ACCURACY OF MATLAB SELF-CODED PROGRAM FOR POWER FLOW ANALYSIS IN COMPARISON WITH STANDARD SOFTWARE PACKAGES

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Abstrak

Power flow analysis is crucial for power system analysis and design. For these reasons, it is commonly necessary to have different inputs for the program to have different generated results for further analyses. As a basic program, power flow program may be employed by the other programs for evaluating the power system for the given input parameters. The program is therefore required to be interactive or has open connectivity with the other program or may be modified and included as a sub routine in the upper level program. It is unfortunate since the available package programs normally do not provide the aforementioned features. Due to this circumstance, power flow program is normally again constructed using the same programming language, which the main program may utilize. Beside additional effort that may be time consuming, the coded power flow program may still need to be verified to generate accurate results. This paper presents the program for power flow analysis using Newton Raphson method. The program is constructed using Matlab and the generated results are then confirmed with those generated by two standard package program (ETAP and HARMFLOW). The verification is necessary to assure that the generated results are accurate. Since the results of the coded programs may be used for further calculations, the precision of the results will significantly contribute the accuracy of the results of analysis and design. The coded program has been implemented in the IEEE 18-bus standard system and has successfully generated results with acceptable accuracy.

Keywords*: accuracy; open connectivity; power flow; self coded program*

Introduction

Power flow calculation is the backbone of power system analysis and design. It generates the results that are normally required for further calculation of analysis and design. This is initially performed by formulating the network equation. Node-voltage method, which is the most suitable form for many power system analyses, is commonly used. The calculation can then be carried out by solving the following equation.

$$I_{bus} = Y_{bus}V_{bus} \qquad (1)$$

Where

I_{bus} : vector of bus injection current

V_{bus}: vector of bus voltage

Y_{bus} : Bus admittance matrix.

Mathematically, power flow problem requires solution of simultaneous nonlinear equations and normally employs an iterative method, such as Gauss-Seidel, Newton-Raphson, or Fast Decouple method

For analyses purposes, power flow calculation is normally repeatedly carried out for different system cases. The calculations may also be combined with or incorporated to the other calculations for performing some analyses on power system. It is therefore required to have power flow program interactive with the other programs. Unfortunately the available power flow programs are normally closed program, where no connection with external program that may be established. Due to this problem, power flow program is normally again constructed using the same programming language, which the main program may utilize. This effort may be time consuming and furthermore the coded power flow program may still need to be verified to generate accurate results.

This paper presents the program for power flow analysis using Newton Raphson method. The program is constructed using Matlab and the generated results are then confirmed with those generated by two standard package program (ETAP and HARMFLOW). The verification is necessary to assure that the generated results are accurate. Since the results of the coded programs may be used for further calculations, the precision of the results will

significantly contribute the accuracy of the results of analysis and design. The coded program has been implemented in the IEEE 18-bus standard system and has successfully generated results with acceptable accuracy.

Power flow calculation

At the fundamental frequency, system is modeled using the conventional approach where the admittance of line section between bus i and bus $i+1$ is expressed as follows.

$$y_{i,i+1} = \frac{1}{R_{i,i+1} + jX_{i,i+1}} \tag{2}$$

Where :

$R_{i,i+1}$: Resistance of line section between buses i and $i+1$

$X_{i,i+1}$: Inductance of line section between buses i and $i+1$

The magnitude and phase angle of bus voltage is then calculated using the following mismatch equations (Baghzouz and S. Ertem 1990; Y. Baghzouz 1991; Chin 1995).

$$P_i - \sum_{j=i-1}^{i+1} \left|Y_{ji}^1\right|\left|V_j^1\right|\left|V_i^1\right|\cos(\delta_i^1 - \delta_j^1 - \theta_{ji}^1) = 0 \tag{3}$$

$$Q_i - \sum_{j=i-1}^{i+1} \left|Y_{ji}^1\right|\left|V_j^1\right|\left|V_i^1\right|\sin(\delta_i^1 - \delta_j^1 - \theta_{ji}^1) = 0 \tag{4}$$

Where

$$Y_{ji}^1 = \left|Y_{ji}^1\right|\angle\theta_{ji}^1 = \begin{cases} -y_{ji}^1, & if \ j \neq i \\ y_{i-1,i}^1 + y_{i+1,i}^1 + y_{ci}^1, & if \ j = i \end{cases} \tag{5}$$

And

V_i^1 : The respective voltage

y_{ci}^1 : The admittance of shunt capacitor at bus I

P_i : The respective total active power at bus i.

Q_i : The respective total reactive powers at bus i.

The power loss in the line section between buses i and $i+1$ may then be calculated by the following equation.

$$P_{loss(i,i+1)}^1 = R_{i,i+1}\left(\left|V_{i,i+1}^1 - V_i^1\right|\left\|y_{i,i+1}^1\right\|\right)^2 \tag{6}$$

Newton Raphson iterative method

Consider the nonlinear set of algebraic equations. If the presumed solution is x^0 then the correct solution will be updated using $x = x^0 + \Delta x$. Therefore:

$$f(x^0 + \Delta x) = f(x^0) + \Delta x \frac{\partial f}{\partial x^0} + \frac{\Delta x}{2!}\frac{\partial^2 f}{(\partial x^0)^2} + \dots \tag{7}$$

By assuming that $\underline{f}(x) = 0$ and disregarding the higher orders,

$$\Delta x = -\left(\frac{\partial f}{\partial x^0}\right)^{-1} f(x^0) \tag{8}$$

and

$$x' = x^0 + \Delta x \tag{9}$$

The Newton-Raphson method yields an iterative solution of the form

$$\underline{x}^{n+1} = \underline{x}^n - \left(\frac{\partial \underline{f}}{\partial \underline{x}^0}\right)^{-1}_n f(\underline{x}^n) \tag{10}$$

Application of Newton Raphson method for power flow problem

Consider an n bus power system where all buses are load bus except bus 1 which is the swing bus. Therefore, $V_1\angle\delta_1$ is known. Since the remaining bus is load bus, P_k and Q_k are known and $V_k\angle\delta_k$ are known. The vector of unknown may be formed as follows:

$$\begin{bmatrix} \delta_2 \\ \delta_3 \\ \text{M} \\ \delta_n \\ V_2 \\ V_3 \\ \text{M} \\ V_n \end{bmatrix} \quad \text{size: } (2n\text{-}2) \times 1 \tag{11}$$

The mismatch between real and reactive power is denoted ΔP_k and ΔQ_k, respectively and is defined as follows:

$$\Delta P_k = P_{k,calc} - P_{k,spec}$$
$$\Delta Q_k = Q_{k,calc} - Q_{k,spec} \tag{12}$$

Therefore

$$\Delta P_k = +\sum_{i=1}^{n} |V_k||V_i||Y_{ki}|\cos(\delta_k - \delta_i - \theta_{ki}) - P_{k,spec}$$

$$\Delta Q_k = +\sum_{i=1}^{n} |V_k||V_i||Y_{ki}|\sin(\delta_k - \delta_i - \theta_{ki}) - Q_{k,spec} \tag{13}$$

The iterative calculations for adjusting the voltage and angle are continuously carried out until the convergence is achieved, where ΔP_k and ΔQ_k close to zero or no higher than the prescribed tolerance for bus k (k = 2, 3, 4, …, n). Application of Newton Raphson for power flow problem results in the following iterative formula:

$$\begin{bmatrix} \delta_2^{j+1} \\ \text{M} \\ \delta_n^{j+1} \\ V_2^{j+1} \\ \text{M} \\ V_n^{j+1} \end{bmatrix} = \begin{bmatrix} \delta_2^{j} \\ \text{M} \\ \delta_n^{j} \\ V_2^{j} \\ \text{M} \\ V_n^{j} \end{bmatrix} - [J]^{-1} \begin{bmatrix} \Delta P_2^{j} \\ \text{M} \\ \Delta P_n^{j} \\ \Delta Q_2^{j} \\ \text{M} \\ \Delta Q_n^{j} \end{bmatrix} \tag{14}$$

The dimension of Jacobian matrix $[J]$ and vector ΔP_k and ΔQ_k are $(2n\text{-}2) \times (2n\text{-}2)$ and $(2n\text{-}2) \times 1$, respectively.

Where n is the number of bus. The Jacobian matrix $[J]$ is defined as:

$$J = \begin{bmatrix} \dfrac{\partial \Delta P_2}{\partial \delta_2} & \Lambda & \dfrac{\partial \Delta P_2}{\partial \delta_n} & \text{M} & \dfrac{\partial \Delta P_2}{\partial V_2} & \Lambda & \dfrac{\partial \Delta P_2}{\partial V_n} \\ \text{M} & \text{O} & \text{M} & \text{M} & \text{M} & \text{O} & \text{M} \\ \dfrac{\partial \Delta P_n}{\partial \delta_2} & \Lambda & \dfrac{\partial \Delta P_n}{\partial \delta_n} & \text{M} & \dfrac{\partial \Delta P_n}{\partial V_2} & \Lambda & \dfrac{\partial \Delta P_n}{\partial V_n} \\ \Lambda & \Lambda & \Lambda & \text{M} & \Lambda & \Lambda & \Lambda \\ \dfrac{\partial \Delta Q_2}{\partial \delta_2} & \Lambda & \dfrac{\partial \Delta Q_2}{\partial \delta_n} & \text{M} & \dfrac{\partial \Delta Q_2}{\partial V_2} & \Lambda & \dfrac{\partial \Delta Q_2}{\partial V_n} \\ \text{M} & \text{O} & \text{M} & \text{M} & \text{M} & \text{O} & \text{M} \\ \dfrac{\partial \Delta Q_n}{\partial \delta_2} & \Lambda & \dfrac{\partial \Delta Q_n}{\partial \delta_n} & \text{M} & \dfrac{\partial \Delta Q_n}{\partial V_2} & \Lambda & \dfrac{\partial \Delta Q_n}{\partial V_n} \end{bmatrix} \tag{15}$$

The iterative process continuous until

$$\begin{bmatrix} \delta_2^{j+1} \\ M \\ \delta_n^{j+1} \\ V_2^{j+1} \\ M \\ V_n^{j+1} \end{bmatrix} - \begin{bmatrix} \delta_2^{j} \\ M \\ \delta_n^{j} \\ V_2^{j} \\ M \\ V_n^{j} \end{bmatrix} \leq \varepsilon \tag{16}$$

Where ε is the prescribed tolerance normally set to $0.001 \rightarrow 0.01$.

For the voltage controlled bus $\dfrac{\partial P_k}{\partial V_k}$ are eliminated from the Jcobian matrix $[J]$ and calculation of Q_k is postponed until δ_k solved and therefore Q_k may be obtained.

For PV buses in Newton Raphson algorithm only the equation for ΔP_k is used since $Q_{k,spec}$ for ΔQ_k is not known. For the slack bus δ is not calculated and no change in voltage calculations for PV bus. For each voltage controlled bus V_k and P_k are known. Therefore V_k is eliminated from the δ/V vector and the following partial derivations:

$$\frac{\partial P_k}{\partial V_k} , \frac{\partial Q_k}{\partial \delta_k} \text{ and } \frac{\partial P_k}{\partial V_k}$$

Are all eliminated from matrix $[J]$. At the end of each iteration Q_k is calculated and Q_{gk} is obtained as $Q_{gk} = Q_k + Q_{Lk}$. If Q_{gk} exceeds reactive power limit of generator then it is set to reactive power limit (Q_{limit}) and the bus changes to load bus until Q_{gk} is within limit and the bus then changes back to voltage controlled or PV bus.

Implementation of Newton Raphson method for power flow calculation

The aforementioned method is implemented for power flow calculation for IEEE 18-bus standard system. The generated results will then be compared the results given by standard package programs, ETAP and HARMFLOW. The use of IEEE 18-bus system is due to the largest system that may be analyzed by HARMFLOW is 18 bus system. Analysis for the larger system may be carried out once the result of the 18 bus system is known to be accurate. This is due to the calculation of power flow is already complicated even for the small system. The only different is computation charge for the small system is less than that for the large system. If implementation of power flow program for the small is successful to converge with accurate result, the application of the program for the program for the larger is expected to successful, as well.

The algorithm of power flow program using Newton Raphson method is shown in the flowchart of Fig. 1. The Algortithm employs the maximum tolerance of power mismatch as well as limit the maximum iteration. The program still gives the output results even it fails to converge.
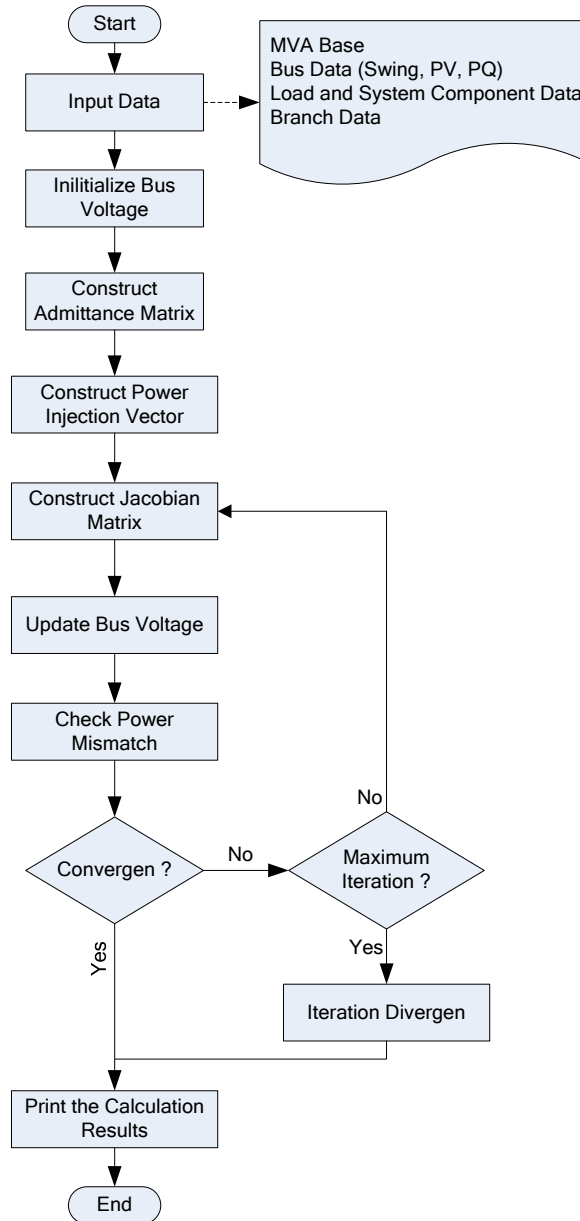
Fig. 1. Flowchart of power flow calculation using Newton Raphson

Analyses of Accuracy
System Data
    The algorithm is implemented for IEEE 18 bus system depicted in Fig. 2. The bus and branch data is given in Table 1 and Table 2, respectively. The MVA base of the system is 10 MVA dan bus 51 is set to be swing bus with active power generation is limited on interval of 10 MW and 300 MW while the reactive power generation is ranged from -50 MVAR to 100 MVAR. The voltage of swing bus is set 105% and the system basekV is 10 kV.
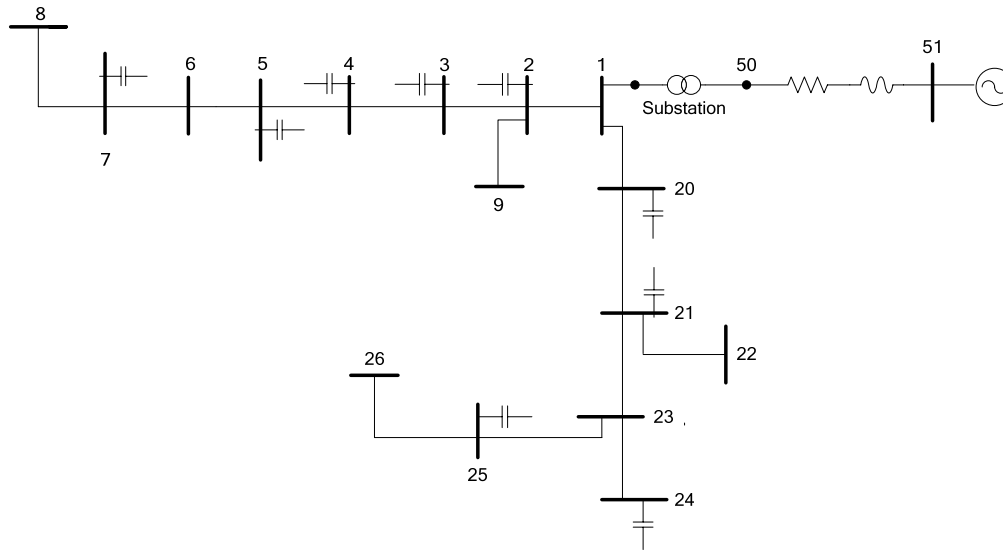
Fig. 2. IEEE 18 bus system used for power flow analysis

Table 1. Bus data for IEEE 18 bus system

Bus ID	Type	Pd	Qd	Gs	Bs	Vm	Va	baseKV	zone	Vmax	Vmin
		(p.u.)								(p.u.)	
1	PQ	0	0	0	0	1	0	12.5	1	1.05	0.95
2	PQ	0.2	0.12	0	1.05	1	0	12.5	1	1.05	0.95
3	PQ	0.4	0.25	0	0.6	1	0	12.5	1	1.05	0.95
4	PQ	1.5	0.93	0	0.6	1	0	12.5	1	1.05	0.95
5	PQ	3	2.26	0	1.8	1	0	12.5	1	1.05	0.95
6	PQ	0.8	0.5	0	0	1	0	12.5	1	1.05	0.95
7	PQ	0.2	0.12	0	0.6	1	0	12.5	1	1.05	0.95
8	PQ	1	0.62	0	0	1	0	12.5	1	1.05	0.95
9	PQ	0.5	0.31	0	0	1	0	12.5	1	1.05	0.95
20	PQ	1	0.62	0	0.6	1	0	12.5	1	1.05	0.95
21	PQ	0.3	0.19	0	1.2	1	0	12.5	1	1.05	0.95
22	PQ	0.2	0.12	0	0	1	0	12.5	1	1.05	0.95
23	PQ	0.8	0.5	0	0	1	0	12.5	1	1.05	0.95
24	PQ	0.5	0.31	0	1.5	1	0	12.5	1	1.05	0.95
25	PQ	1	0.62	0	0.9	1	0	12.5	1	1.05	0.95
26	PQ	0.2	0.12	0	0	1	0	12.5	1	1.05	0.95
50	PQ	0	0	0	1.2	1	0	138	1	1.05	0.95
51	Slack	0	0	0	0	1.05	0	138	1	1.05	0.95

Table 2. Branch data for IEEE 18 bus system

From bus	To bus	R (p.u.)	X (p.u.)	B (p.u.)
1	2	0.00431	0.01204	3.50E-05
2	3	0.00601	0.01677	4.90E-05
3	4	0.00316	0.00882	2.60E-05
4	5	0.00896	0.02502	7.30E-05
5	6	0.00295	0.00824	2.40E-05
6	7	0.01720	0.02120	4.60E-05
7	8	0.04070	0.03053	5.10E-05

From bus	To bus	R (p.u.)	X (p.u.)	B (p.u.)
2	9	0.01706	0.02209	4.30E-05
1	20	0.02910	0.03768	7.40E-05
20	21	0.02222	0.02877	5.60E-05
21	22	0.04803	0.06218	0.000122
21	23	0.03985	0.05160	0.000101
23	24	0.02910	0.03768	7.40E-05
23	25	0.03727	0.04593	0.0001
25	26	0.02208	0.02720	5.90E-05
25	26	0.02208	0.02720	5.90E-05
50	1	0.00312	0.06753	0
50	51	0.00050	0.00344	0

Calculation result and analysis of accuracy

The results generated by the program are compared with those generated by ETAP and HARMFLOW. The appointment of these package programs is due to the programs may generate results fully acceptable in term of accuracy. The comparison is shown in Table 3. For more detail analysis, the deviation of the results generated by the coded program to those generated by the packages is given in Table 4. It has demonstrated that the coded program is able to generate the power flow calculation results very close to those generated by the package. In term of losses calculation, the comparison is given in Table 5. It is again confirmed that the results generated by the program is quite accurate. The comparison of reactive power loss calculation with HARMFLOW cannot be carried out due to the result from HARMLOW is not available.

Table 3. Result comparison, program, ETAP dan HARMFLOW

Bus ID	Program	ETAP	HARMFLOW
1	1.0545	1.0545	1.0545
2	1.0511	1.0511	1.0510
3	1.0456	1.0456	1.0455
4	1.0425	1.0425	1.0424
5	1.0359	1.0359	1.0358
6	1.0348	1.0348	1.0347
7	1.0326	1.0326	1.0325
8	1.0268	1.0268	1.0267
9	1.0496	1.0496	1.0496
20	1.0505	1.0505	1.0504
21	1.0496	1.0496	1.0495
22	1.0479	1.0479	1.0479
23	1.0451	1.0451	1.0451
24	1.0485	1.0485	1.0485
25	1.0419	1.0419	1.0418
26	1.0415	1.0411	1.0414
50	1.0501	1.0501	1.0501
51	1.0500	1.0500	1.0500

Table 4. Result deviation of voltage magnitude calculation

Bus ID	Deviation with			
	ETAP		HARMFLOW	
	per unit	persen	per unit	persen
1	0	0	0	0
2	0	0	1E-04	9.51E-05
3	0	0	0.0001	9.56E-05
4	0	0	1E-04	9.59E-05
5	0	0	1E-04	9.65E-05
6	0	0	1E-04	9.66E-05
7	0	0	1E-04	9.68E-05

Bus ID	Deviation with			
	ETAP		HARMFLOW	
	per unit	persen	per unit	persen
8	2.22E-16	2.16E-16	1E-04	9.74E-05
9	2.22E-16	2.12E-16	2.22E-16	2.12E-16
20	0	0	1E-04	9.52E-05
21	2.22E-16	2.12E-16	1E-04	9.53E-05
22	0	0	0	0
23	2.22E-16	2.12E-16	2.22E-16	2.12E-16
24	0	0	0	0
25	0	0	1E-04	9.6E-05
26	0.0004	0.000384	1E-04	9.6E-05
50	0	0	0	0
51	0	0	0	0
Maximum	0.0004	0.000384	0.0001	9.74E-05
Average	2.22E-05	2.13E-05	6.11E-05	5.87E-05

Table 5. Losses comparison between the program and the packages

Real power loss (MW)			Reactive power loss (MVAR)		
Program	ETAP	HARMFLOW	Program	ETAP	HARMFLOW
0.260	0.260	0.260	1.310	1.301	Not available

Conclusion

Power flow calculation has been successfully carried out using Newton Raphson method and coded in Matlab programming language. The results generated by the coded program have been verified with two standard package programs indicating that the program has successfully generated very accurate results.

Acknoledgement

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