Load Flow Solution For Power Distribution System Using Gauss-Seidel Model

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Abstract— **In this paper, load flow solution for power distribution system using Gauss-Seidel model is presented. The key analytical expressions relevant to the implementation of the Gauss-Seidel model were presented. Also, a high level procedure of the Gauss-Seidel load flow model was then employed in the development of a MATLAB program which was used to carry out the various load flow computations based on the Gauss-Seidel model. The results obtained include bus voltages, phase angles, load active power, load reactive power, generator active power, and generator reactive power. During the simulation in MATLAB, the Gauss-Seidel method converged on the 32nd iteration. The results on the bus voltages show that only 4 buses (bus 1, bus 2, bus 19 and bus 20) satisfied the voltage level requirement. In all, the results show that the case study bus network may need stability enhancement given that majority of the buses (29 out of 33 buses) have voltage levels that are below the acceptable minimum value.**

Keywords— Load Flow Analysis, Power Distribution System, Slack bus, Gauss-Seidel Model, Bus Voltage, IEEE 33 Bus System

1.0 Introduction

Nowadays, in Nigeria, more households and institutions are acquiring alternative power systems due to the poor and epileptic power supply from the national grid [1,2,3,4,5,6,7,8,9, 10,11, 12]. This is also due to the fact that wind and solar energy resource are readily available in virtually every part of the country and the continual decrease in the acquisition and running cost of the renewable power system [13, 14,15, 16,17,18, 19, 20, 21, 22,23, 24,25,26,27]. However, as the days go by, technological advancements and associated policy changes continue to drive humans to become more dependent on devices, software, networks and systems that require electricity [28,29,30,31,32, 33,34,35,36,37,38, 39,40,41, 42,43,44,45, 46, 47, 48] . Notable, eLearning solutions, smart systems, Internet of Things, social media, cashless policies, and many other solutions require electric power supply [49,50,51,52, 53, 54, 55, 56, 57, 58, 59, 60,61,62]. As such there is still insatiable demand for more electric power. Establishing reliable power system network to meet such demand is a running challenge.

Basically, in power system networks, the generating station injects active and reactive power which flows in along the buses and transmission lines to the load [63,64,65,66]. The bus voltage magnitudes and their corresponding phase angles are affected by the active and reactive power flow [67,68,69,70]. Notably, there are certain range of acceptable values for bus voltage magnitudes and any bus voltage that violates such acceptable range is said to be unstable. Power planning experts are very much interested in ensuring the voltage stability of the power network and this can be determined through load flow analysis.

More so, planning for various loading and generation configuration can be done through examination of the load flow analysis results obtained for each configuration scenario [71,72,73]. In that case, integration of consumer generated energy from solar system, wind power system, biomass energy system, and micro hydro power plant, among others can be properly planned ahead through load flow analysis of the diverse possible scenarios of energy mix.

Accordingly, this paper presented load flow solution for power distribution system using Gauss-Seidel method [74,75,76,77]. The key analytical expressions relevant to the implementation of the Gauss-Seidel model are presented. Also, a high level procedure of the Gauss-Seidel load flow model is employed in the development of a MATLAB program which is used to carry out the various load flow computations based on the Gauss-Seidel model. The model outputs include bus voltages, phase angles, load active power, load reactive power, generator active power, and generator reactive power. The ideas presented in this paper can be employed in studying the load flow in the power system operated under various power generation, load consumption and system components parameters configurations.

2.0 Methodology

2.1 The Gauss-Seidel model for load flow analysis

Gauss-Seidel method involves the modification of Gauss-Iterative method. This modification obviously reduces the numbers of iterations. The standard Gauss-Seidel model for load flow analysis is given as:

$$V_p = \frac{1}{V_{pp}} \times \left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1 \\ q \neq p}}^{n} \left(Y_{pq} V_q\right)\right], \; p = 2,3,4 \ldots n \quad (1)$$

The following nomenclatures are used in the description of the Gauss-Seidel load flow analysis

V_i denotes the voltage of the *ith* bus

V_j denotes the voltage of the *jth* bus

Y_{ij} denotes the Admittance of the power line connecting the ith bus and the *jth* bus

Y_{ii} denotes the self Admittance of the ith bus

P_i denotes the Real power that is injected into the *ith* bus

Q_i denotes the Reactive power that is injected into the *ith* bus

I_i denotes the current flowing through the *ith* bus

θ_{ij} denotes the Angle of the Y_{ij} of the Y_{bus}

δ_i denotes the voltage phase angle of the *ith* bus

n denotes the number of buses while i and j are integers in the range 1,2,3,…n.

In the Gauss-Seidel load flow analysys method, the voltage of the slack bus is assumed to be $V_1 = 1 < 0° \, p.u.$ With the assumption of the slack bus voltage, the voltages at the remaing buses numbering n-1 are computed using iterative approach as follows;

(i) The static load flow equations are used to determine the real power, P_i and the reactive power, Q_i as follows;

$$P_i = \sum_{j=1}^{n} \left(|V_i||V_j||Y_{ij}|\left(\text{Cos}\,\theta_{ij} - \delta_i + \delta_j\right)\right) \quad (2)$$

$$Q_i = -\sum_{j=1}^{n} \left(|V_i||V_j||Y_{ij}|\left(\text{Sin}\,\theta_{ij} - \delta_i + \delta_j\right)\right) \quad (3)$$

(ii) Then, current, I_i flowing through the *ith* bus is determined as follows;

$$I_i = \frac{P_i - Q_i}{{V_i}^*} \quad (4)$$

(iii) Then the the bus voltage, V_i at the remaing n-1buses are computed as follows;

$$V_i = \left(\frac{1}{Y_{ij}}\right)\left(I_i - \sum_{j=1,\; j\neq i}^{n}\left(\left(Y_{ij}\right)\left(V_j\right)\right)\right) \quad \text{i=1,2,3,…,n} \quad (5)$$

In terms of the iteration counter, denoted as k, the bus voltage, ${V_i}^{k+1}$ at the K+1 iteration is give as;

$$ {V_i}^{k+1} = \left(\frac{1}{Y_{ij}}\right)\left(\left(\frac{P_i - Q_i}{\left({V_i}^{k}\right)^*}\right) - \left\{\sum_{j=1}^{i-1}\left(\left(Y_{ij}\right)\left({V_j}^{k}\right)\right)\right\} - \left\{\sum_{j=i+1}^{n}\left(\left(Y_{ij}\right)\left({V_j}^{k}\right)\right)\right\}\right) \quad \text{i=1,2,3,…,n} \quad (6)$$

As can be seen, Equation 6 is of the same form as the standard Gauss-Seidel model presented in Equation 1.

2.2 The Gauss-Seidel load flow model procedure and simulation using case study dataset

The high level procedure of the Gauss-Seidel load flow model as used in developing the MATLAB program is described as follows:

1: Reset case voltages
2: Set Generator output power
3: Initiate the iteration for PQ busses
4: Initiate iterations for PV busses
5: **for** each iteration:
6: determine and update the value of Q and δ using the bus equation
7: **if** the solution converges
8: end iteration
9: **if** iteration exceed max iteration count
10: end iteration
11: **endif**
12: **endif**
13: **end for**
14: Print voltages and Phase angle

The IEEE 33 bus system dataset was used for the case study. For the Gauss-Seidel load flow model simulation in MATLAB, some customized functions were developed using MATLAB software. Also, during the Gauss-Seidel load flow model simulation, the IEEE 33 bus system's Bus 1 was taken as the slack bus while remaining buses in the IEEE 33 bus system are the taken as the load buses.

3. Results and discussion

Notably, the Gauss-Seidel load flow MATLAB program was used to determine the voltages and phase angles on the other buses (except the slack bus). Also, computed are the load active and reactive power, as well as the generator active and reactive power and the results are presented in Table 1. During the simulation in MATLAB, the Gauss-Seidel method converged on the 32nd iteration. The scatter graph plot in Figure 1 shows the bus voltage (p.u.) generated by the Gauss-Seidel method while the bar chart of Figure 2 shows the bus voltage (p.u.) and also shows the minimum acceptable bus voltage level. The bar chart also shows that only 4 buses satisfied the voltage level requirement. Also, Figure 3 shows the scatter plot of the phase angles generated by the Gauss-Seidel method.

Table 1: The bus voltages, phase angles, load active power, load reactive power, generator active power, generator reactive power computed using Gauss-Seidel method.

Bus No.	Bus Voltage (p.u.) obtained with Guss-Seidel Model	Phase Angle Gauss-Seidel Method	Load (MW)	Load (MVar)	Generator (MW)	Generator (MVar)
1	1	0	0	0	260.95	-17.021
2	0.9862	0.011602	21.7	12.7	40	48.836
3	0.927	0.074328	2.403	1.2	0	0
4	0.8924	0.1218	7.6	1.6	0	0

5	0.8607	0.1739	94.201	19	0	35.989
6	0.7693	0.2954	0	0	0	0
7	0.7277	0.3218	22.801	10.9	0	0
8	0.7236	0.3904	30.01	30	0	30.759
9	0.7036	0.4948	0	0	0	0
10	0.6954	0.5951	5.8	2	0	0
11	0.6981	0.6094	0	0	16.113	0
12	0.7032	0.632917	11.2	7.5	0	0
13	0.7077	0.7334	0	0	0	0
14	0.7053	0.773222	6.202	1.6	0	0
15	0.7085	0.8019	8.204	2.5	0	0
16	0.7135	0.8253	3.509	1.801	0	0
17	0.715	0.8631	9.006	5.805	0	0
18	0.717	0.870032	3.201	0.903	0	0
19	0.9821	0.0116	9.502	3.401	0	0
20	0.9543	0.0124	2.2	0.7	0	0
21	0.9486	0.0118	17.5	11.2	0	0
22	0.9432	0.011	0	0	0	0
23	0.9198	0.0769	3.2	1.6	0	0
24	0.9094	0.08	8.7	6.7	0	0
25	0.9042	0.0814	0	0	0	0
26	0.7635	0.3074	3.5	2.3	0	0
27	0.7568	0.322316	0	0	0	0
28	0.7226	0.3739	0	0	0	0
29	0.7025	0.408764	2.4	0.9	0	0
30	0.6971	0.427247	10.6	1.9	0	0
31	0.6815	0.455514	3.5	2.4	0	0
32	0.6776	0.46178	8.7	3.5	0	0
33	0.6746	0.465189	3.5	2.4	0	0

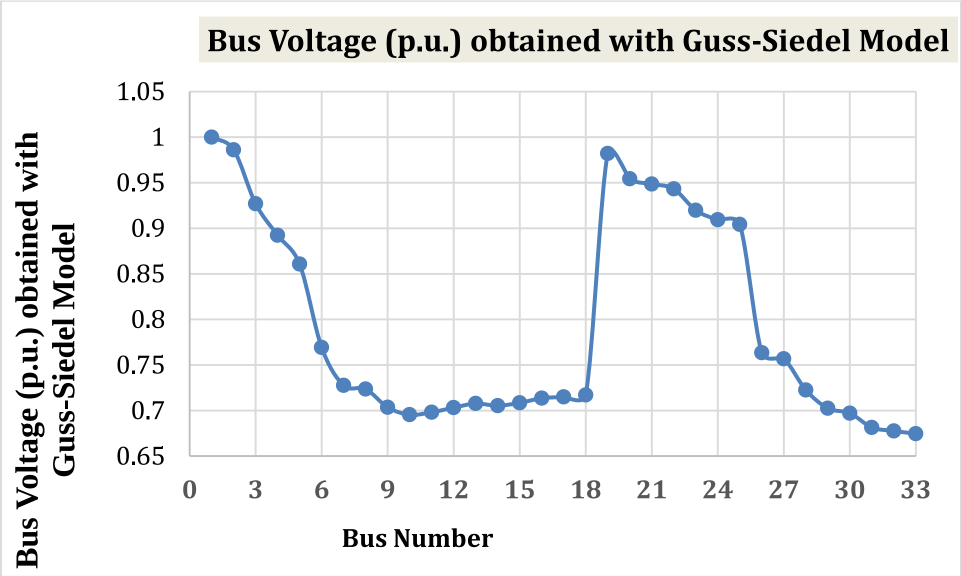

Figure 1: **Bus Voltage (p.u.) generated by the Gauss-Seidel Method**

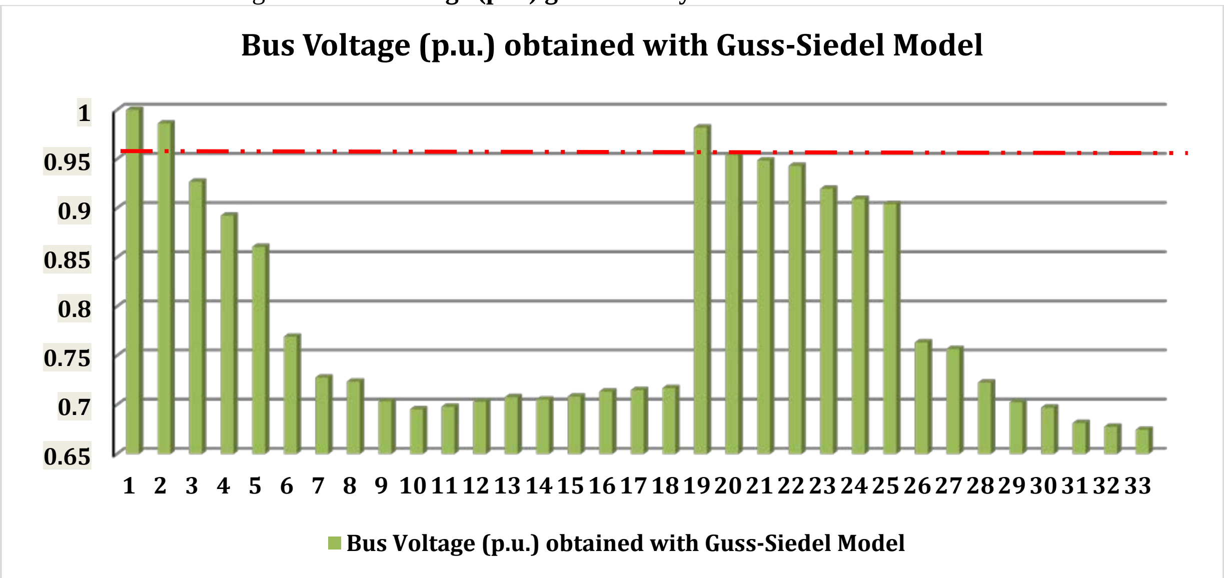

Figure 2 The bar chart of the bus voltage (p.u.) obtained with Guss-Seidel model showing the minimum acceptable bus voltage level

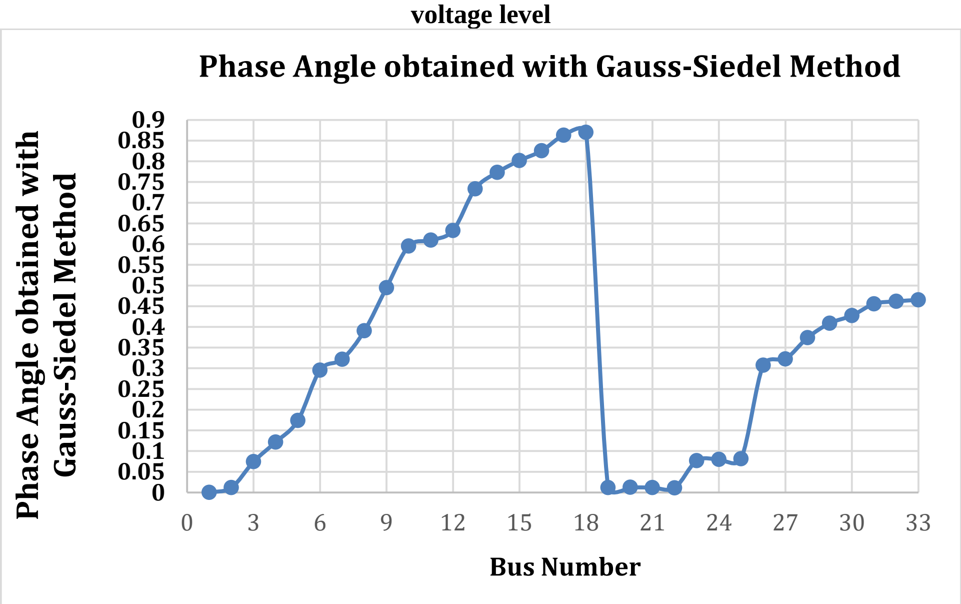

Figure 3: Phase angles generated by the Gauss-Seidel Method

4. Conclusion

The Gauss-Seidel load flow analysis method is presented. The load flow was conducted on a case study IEEE 33 bus system. The fundamental mathematical expressions for the Gauss-Seidel load flow method are presented along with the procedure for implementation of the Gauss-Seidel load flow analysis. Gauss-Seidel load flow MATLAB program was also developed and employed in the simulation of the load flow analysis. The results obtained include bus voltages, phase angles, load active power, load reactive power, generator active power, and generator reactive power.

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