A Modified Fast Decoupled Power Flow Algorithm

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ABSTRACT

A modified fast decoupled method is introduced to improve performance over traditional power flow analysis methods. These techniques include Newton-Raphson and Fast Decoupled Load Flow methods. For a modified version of the Fast Decoupled method, both of the change in voltage magnitude and voltage angle are computed and applied in the same iteration so that the overall computation time is minimized. The comparison between the traditional and the proposed methods are based on various numbers of system buses. The results show that the proposed method is superior to the traditional methods in the number of iterations and computation time.

1. INTRODUCTION

Power system load flow is one of the fundamental topics in power analysis including power system estimation, fault study, and economic operation. There are several algorithms that can be used to find the solution of system load flow. Among these techniques, Newton-Raphson (N-R) [1] is the most well-known method for load flow analysis. One advantage of N-R method is that the system size does not influent the number of iterations. The complexity, however, occurs in retrieving the Jacobian matrices. In addition, on-line load flow calculation is not applicable since computation time for a single iteration is very extensive. Another advanced load flow algorithm proposed by Stott and Alsac is called Fast Decoupled Load Flow (FDLF) [2] method. This approach has benefits in higher computation speed and efficiency. The required memory for computation is also compact compared to N-R method. As many researches [3-5] focusing on the improvement of power system load flow algorithm to satisfy the speed, accuracy, and efficiency, this paper presents a modified fast decoupled load flow method (M-FDLF) to provide higher computation speed and fewer number of iterations. The details of the proposed technique are given in the following context.

Generally, the power flow can be written in terms of Jacobian matrices [6], phase angle, and voltage magnitude as defined by:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{1}$$

where, the diagonal and off-diagonal element for each Jacobian matrix can be obtained as follows:

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2}$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j); \qquad j \neq i \tag{3}$$

For J_1,

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}|\cos(\theta_{ii}) + \sum_{j \neq i} |V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \tag{4}$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j); \qquad j \neq i \tag{5}$$

For J_2,

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \tag{6}$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j); \qquad j \neq i \tag{7}$$

For J_3, and

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin(\theta_{ii}) - \sum_{j \neq i} |V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \tag{8}$$

$$\frac{\partial Q_i}{\partial |V_j|} = -|V_i||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j); \qquad j \neq i \tag{9}$$

For J_4.

As shown above, finding a Jacobian matrix is complicate and it extensively requires memory and computation time. Conversely, by applying the assumptions that ΔV and $\Delta\delta$ have only small effect on the active power ΔP and the reactive power, respectively, resulting to overcome those problems. Consequently, J_2 and J_3 are assumed to be zero and the Jacobian matrices from Eq. (1) can be rewritten to

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & 0 \\ 0 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{10}$$

Which, then gives

$$\Delta P = J_1 \Delta\delta = \frac{\partial P}{\partial \delta} \cdot \Delta\delta \tag{11}$$

$$\Delta Q = J_4 \Delta|V| = \frac{\partial Q}{\partial |V|} \cdot \Delta|V| \tag{12}$$

And J_1 can be obtained from

$$\frac{\partial P_i}{\partial \delta_i} = \sum |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) - |V_i|^2|Y_{ij}|\sin(\theta_{ii}) \tag{13}$$

From Eq. (6), the first term of equation above is equal to -Q_i which gives

$$\frac{\partial P_i}{\partial \delta_i} = -Q_i - |V_i|^2 |Y_{ii}| sin(\theta_{ii})$$

$$= -Q_i - |V_i|^2 B_{ii} \tag{14}$$

Where, $B_{ii} = |Y_{ii}| sin(\theta_{ii})$. By assuming that $B_{ii} >> Q_i$, $|V_i|^2 \approx |V_i|$, and $\theta_{ii} - \delta_i + \delta_j \approx \theta_{ii}$ Eq. (14) can be written to

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j|B_{ij} \tag{15}$$

From the elements in J_4,

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||Y_{ii}| sin(\theta_{ii}) - \sum |V_i||V_j||Y_{ij}| sin(\theta_{ij} - \delta_i + \delta_j) \tag{16}$$

Similarly, the second term of Eq. (16) is equal to -Q_i. Let $B_{ii} = |Y_{ii}| sin(\theta_{ii})$ and assume that $B_{ii} >> Q_i$, $|V_i|^2 \approx |V_i|$, and $\theta_{ii} - \delta_i + \delta_j \approx \theta_{ii}$, thus Eq. (16) is transformed to

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i| B_{ij} \tag{17}$$

The procedure of finding load flow solution by using the FDLF method is shown in Fig. 1. The similar scheme used in FDLF method is also applied to M-FDLF method. However, the procedure is adapted for limiting both $\left|\frac{\Delta P}{V_i}\right|$ and $\left|\frac{\Delta Q}{V_i}\right|$ with a certain tolerance. This is to assure that both quantities are appropriate to be transferred to the next step resulting in improving the number of iterations and computation time. The flow chart of this procedure is depicted in Fig. 2.

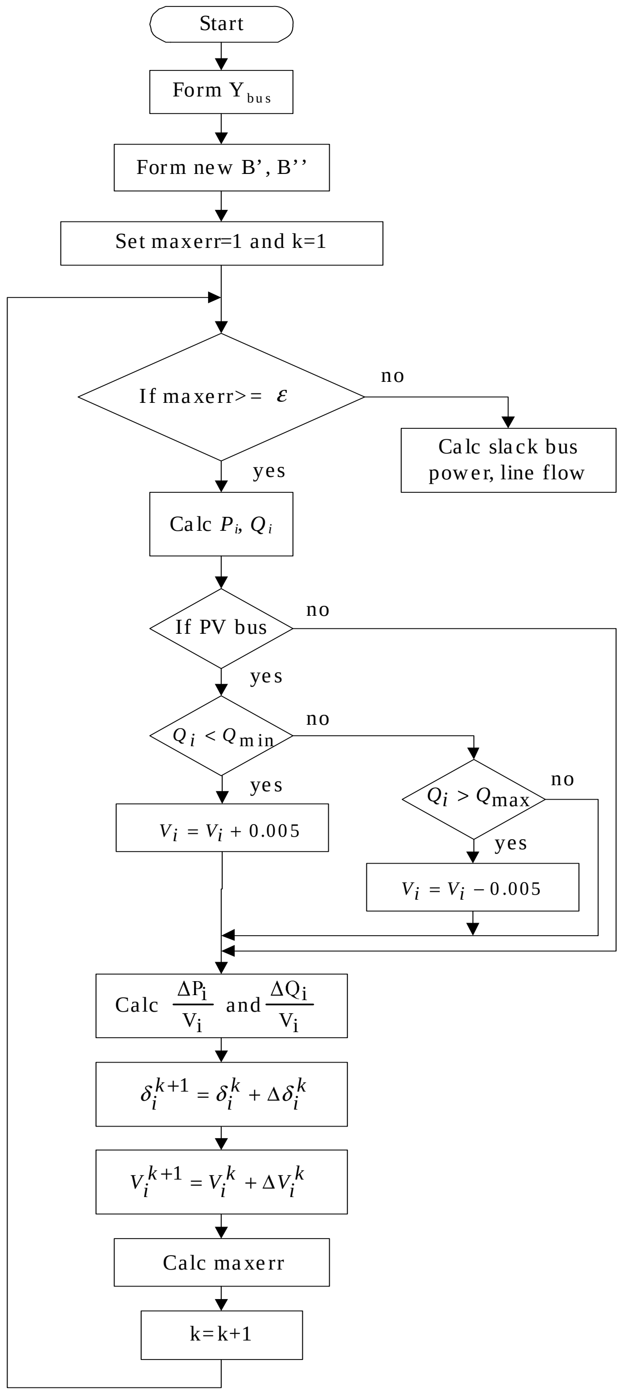

Fig. 1 FDLF flow chart

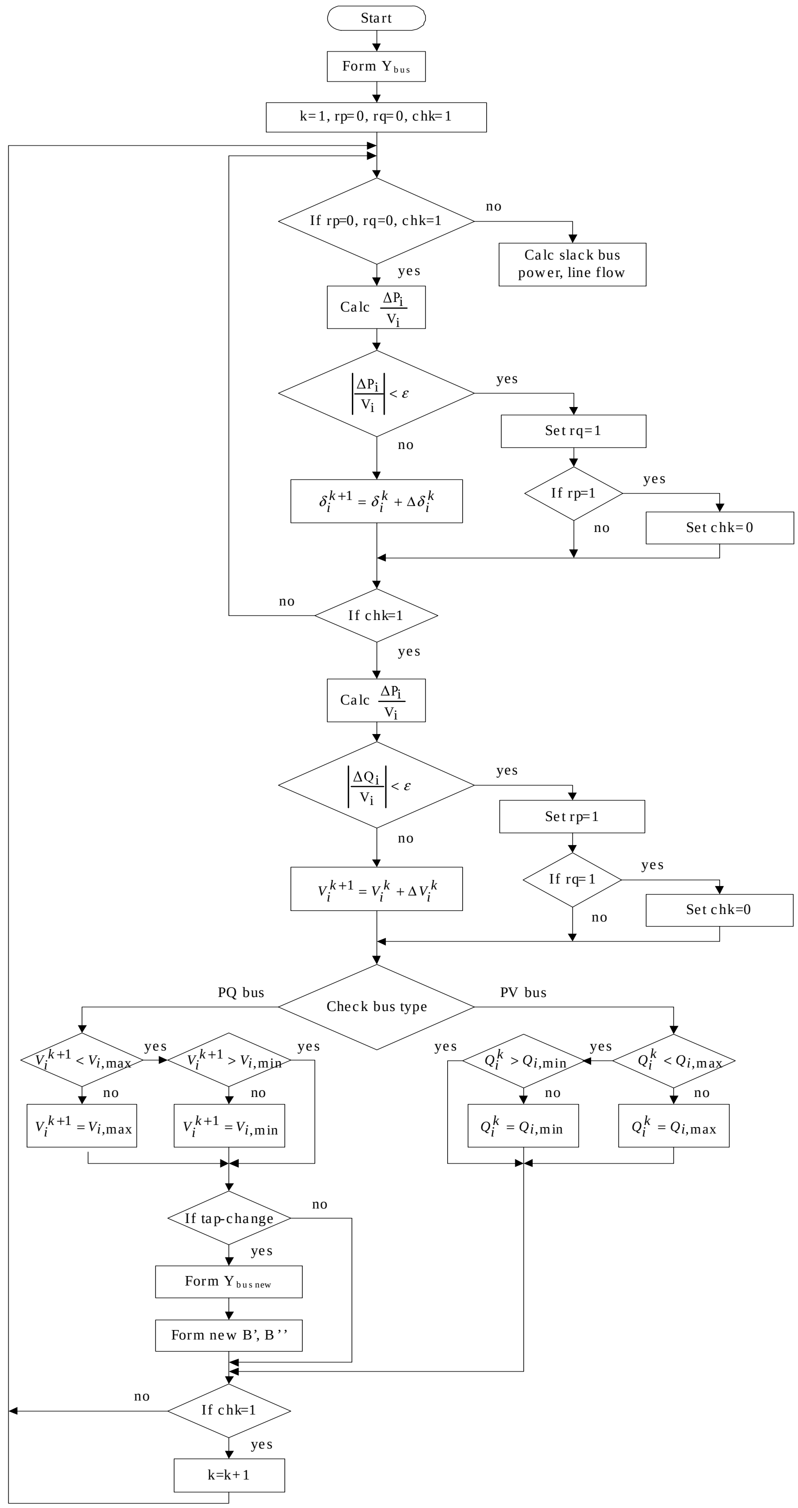

Fig. 2 M-FDLF flow chart

2. IMPLEMENTATION

The graphic user interface (GUI) is implemented to allow users to conveniently interact with the system in simulation. To perform the simulator, the users can simply enter the system parameters into a formatted Microsoft Excel spreadsheet as shown in Fig. 3. The simulator, which will be described in next, then accesses these provided data from the spreadsheet during the process of simulation.

	A	B	C	D	E	F	G	H	I	J	K
1	6	Number of Bus									
2	5	Number of Line									
3	2	Number of Transformer									
4	100	Base MVA									
5	BUS	BUS	Voltage	Angle	Load		Generator				Injected
6	No.	type	pu	Degree	Mw	Mvar	Mw	Mvar	Qmin	Qmax	Mvar
7	1	1	1.06	0	0	0	0	0	0	0	0
8	2	2	1.04	0	0	0	150	0	0	140	0
9	3	2	1.03	0	0	0	100	0	0	90	0
10	4	0	1	0	100	70	0	0	0	0	0
11	5	0	1	0	90	30	0	0	0	0	0
12	6	0	1	0	160	110	0	0	0	0	0
13	Element	Bus		Self		Bus	Mutual		1/2 B		
14	No.	from	to	Resistance	Reactance	mutual	Resistanc	Reactanc	pu		
15	1	1	4	0.035	0.225	0	0	0	0.0065		
16	2	1	5	0.025	0.105	0	0	0	0.0045		
17	3	1	6	0.04	0.215	0	0	0	0.0055		
18	4	4	6	0.028	0.125	0	0	0	0.0035		
19	5	5	6	0.026	0.175	0	0	0	0.03		
20	Element	Bus		Resistance	Reactance	1/2 B	Tap	Type			
21	No.	from	to	pu	pu	pu					
22	1	2	4	0	0.035	0	1	1			
23	2	3	5	0	0.042	0	1	1			

Fig. 3 Program input from Microsoft Excel

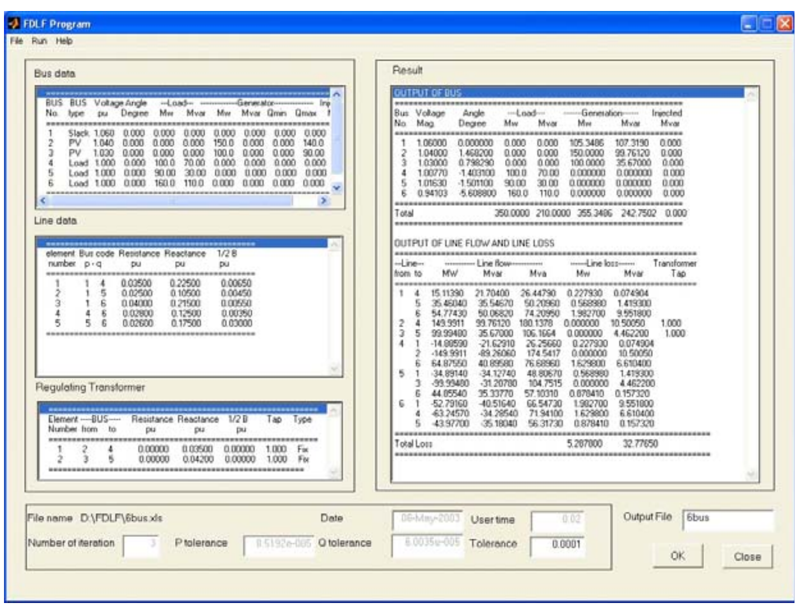

Fig. 4 Load flow program

For the simulator part, it is compiled under MATLAB environment to be executed as a standalone application. A reason behind is to avoid an obligation of installation of the entire MATLAB package in order to perform the load flow simulation. For more convenient, The input and output of the simulator are displayed inside the window of the simulator as shown below. In addition, the result of the simulation can alternatively be reported in the text file, which can be opened in word program such as Microsoft Word as shown in Fig. 5.

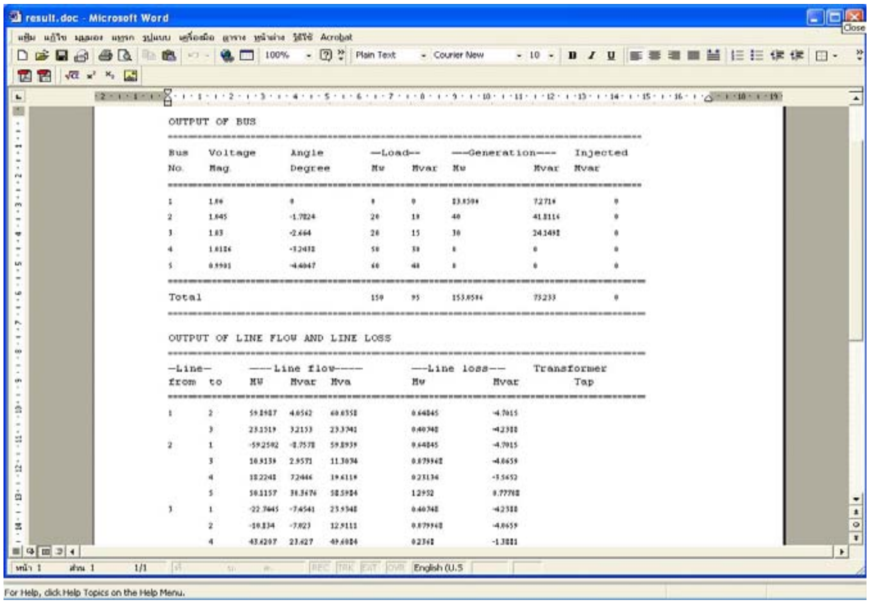

Fig. 5 Program report in text format

3. COMPARISON RESULTS

The comparison between load flow algorithms described above can be classified into several aspects comprising of accuracy, number of iterations, speed per iteration, and overall speed. The results are compared for many different numbers of system buses, namely, 5, 6, 9, 14, and 30 buses.

Table 1 Error between N-R and M-FDLF

Bus	Error (%)	
	Absolute Voltage	Phase Angle
5	0.0000	0.0060
6	0.0000	0.1161
9	0.0000	0.0035
14	0.0067	0.0701
30	0.0098	0.0538
Average	0.0033	0.0499

For the accuracy aspect of the algorithm, the comparison is only made between M-FDLF and N-R methods since the results of M-FDLF and FDLF schemes are similar. The accuracy examination is made by measuring the error between M-FDLF and N-R schemes as illustrated in Table 1 below. The result shows that the absolute voltage and phase angle of M-FDLF scheme is in average of 99.9967% and 99.9501%, respectively. The total average error of M-FDLF method is then 99.9734% of N-R technique.

Based on an objective of M-FDLF method, which reduces the number of iterations compared to that of FDLF scheme, the number of iterations of N-R, FDLF, and M-FDLF methods are compared in Table 2. The results indicate an improvement of the number of iterations used in M-FDLF method. Furthermore, the number of iterations of M-FDLF technique tends to approach that of N-R method when the number of buses is increased. Therefore, it is clearly shown that M-FDLF method improves the weakness of FDLF scheme in number of iterations aspect.

Table 2 Comparison of the number of iterations

Bus	Number of iterations		
	N-R	FDLF	M-FDLF
5	3	10	4
6	4	7	3
9	3	11	5
14	4	31	5
30	4	15	4

As described in M-FDLF procedure, computation speed used in one iteration of M-FDLF increases compared to that of FDLF because of the additional procedure created to reduce the number of iterations. The results in Table 3 clearly prove this presumption of the computation speed for various numbers of system buses. On the other hand, the average computation time of one iteration of both M-FDLF and FDLF methods are obviously shorter than that of N-R scheme.

Table 3 Comparison of computation time for single iteration

Bus	Computation time for single iteration (sec)		
	N-R	FDLF	M-FDLF
5	0.1500	0.0280	0.0550
6	0.1275	0.0357	0.0767
9	0.0967	0.0227	0.0440
14	0.1300	0.0158	0.0620
30	0.1775	0.0433	0.1200

Table 4 shows the elucidation of optimum number of iterations bringing up to the best overall computation time. As described in previous two tables, even though the computation time employed in one iteration of M-FDLF scheme is longer but the reduction of the number of iterations is much more dominant resulting that M-FDLF scheme becomes the fastest method compared to FDLF and N-R techniques.

Table 4 Comparison of the over all computation speed

Bus	Overall computation time (sec)		
	N-R	FDLF	M-FDLF
5	0.45	0.28	0.22
6	0.51	0.25	0.23
9	0.29	0.25	0.22
14	0.52	0.49	0.31
30	0.71	0.65	0.48

4. CONCLUSIONS

This paper describes a power system load flow study based on M-FDLF method. This method is adapted from FDLF scheme to reduce the number of iterations. The modification technique increases the computation time for each iteration, however, it does not affect the overall computation performance. This is because the reduction of number of iterations is much more influence. Finally, the results based on various numbers of system buses shows that M-FDLF method has is superior to N-R and FDLF schemes.

5. REFERENCES

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