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BACKWARD/FORWARD SWEEP POWER FLOW ANALYSIS FOR RADIAL DISTRIBUTION NETWORK IN UYO AKWA IBOM STATE

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ABSTRACT
In this paper, backward/forward sweep (BFS) power flow analysis of radial distribution network in Uyo, Akwa Ibom State is presented. The case study RDN dataset is the (2 X 15MVA, 33/11k) injection substation an the data was obtained from the Port Harcourt Electricity Distribution Company (PHED) Uyo branch, Akwa Ibom State. The RDN is modelled using mathematical equations which are based on the 3-bus radial distribution network. The models are then implemented in MATLAB. The simulation results showed that for the AKA 11 kV distribution feeder, the total active and reactive power demands are 2108.68 kW and 7715.29 kVAR, respectively. In all, the BFS method proved effective in computing voltage profiles and power losses across the network, providing a reliable baseline for further analysis.
Keywords: Backward/Forward Sweep, Distribution Substation, Power Flow Analysis, Radial Distribution Network, Reactive Power Losses

INTRODUCTION
Over the years, it has been established that electric power supply is the bedrock of national economic development [1,2,3]. To this end, experts, investors, consumers and government institutions are making conscious effort to ensure access to electric power supply and also to ensure that adequate supply is ensured [4,5]. However, there are several factors that militate against such effort. Even when there is power supply, the stability of the power system, the voltage profile, the active and reactive power in the network can be a great concern [6,7,8]. Also, in this era of distributed power generation (DG) system, the power distribution network parameters are considered in order to determine the appropriate size and location of placement of the DG [9,10,11].

In all these case, load flow analysis is required for the power system [12,13]. Load flow analysis provides the requisite information on the distribution of the voltages, the active and reactive power on the various buses on the power distribution network [14,15,16]. Such information are essential for understanding the stability of the power system and its ability to effectively deliver the desired power. Accordingly, in this work, the Backward/Forward Sweep Power Flow Analysis of radial distribution network is presented [17,18]. The focus is on a radial distribution network (RDN) and the study is conducted for a base case where there is no DG installed on the RDN. The study is meant to provide the preliminary scenario for the installation of DGs on the RDN.

METHODOLOGY
In this study, backward/forward sweep power flow analysis of radial distribution network (RDN) in Uyo, Akwa Ibom State. The case study RDN dataset is the (2 X

15MVA, 33/11k) injection substation an the data was obtained from the Port Harcourt Electricity Distribution Company (PHED) Uyo branch, Akwa Ibom State. The dataset contains the RDN line parameters resistance, the line reactance, the bus loads (active and reactive power), and the RDN topology from 11kV distribution substation. The case study AKA 11kV distribution feeder network single-line diagram of is presented in Figure 1. The RDN is modelled using mathematical equations which are based on the 3-bus radial distribution network give in Figure 2. The models are then implemented in MATLAB. The initial voltage of all the buses are given a flat start, which is the injected voltage into the network at bus 1.

$$V^{0}_{1} = 1\angle 0° \text{ pu} \qquad (1)$$

$$V^{0}_{2} = 1\angle 0° \text{ Pu} \qquad (2)$$

$$V^{0}_{3} = 1\angle 0° \text{pu} \qquad (3)$$

The branch resistance and reactance are kept constant, the active and reactive power demand at each bus is also kept constant. The load current of the network is therefore given by:

$$I_2 = \left[\frac{S_2}{V_2}\right]^* = \left[\frac{P_{L2}+jQ_{L2}}{V_2}\right]^* = \frac{P_{L2}-jQ_{L2}}{V_2^*} \qquad (4)$$

Similarly,

$$I_3 = \left[\frac{S_3}{V_3}\right]^* = \left[\frac{P_{L3}+jQ_{L3}}{V_3}\right]^* = \frac{P_{L3}-jQ_{L3}}{V_3^*} \qquad (5)$$

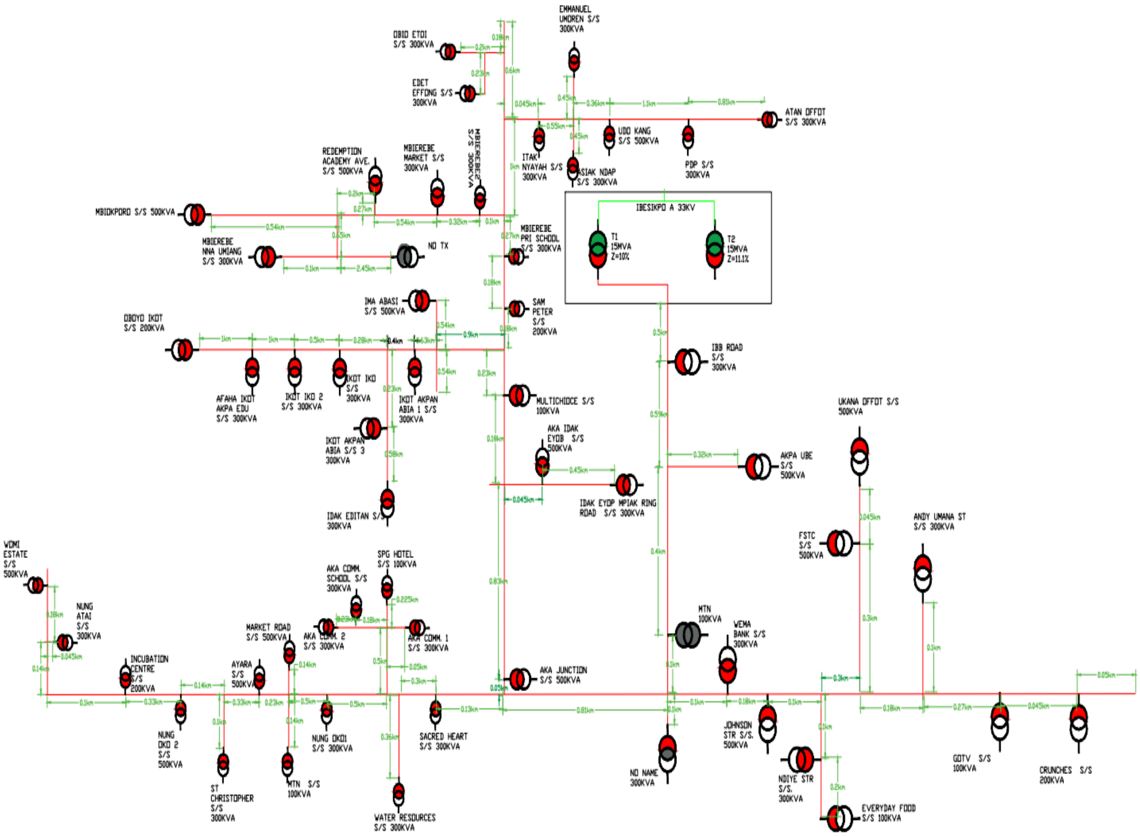

Figure 1: Single-line diagram of AKA 11kV distribution feeder network.

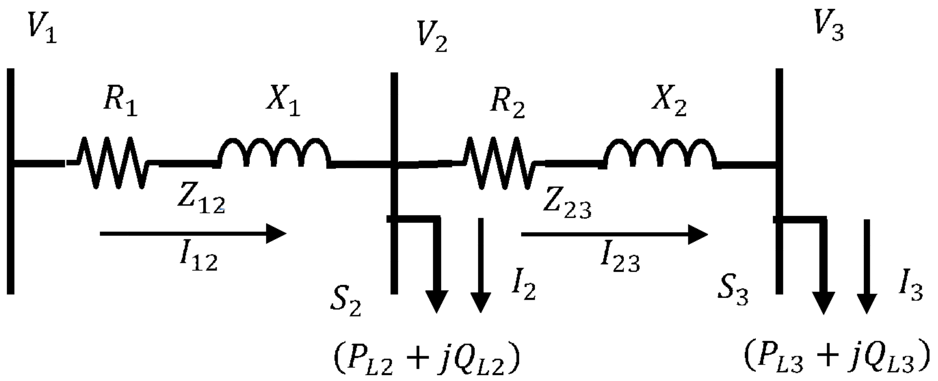

Figure 2: A 3-bus radial distribution network

Backward sweep: starting from the last feeder, the branch current entering bus 3, using KCL is given by:

$$I_{23} = I_3 \quad (6)$$

In the same vein, applying KCL at bus 2,

$$I_{12} = I_2 + I_{23} \quad (7)$$

From (I_2, $I_{23} = I_3$. Therefore,

$$I_{12} = I_2 + I_3 \quad (8)$$

Forward sweep:

$$Z_{12} = R_1 + X_1 \quad (9)$$

$$Z_{23} = R_2 + X_2 \quad (10)$$

Applying KVL between bus 1 and 2;

$$V^1_2 = V_1 - I_{12} * Z_{12} \quad (11)$$

Similarly, applying KVL between bus 2 and 3

$$V^1_3 = V_2 - I_{23} * Z_{23} \quad (12)$$

Error calculation in the voltage;

$$e^1_2 = [V^1_2 - V^0_2] \quad (13)$$

$$e^1_3 = [V^1_3 - V^0_3] \quad (14)$$

$$e^1_{max} = max\left(e^1_2, e^1_3\right) \quad (15)$$

Check for convergence: If $e^1_{max} \leq \varepsilon$ is true, where $\varepsilon = 1 * 10^{-5} = 0.00001$ then stop the iteration and print the results, else increase the iteration count to 2. If the iteration converges or the desired accuracy is met, the active and reactive power losses can then be calculated using the following equations:

$$P_{loss(1)} = I^2_{12} * R_1 \quad (16)$$

$$Q_{loss(1)} = I^2_{12} * X_1 \quad (17)$$

$$P_{loss(2)} = I^2_{23} * R_2 \quad (18)$$

$$Q_{loss(2)} = I^2_{23} * X_2 \quad (19)$$

$$P_{Loss(total)} = P_{loss(1)} + P_{loss(2)} \quad (20)$$

$$Q_{Loss(total)} = Q_{loss(1)} + Q_{loss(2)} \quad (21)$$

The flowchart for the backward/forward sweep power flow analysis adopted is presented in Figure 3. Specifically, the study utilized the 11 kV, 56-bus AKA radial feeder within the Uyo distribution network. The network line data for the AKA 11 kV, 56-bus radial feeder are presented in Table 1. This data includes distances between substations, line resistance, and line reactance. To further understand the electrical characteristics of the AKA 11 kV feeder, (Table.2) presents the critical feeder parameters for the cables used in the network. The critical feeder parameters data include the cable type, configuration, size, resistance per kilometer (Ω/km), reactance per kilometer (Ω/km), and maximum current carrying capacity (A). Furthermore, the detailed network load data for the AKA 11 kV feeder was also compiled. This data includes the bus location, voltage level (kV), transformer rating (kVA), active power demand (kW), and reactive power demand (kVar) at a power factor of 0.9.

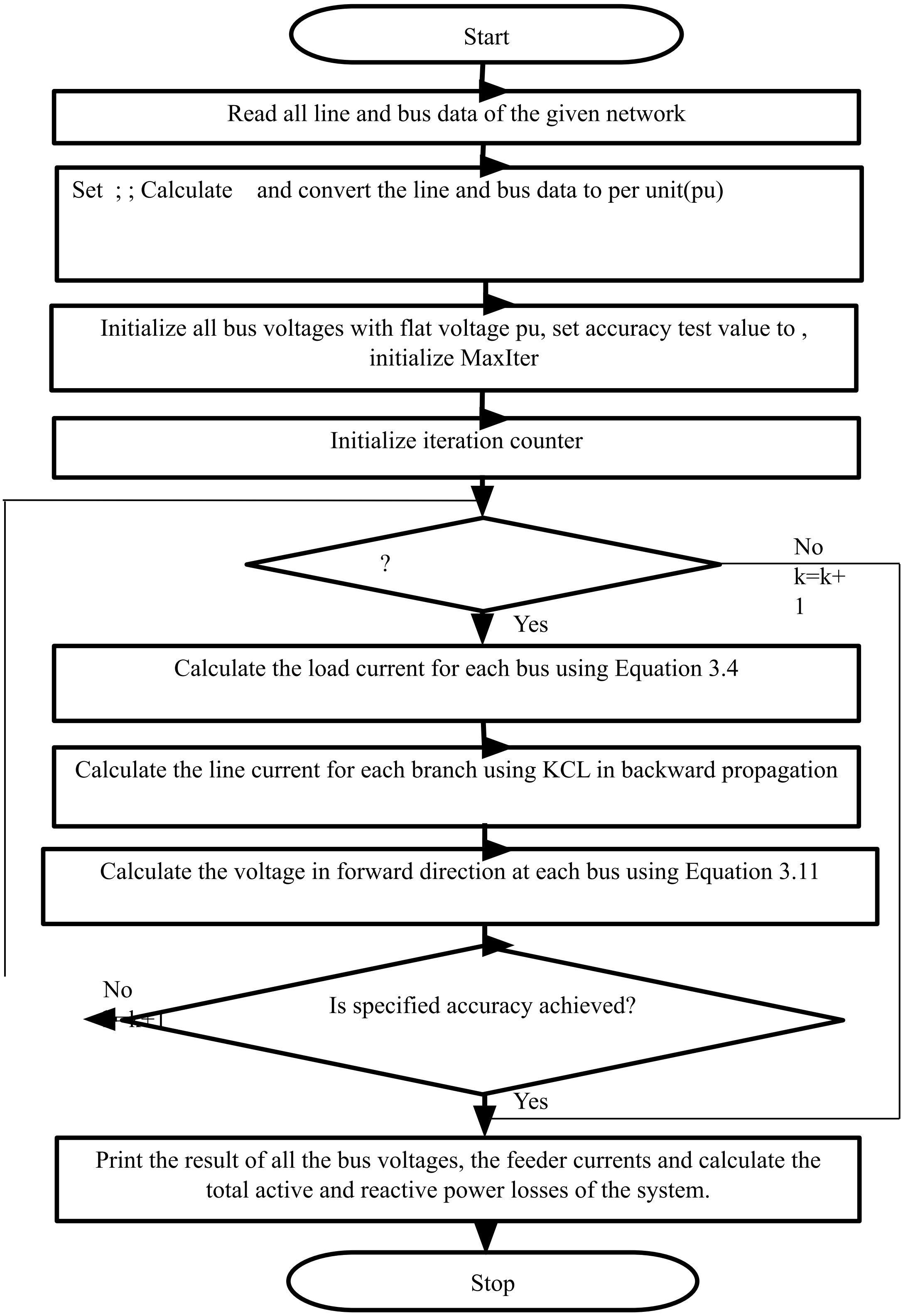

Figure 3: Flowchart for load flow analysis in a radial distribution network using the Backward/Forward Sweep method

Table 1: The network line data for the AKA 11 kV, 56-bus radial feeder

S/N	From Bus	To Bus	Distance (km)	Line Resistance (Ω)	Line Reactance (Ω)	S/N	From Bus	To Bus	Distance (km)	Line Resistance (Ω)	Line Reactance (Ω)
1	1	2	0.5	0.1260	0.0464	29	29	30	0.23	0.0580	0.0213
2	2	3	0.91	0.2293	0.0844	30	15	31	0.875	0.2205	0.0812
3	3	4	0.72	0.1814	0.0668	31	31	32	0.45	0.1134	0.0418
4	4	5	0.2	0.0504	0.0186	32	31	33	0.225	0.0567	0.0209
5	5	6	0.2	0.0504	0.0186	33	33	34	0.41	0.1033	0.0380
6	6	7	0.8	0.2016	0.0742	34	34	35	0.18	0.0454	0.0167
7	7	8	0.2	0.0504	0.0186	35	35	36	1.92	0.4838	0.1782
8	8	9	0.2	0.0504	0.0186	36	36	37	0.43	0.1084	0.0399
9	7	10	0.7	0.1764	0.0650	37	35	38	0.37	0.0932	0.0343
10	10	11	0.045	0.0113	0.0042	38	38	39	0.32	0.0806	0.0297
11	10	12	0.58	0.1462	0.0538	39	39	40	0.81	0.2041	0.0752
12	12	13	0.37	0.0932	0.0343	40	40	41	1.22	0.3074	0.1132
13	13	14	0.045	0.0113	0.0042	41	41	42	1.29	0.3251	0.1197
14	5	15	0.96	0.2419	0.0891	42	33	43	1.67	0.4208	0.1550
15	15	16	0.18	0.0454	0.0167	43	43	44	0.63	0.1588	0.0585
16	16	17	0.66	0.1663	0.0612	44	44	45	0.63	0.1588	0.0585
17	17	18	0.86	0.2167	0.0798	45	45	46	0.58	0.1462	0.0538
18	18	19	0.64	0.1613	0.0594	46	45	47	0.51	0.1285	0.0473
19	19	20	0.28	0.0706	0.0260	47	47	48	0.5	0.1260	0.0464
20	20	21	0.37	0.0932	0.0343	48	48	49	1	0.2520	0.0928
21	21	22	0.43	0.1084	0.0399	49	49	50	1	0.2520	0.0928
22	22	23	0.24	0.0605	0.0223	50	35	51	1.315	0.3314	0.1220
23	23	24	0.33	0.0832	0.0306	51	51	52	1	0.2520	0.0928
24	24	25	0.285	0.0718	0.0264	52	52	53	0.9	0.2268	0.0835
25	25	26	0.18	0.0454	0.0167	53	53	54	0.81	0.2041	0.0752
26	17	27	0.91	0.2293	0.0844	54	54	55	1.1	0.2772	0.1021
27	27	28	0.275	0.0693	0.0255	55	55	56	0.8	0.2016	0.0742
28	28	29	0.18	0.0454	0.0167						

Table 2: The critical feeder parameters for the cables used in the AKA 11 kV feeder line

Cable Type	Configuration	Cable Size	Resistance (Ω/km)	Resistance (Ω/km)	Maximum Current Capacity (A)
Aluminum Conductor Steel Reinforced (ACSR)	Overhead	150mm^2	0.252	0.0928	331

RESULTS AND DISCUSSIONS

The RDN data acquired was used for accurate modelling and analysis of the specific RDN considered in the study. In addition, the acquired data was used in the Backward/Forward Sweep (BFS) power flow analysis of the case study network which was implemented in MATLAB software. The base case voltage profile analysis results obtained using the BFS method is presented in Table 3. The results in Table 3 provide details of the bus locations, voltage magnitudes (pu), and voltage angles (deg).

Table 3: The base case voltage profile analysis results obtained using the BFS method

Bus Location	Bus No.	Voltage Mag. (pu)	Voltage Angle (deg)	Bus Location	Bus No.	Voltage Mag. (pu)	Voltage Angle (deg)
Injection Substation	1	1.0000	0.000	Aka Community School II S/S	29	0.8897	0.137
IBB Road S/S	2	0.9834	0.010	Aka Community School III S/S	30	0.8896	0.143
Akpa Ube S/S	3	0.9536	0.031	Aka Idak Eyop S/S	31	0.8852	0.101
MTN S/S	4	0.9306	0.048	Idak Eyop Mpiak Ring Road S/S	32	0.8849	0.114
No Name	5	0.9243	0.053	Multichoice S/S	33	0.8819	0.107
Wema Bank S/S	6	0.9232	0.058	Samuel Peter S/S	34	0.8780	0.119
Johnson St S/S	7	0.9196	0.078	Mbietebe Primary School S/S	35	0.8763	0.124
Ndiya St S/S	8	0.9195	0.083	Edet Effiong S/S	36	0.8741	0.177
Everyday Food S/S	9	0.9194	0.088	Obio Etoi S/S	37	0.8739	0.190
FSTC S/S	10	0.9176	0.096	Mbietebe II S/S	38	0.8750	0.134
Ukana Offot S/S	11	0.9175	0.097	Mbietebe Market S/S	39	0.8740	0.143
Andy Umana St S/S	12	0.9169	0.111	Redemption Academy Avenue S/S	40	0.8720	0.166
GOTV S/S	13	0.9167	0.120	Mbietebe Nna Umiang S/S	41	0.8701	0.200
Crunchies S/S	14	0.9167	0.121	Mbiokporo S/S	42	0.8689	0.237
Aka Junction S/S	15	0.8992	0.078	Ima Abasi S/S	43	0.8739	0.154
Sacred Heart S/S	16	0.8976	0.082	Ikot Akpa Abia I S/S	44	0.8715	0.172
Water Resources S/S	17	0.8920	0.100	Ikot Akpa Abia II S/S	45	0.8694	0.190
Nung Oko I S/S	18	0.8868	0.123	Idak Editan S/S	46	0.8691	0.206
MTN S/S	19	0.8833	0.141	Ikot Iko I S/S	47	0.8683	0.204
Market Road S/S	20	0.8818	0.149	Ikot Iko II S/S	48	0.8676	0.218
Ayara S/S	21	0.8802	0.159	Afaha Ikot Akpa Edu S/S	49	0.8666	0.247
ST. Christopher S/S	22	0.8787	0.171	Oboyo Ikot S/S	50	0.8662	0.276
Nung Oko II S/S	23	0.8780	0.178	Itak Nyayah S/S	51	0.8712	0.161
Incubation Centre S/S	24	0.8774	0.187	Nsiak Ndap S/S	52	0.8680	0.189
Nung Atai S/S	25	0.8769	0.195	Emmanuel Umoren S/S	53	0.8655	0.215
Womi Estate S/S	26	0.8768	0.200	Udo Kang S/S	54	0.8638	0.238
Aka Community School I S/S	27	0.8903	0.125	PDP S/S	55	0.8625	0.270
SPG Hotel S/S	28	0.8899	0.132	Atan Offot S/S	56	0.8621	0.293

The summary of the critical power system parameters for the power network is presented in Table 4. Furthermore, the results of the voltage profile of the base case scenario (without DG) is presented in Figure 4. In all, the BFS method proved effective in computing voltage profiles and power losses across the network, providing a reliable baseline for further analysis. Also, for the AKA 11 kV distribution feeder, the total active and reactive power demands were calculated to be 2108.68 kW and 7715.29 kVAR, respectively. A base case analysis, conducted without DG, revealed total active and reactive power losses of 278.98 kW and 776.537 kVAR. This represented a 13.23% loss in active power and a 10.07% loss in reactive power due to the network's configuration.

Table 4: Base case summary of key power system metrics

Parameters	Base Case
Total real power demand (kW)	15938.62
Total reactive power demand (kVar)	7715.29
Total real power loss (kW)	2108.68
Percentage of total real power loss to the total real power (%)	13.23716259
Total reactive power loss (kVar)	776.537
Percentage of total reactive power loss to the total reactive power (%)	10.06491007
Minimum voltage (pu)	0.8621
Minimum voltage bus number	56
Maximum Voltage (pu)	0.9834
Maximum voltage Bus number	2
Voltage deviation index (%)	11.28

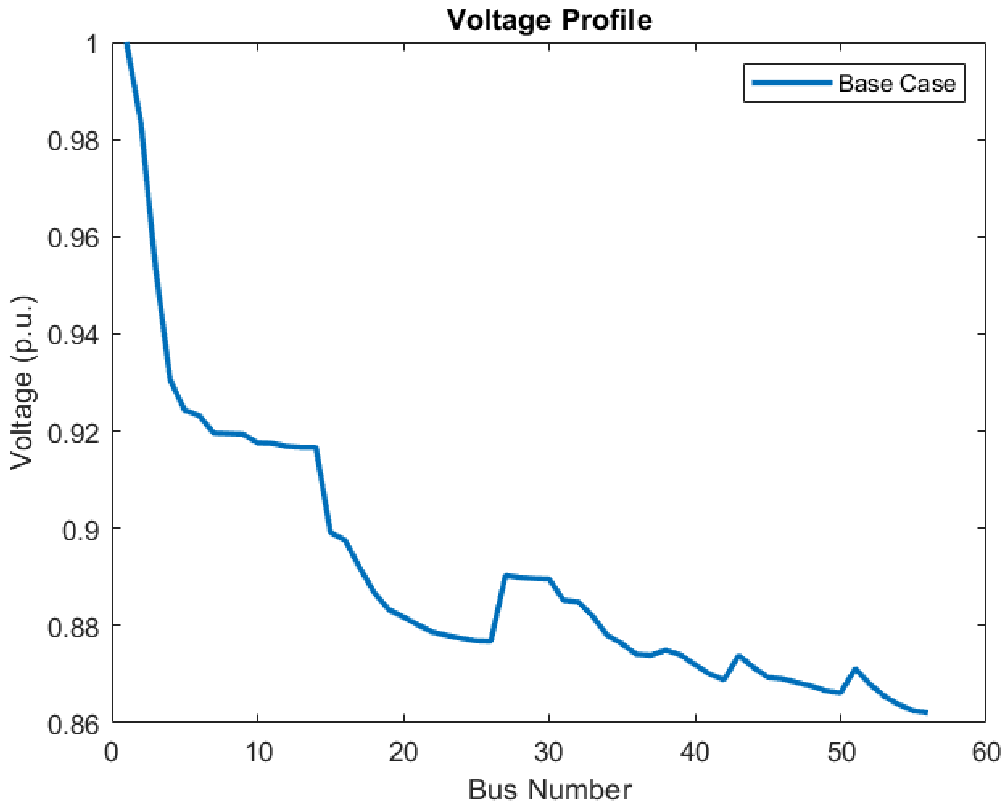

Figure 4: Voltage profile of the base case scenario (without DG).

CONCLUSION

Load flow analysis is presented for a case study radial distribution network located in Uyo Awka Ibom State. The Backward/Forward Sweep technic is used for load flow analysis. The mathematical details of the load flow in the network are presented based on the single line network model. Mathlab software was used for the modelling and simulation. The result obtained includes all the bus voltages, the feeder currents, the total active and reactive power losses of the system.

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