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Fast Decoupled Load Flow Analysis Of IEEE 33 Bus Distribution System

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***Abstract*— In this paper, fast decoupled load flow analysis of IEEE 33 bus distribution system is presented. The relevant mathematical equations for computing the bus voltages, power and phase angles based on the fast decoupled method are presented. The fast decoupled power flow method was simulated in MATLAB software and the case study dataset of the IEEE 33 bus system was utilized such that Bus 1 was taken as the slack bus while the other buses constitute the load buses. The load flow simulation iteration converged on the 15th cycle. The results show that only bus 1 , 2 and bus 3 satisfied the required voltage level above 0.95 and below 1.05. The voltage levels for the remaining 30 buses are outside the acceptable voltage rang of 0.95 to 1.05. Apart from the bus voltages, the results also include Fast decoupled load flow generated phase angle, load active and reactive power as well as generator active and reactive power.**

Keywords*— *Fast Decoupled Method, Load Active Power, Distribution Power Network, Bus Voltage, Load Flow Analysis, IEEE 33 Bus System , Phase Angle

1.0 Introduction

As Nigeria struggle to tackle its power shortage and the widening power deficit, proper analysis of the various power distribution networks is essential [1,2,3,4,5,6,7,8,9,10]. Also, proper estimation of the load demand in various sectors is also essential [11,12,13,14,15,16,17,18,19,20]. Moreover, the use of renewable energy generation systems to augment the generation capacity of the national power system has been widely advocated. This is due to the abundance of solar and wind energy resources across the nation [21,22,23, 24,25, 26,27,28,29, 30,31,32,33,34,35,36,37,38,39]. However, in all these, adequate planning and careful design is paramount. This is because the power system nowadays are faced with myriads of challenges and design options that require careful selection of parameters to achieve optimal operation of the power system is highly needed[40,41,42]. For instance, well designed power network can suffer excessive power loss due to some factors that relates to the power network [43,44,45,46,47,48]. Also, power theft and breakdown of transformers and loss of power lines can trigger unexpected losses and unwelcomed consequences on the power network [49,50,51]. Also, the injection of power to the network through distributed power generation can also cause instability in the power network [52,53,54,55].

In addition, where consumers are allowed to connect their alternative power supply system to the national grid proper load flow analysis is required to determine the stability of the system. In all these stated scenarios and many others, load flow analysis will enable the power system analyst to evaluate the stability of the power system under different loading and power generation configurations [56,57,58]. It is also possible to evaluate the impact of loss of certain components of the power system. In this way, proper contingency plan can be put in place before such incidence occurs.

Consequently, in this paper, fast decoupled load flow analysis of a case study bus distribution system is presented. The relevant mathematical equations for computing the bus voltages, power and phase angles based on the fast decoupled method are presented. The fast decoupled power flow method is simulated in MATLAB software based on the case study bus distribution system dataset.

2.0 Methodology

In the newton Raphson method of load flow analysis the Jacobian matrix, [J] affords a linearized form of relation between this set of two parameters $\Delta\delta$ and ΔV on one part and the second set of two parameters, ΔP and ΔQ where $\Delta\delta$ stands for small changes in the voltage angle, ΔV stands for small changes in the voltage magnitude, ΔP stands for small changes in the active power and ΔQ stands for small changes in the reactive power. Specifically, for the Newton Raphson method, the relationship is expressed as follows;

$$\begin{bmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{bmatrix} = [\mathrm{J}]\begin{bmatrix}\Delta\delta\\ \Delta \mathrm{V}\end{bmatrix} \quad (1)$$

$$[\mathrm{J}] = \begin{bmatrix}\mathrm{J}_1 & \mathrm{J}_2\\ \mathrm{J}_3 & \mathrm{J}_4\end{bmatrix} \quad (2)$$

However, in the Fast Decoupling method some assumptions are made which lead to

$$\mathrm{J}_2 \approx 0 \quad (3)$$

$$\mathrm{J}_3 \approx 0 \quad (4)$$

Some of the assumptions made in the Fast Decoupling method include;

- The buses voltage magnitudes are almost equal to one per unit at steady state operation;
- The values of the conductance, G_{ij} and the susceptance B_{ij} is such that $B_{ij} \gg G_{ij}$
- At steady state, differences in the voltage phase angle are very small

Hence, with the assumptions;

$$\begin{bmatrix}\Delta \mathrm{P}\\ \Delta \mathrm{Q}\end{bmatrix} = \begin{bmatrix}\mathrm{J}_1 & 0\\ 0 & \mathrm{J}_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta \mathrm{V}\end{bmatrix} \quad (5)$$

Which for a power network with n system's buses and m load buses leads to the expression;

$$\frac{\Delta \mathrm{P}}{V} = [-\mathrm{B}]\Delta\delta = [\mathrm{B}']\Delta\delta \quad (6)$$

$$\frac{\Delta \mathrm{Q}}{V} = [-\mathrm{B}]\Delta\delta = [\mathrm{B}'']\Delta \mathrm{V} \quad (7)$$

Where $[\mathrm{B}']$ is an (n-1)x(n-1) constant matrix for all the buses except the slack bus and $[\mathrm{B}']'$ is an (m)x(m) constant matrix for all the load buses . Actually, B' and B'' are the imaginary part in the admittance matrix of the bus.

The procedure for the load flow analysis using the fast decoupled method

Step 1: Input the load flow dataset and create the admittance matrix, and from the admittance matrix formulate the two constant matrices, $[\mathrm{B}']$ and $[\mathrm{B}'']$

Step 2: Input the value for tolerance parameter, ε

Step 3 $V_i = V_{i,spec} < 0°$ at all the PV buses and $V_i = 1 < 0°$ at all the PQ buses except the slack bus

Step 4: Initialize the iteration count parameter, k= 0 and start the iteration;

Step 5 Set bus counter, i=2

Step 6 Calculate P_i (the real power,) and Q_i (the reactive power) as follows;

$$P_i = \sum_{j=1}^{n}\left(|V_i||V_j||Y_{ij}|\left(\mathrm{Cos}\,\theta_{ij} - \delta_i + \delta_j\right)\right) \quad (8)$$

$$Q_i = -\sum_{j=1}^{n}\left(|V_i||V_j||Y_{ij}|\left(\mathrm{Sin}\,\theta_{ij} - \delta_i + \delta_j\right)\right) \quad (9)$$

Step 7: Compute the real power mismatch, $\Delta \mathrm{P}^k$ and the reactive power mismatch, $\Delta \mathrm{Q}^k$

Step 8 Solve for $\Delta\delta_i{}^k$ and $\Delta V_i{}^k$ for i= 2,3,4,…, n using the expressions as follows;

$$\frac{\Delta \mathrm{P}_i{}^k}{\mathrm{V}_i{}^k} = [\mathrm{B}']\Delta\delta_i{}^k \quad (10)$$

$$\frac{\Delta \mathrm{Q}_i{}^k}{\mathrm{V}_i{}^k} = [\mathrm{B}'']\Delta V_i{}^k \quad (11)$$

STEP 9: Re-calculate values of V_i and δ_i as follows;

$$\delta_i{}^{k+1} = \delta_i{}^k + \Delta\delta_i{}^k \quad (12)$$

$$V_i{}^{k+1} = V_i{}^k + \Delta V_i{}^k \quad (13)$$

STEP 10: End the fast decoupled iteration if the values of $\Delta \mathrm{P}^k$ and $\Delta \mathrm{Q}^k$ are less than or equal to ε. However, if $\Delta \mathrm{P}^k$ or $\Delta \mathrm{Q}^k$ are greater than ε, the iteration counter k is increased by 1 and the iteration is repeated starting from Step 6.

3. Results and discussion

The fast decoupled power flow method was simulated using a MATLAB program based on load flow dataset of the IEEE 33 bus system. In the simulation, the slack is Bus 1 bus and the other buses constitute the load buses. In the fast decoupled power flow simulation, the bus voltages and phase angles are computed along with the reactive power and active power of the load and the generators. The load flow simulation solution converged at the 15th iteration and the results are presented in Table 1 and Table 2. The results in Table 1 show the Fast decoupled load flow generated Bus Voltage (p.u.) and phase angle (in Radian) while Table 2 shows the Fast decoupled load flow generated load active and reactive power as well as generator active and reactive power. The scatter plot in Figure 1 show the plot of Bus Voltage (p.u.) versus bus number which shows that only bus 1 , 2 and bus 3 satisfied the required voltage level above 0.95 and below 1.05. The voltage levels for the remaining 30 buses are outside the acceptable voltage rang of 0.95 to 1.05. Finally, Figure 2 show that phase angle plotted against the bus number, where the angles are expressed in radians.

Table 1 Fast decoupled load flow generated Bus Voltage (p.u.) and phase angle (in Radian)

Bus Number	Fast Decoupled Load Flow Generated Bus Voltage (p.u.)	Fast Decoupled Load Flow Generated Phase Angle (Radian)	Bus Number	Fast Decoupled Load Flow Generated Bus Voltage (p.u.)	Fast Decoupled Load Flow Generated Phase Angle (Radian)
1	1	0	17	0.703656	0.838847
2	0.958488	0.011276	18	0.702684	0.847591
3	0.900951	0.072239	19	0.951587	0.011274
4	0.867324	0.1185	20	0.931372	0.01203
5	0.836514	0.169131	21	0.921944	0.011468
6	0.747683	0.290626	22	0.91864	0.010678
7	0.707252	0.312757	23	0.892982	0.074739
8	0.703267	0.37943	24	0.883846	0.077752

9	0.683829	0.480896	25	0.878792	0.079113
10	0.675859	0.578378	26	0.742046	0.298762
11	0.678483	0.592276	27	0.735534	0.313259
12	0.687328	0.615132	28	0.702295	0.363393
13	0.683926	0.70953	29	0.68276	0.397277
14	0.683537	0.751494	30	0.677511	0.415242
15	0.689563	0.779367	31	0.661378	0.462167
16	0.697338	0.802109	32	0.658559	0.461322
17	0.703656	0.838847	33	0.655644	0.464708

Table 2: Fast decoupled load flow generated load active and reactive power as well as generator active and reactive power

Bus No.	Load (MW)	Load (MVar)	Gen. (MW)	Gen. (MVar)
1	0.000	0.000	260.910	-17.010
2	21.700	12.400	40.000	48.826
3	2.400	1.210	0.000	0.000
4	7.600	1.640	0.000	0.000
5	94.200	19.100	0.000	35.995
6	0.000	0.000	0.000	0.000
7	22.801	10.900	0.000	0.000
8	30.004	30.000	0.000	30.759
9	0.000	0.000	0.000	0.000
10	5.803	2.000	0.000	0.000
11	0.000	0.000	16.113	0.000
12	11.210	7.500	0.000	0.000
13	0.000	0.000	0.000	0.000
14	6.206	1.600	0.000	0.000
15	8.220	2.500	0.000	0.000
16	3.570	1.800	0.000	0.000
17	9.010	5.800	0.000	0.000
18	3.250	0.900	0.000	0.000
19	9.570	3.400	0.000	0.000
20	2.210	0.700	0.000	0.000
21	17.400	11.300	0.000	0.000
22	0.000	0.000	0.000	0.000
23	3.200	1.600	0.000	0.000
24	8.740	6.700	0.000	0.000
25	0.000	0.000	0.000	0.000
26	3.510	2.300	0.000	0.000
27	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000
29	2.400	0.900	0.000	0.000
30	10.609	1.910	0.000	0.000
31	3.520	2.480	0.000	0.000
32	8.710	3.520	0.000	0.000
33	3.500	2.410	0.000	0.000

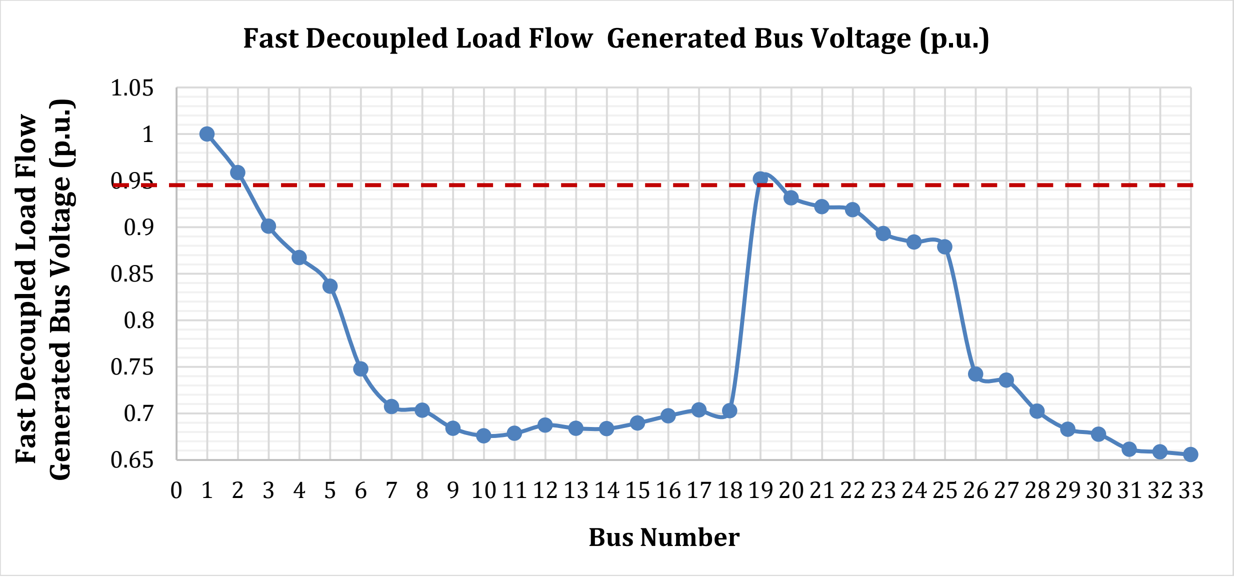

Figure 1 Fast Decoupled Load Flow Generated Bus Voltage (p.u.)

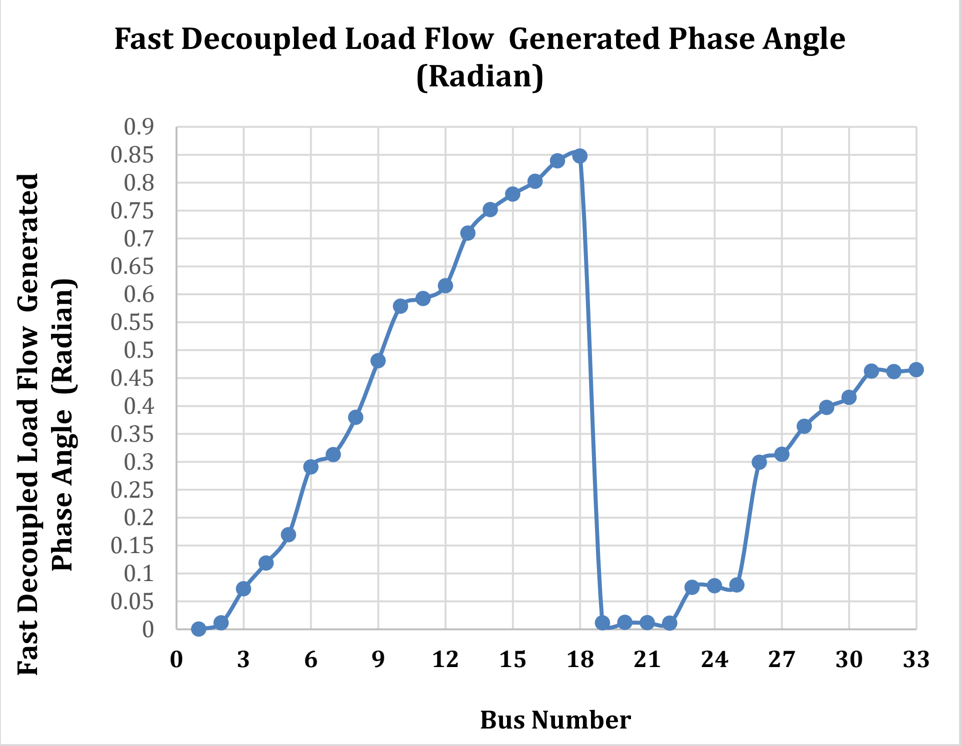

Figure 2 Fast Decoupled Load Flow Generated Phase Angle (in Radian)

4. Conclusion

Fast Decoupled load flow approach is employed in the computation of the bus voltages, phase angles, load reactive power, load active power, generator reactive power and generator active power for IEEE 33 bus network. MATLAB program was developed based on the Fast Decoupled load flow approach and then employed in carrying out the iterative computations from which the required parameter values were obtained.

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