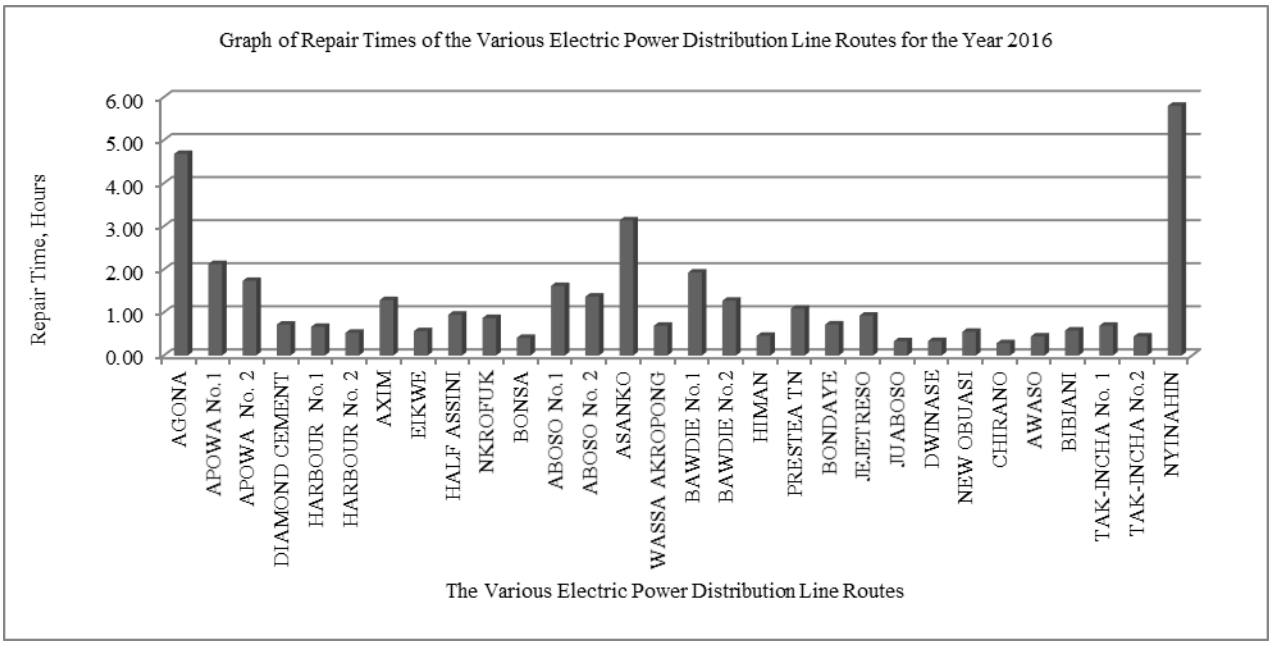

Chart – 7: Graph of Repair Times for the Various Electric Power Distribution Line Routes

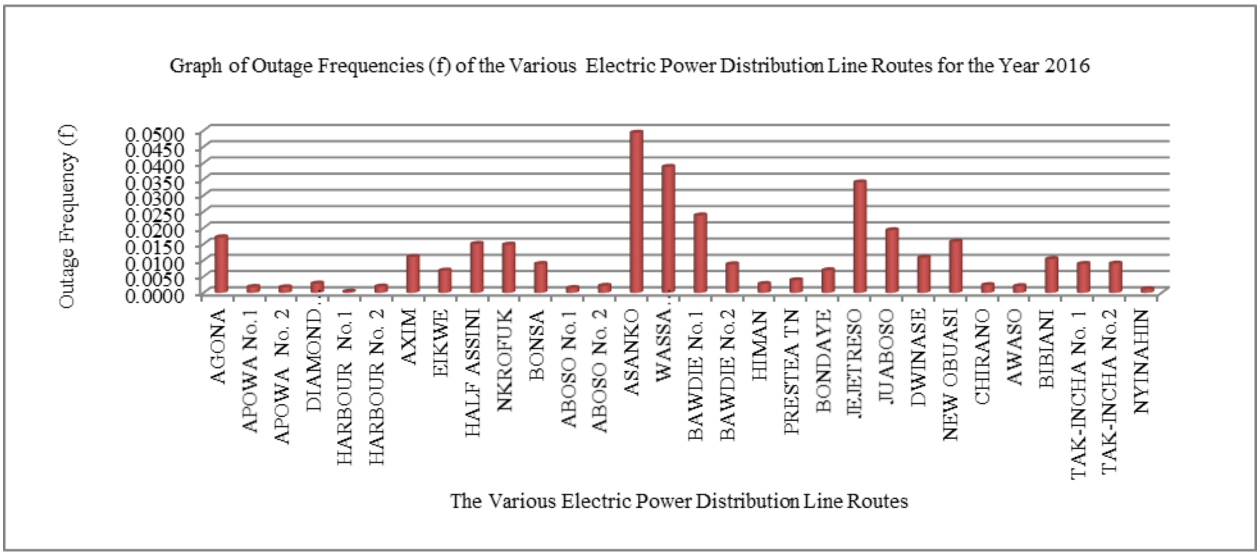

Chart – 8: Graph of Outage Frequencies for the Various Electric Power Distribution Line Routes

REFERENCES

[1] Wei, N., "A Line Outage Study for Prediction of Static Power Flow Redistribution", *M.Sc. Thesis*, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, U.S.A., 2016, pp. 1 – 5.

[2] Lantharthong, T., and Phanthuna, N., "Techniques for Reliability Evaluation in Distribution System Planning", *World Academy of Science, Engineering and Technology,* Vol. 64, 2012, pp. 431 – 434.

[3] Žaneta, E., Anton, B., "Blackout in the power system", *AT & P journal PLUS2,* 2008, pp. 58 – 60.

[4] Davis, W. P., "Analysis of Faults in Overhead Transmission Lines", *M.Sc. Thesis*, California State University, Sacramento, U.S.A. 2012, pp. 1 – 15.

[5] Wang, L., "The Fault Causes of Overhead Lines in Distribution Network", *the International Seminar on Applied Physics, Optoelectronics and Photonics,* Shanghai, China, May 28-29, 2016, pp. 1 – 5.

[6] Panth, D., "Reasons for Failure of Transmission Lines and their Prevention Strategies", *International Journal of Electrical, Electronics and Data Communication,* Vol. 2, Issue 1, 2014, pp. 1 – 4.

[7] Gonen, T., Electric Power Distribution System Reliability Engineering, 2nd edition, CRC Press, Taylor & Francis Group, NW, USA, 2008, pp. 163 – 229.

[8] Olusuyi, K., Ayodele Sunday Oluwole, A. S., Temitope Adefarati, T. and Babarinde, A. K., "A Fault Analysis of 11kv Distribution System (A Case Study of Ado Ekiti Electrical Power Distribution District)", *American Journal of Electrical Power and Energy Systems,* Vol 3, Issue 2, 2014, pp. 27 – 36.

[9] Tatietse, T. T. and Voufo, J., "Fault Diagnosis on Medium Voltage (MV) Electric Power Distribution Networks: The Case of the Downstream Network of the AES-SONEL Ngousso Sub-Station", *Energies*, Vol. 2, 2009, pp. 243 – 257.

[10] Ashok, V. and Harikrishna, K. V., Chandrashekar, P., and Raghunatha, T., "Performance Assessment in Power Distribution System Based on Reliability Indices", World Academy of Engineering, Science and Technology, Vol. 73, 2013, pp. 689 – 694.

[11] Musa, B. U., Ngajia, T. B., Kalli, B. M. and Tijjani, B. U., "Outage Analysis on Distribution Feeder in North East Nigeria", *Journal of Multidisciplinary Engineering Science and Technology,* Vol. 2, Issue 1, 2015, pp. 1 – 4.

[12] Jibril, Y. and Ekundayo, K. R., "Reliability Assessment of 33 kV Kaduna Electricity Distribution Feeders, Northern Region, Nigeria", *Proceedings of the World Congress on Engineering and Computer Science,* San Francisco, USA, Vol. 1, 2013, pp. 1 – 4.

[13] Onime, F. and Adegboyega, G. A., "Reliability Analysis of Power Distribution System in Nigeria: A Case Study of Ekpoma Network, Edo State", *International Journal of Electronics and Electrical Engineering,* Vol. 2, No. 3, 2014, pp. 175 - 182.

[14] Dorji, T., "Reliability Assessment of Distribution Systems - Including a Case Study on Wangdue Distribution System in Bhutan", *MSc Thesis,* Norwegian University of Science Technology, Trondheim, Norway, 2009, pp. 5 - 31.

[15] Venu, B., Bhargava, C. and Sumanth, K., "Reliability Assessment of Radial Distribution System by using Analytical Methods", *International Journal of Professional Engineering Studies,* Vol. 4, Issue 4, 2014, pp. 185 – 195.

[16] Kesavakumar, M. V., Srihari, V. and Sarvesh, B., "Improvement in Reliability Indices of a Power Distribution System: A Case Study, *International Journal of Research in Engineering and Technology,* Vol. 04, Special Issue 12, 2015, pp. 21 – 28.

[17] Roy, P. and Gupta, S. K., "Digital Technique of fault study of power system", International Research Journal of Engineering and Technology, Vol. 3, Issue 7, 2016, pp. 162 – 169.

[18] Srinivas, K. and Satyanarayana, R.V.S., EHT Transmission Performance Evaluation: Emerging Research and Opportunities, IGI Global Publications, USA, 2018, pp. 65 – 76.

[19] Razzaq, M. R., "Reliability Analysis of Smart Electrical Transmission System and Modelling Through Dynamic Flowgraph Methodology", *M.Sc. Thesis*, University of Ontoario Institute of Technology, Oshawa, Ontario, Canada, 2011, pp. 1 – 10.

[20] Almuhaini, M., "An Innovative Method for Evaluating Power Distribution System Reliability", PhD Thesis,Arizona State University, Arizona, USA, 2012, pp. 1 – 20.

[21] Gonen, T., Electrical Power Transmission System Engineering- Analysis and Design, 3rd edition, CRC Press, New York, USA, 2014, pp. 694 – 702.

[22] Ajenikoko, G. A. and Ogunwuyi, O. J., "A Model for Assessment of Power System Outages on Nigerian Transmission Network", The International Journal of Engineering and Science, Vol. 4, Issue 4, 2015, pp. 73 – 80.

[23] Rashed, G. I., "Determination of Data for Reliability Analysis of a Transmission System in Sulaimani-Erbil Network", Information Technology Journal, Vol. 4, Issue 2, 2005, pp. 106 – 113.

[24] Shavuka, O. and Awodele, O., Chowdhury, S. P., and Chowdhury, S., "Reliability Analyses of Distribution Network", 2010 International Conference on Power System Technology.

[25] Chowdhury, A. A. and Korval, D. O. and Kalen, S. M., "A Reliabilty based Model for Electricity Pricing", 2008 Australian Universities Power Engineering Conference (AUSPEC'08).

[26] Billinton, R. and Allan, R. N., "*Reliabilty Evaluation of Power Systems*", Plenum Press, New York, 1996.

[27] Al-Muhaini, M. and Heydt, G. T. and Huynh, A., "The Reliability of Power Distribution Systems as Calculated using System Theoretical Concepts", *in Proc. IEEE Conference on Power and Energy Society General Meeting,* USA, 2010.

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