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Original Research Article

A Methodology Evaluation of the IEEE 33-Bus Network Losses Using ETAP 19.0

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ABSTRACT

Power system installation and distribution networks are usually faced with varied power losses and fluctuations in voltage profile magnitude no matter how stable or balanced the network may be, hence the need for a continuous evaluation to check this setback that may arise in the course of power system distribution. This work seeks to carry out a methodology approach for investigating the distribution network losses as a result of unbalanced loading of the IEEE 33-Bus network. The method adopted is the Newton-Raphson method using the Electrical Transient Analyzer Program 19 (ETAP) software for the power flow analysis. The results of the load flow study showed that the system had a cumulative power losses corresponding to real and reactive power loss of 199.2 kW and 134.9 kVAR respectively. The result further showed that lines 2, 7 and 5 had the highest losses of 49.6 kW and 25.2 kvar, 36 kW and 31.3kvar followed by 18.9 kW and 9.6 kVAR respectively. The system losses obtained is quite minimal which confirms the balanced load network of IEEE 33-bus system.

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1. INTRODUCTION

Electrical power system complexity requires continuous load flow analysis which enables Power Systems Engineers and other relevant stakeholders to effectively carry out planning, system operation, optimization and cost effective running of the power system network (Madjissembaye et al., 2016). This is important due to the rising cases of power system load demand making the system more complex leading to higher system losses and poor voltage profile regulation.

The distribution link of a power system is to deliver electrical power from the transmission network to end users which are usually unbalanced and have a high resistance to reactance (R/X) ratio compared to transmission systems thereby resulting in high voltage drops and power losses in the distribution feeders (Mahdi and Meysam 2016). It is evident that following the huge expansion of power system network, there have been noticeable three phase unbalanced problem in low voltage distribution grid.

Arising from the aforementioned, continuous power demand gives rise to different problem like power losses, voltage unbalance, line overloading, power cogging/surplus etc (Bhavana and Smarajit 2017).

Yongxia and Yulei (2018) stated that asymmetrical and uneven single phase load exists widely in low voltage distribution grid systems which is not only related to the user load characteristic and the time of use, but also related to the load distribution of the power system. Many techniques have been deployed in resolving distribution network losses by different researchers around the globe. Rupa and Ganesh (2014) proposed and carried out power flow studies for radial distribution system using Backward/Forward Sweep Method (BFS) using forward propagation in calculating the voltage magnitudes at each node. Many researchers have carried out work on power losses in distribution network but all the approaches differ from each other by way of their problem formulation and the problem solution method employed (Neelima and Subramanyam 2012).

A study on unbalanced power flow in distribution systems with embedded transformers was presented using a direct approach to simultaneously solve the whole system of equations by means of the trust-region-dogleg algorithm and MATLAB toolbox, the proposed model was successfully validated by comparing the obtained results for the IEEE 4 node test feeder (Pablo et al., 2012).

Therefore, the aim of this work is to analyze the power losses of the IEEE 33-Bus Network using Newton-Raphson method in ETAP 19 software to validate the veracity of the ETAP 19 software in carrying out the load flow study of the IEEE 33-bus network from the previous works using backward forward sweep method with matlab software.

2. MATERIALS AND METHODS

2.1. Newton-Raphson Load Flow Method

The evaluation of the IEEE 33-Bus Network was carried out using the Standard input line and load data of the distribution system. This was done by applying Newton-Raphson method in ETAP 19 software to carry out the load flow analysis. The Newton-Raphson load flow method has the ability of quick and fast convergence using minimum number of iterations during the process, it also increases linearly with the network size. The Newton-Raphson method is more accepted and widely used in solving power system load flow problem due to its faster convergence adaptability which makes it more superior to the Gauss-Seidel load flow method (Idoniboyeobu and Ibeni 2017).

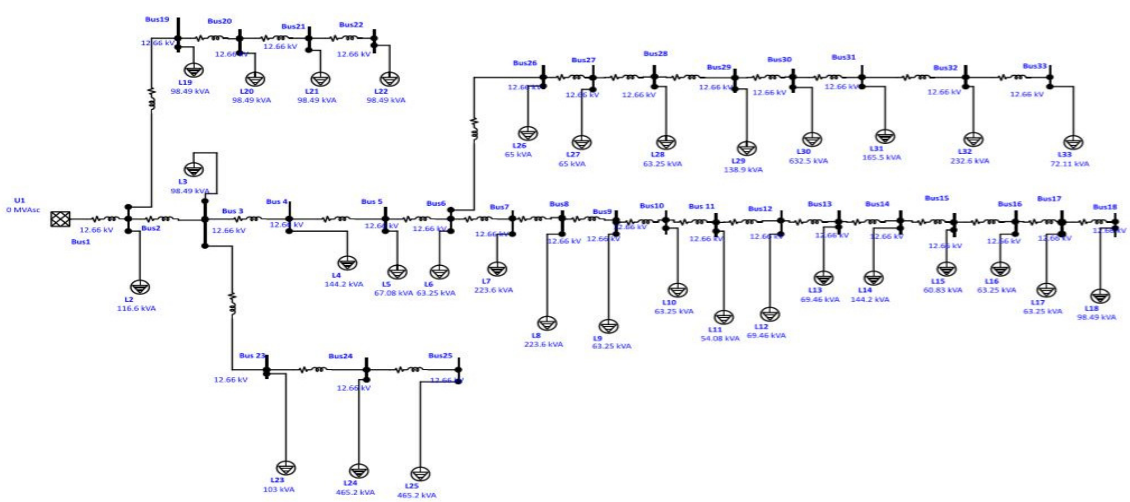

Figure 1: IEEE 33-bus network in the edit mode

The network architecture is a radial distribution system shown in Figure 1. The network has thirty-three load buses with a standard voltage of 12.66 kV each. The network is fed by a synchronous generator, while it is loaded from 3.715 MW and 2.3 MVar connected to thirty-two buses of different power factors. Table 1 and 2 are the IEEE 33-Bus network load and line data respectively used in this work as extracted from (Vasiliki 2017) who used decision-making algorithm in matlab environment to develop the optimum size and placement of distributed generation units in distribution networks.

Table 1: Load data of the IEEE 33-bus radial distribution system (Vasiliki 2017)

Load	Bus location	Real load (kW)	Reactive load (kVAR)
L1	1	0	0
L2	2	100	60
L3	3	90	40
L4	4	120	80
L5	5	60	30
L6	6	60	20
L7	7	200	100
L8	8	200	100
L9	9	60	20
L10	10	60	20
L11	11	45	30
L12	12	60	35
L13	13	60	35
L14	14	120	80
L15	15	60	10
L16	16	60	20
L17	17	60	20
L18	18	90	40
L19	19	90	40
L20	20	90	40
L21	21	90	40
L22	22	90	40
L23	23	90	50
L24	24	420	200
L25	25	420	200
L26	26	60	25
L27	27	60	25
L28	28	60	20
L29	29	120	70
L30	30	200	600
L31	31	150	70
L32	32	210	100
L33	33	60	40

Table 2: Line data of the IEEE 33-bus radial distribution system (Vasiliki 2017)

From bus	To bus	Resistance R (Ohm/km)	Reactance X (Ohm/km)	Length (km)
1	2	0.0922	0.0470	1
2	3	0.4930	0.2511	1
2	19	0.1640	0.1565	1
3	4	0.3660	0.1864	1
3	23	0.4512	0.3083	1
4	5	0.3811	0.1941	1
5	6	0.8190	0.7070	1
6	7	0.1872	0.6188	1
6	26	0.2030	0.1034	1
7	8	0.7114	0.2351	1
8	9	1.0300	0.7400	1
9	10	1.0440	0.7400	1
10	11	0.1966	0.0650	1
11	12	0.3744	0.1238	1
12	13	1.4680	1.1550	1
13	14	0.5416	0.7129	1
14	15	0.5910	0.5260	1
15	16	0.7463	0.5450	1
16	17	1.2890	1.7210	1
17	18	0.7320	0.5740	1
19	20	1.5042	1.3554	1
20	21	0.4095	0.4784	1
21	22	0.7089	0.9373	1
23	24	0.8980	0.7091	1
24	25	0.8960	0.7011	1
26	27	0.2842	0.1447	1
27	28	1.0590	0.9337	1
28	29	0.8042	0.7006	1
29	30	0.5075	0.2585	1
30	31	0.9744	0.9630	1
31	32	0.3105	0.3619	1
32	33	0.3410	0.5302	1

2.2. Newton-Raphson Model Load Flow Problem Formulation

The bus loading system of a distribution line represented by an equivalent π-model is as shown in Figure 2.

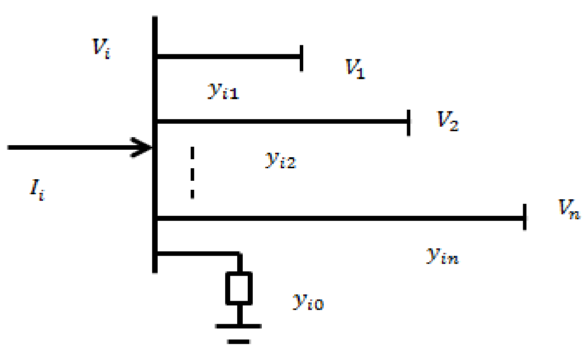

Figure 2: Typical bus of a power system network

The power equation is given in Equation 1:

$$S = V_i I_i^* \tag{1}$$

The complex power delivered to bus i is:

$$S = P_i + jQ_i \tag{2}$$

or $S = P_i - jQ_i$

$$S = P_i \pm jQ_i = V_i I_i^* \tag{3}$$

Re-writing Equation (3) gives:

$$P_i - jQ_i = V_i I_i^* \tag{4}$$

Making the current the subject of the formula from Equation (4), we have:

$$I_i^* = {}^{P_i - jQ_i}/_{Vi} \tag{5}$$

The first step in performing load flow analysis is to form the Y_{bus} admittance using the distribution line and transformer input data. The nodal equation for a power system network using Y_{bus} can be written as follows:

$$I = Y_{bus}V \tag{6}$$

The nodal Equation (6) can be written in a generalized form for an i bus system

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{7}$$

Where I = Current, V = Bus voltage, Y_{bus} = Bus admittance

Let $i = 1,2,3\ldots$ n

P = Active power and Q = Reactive power

The voltage profile range set for this analysis is $0.95 \leq 1.05\ pu$

3. RESULTS AND DISCUSSION

Figure 3 shows the load flow output in the Run mode, the load flow report includes power losses in each load buses, voltage profile magnitude value and the voltage drop in each line. Table 3 shows the IEEE 33-Bus network unbalanced load flow power losses. The results of the ETAP 19 load flow study shows that the system had a cumulative power losses corresponding to real and reactive power loss of 199.2 kW and 134.9 kVAR respectively. The system losses obtained is quite minimal which further confirms the balanced load network of IEEE 33-bus system. The results obtained is same with other results previously obtained by various researchers like Prakash (2021) and Saad and Abdeljabbar (2020) who used backward-forward sweep method in Matlab in their various researches. The result further shown that line 2, 7 and 5 had the highest losses of 49.6 kW and 25.2 kVAR, 36 kW and 31.3 kVAR followed by 18.9 kW and 9.6 kVAR respectively.

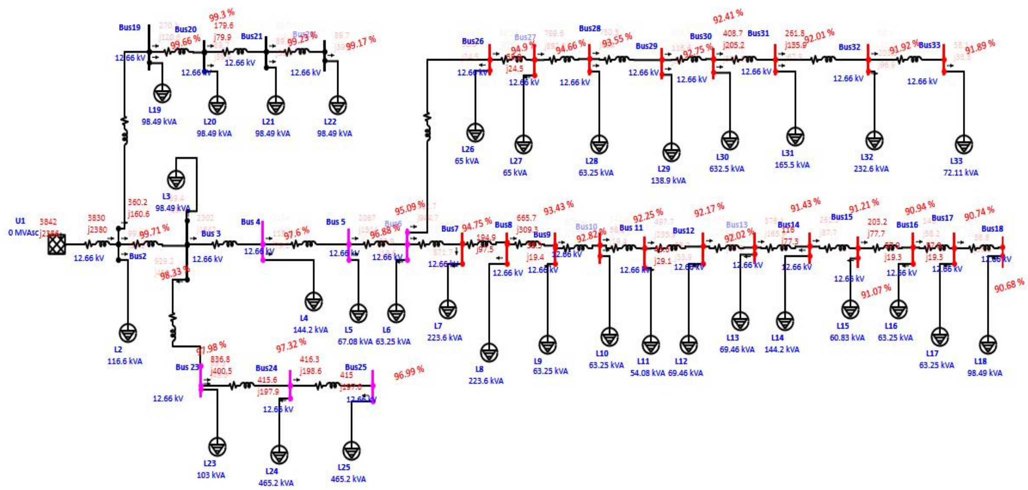

Figure 3: IEEE 33-bus network in the run mode

Table 3: Result of IEEE 33-bus network power losses

Branch ID	From-To bus flow		To-From bus flow		Losses		% Bus voltage		Voltage Drop in V_{mag}
	MW	Mvar	MW	Mvar	kW	kVAR	From	To	
Line 1	3.842	2.386	-3.830	-2.380	11.8	6.0	100.0	99.7	0.29
Line 10	0.666	0.309	-0.662	-0.306	4.0	2.9	93.4	92.8	0.61
Line 11	0.603	0.287	-0.600	-0.285	3.4	2.4	92.8	92.3	0.57
Line 12	0.542	0.265	-0.541	-0.265	0.5	0.2	92.3	92.2	0.08
Line 13	0.498	0.236	-0.497	-0.236	0.8	0.3	92.2	92.0	0.15
Line 14	0.439	0.202	-0.436	-0.200	2.5	2.0	92.0	91.4	0.59
Line 15	0.378	0.166	-0.377	-0.165	0.7	0.9	91.4	91.2	0.22
Line 16	0.261	0.088	-0.261	-0.087	0.3	0.3	91.2	91.1	0.14
Line 17	0.203	0.078	-0.203	-0.078	0.3	0.2	91.1	90.9	0.13
Line 18	0.145	0.058	-0.145	-0.058	0.2	0.3	90.9	90.7	0.20
Line 19	0.087	0.039	-0.087	-0.039	0.1	0.0	90.7	90.7	0.06
Line 2	3.370	2.159	-3.321	-2.134	49.6	25.2	99.7	98.3	1.38
Line 21	0.270	0.121	-0.269	-0.120	0.8	0.7	99.7	99.3	0.36
Line 22	0.180	0.080	-0.179	-0.080	0.1	0.1	99.3	99.2	0.07
Line 23	0.090	0.040	-0.090	-0.040	0.0	0.1	99.2	99.2	0.06
Line 24	0.923	0.945	-0.920	-0.943	2.4	1.2	95.1	94.9	0.19
Line 25	0.837	0.400	-0.832	-0.396	5.0	4.0	98.0	97.3	0.66
Line 26	0.416	0.199	-0.415	-0.198	1.3	1.0	97.3	97.0	0.33
Line 27	0.861	0.919	-0.858	-0.917	3.1	1.6	94.9	94.7	0.25
Line 28	0.800	0.893	-0.789	-0.883	10.6	9.3	94.7	93.5	1.11
Line 29	0.731	0.864	-0.723	-0.858	7.3	6.4	93.5	92.8	0.80
Line 3	0.929	0.452	-0.926	-0.450	3.1	2.1	98.3	98.0	0.35
Line 30	0.607	0.790	-0.603	-0.788	3.6	1.9	92.8	92.4	0.34
Line 31	0.409	0.205	-0.407	-0.204	1.5	1.5	92.4	92.0	0.40
Line 32	0.262	0.136	-0.262	-0.136	0.2	0.2	92.0	91.9	0.09
Line 33	0.058	0.039	-0.058	-0.039	0.0	0.0	91.9	91.9	0.03
Line 4	0.360	0.161	-0.360	-0.160	0.2	0.2	99.7	99.7	0.05
Line 5	2.302	1.642	-2.283	-1.632	18.9	9.6	98.3	97.6	0.73
Line 6	2.164	1.553	-2.147	-1.544	17.7	9.0	97.6	96.9	0.72
Line 7	2.087	1.514	-2.051	-1.483	36.2	31.3	96.9	95.1	1.79
Line 8	1.069	0.519	-1.068	-0.513	1.8	6.0	95.1	94.8	0.34
Line 9	0.872	0.415	-0.861	-0.407	11.1	8.0	94.8	93.4	1.32

Table 4 shows the voltage profile of IEEE 33-Bus Network load flow analysis Result. The load flow results in Table 4 shows that buses 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 28, 29, 30, 31, 32 and 33 violated the voltage profile constraint limit of $95\% \leq Vi \leq 100\%$ set for the test analysis experiencing low voltage profile magnitude of 93.43%, 92.82%, 92.25%, 92.17%, 92.02%, 91.43%, 91.21%, 91.07%, 90.94%, 90.74%, 90.68%, 93.55%, 92.75%, 92.41%, 92.01%, 91.92%, and 91.89% respectively, while fifteen (15) buses satisfied the voltage set limit for the IEEE 33-Bus network.

Table 4: Voltage profile magnitude and bus loading of the IEEE 33-bus network

Bus ID	Nominal kV	Voltage profile	MW loading	Mvar loading	Amp loading	Rating/Limit kVA	Power factor (PF %)
Bus1	12.66	100.00	3.842	2.386	206.2		
Bus2	12.66	99.71	3.83	2.38	206.2	116.60	85.75
Bus 3	12.66	98.33	3.321	2.134	183.1	98.49	91.38
Bus 4	12.66	97.60	2.283	1.632	131.1	144.20	83.21
Bus 5	12.66	96.88	2.147	1.544	124.5	67.08	89.44
Bus6	12.66	95.09	2.051	1.483	121.4	63.25	94.87
Bus7	12.66	95.00	1.068	0.513	57.0	223.60	89.44
Bus8	12.66	93.43	0.861	0.407	46.4	223.60	89.44
Bus9	12.66	92.82	0.662	0.306	35.8	63.25	94.87
Bus10	12.66	92.25	0.600	0.285	32.8	63.25	94.87
Bus 11	12.66	92.17	0.541	0.265	29.8	54.08	83.21
Bus12	12.66	92.02	0.497	0.236	27.2	69.46	86.38
Bus13	12.66	91.43	0.436	0.2	23.93	69.46	86.38
Bus14	12.66	91.21	0.377	0.165	20.6	144.2	83.21
Bus15	12.66	91.07	0.261	0.0874	13.79	60.83	98.64
Bus16	12.66	90.94	0.203	0.0775	10.89	63.25	94.87
Bus17	12.66	90.74	0.145	0.0579	7.835	63.25	94.87
Bus18	12.66	90.68	0.086	0.0386	4.777	98.49	91.38
Bus19	12.66	99.66	0.360	0.160	18.04	98.49	91.38
Bus20	12.66	99.30	0.269	0.120	13.54	98.49	91.38
Bus21	12.66	99.23	0.179	0.079	9.027	98.49	91.38
Bus22	12.66	99.17	0.089	0.039	4.514	98.49	91.38
Bus 23	12.66	97.98	0.926	0.450	47.93	103.00	87.42
Bus24	12.66	97.32	0.832	0.396	43.18	465.20	90.29
Bus25	12.66	96.99	0.415	0.198	21.61	465.20	90.29
Bus26	12.66	95.00	0.920	0.943	63.33	65.00	92.31
Bus27	12.66	95.00	0.858	0.917	60.53	65.00	92.31
Bus28	12.66	93.55	0.789	0.883	57.74	63.25	94.87
Bus29	12.66	92.75	0.723	0.858	55.16	138.90	86.38
Bus30	12.66	92.41	0.603	0.788	48.95	632.50	31.62
Bus31	12.66	92.01	0.407	0.204	22.57	165.50	90.62
Bus32	12.66	91.92	0.262	0.136	14.62	232.60	90.29
Bus33	12.66	91.89	0.058	0.038	3.467	72.11	83.21

4. CONCLUSION

In this work, a methodology approach for the evaluation of the IEEE 33-Bus Network Losses using ETAP 19 has been determined. The proposed network has thirty-three load buses with thirty-two lines. This was achieved by applying the Newton-Raphson method in carrying out load flow studies of IEEE 33-Bus Network to determine whether significant losses and voltage profile violations are visible. The results show that the system had a cumulative power losses corresponding to real and reactive power loss of 199.2 kW and 134.9 kVAR respectively. The system losses obtained is quite minimal which further confirms the balanced load network of IEEE 33-bus system.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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