Statistical Analysis of Electric Power Distribution Grid Outages

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Abstract — **Power systems in general supply consumers with electrical energy as economically and reliably as possible. Reliable electric power systems serve customer loads without interruptions in supply voltage. Electric power generation facilities must produce enough power to meet customer demand. Electrical energy produced and delivered to customers through generation, transmission and distribution systems, constitutes one of the largest consumers markets the world over. The benefits of electric power systems are integrated into the much faster modern life in such extent that it is impossible to imagine the society without the electrical energy. The rapid growth of electric power distribution grids over the past few decades has resulted in a large increment in the number of grid lines in operation and their total length. These grid lines are exposed to faults as a result of lightning, short circuits, faulty equipment, mis-operation, human errors, overload, and aging among others. A fault implies any abnormal condition which causes a reduction in the basic insulation strength between phase conductors or phase conductors and earth, or any earthed screens surrounding the conductors. In this paper, different types of faults that affected the electric power distribution grid of selected operational districts of Electricity Company of Ghana (ECG) in the Western region of Ghana was analyzed and the results presented. Outages due to bad weather and load shedding contributed significantly to the unplanned outages that occurred in the medium voltage (MV) distribution grid. Blown fuse and loose contact faults were the major contributor to unplanned outages in the low voltage (LV) electric power distribution grid.**

Index Terms — **Electric Power Distribution Grid, Faults, Low Voltage (LV), Medium Voltage (MV), Outages.**

I. Introduction

A power system basically comprises of a generating, a transmission and distribution systems. Power systems usually supply electrical energy to its customers in an economic and reliable manner as possible. An electric power system is one of the largest and the most complex systems established by mankind for comfort and survival. Electrical energy produced and delivered to customers through generation, transmission and distribution systems, constitutes one of the largest consumer markets in the world, and the demand for it is still growing. The benefits of electric power systems are integrated into the much faster modern life in such extent that it is impossible to imagine the society without the electrical energy. The world is so dependent on electricity in the 21st century that any interruption or failure in the electric service system could lead to major disruption of daily life activities as well economic losses. Reliable electric power systems serve customer loads without interruptions in supply voltage throughout the year. Generation plants and facilities must produce enough power to meet customer demand. Electric power transmission systems must transport bulk power over long distances without overheating or jeopardizing system stability. Electric power distribution grids must deliver electrical energy to each customer's service entrance without interruption. Electric power transmission lines are used to transmit electric power to distant large load centers. The rapid growth of electric power grids over the past few decades have resulted in a large increase of the number of distribution lines in operation and their total length. These lines are exposed to faults as a result of lightning, short circuits, faulty equipment, mis-operation, human errors, overload, and aging among others. Many electrical faults manifest in mechanical damages, which must be repaired before returning the line into service. A fault on an electric power transmission lines implies any abnormal condition which causes a reduction in the basic insulation strength between phase conductors or phase conductors and earth, or any earthed screens surrounding the conductors. Such reduction of the insulation resistance is not considered as a fault until it produces some effect on an electric power grid. Again, until it results either in an excess current or in the reduction of the impedance between conductors and earth to a value below that of the lowest load impedance of the circuit. There are many causes of power failure in an electric power distribution grids. Examples include faults at substations stations, damage to electric transmission or distribution lines, short circuits, open circuits or the over loading of the electric power distribution lines. Electric power is conveyed from central and remote generation stations to a distant locations or centers for the end users by transmission and distribution grids with the distribution grids being the closest to the consumers. These electric power distribution grids can be radial or ring, but in most cases traditional radial network is adopted due to its low cost, simple protection schemes, facilitates network stability and reduction in number of protective devices. Radial network is a form of unidirectional power flow from the source to the load points or centers. The probability of failure or occurrence of abnormal condition is more in an overhead electric power transmission and distribution lines. This is due to their greater length, and exposure to the atmosphere without any form of protection [1]-[9].

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II. Fault Incident Rates for Different Components of an Electric Power System

Table I shows the contribution of fault incidents by each component of a power system to its failure [7].

TABLE I: Fault Incident Rates of Different Components of Power System Which Contributes to Its Failure

S/N	Component Name	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

III. Types of Faults In Electric Power Distribution Grids

Faults in an electric power distribution grids can be categorized as shunt faults (short circuits), series faults (open conductor), and simultaneous faults. Simultaneous faults are faults that occur more than one at the same time.

The types of shunt, series and simultaneous faults that do occur frequently in electric power distribution grids include:

1) Single phase to ground faults;
2) Single phase to ground faults through a resistor;
3) Double phase to ground faults;
4) Double phase faults;
5) Three phase faults;
6) Three phase to ground faults; and
7) Open circuit faults.

The appropriate percentages of occurrences of various line faults are as given in Table II [10].

TABLE II: 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

The various types of faults are indicated respectively in Fig.1-7 [11][15].

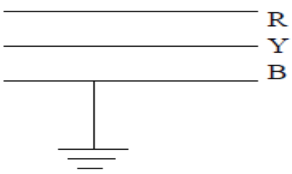

Fig. 1. Single Phase to Ground Fault.

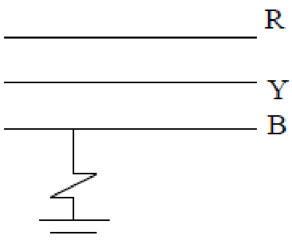

Fig. 2. Single Phase to Ground Fault through Resistor.

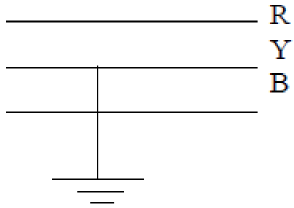

Fig. 3. Double Phase to Ground Fault.

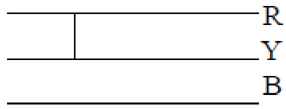

Fig. 4. Double Phase Fault.

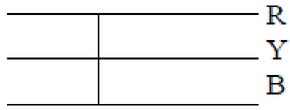

Fig. 5. Three Phase Fault.

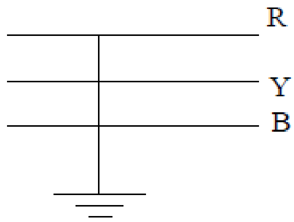

Fig. 6. Three Phase to Ground Fault.

Fig. 7. Open Circuit Fault

IV. Nature and Classification of Electric Power Distribution Grid Outages

It has been reported in the literature that about 80% of the power outages are caused by the faults in the electric power distribution system. A fault is inevitable in an electric power distribution grid for many uncontrollable factors such as animals, and weather related factors. The nature of a fault is simply defined as any abnormal condition, which causes a reduction in the basic insulation resistance level between phase conductors, or between phase conductors and earth or any earthed screens surrounding the conductors. The main causes of an electric power grid line outages are lightning strokes, environmental or air pollution, and bush fires. Other causes of faults on overhead lines are falling trees, birds, flying aircraft, fog, ice, snow loading, punctured or broken insulators, open-circuit conductors and unnecessary over loading [14], [16], [17]. The occurrence of a fault results in system outage which usually affects the end users. A partial system outage describes a component state where the capacity of the component to perform its function is reduced but not completely eliminated. A total outage is system outage is where the component is completely incapable of performing its function as required.

A forced system outage is an outage that results from emergency conditions directly associated with a faulty component which must be taken out of service immediately either automatically or through switching operations. Forced outages can be associated with ageing equipment or defects, lightening strikes, wind, birds or animals, vandalisation, accidents and poor workmanship by electrical contractors. However, forced outages can be minimized if the system is properly designed and maintained but cannot be completely eliminated. Planned outages are outages due to planned or scheduled maintenance when a component is deliberately taken out of service at a selected time, usually for the purposes of construction, preventive maintenance or repairs. This could be either on the electric distribution grid or substation equipment. Emergency outages arise from loss of power supply from the generating station either due to inadequate generation or drop in the load coordination frequencies [8].

V. Materials and Method

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 operational districts in the region for the years 2015 and 2016. The MS Excel was used in carrying out the analyses.

The analyses covered the 33 kV and 11 kV medium voltages (MV) as well as the low voltage (LV) electric power distribution grids of major towns and cities within the region. The tabulated monthly outages for the year 2015 are as given in Table III, Table IV and Table V respectively for the MV and LV networks. Summary of various faults and other factors that contributed to outages in the 33 kV, 11 kV and LV electric power distribution grids are also given in Table 6, Table VII and Table VIII respectively. Given in Table IX, Table X and Table XI respectively, are the tabulated monthly outages for the year 2016. Summary of various faults and other factors that contributed to outages in the MV and LV grids are also given in Table XII, Table XIII and Table XIV, respectively. Graphs of annual outages for the 33 kV, 11 kV and LV electric power distribution grids for the years 2015 and 2016 are as indicated in Fig. 8, Fig. 9 and Fig. 10, respectively. The 11 kV electric power distribution grid operates in five operational districts. Graphs of outage durations for MV and LV electric power distribution grids are respectively given in Fig. 11-13.

TABLE III: Summary of Monthly Outages for The 33 kV Grid for the Year 2015

Operational Districts	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Asankragwa	29	54	53	93	72	40	27	34	40	69	46	21	578
Axim	50	82	85	60	62	52	66	56	42	48	58	38	699
Bogoso	44	90	87	72	50	46	56	52	37	74	80	58	746
Enchi	32	29	36	45	16	44	38	41	47	34	52	14	428
Half Assini	32	27	34	18	24	20	31	15	17	25	22	9	274
Sefwi Wiawso	128	136	250	123	180	129	206	148	127	201	186	84	1898
Sekondi	156	134	128	67	126	111	156	143	36	68	84	44	1253
Takoradi	72	68	82	63	58	77	52	55	40	56	62	60	745
Tarkwa	61	72	88	79	65	75	160	69	42	74	64	63	912

TABLE IV: Summary of Monthly Outages for the 11 kV Grid for the Year 2015

Operational Districts	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Axim	6	10	8	9	7	11	14	12	10	9	8	13	117
Sefwi Wiawso	13	14	26	11	22	28	26	31	10	20	17	9	227
Sekondi	122	109	135	144	149	125	152	129	110	96	142	102	1515
Takoradi	305	268	354	440	480	436	344	214	141	135	267	213	3597
Tarkwa	72	84	92	75	85	72	114	54	45	59	68	61	881

TABLE V: Summary of Monthly Outages for the LV Grid for the Year 2015

Operational Districts	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Asankragwa	38	47	45	34	54	52	50	48	61	49	53	42	573
Axim	41	36	58	54	37	52	55	51	64	66	65	55	634
Bogoso	22	18	29	27	26	31	27	35	29	27	33	28	332
Enchi	35	28	25	32	17	24	32	40	52	47	39	24	395
Half Assini	45	42	88	55	59	54	64	46	57	53	62	41	666
Sefwi Wiawso	36	32	27	43	20	54	42	33	41	28	21	33	410
Sekondi	223	142	158	168	180	170	189	183	164	160	255	236	2228
Takoradi	265	213	271	226	278	257	222	272	257	272	328	275	3136
Tarkwa	126	134	98	82	70	48	41	55	109	125	74	83	1045

TABLE VI: Summary of Faults in the 33 kV Distribution Grid for the Year 2015

Operational Districts	Total Outage Frequency/Year	Total Outage Duration (Hours)/year	Planned Outages	Unplanned Outages									
				Phase Fault	Earth Fault	Falling Tree Fault	Blown Fuse Fault	Conductor Related Fault	Loose Contact Fault	Surge Arrester Failure	Outage Due to Faulty Equipment	Outage Due to Bad Weather	Outage Due to Load Shedding
Asankragwa	578	466.23	156	x	x	182	65	25	x	1	4	178	88
Axim	699	921.01	123	x	96	87		7	x	1	1	164	267
Bogoso	746	942.61	97	31	45	44		30	x	8	13	78	82
Enchi	428	940.01	55	x	x	12	35	14	x	14	x	79	65
Half Assini	274	470.8	308	254	370	x	87	22	x	24	x	256	577
Sefwi Wiawso	1898	3019.4	155	x	135	x	124	35	97	8	x	187	512
Sekondi	1253	1982.2	78	x	125	28	65	55	x	x	x	185	209
Takoradi	745	2209.7	100	78		55	68	32	x	x	x	223	356
Tarkwa	912	2442.12	x	x	x	x	x	x	x	x	x	x	x

TABLE VII: SUMMARY OF FAULTS IN THE 11 KV DISTRIBUTION GRID FOR THE YEAR 2015

Operational Districts	Total Outage Frequency/Year	Total Outage Duration (Hours)/year	Planned Outages	Unplanned Outages									
				Phase Fault	Earth Fault	Falling Tree Fault	Blown Fuse Fault	Conductor Related Fault	Loose Contact Fault	Surge Arrester Failure	Outage Due to Faulty Equipment	Outage Due to Bad Weather	Outage Due to Load Shedding
Axim	117	173.4	24				10	x	x	x	x	25	58
Sefwi Wiawso	227	231.3	45	36	24	12	8	8	7	x	x	36	51
Sekondi	1515	3253.3	187		127		8	10	14	22	x	462	685
Takoradi	3597	26039.9	201	116	78		70	55	24		x	998	2055
Tarkwa	881	2592.6	28	x	x	8	55	24	x	5	x	271	490

TABLE VIII: SUMMARY OF FAULTS IN THE LV DISTRIBUTION GRID FOR THE YEAR 2015

Operational Districts	Total Outage Frequency /Year	Total Outage Duration (Hours)/year	Planned Outages	Unplanned Outages									
				Phase Fault	Earth Fault	Falling Tree Fault	Blown Fuse Fault	Conductor Related Fault	Loose Contact Fault	Surge Arrester Failure	Outage Due to Faulty Equipment	Outage Due to Bad Weather	Outage Due to Load Shedding
Asankragwa	573	443.4	47	55	x	38	125	51	96	x	x	74	87
Axim	634	179.63	45		x		154	87	165	x	4	74	105
Bogoso	332	464.74	22		x	45	74	41	48	x	x	41	61
Enchi	395	400.7	25	40	x	22	87	30	82	x	1	46	62
Half Assini	666	1596.42	89	107	x	55	68	130	105	x	1	47	64
Sefwi Wiawso	410	592.3	45	11	2	35	79	45	97	x	x	40	56
Sekondi	2228	5881.9	150	98	x	22	325	356	836	x	x	247	194
Takoradi	3136	1727.54	57	47	x	52	555	350	751	x	x	540	784
Tarkwa	1045	1536.34	76	x	x		258	156	247	x	x	108	200

TABLE IX: SUMMARY OF MONTHLY OUTAGES FOR THE 33 KV GRID FOR THE YEAR 2016

Operational Districts	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Asankragwa	42	45	59	57	69	52	59	51	53	63	48	59	657
Axim	45	47	75	51	48	51	37	47	37	50	56	37	581
Bogoso	75	129	119	92	123	102	48	56	42	55	73	61	975
Enchi	11	17	23	28	25	21	29	43	28	32	14	27	298
Half Assini	17	22	25	21	11	36	17	12	11	20	17	21	230
Sefwi Wiawso	121	136	115	169	137	124	131	92	105	85	97	113	1425
Sekondi	45	40	62	49	67	104	58	46	55	48	51	74	699
Takoradi	29	49	70	51	62	55	63	58	77	58	57	39	668
Tarkwa	27	26	31	30	38	42	43	31	12	23	25	32	360

TABLE X: SUMMARY OF MONTHLY OUTAGES FOR THE 11 KV GRID FOR THE YEAR 2016

Operational Districts	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Axim	8	6	9	7	6	7	6	5	8	4	6	5	77
Sefwi Wiawso	47	34	52	44	26	38	29	31	49	37	41	46	474
Sekondi	64	55	74	85	71	236	92	87	82	30	43	59	978
Takoradi	56	43	92	64	183	175	244	109	122	35	42	117	1282
Tarkwa	18	32	30	50	52	43	66	17	31	17	30	14	400

TABLE XI: SUMMARY OF MONTHLY OUTAGES FOR THE LV GRID FOR THE YEAR 2016

Operational Districts	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Asankragwa	12	13	22	19	10	24	15	17	14	26	23	18	213
Axim	63	59	70	68	70	64	58	69	59	52	69	61	762
Bogoso	23	17	20	15	22	31	12	19	14	26	65	36	300
Enchi	26	29	32	27	32	39	31	26	21	25	30	29	347
Half Assini	33	38	52	34	48	55	28	33	36	29	37	33	456
Sefwi Wiawso	52	47	29	41	33	54	47	45	52	39	55	51	545
Sekondi	200	217	186	198	234	269	241	222	206	234	229	217	2653
Takoradi	302	347	283	267	311	246	235	280	274	238	249	241	3273
Tarkwa	135	91	119	120	110	96	100	121	110	105	122	116	1345

TABLE XII: SUMMARY OF FAULTS IN THE 33 KV DISTRIBUTION GRID FOR THE YEAR 2016

Operational Districts	Total Outage Frequency/Year	Total Outage Duration (Hours)/year	Planned Outages	Unplanned Outages									
				Phase Fault	Earth Fault	Falling Tree Fault	Blown Fuse Fault	Conductor Related Fault	Loose Contact Fault	Surge Arrester Failure	Outage Due to Faulty Equipment	Outage Due to Bad Weather	Outage Due to Load Shedding
Asankragwa	657	447.62	71	45	74	14		15	x	2	5	147	284
Axim	581	381.31	115	66	12	37	23	32	x	x	x	145	151
Bogoso	975	797.8	147	38	52	14	45	26	x	x	8	277	368
Enchi	298	1839.43	47	9	5	x	8	x	x	x	62	75	92
Half Assini	230	2921.24	55	21	32	x	x	x	x	x	35	35	52
Sefwi Wiawso	1425	1149.23	187	102	86	x	4	8	x	x	23	447	568
Sekondi	699	901.5	84	23	45	x	6	8	x	x	x	274	259
Takoradi	668	1334.62	74	56	120	60	23	74	x	2	x	103	156
Tarkwa	360	656.1	x	x	x	32	x	25	x	x	23	93	187

TABLE XIII: SUMMARY OF FAULTS IN THE 11 KV DISTRIBUTION GRID FOR THE YEAR 2016

Operational Districts	Total Outage Frequency/Year	Total Outage Duration (Hours)/year	Planned Outages	Unplanned Outages									
				Phase Fault	Earth Fault	Falling Tree Fault	Blown Fuse Fault	Conductor Related Fault	Loose Contact Fault	Surge Arrester Failure	Outage Due to Faulty Equipment	Outage Due to Bad Weather	Outage Due to Load Shedding
Axim	77	175.24	22	x	x		15	7	x	x	6	14	13
Sefwi Wiawso	474	530.1	55	32	52	x	x	8	x	x	21	144	162
Sekondi	978	1977.4	22	x	x	25		8	x	x	x	587	336
Takoradi	1282	4973.44	147	x	47		54	25	x	2	42	470	495
Tarkwa	400	825.53	22	x	21	15	28	14	x			147	153

TABLE XIV: SUMMARY OF FAULTS IN THE LV DISTRIBUTION NETWORK FOR THE YEAR 2016

Operational Districts	Total Outage Frequency /Year	Total Outage Duration (Hours)/year	Planned Outages	Unplanned Outages									
				Phase Fault	Earth Fault	Falling Tree Fault	Blown Fuse Fault	Conductor Related Fault	Loose Contact Fault	Surge Arrester Failure	Outage Due to Faulty Equipment	Outage Due to Bad Weather	Outage Due to Load Shedding
Asankragwa	213	228.5	28	x	x	23	42	x	45	x	x	75	x
Axim	762	164.1	48	x	x	25	154	45	187	x	5	298	x
Bogoso	300	888.2	52	x	x	23	54	42	56	x	31	42	x
Enchi	347	450.8	45	7	x	x	154	38	45	x	12	46	x
Half Assini	456	916.63	52	78	x	7	62	87	78	x	9	83	x
Sefwi Wiawso	545	524.2	142	56	x	23	45	13	78	x	14	174	x
Sekondi	2653	3857.6	203	47	x	21	805	104	774	x	41	658	x
Takoradi	3273	2060.6	257	x	x	12	741	174	785	x	25	1279	x
Tarkwa	1345	1965.6	154	x	x	42	391	45	324	x	15	374	x

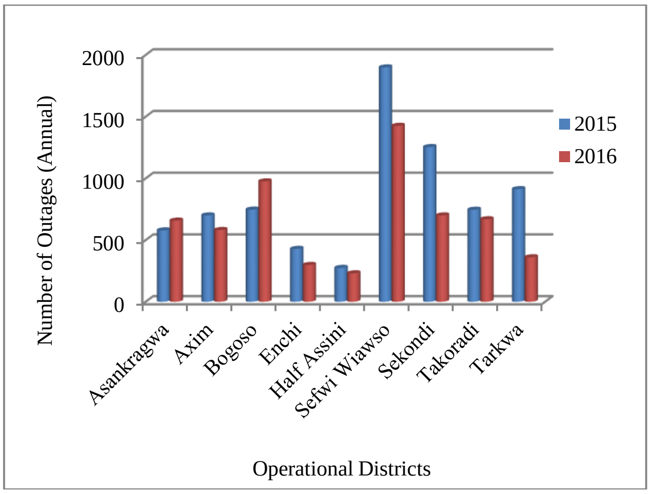

Fig. 8. Graph of Total Outages for the 33 kV Grid for the Years 2015 and 2016.

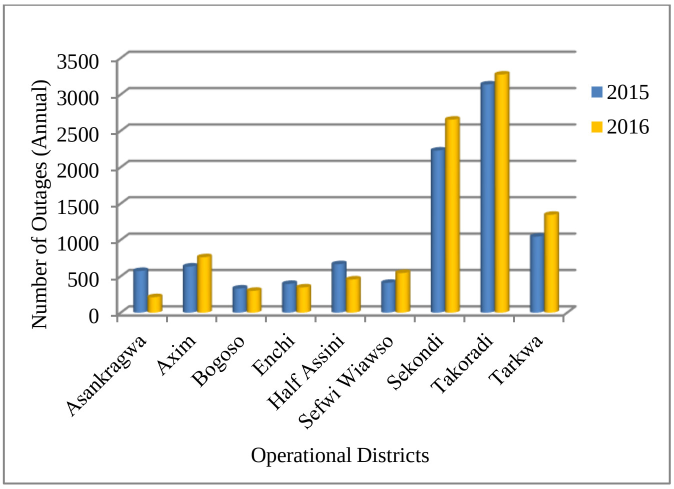

Fig. 10. Graph of Total Outages for the LV Grid for the Years 2015 and 2016.

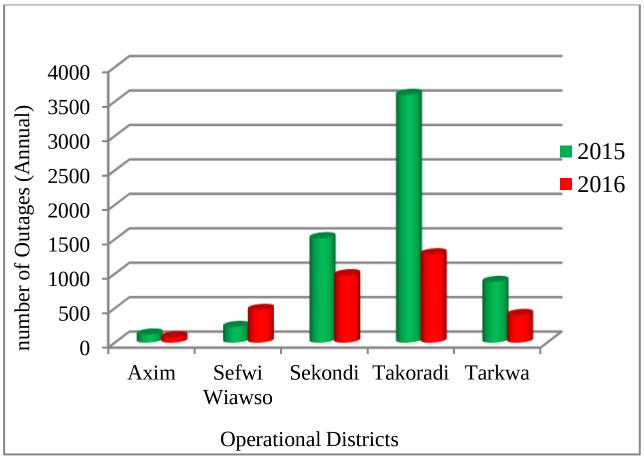

Fig. 9. Graph of Total Outages for the 11 kV Grid for the Years 2015 and 2016.

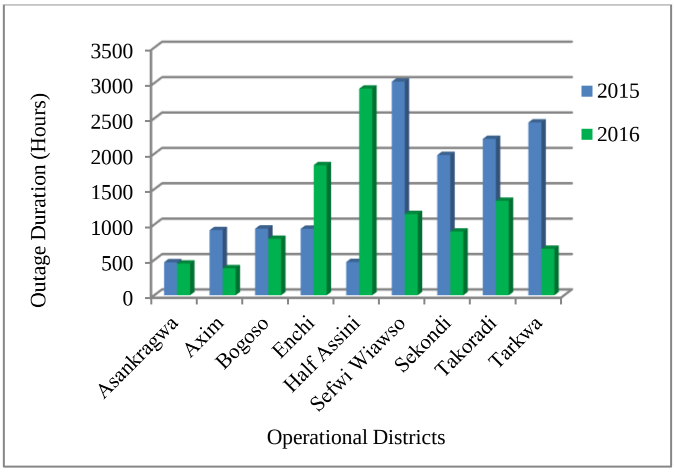

Fig. 11. Graph of Annual Outage Durations for the 33 kV Grid for the Years 2015 and 2016.

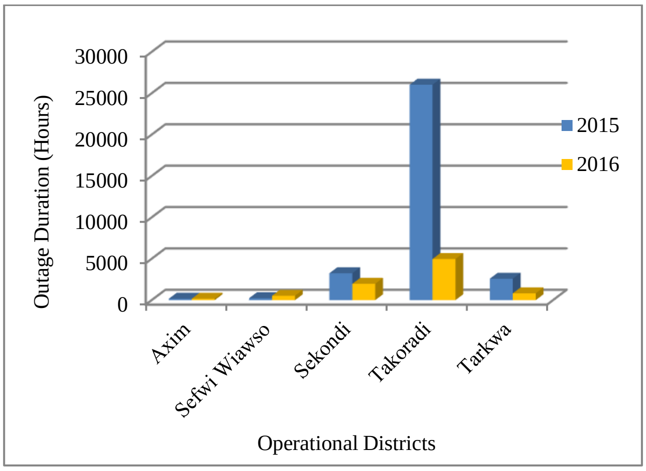

Fig.12. Graph of Annual Outage Durations for the 11 kV Grid for the Years 2015 and 2016.

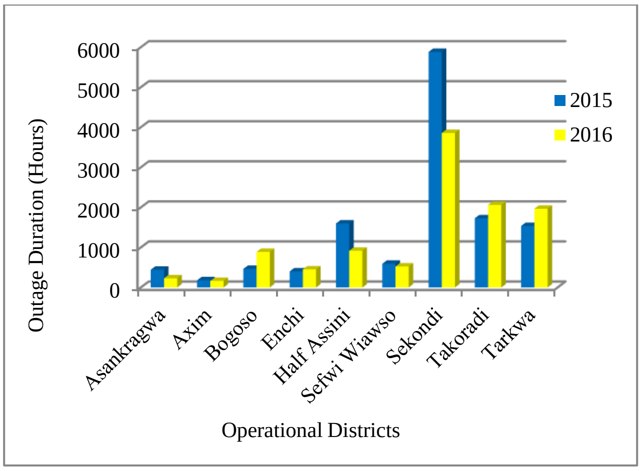

Fig. 13. Graph of Annual Outage Durations for the LV Grid for the Years 2015 and 2016.

VI. Discussion of Results

In the year 2015, the operational district with the highest number of outages (planned and unplanned) occurring in the 33 kV electric power distribution grid is Sefwi Wiawso ECG operational district. The total number of outages (planned and unplanned) stood at 1898 lasting for 3019.4 hours. Followed closely was Sekondi ECG operational district with a total number of outages (planned and unplanned) at 1253 lasting for 1982.2 hours as given in Table VI as well as Fig. 8 and Fig. 11, respectively. Takoradi operational district experienced the highest number of outages (planned and unplanned) in the 11 kV electric power distribution grid which stood at 3597 lasting for 26039.9 hours. Sekondi ECG operational district followed closely with 1515 number of outages (planned and unplanned) lasting for 3253.3 hours as respectively given in Table VII as well as Fig. 9 and Fig. 12. Takoradi ECG operational district had 3136 planned and unplanned outages lasting for 1727.54 hours, followed by Sekondi operational district of a total number of planned and unplanned outages of 2228 lasting for 5881.9 hours in the LV electric power distribution grid as given in Table VIII as well as Fig. 10 and Fig. 13, respectively.

For the year 2016, Sefwi Wiawso ECG operational district again experienced a total number of planned and unplanned outages of 1425 lasting for 1149.23 hours. Bogoso operational district followed closely with 975 planned and unplanned outages lasting for 797.8 hours in the 33 kV electric power distribution grid as shown in Table XII as well as Fig. 8 and Fig. 11, respectively. This contrast sharply with that of Half Assini operational district with only 230 planned and unplanned outages lasting for 2921.24 hours. Takoradi ECG operational district had 1282 planned and unplanned outages lasting for 4973.44 hours, followed by Sekondi operational district with 978 planned and unplanned outages lasting for 1977.4 hours in the 11 kV electric power distribution grid as indicated in Table XIII as well as Fig. 9 and Fig. 12, respectively. Takoradi operational district experienced a total of 3273 planned and unplanned outages lasting for 2060.6 hours, followed by Sekondi operational district with 2653 planned and unplanned outages lasting for 3857.6 hours in the LV electric power distribution grid as shown in Table XIV as well as Fig. 10 and Fig. 13, respectively. Comparing Table 3 and Table 9 for the year 2015 and 2016 respectively, the total number of outages experienced on the Sefwi Wiawso ECG operational district 33 kV feeder reduced marginally from 1898 to 1425. The same thing can be said of the 11 kV feeder for Takoradi and Sekondi ECG operational districts. Whilst the outage declined from 3597 in the year 2015 to 1282 in the year 2016 as indicated respectively by Table IV and Table X. That of Sekondi ECG operational district declined marginally from 1515 in the year 2015 to 978 in the year 2016 on the 11 kV feeder. The tally for the LV distribution network showed that the total faults for Takoradi ECG operational district increased marginal from 3136 in the year 2015 to 3273 in the year 2016 as illustrated respectively by Table V and Table XI1. The same thing can be said of Sekondi ECG operational district. The total number of faults that occurred in the LV distribution network increased from 2228 in the year 2015 to 2653 in the year 2016 as indicated by Table V and Table XI respectively.

VII. Conclusion

Outages due to bad weather and load shedding contributed significantly to the unplanned outages that occurred in the MV electric power distribution grid. Falling tree and instantaneous earth faults also played a major role. Blown fuse faults and loose contact faults were the major contributors to unplanned outages in the LV electric power grid. For both MV and LV electric power distribution grids, planned outages were minor as compared to unplanned outages that occurred.

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