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A Comparative Power Flow Analysis of Dumez 11kv Distribution Network in Nigeria

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ABSTRACT: *Electrical Power Distribution system in Nigeria is constantly faced with an ever-growing load demand. The growth in load demand can be ascertained by conducting power flow analysis on the existing distribution system to ascertain the true performance of the network. Existing distribution system infrastructures having stayed for many years, are weak, obsolete and witness high energy losses. Most distribution substations are overloaded and cannot match with the increasing load demand of the consumers. This has resulted to irregular supply and under-voltage in the system which has led to incessant load shedding by the Distribution Company's (DISCOs) as an alternative to mitigate this challenge. This research involved actual measurement of data from existing Dumez 11KV feeder network, making the best model of the network based on the existing data in two different software environments, viz: DIgsilent Power Factory 2016 and Electrical Transient Analyzer Program (ETAP) 7.0. Load flow analysis was carried out on the 11kv DUMEZ feeder network using Newton-Raphson power flow algorithm embedded in both software's to determine the disparity in the results obtained from the two software's, find out the steady state condition of the existing network, suggest ways or adjustments that can be made in the properties of the existing model to improve the entire system. Following the result analysis, the results obtained from both software's are similar with very slight differences. The result analytically showed violation of voltage statutory limits. Out of a total of 47 load buses, voltage violation occurred in 46 buses (under voltage bus) operating under steady state condition. Only Otovwodo bus was within the marginal voltage acceptable limit of 97.8 %. However, in order to operate the entire system within the marginal voltage acceptable limit (marginal under voltage < 97%; marginal over voltage > 102%), there is need for upgrade in the form of Distributed Generation (DG).*

Keywords: *Load Flow Analysis, Network model, Radial Distribution Network, Bus Voltage Profile, Line Losses and Load Violation.*

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I. INTRODUCTION

Electrical Power Distribution system in Nigeria is constantly faced with an ever-growing load demand. The growth in load demand can be met by conducting power flow analysis on the existing distribution system to ascertain the true performance of the network. This ensures that electric power system meets itsprimary function, as to enhance optimal supply of uninterrupted electrical power to its teeming population of consumers. Existing distribution system infrastructures having stayed for many years, are weak, obsolete and witness high energy losses. Most substations are overloaded and cannot match with the increasing load demand of the consumers. This has resulted to under-voltage in the system which has led to incessant load shedding by the Distribution Company's (DISCOs) as an alternative to mitigate this challenge. The irregularity in supply of power has caused households and commercials to purchase and run their independent power to meet their daily electricity demand.

II. LITERATURE REVIEW

Power flow analysis is a very important and basic tool for analyzing electrical power system network performance. It is executed to determine the steady state operation of the installed network.Distributed generations are electrical power generation made at a site close to customers. They consist of electric power generator sources connected/tied to an electric distribution system/network which are used for generating electricity on-site. According to Ackermann et.al [1], Distributed Generation (DG) is an electric power source connected directly to the distribution network or connected to the network on the customer site of the meter. These electric generator sources are generally referred to as customer site/decentralized generators. Examples of these generator sources are synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high energy fossil fuels such as propane, oil, natural gas, gasoline or diesel), combustion gas turbines fuel cells, solar photovoltaic (PV), and wind turbines.

Distributed generators can be used in the following ways to meet the load requirement of a particular geographical distribution area [EPCOR, 2002][2]:

- For peak shaving: (generating a portion of customer's electricity onsite to reduce the amount of electricity purchased during peak price periods).
- For standby or emergency generation (as a backup to wires owners power supply).
- As wholly a green power source (using renewable technology for improved reliability).
  According to McDonald, et.al[3], distributed generation (DG) or decentralized electricity generation is not a new industry concept.

According to Baker[4], Scotland continues to lead the frontier for the battle against global warming and climate change and had pledged to reach 100% renewable sustainability for energy production by the year 2020. Scotland recently announced its push to @zero carbon emission" by year 2020 [5]. However, Scotland currently utilizes 39% renewable energy, 33% nuclear energy and 28% fossil fuel generation. The country is estimated to have the largest oil reserves in Europe and they recently made a national history by providing more than 20,000 homes their energy through wind generation alone. They have opened the world's First Ever Floating Wind Farm [5]. They also make use of tidal energy, solar and hydro. The sustenance of renewable energy had provided about 21,000 jobs across the country.

According to Agbetuyi [6], power flow analysis is used to determine the operating voltage at each bus and the power flow in all branches in the circuit. It determines if voltage remain within specified limits under various contingency conditions and whether equipment such as transformers and conductors are overloaded. Dorji[7], further buttressed the importance of power flow analysis as it can be used to identify the need for additional generation, the need for capacitive or inductive VAR support to existing systems or the need for placement of capacitors to maintain voltage within specified limits. However, power flow analysis is used duringthe planning and design stages, also during operational stages of a power system as well as solving optimization problems. Whichever application it is used for, it must be robust and time efficient. Power flow analysis can be easily performed to overcome the computational problems of load-flow solutions by using load-flow iterative techniques viz: Newton Raphson and Gauss Siedel algorithm embedded in computer modelling and simulation software's specifically designed for its use. This can be achieved by making the best model of the network using real and existing data and doing the simulations. Thus, by carrying out simulations on the existing network expected results can be observed and changes or adjustments can be made in the properties of the model to improve the weak points of the system.In this research, the modelling and simulation of 11KV DUMEZ distribution network on two different Load flow analysis software's are conducted with the aim of determining the steady state condition of the network and suggest ways by which the network can be improved.

III. METHODOLOGY

3.1 DUMEZ 11KV DISTRIBUTION NETWORK

The single line diagram of Dumez 11kv distribution network is shown in Fig.1 which shows how power is sent from the Otovwodo 15MVA, 33/11KV injection substation to the Dumez distribution feeder. The Dumez distribution feeder network has an 11KV system with substations and transformers which step down the voltage to 0.415KV at the secondary level. The Otovwodo 15MVA, 33/11KV injection substation transformer consists of two feeders namely: the Isoko road 11KVfeeder and the Dumez road 11KV feeder. However, the Isoko road feeder and Dumez road feeder are made up of 44 and 47 distribution substations respectively. Dumez distribution feeder is considered in this research to accommodate the number of bus-bars made available by the Power Factory 2016 license provider. Due to non-availability of relevant data, the data for this research were sourced by visitations to the area under study and actual measurementswere obtained using a Digital Clamp-on Meter Mastech Model MS2203. The data acquired are based on actual load values in each of the distribution substation, route lengths, transformer ratings, Aluminium Conductor Steel Reinforced conductor type (ACSR) and size and power factor.

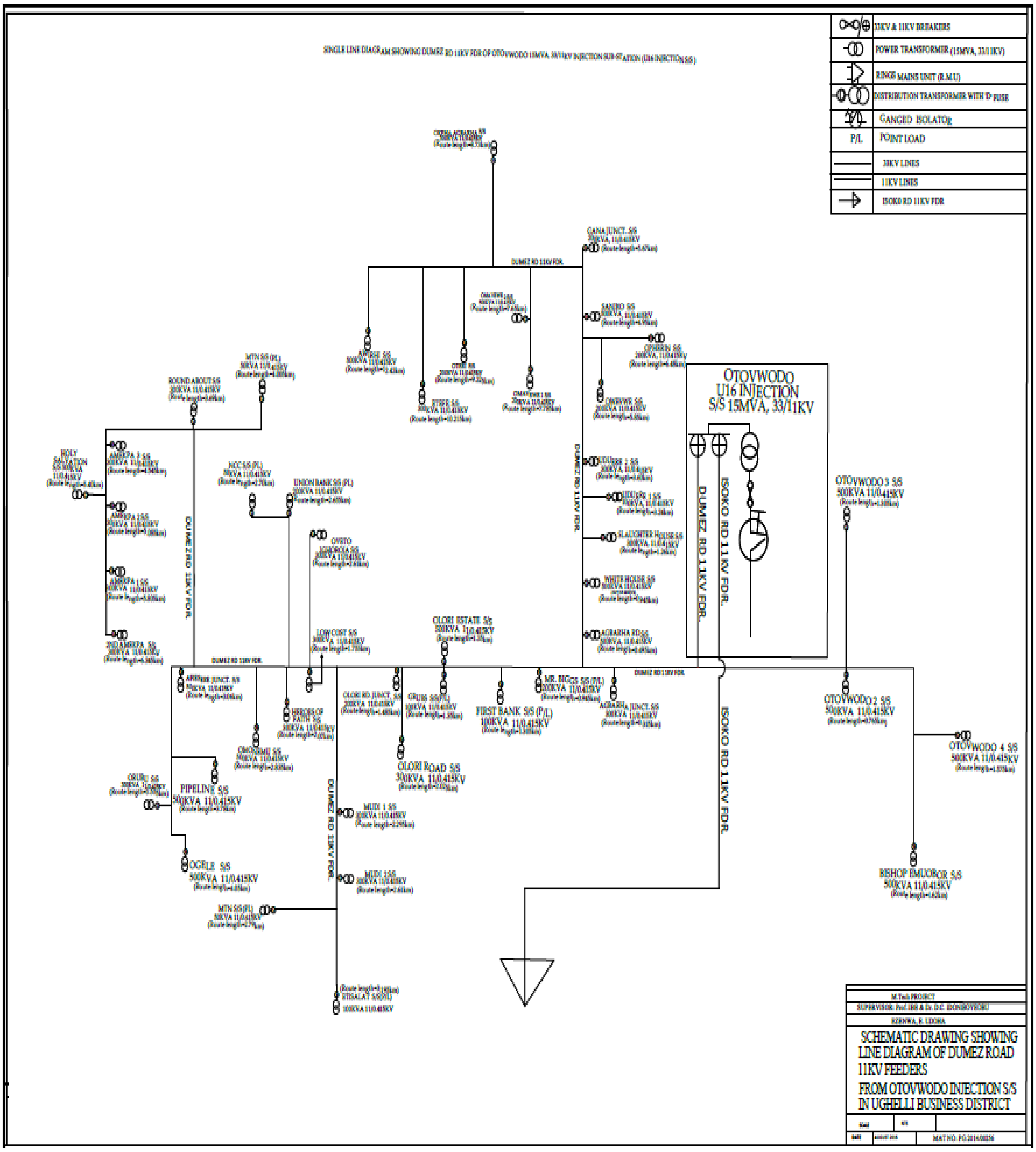

Figure 1. Single line diagram showing Dumez 11kv feeder network

3.2 MODELLING CONSIDERATIONOF DUMEZ 11KV FEEDER NETWORK IN POWER FACTORY 2016 AND ETAP 7.0

As earlier stated, power flow programs are used in both operational and planning stages and it provides the planning Engineer with detailed information concerning the system when it is operating under normal steady-state conditions. The modelling and simulation of Dumez 11kv network is done based on real and valid data which represents real condition of the network. DigSILENT Power Factory 2016 and Electrical Transient Analyzer Program (ETAP) 7.0 are used to perform the load flow analysis. They are fully integrated suite of electrical software applications that provides intelligent power monitoring, energy management, system optimization, advanced automation and real-time prediction.According to Ekwue and Akintunde[8], the former software is capable of carrying out balanced and unbalanced power flow, optimal power flow, low voltage network analysis and it's suitable for radial distribution networks.

Basic Assumptions Considered in Both Software:

- System type is 3 phase AC Overhead Distribution line conductors.
- Conductor type is Aluminum Conductor Steel Reinforced (ACSR)
- Line Model is Lumped parameter (Pi), Load type is Constant load of 50Hz Nominal frequency and 11kv

Nominal voltage.

- Percentage Voltage limits: Critical under voltage < 95%; Critical over voltage > 105%

Marginal under voltage < 97%; Marginal over voltage> 102%

- Otovwodo 33kv bus is made the slack or reference bus-bar.

The Dumez 11KV network consist of 47-node radialdistribution substations obtained from existing network in Ughelli, Delta State, Nigeria. Table 1 represents the measured distribution substation network data. This network data was modelled in the DIgSILENT Power Factory 2016 and Electrical Transient Analyzer Program (ETAP) 7.0 software's as shown in Figure 2 and Figure 3 respectively. DIgSILENT Power Factory mauals were used [9], [10]. The load flow was analyzed using Newton-Raphson (N-R) method which is embedded in the software's. Table 2 and 3 present's comparative summary of the result for both software's from the network. The assumptions stated above were considered for both the DIgSILENT model and the ETAP 7.0 model.

Table 1: Dumez 11KV Radial Network Data showing Transformer Rating, Route length, and Average Load Values

S/No.	NAME OF SUBSTATION	TRANSFORMER RATING (KVA)	ROUTE LENGTH (KM)	AVERAGE LOAD VALUES		
				KW	P.F	KVA
1	Otovwodo 2	500	0.765	259.380	0.713	363.787
2	Otovwodo 3	500	1.305	277.500	0.900	308.333
3	Otovwodo 4	500	1.575	203.600	0.850	239.529
4	Bishop Emuobor	500	1.620	295.410	0.948	311.613
5	Agbarha Junction	300	0.315	197.580	0.758	260.660
6	Agbarha rd	500	0.495	134.010	0.726	184.587
7	White house	200	0.945			
8	slaughter House	300	1.260	85.890	0.932	92.157
9	Uduere 2	300	3.600	98.250	0.850	115.588
10	Uduere 1	100	3.240	63.330	0.942	67.229
11	Owevwe	200	5.850	78.45	0.805	97.45
12	Opherin	200	6.480	95.139	0.852	111.665
13	Saniko	500	4.950	187.239	0.891	210.145
14	Gana Junction	200	5.670	112.000	0.730	153.425
15	Omavewe 2	200	7.650	29.040	0.941	30.861
16	Omavewe 1	500	7.785	323.529	0.934	346.390
17	Okpha-Agbara	300	8.730	97.560	0.954	102.264
18	Oteri	200	9.225	75.370	0.978	77.065
19	Etefe	300	10.215	58.040	0.804	72.189
20	Awirhi	200	12.420	44.820	0.797	56.236
21	Mr Biggs (P/L)	200	0.945	63.537	0.850	74.749
22	First Bank (P/L)	100	1.305	41.610	0.897	46.388
23	Olori Estate	500	1.350	411.690	0.902	456.419
24	Grubs (P/L)	100	1.350	37.608	0.811	46.372
25	Olori rd Junction	200	1.485	115.530	0.959	120.469
26	Olori Road	300	2.025	243.210	0.850	286.129
27	Low Cost	300	1.755	232.680	0.897	259.397
28	Mudi 1	300	2.295	183.130	0.719	254.701
29	Mudi 2	300	2.610	254.440	0.900	282.711
30	MTN (P/L)	50	2.790	1.212	0.850	1.426
31	Etisalat (P/L)	100	3.195	37.311	0.945	39.483
32	Heroes of Faith (P/L)	300	2.070	13.200	0.942	14.013
33	Oveto (Ighovoja)	300	2.610	47.310	0.850	55.659
34	Union Bank (P/L)	200	2.655	73.760	0.805	91.627
35	NCC (P/L)	50	2.700	23.550	0.931	25.295
36	Omonemu	500	2.835	134.280	0.910	147.560
37	Afiesere Junction	500	3.060	386.100	0.920	419.674
38	PipeLine	500	3.780	343.590	0.752	456.902
39	Orubu	500	3.555	287.130	0.739	388.539
40	Ogele	500	4.050	365.210	0.880	415.011
41	Round about	300	3.690	116.809	0.871	134.109
42	MTN 1 (P/L)	50	4.005	3.210	0.850	3.776
43	Amekpa 3	300	4.545	100.440	0.850	118.165
44	Amekpa 2	300	5.085	275.610	0.866	318.256
45	Holy Salvation	500	5.400	367.701	0.911	403.623
46	Amekpa 1	300	5.805	190.140	0.811	234.451
47	2^{nd}Amekpa	300	6.345	217.29	0.850	255.635

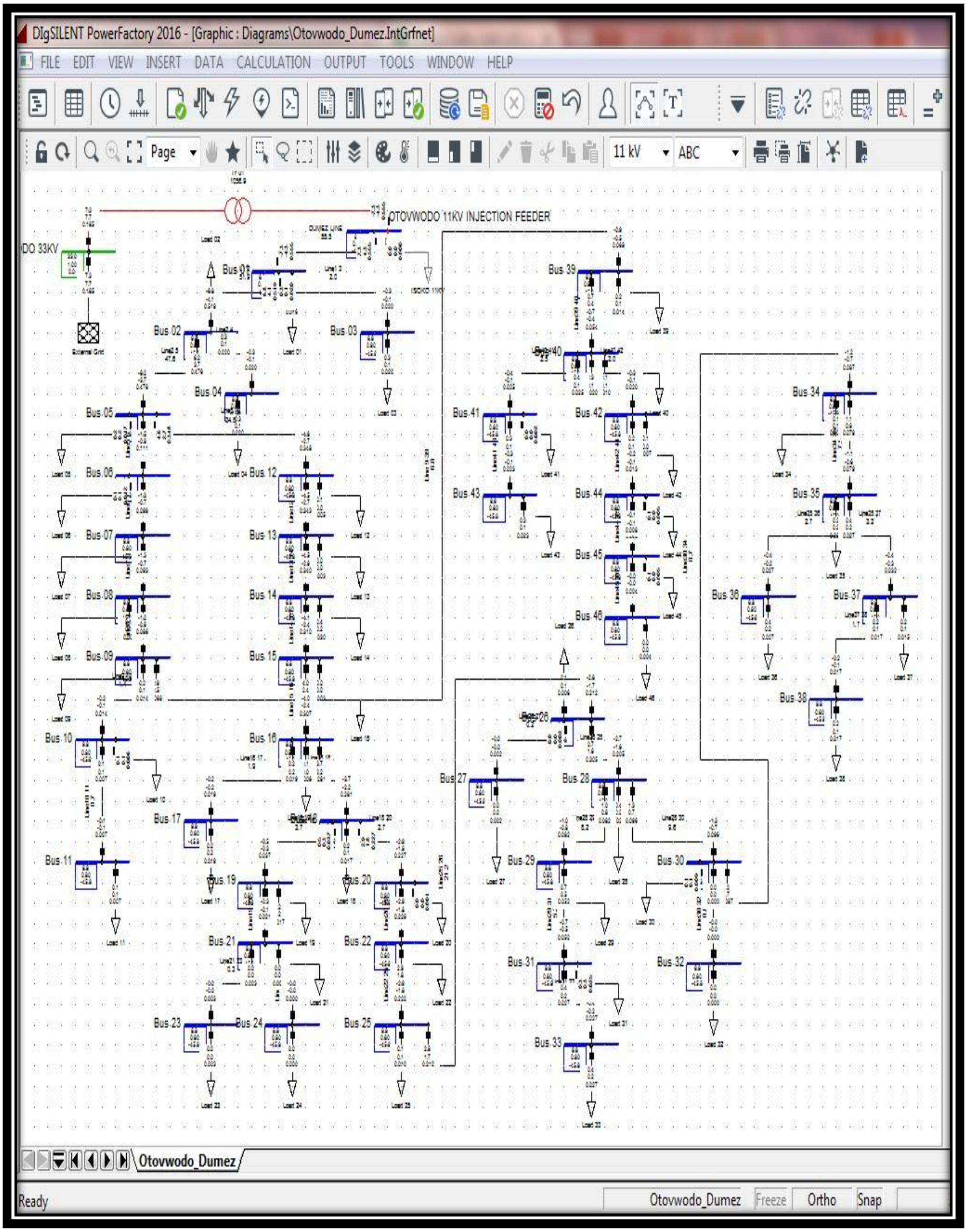

Figure 2: Dumez 11KV Distribution Network Modelled in DIgSILENT Power Factory 2016 Software

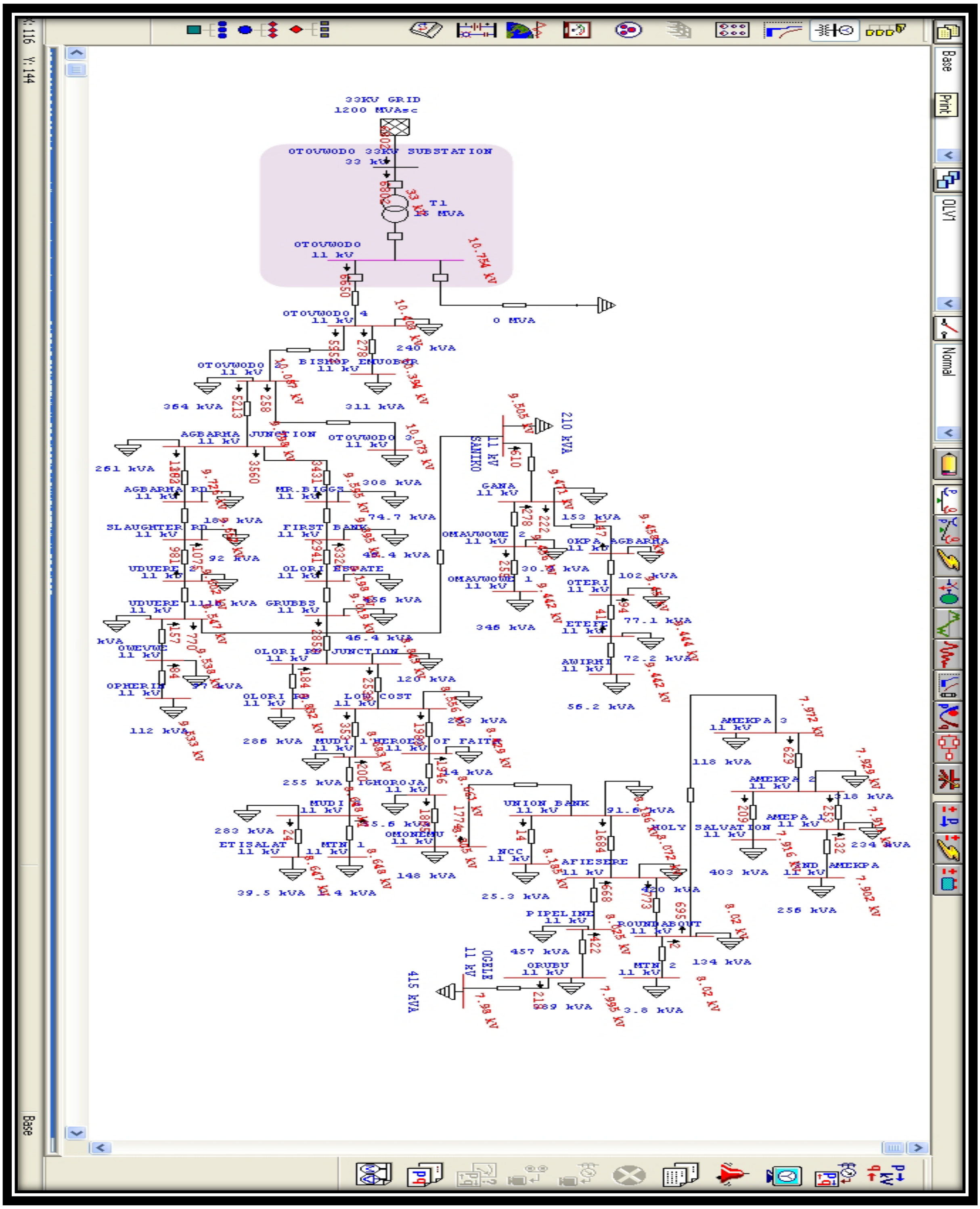

Figure 3: Dumez 11KV Distribution Network Modelled in ETAP 7.0 Software

IV. RESULT AND DISCUSSION

Table 2: Summary of Load Flow Report from DIgSILENT Power Factory 2016 and ETAP 7.0 Software

	DIgSILENT Power Factory 2016	ETAP 7.0
Voltage Violation	Voltage violation occurred in a total of 46 buses out of 47	Voltage violation occurred in a total of 46 buses out of 47
Total Losses	0.67781MW 0.8728MVar	722.7KW 972.8KVar
Range of Percentage Voltage Drop	3.05% - 0.01%	3.17% - 0.01%

It can be observed from Table 2 above, that the results obtained from both software's are similar with very slight differences. Hence, further analysis and implementation can be done with either of the result from both software to ensure accuracy of results.

Table 3: Comparison of Line Losses from DIgSILENT Power Factory 2016 and ETAP 7.0

Branch Connections		DIgSILENT 2016	ETAP 7.0
From Bus	To Bus	Losses	
		MW	KW
Amekpa 1	2nd Amekpa	0.00011	0.1
Union Bank	Afiesere	0.01562	15.5
Afiesere	Pipeline	0.00215	2.5
Afiesere	Roundabout	0.00314	3.4
Otovwodo 2	Agbarha junction	0.09717	97.7
Agbarha junctn	Agbarha RD	0.00659	6.5
Agbarha junctn	MR Biggs	0.04613	48.3
Agbarha RD	Slaughter RD	0.00511	5.1
Amekpa 3	Amekpa 2	0.00223	2.3
Amekpa 2	Holy Salvation	0.00031	0.3
Amekpa 2	Amekpa 1	0.00052	0.4
Amekpa 3	Roundabout	0.00265	2.7
Etefe	Awirhi	0.00021	0.2
Otovwodo 4	Bishop Emuobor	0.00041	0.4
Oteri	Etefe	0.00022	0.2
Mudi 2	Etisalat	0.00023	0.2
MR Biggs	First Bank	0.0468	46.8
First Bank	Olori Estate	0.0468	45.8
Saniko	Gana	0.00151	1.5
Gana	Omavwowe 2	0.00034	0.3
Gana	Okpa Agbarha	0.00021	0.2
Olori Estate	Grubbs	0.0374	37.4
Grubbs	Olori RD Junctn	0.0366	36.6
Low Cost	Heroes of Faith	0.0191	19.1
Heroes of Faith	Ighoroja	0.0179	17.9
Ighoroja	Omonemu	0.0183	18.3
Olori RD Junctn	Low Cost	0.0308	30.8
Low Cost	Mudi 1	0.00059	0.6
Mudi 2	MTN 1	0.00023	0.2
Roundabout	MTN 2	0.00043	0.3
Mudi 1	Mudi 2	0.00032	0.2
Union Bank	NCC	0.00021	0.2
Orubu	Ogele	0.00032	0.3
Okpa Agbarha	Oteri	0.00001	0.1
Olori RD Junctn	Olori RD	0.00023	0.2
Omavwowe 2	Omavwowe 1	0.00032	0.3
Omonemu	Union Bank	0.01675	16.7
Owevwe	Opherin	0.00032	0.2
Pipeline	Orubu	0.00053	1
Otovwodo	otovwodo 4	0.13669	139.6
Otovwodo 33KV	Otovwodo	0.01352	13.5
Otovwodo 4	Otovwodo 2	0.0575	97.5
Uduere 1	Owevwe	0.00022	0.2
Otovwodo 2	Otovwodo 3	0.00044	0.4
Uduere 1	Saniko	0.00225	2.4
Slaughter RD	Uduere 2	0.00451	4.5
Uduere 2	Uduere 1	0.00386	3.8
TOTAL		**0.67781**	**722.7**

Table 4: Comparison of Percentage Magnitude of Bus Voltages from DIgSILENT Power Factory 2016 and ETAP 7.0

Bus Name	DIgSILENT 2016	ETAP 7.0
	Voltage % Mag	
2nd Amekpa	71.992	72.513
Afiesere	75.071	74.071
Agharha Junctn	79.091	89.91
Agharha RD	94.245	89.245
Amekpa 2	73.062	72.762
Amekpa 3	73.15	73.156

Amekpa 1	73.097	72.597
Awirhi	84.64	86.642
Bishop Emuobor	93.521	94.421
Etefe	85.965	86.665
Etisalat	80.548	79.349
First Bank	87.313	86.213
Gana	85.005	86.905
Grubbs	83.664	82.765
Heroes of Faith	76.411	78.512
Holy Salvation	73.005	72.635
Ighoroja	75.459	77.349
Low Cost	75.459	79.681
Mr Biggs	87.749	88.046
MTN 1	80.568	79.361
MTN 2	76.681	73.589
Mudi 1	78.595	79.472
Mudi 2	80.001	79.361
NCC	73.985	75.111
Ogele	73.459	73.228
Okpa Agbarha	85.316	86.793
Olori Estate	83.519	84.403
Olori RD	80.998	81.043
Olori RD Junctn	80.989	81.149
Omavwowe 1	85.534	86.643
Omavwowe 2	85.658	86.769
Omonemu	77.311	76.209
Opherin	86.585	87.482
Orubu	75.001	73.363
Oteri	85.007	86.717
Otovwodo	97.752	97.764
Otovwodo 2	94.517	92.557
Otovwodo 3	94.413	92.433
Otovwodo 4	94.601	94.592
Otovwodo 33KV Substatn	99.989	100
Owevwe	88.029	87.526
Pipeline	74.531	73.636
Roundabout	74.596	73.591
Saniko	87.017	87.217
Slaughter RD	87.969	88.662
Uduere 1	88.951	87.611
Uduere 2	89.955	88.112
Union Bank	76.956	75.119

However, it can be observed from Table 3 and 4, that the results from both software's when compared with the lines losses and percentage magnitude of bus voltages showed some level of similarity with very slight differences. Therefore, in order to avoid some level of ambiguity and achieve clarity of purpose analysis can further be carried out using the result obtained from ETAP 7.0.

The result obtained from load flow analysis for the Dumez radial distribution network of Otovwodo 15MVA 33/11KV injection substation and its associated feeders indicate the following:

i) Following the load flow analysis carried out on the Dumez distribution network with a total of forty seven (47) load buses, voltage violation occurred in forty six (46) buses out of 47 load buses. This practically shows the level of under-voltage that is being witnessed by a typical distribution network in Nigeria under steady state condition of the system. The percentage operating voltage range is approximately between 2nd Amekpa 72.5% and Otowodo_4 with 94.6%. Out of 47 load buses, only Otovwodo bus was found within the system marginal voltage acceptable limit of 97.8 % operating marginal limit. The voltage range being used in Nigeria is ± 6%.

ii) The highest percentage voltage drop was 3.17%, which occurred at branch connection between Otovwodo to Otovwodo_4.

iii) The lowest percentage voltage drop of 0.01% occurred at the following branch connections from Mudi_2 to Etisalat), Mudi_2 to MTN_1, Roundabout to MTN_2 and Union Bank to NCC.

iv) The total losses is 722.7KW, 972.8KVAR (0.7227 MW, 0.972.8MVar).

V. CONCLUSION

This comparative power flow analysis of Dumez 11KV distribution network of Otovwodo 15MVA, 33/11KV Injection substation in Ughelli, Delta State, Nigeria was successfully carried out using DIgSILENT Power Factory 2016 and ETAP 7.0 software. Detailed analysis was done using the Newton Raphson (N-R) load flow method embedded in the software. The results obtained when compared with both software's showed some level of similarity with very slight negligible differences. The result analytically showed violation of voltage statutory limits. Out of a total of 47 load buses, voltage violation occurred in 46 buses (under voltage) operating under steady state condition.Only Otovwodo bus was within the marginal voltage acceptable limit of 97.8 %. This result shows that some transformers on the network are over-loaded. This result practically explains the major cause of incessant load shedding on Nigeria distribution networks.

VI. RECOMMENDATION

In order to meet the load demand of the people living in this surrounding and also take care of their future expansion, there is need for system upgrade in the form Distributed Generation(DG). This is because DG has the capability to provide an immediate solution to the growing energy demand due to its short construction timeline and low installation cost. DG in distribution systems helps to reduce technical losses and improves voltage profile. However, DG improves system efficiency, reliability, safety and quality of service.

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