

Performance Comparison of Electric Power Flow Solutions Using PSCAD

Nurul Huda Ishak¹, Iza Sazanita Isa¹, Samihah Abdullah¹, Syafrudin Masri², Faizal Mohamad Twon Tawi³,

¹Faculty of Electrical Engineering, Universiti Teknologi MARA MALAYSIA

²Universiti Sains Malaysia

³Politeknik Ungku Omar

nurulhuda258@ppinang.uitm.edu.my

Abstract— This paper presents the analysis of electric power flow solution consists of specified power and voltage input conditions to power network and producing the complete voltage information at all the system busses. From this analysis the parameters of current flow and voltages were obtained. Computation of power flow solution is easy if it does not involve with a large power system. But, if a power system is involved with hundred or thousand buses it is complicated to calculate using calculator or iteration method. The Power System Computer Aided Design (PSCAD) software was chosen to solve the problem of power flow solution. There are many software programs such as Matlab, PSCAD and PSpice but PSCAD was chosen to solve power flow solution. It was because PSCAD is the best simulation method and provided quick and economic results with high accuracy. Computer simulation was used extensively in the power flow study because of the large scale nature of the problem and the complexity involved. The main purpose of this project was to solve power flow solution system by using PSCAD, hence developed the power flow model by using PSCAD. This model was used to analyze and observes the project result based on theoretical and simulation method. The result of performance shown for this project was successful depends on simulation using PSCAD software. It was easier to analyze complicated power flow solution by using PSCAD.

Keywords—Power Flow; PSCAD; IEEE Bus; Matlab

I. INTRODUCTION

Power flow study or load flow study is an important technique for power system analysis and design. Compared to traditional circuit analysis, a power flow study usually used simplified notation such as a one-line diagram and per unit system, and focuses on various forms of AC power for example reactive, real, and apparent. In this analysis the transmission system was modelled by a set of busses or nodes interconnected by transmission line. Generators and loads are connected to various nodes of system, inject and remove power from the transmission system.

A power flow study is an analysis of the voltages, currents and power flows in a power system under steady state condition. Since a modern electric power system had a great number of different components, performing its power flow computation can be challenging due to large size and high complexity of the system. The computer aided solution to power system problems was receiving

increase attention. In power system studies, the computer solution was the best means of providing quick and economical results of high accuracy [1].

The great importance of power flow or load-flow studies was in planning to future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study was the magnitude and phase angle of the voltage at each bus and the real and reactive power flowing in each line. The study of the Power flow was very significant, because it makes it possible to provide information of large importance in order to better plan, to control and finally ensure the correct operation of the electrical supply networks.

In order to have an accurate, efficient and user friendly power flow program, a suitable solution method must be chosen. Optimized program with a graphical user interface was in demand. To have a high solution speed, the efficient programming techniques and the powerful convergence improvements methods have been applied in the program's development. Integrating it with PSCAD/EMTDC (electromagnetic transient) was being undertaken.

II. LITERATURE REVIEW

The power flow analysis involves the calculation of power flows and voltages of a transmission network for specified terminal or bus conditions. The results are used to evaluate the line or transformer loading and the acceptability of bus voltages. In this analysis, the transmission system is modelled by a set of busses or nodes interconnected by transmission link.

There are many research involved in analysis of power flow solution by using various method or technique such as iteration methods, digital computer solution, and Matlab implementation. The main objective of those technique and method is to understand the analysis of the power flow solution for improving the accuracy.

A. Iterative Method

Iterative method is a computational mathematics attempts to solve a problem by finding successive approximations to the solution starting from an initial guess [2]. Iteration methods are usually the choice for nonlinear equations. However, iteration methods are also can be used for linear problem involving a large number of variables. The most commons technique used for the

iterative solution of nonlinear algebraic equations are Newton Raphson and Gauss Seidel methods.

B. Newton Raphson Method

Newton Raphson method is based on iterative technique for solving a set of nonlinear equations. The research [3] has described Iterative solvers in the Newton power flow problem. Iterative solvers were more efficient than the factorisation for large power systems.

Since the power flow problem real power and voltage magnitude are specified for the voltage-controlled buses, the power flow equation is formulated in polar form. This equation can be written in terms of the bus admittance matrix as:

$$I_i = \sum_{j=1}^n Y_{ij} V_j \quad (1)$$

Newton's method is successive approximation procedure based on an initial estimate of the unknown and the use of Taylor's series expansion.

C. Gauss Seidal Method

The Gauss Seidel method is also known as the method of successive displacement [4]. It needs numbers of iteration to achieved desired accuracy and there is no guarantee for the convergence. It has also [5] suggested for power flow solution by using a modified Gauss Seidel algorithm. In that method, a three phase distribution network was separated into three single phase distribution networks and can be solved phase by phase. The results show that, the proposed method can obtain a close final solution with lower memory requirement and CPU execution time.

The Gauss Seidel method is the oldest of the power flow solution methods. It is simple, reliable and usually tolerant of poor voltage and reactive power conditions. It also had low computer memory requirements. The iterative method converges slowly and exhibits convergence problems when the system is stressed due to high levels of active power transfer.

The Newton Raphson method has a very good convergence rate or quadratic [1]. The computation time increases only linearly with system size. However, this method had convergence problems when the initial voltages are significantly different from its true value. Once the voltage solution is near the true solution, the convergence was very rapid. The Newton Raphson method is suited for applications involving large systems requiring very accurate solution.

D. Solving Power Flow Solution Using PSCAD

The research by [1] is presented a power flow studies by using PSCAD/EMTDC. This study was extended from the research done by [6] in power flow calculation methods. There are many advantages solving power flow analysis by using PSCAD:

- The computer solution is the best method and provided quick and economic results with high accuracy.

- The results are more accurate and efficient by using computer aided software.
- PSCAD is the user friendly power flow program.
- The user can conveniently adjust the network's power generation and consumption in the power flow studies.
- The results can be obtained quicker and better evaluation of the power flow system.

Compared to the others method, it can concluded that by using computer solution such as PSCAD is the best ways to solve power flow studies. It is because PSCAD can solve the large power system.

III. METHODOLOGY

A. Power Flow Solutions

In order to generate the power flow solution of a power system, the input raw data of the network must be prepared. Generating a raw data file involves labeling buses and branches, assigning bus types, calculating system parameters, assigning powers to loads, setting bus voltages and forming different data sections based on the system's configuration and parameters.

After inputting and processing the data of the power system, the program constructs the system admittance matrix, Y . The complex power at the i -th bus in the power system is given by:

$$P_i + jQ_i = V_i \sum_{j=1}^n Y_{ij} V_j * \quad (2)$$

Where P_i and Q_i are the real and reactive power entered into the i -th bus respectively. V_i and V_j are the voltages at the i -th bus and the j -th bus respectively. Y_{ij} is the admittance of the branch between the i -th bus and the j -th bus. N is the number of buses related to the i -th bus. The real and reactive power mismatches at the i -th bus are given by:

$$\Delta P_i = P_{is} - V_i \sum_{j=1}^n V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij}) \quad (3)$$

$$\Delta Q_i = Q_{is} - V_i \sum_{j=1}^n V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij}) \quad (4)$$

Where P_{is} and Q_{is} are the desired real and reactive power flowing into the i -th bus; G_{ij} and B_{ij} are the conductance and susceptance of the branch between the i -th bus and the j -th bus. Equation (2) and (3) are then solved for the bus voltage amplitude and angle by iteration method.

B. Power Flow Analysis Procedure

The difficulty in solving load flow problems by numerical methods lies in determining the distribution of flow in the network caused by impressed loads. The flow distribution must satisfy the conditions that the algebraic sum of the components of flow into each network junction

and the components of voltage drop around each closed path are both zero.

If the load on the network is expressed in terms of currents, then the relationship between flow and voltage drop is linear. The determination of network flow involves little more than a solution of a set of simultaneous linear equation. In order to analyze the power flow solutions, it is necessary to define the following information as presented in Table 1.

The performance of the analysis is based on the percentage of error between measured value of PSCAD and expected value from Matlab. The performance of correct classification is defined as in (4).

$$\% \text{ Error} = \frac{\text{Measured Value} - \text{Expected Value}}{\text{Expected Value}} \times 100\% \quad (4)$$

C. Application of PSCAD/EMTDC to Analyze Power Flow

The PSCAD/EMTDC software is a simulation tool for power system engineer for simulation analysis purposes. The Power System Computer Aided Design (PSCAD) is a powerful and flexible graphical user interface with EMTDC (Electromagnetic Transient DC) as its simulation engine.

TABLE I.
PARAMETERS ACQUIRED TO ANALYSE POWER FLOW SOLUTIONS

	Parameters
1	Configuration of the network
2	Impedance and susceptance of all network elements
3	Power and reactive demand at all load busses
4	Power and reactive output of all generators accept the swing generator
5	Voltage and phase angle ratio of all transformers
6	Voltage and phase angle at one bus in the network example reference bus
7	Power and reactive flow at each end of all line elements
8	Voltage and phase angle at all buses

This software allows user to schematically construct a circuit, run simulation, and analyze the results. PSCAD contains a few special runtime objects designed to give the user online plotting and control of the data input, as well as the ability to record the output data. Special objects such as Graph Frame, Curve, Meter and Polymeters are used interactively display EMTDC output data, both during a run and following completion of a simulation, so that the system parameters during a simulation run can be altered and view the result directly.

The PSCAD also has its own components library which includes pre-programmed and tested model, ranging from simple passive elements and control function, to more complex models, such as electric machines, FACTS devices, breaker, relays, transmission lines and cables. If a particular model does not exist, PSCAD provides the

flexibility of constructing custom models, either by assembling graphically using existing models or by utilizing an intuitively designed Design Editor. Therefore, with those features, this paper applied the software as a simulator tools.

In order for custom model to be included in either the system dynamic or the electric network solution in EMTDC, the model must first be added as a component in PSCAD. Component such as graphical representation models, allowing the user to supply input parameters, perform pre-calculation on input data and change the component appearance [3].

D. Power Flow Model

A power flow model is necessary in order to analyze all the parameters such as bus voltage, branch current, real power flow, reactive power flow for the specified generation and load condition. The results are used to evaluate the line or transformer loading and the acceptability of bus voltages. In general the power flow solutions are needed for the system under the following conditions [3].

- Various systems loading conditions.
- With certain equipment outage.
- Addition of new generators.
- Addition of new transmission lines or cables.
- Interconnection with other systems.
- Load growth studies.
- Loss of line evaluation

IV. RESULTS AND ANALYSIS

Main objective of this study is to compare the results using PSCAD and conventional method using Matlab. This chapter presents result from the simulation of 30-bus IEEE sample system. The performance of the analysis is based on the percentage of error between calculation using Matlab and PSCAD simulation.

An analysis were carried out on the 30-bus IEEE sample system as shown in Figure 1. This system was selected because it representing the large number of power systems. It contains all the components which normally required to be considered in making a load flow study such as generator, transmission line, transformer and load. A one-line diagram of the system studied is shown in Figure 1. The system is composed of 30 bus, two generators, four synchronous condenser, three transformers, 20 loads and impedances at each transmission lines. The arrow indicating an arbitrary direction of positive flow in each line and to designate sending and receiving ends of each line.

In PSCAD, once the model has been developed, the software will generate its own FORTRAN data and DATA program for each simulation. It consists all information about the schematic such as the value for each component and labelling node at each bus. If the simulation has a problem, all errors can be detected by referring to the FORTRAN and DATA program.

TABLE II.
NETWORK LINE AND DATA BUS

From Bus	To Bus	R pu	X pu
1	2	0.0192	0.0575
1	3	0.0452	0.1852
2	4	0.057	0.1737
3	4	0.0132	0.0379
2	5	0.0472	0.1983
2	6	0.0581	0.1763
4	6	0.0119	0.0414
5	7	0.046	0.116
6	7	0.0267	0.082
6	8	0.012	0.042
6	9	0	0.208
6	10	0	0.556
9	11	0	0.208
9	10	0	0.11
4	12	0	0.256
12	13	0	0.14
12	14	0.1231	0.2559
12	15	0.0662	0.1304
12	16	0.0945	0.1987
14	15	0.221	0.1997
16	17	0.0824	0.1923
15	18	0.1073	0.2185
18	19	0.0639	0.1292
19	20	0.034	0.068
10	20	0.0936	0.209
10	17	0.0324	0.0845
10	21	0.0348	0.0749
10	22	0.0727	0.1499
21	22	0.0116	0.0236
15	23	0.1	0.202
22	24	0.115	0.179
23	24	0.132	0.27
24	25	0.1885	0.3292
25	26	0.2544	0.38
25	27	0.1093	0.2087
28	27	0	0.396
27	29	0.2198	0.4153
27	30	0.3202	0.6027
29	30	0.2399	0.4533
8	28	0.0636	0.2
6	28	0.0169	0.0599

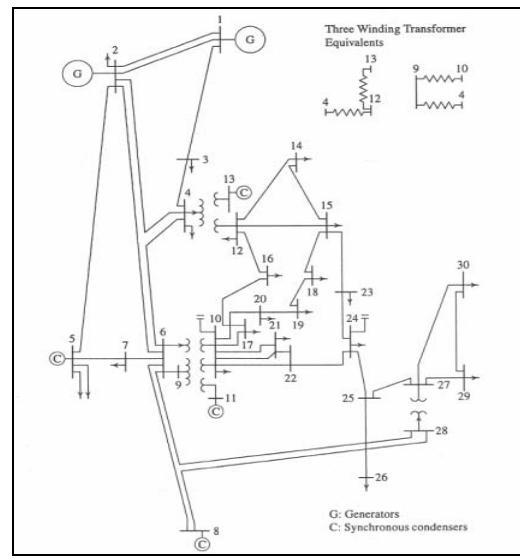


Figure 1. 30 Bus IEEE sample system

A. Network Line and Data Bus

The example of network line and data bus is shown in Table 2. The line data consists of the resistance, R and reactance, X as well as the voltage ratio of each transmission element where all the value in per unit or p.u. The buses data include the power and reactive drawn from each bus as well as scheduled power and reactive generation at all the generator busses other than the swing bus.

B. Simulation Results of 30 Bus IEEE Sample System

Load flow and voltage distribution for the sample system were computed with the PSCAD simulation. From PSCAD the value of each current flow and voltage at each bus can be obtained. After that, all the Apparent power, S, Real power, P and Reactive power, Q can be calculated. All the data were compared with the results from the iteration method that obtain from Power System Analysis. [2]

The method describe in this paper for solving load flow problem was ideally suited for the PSCAD software. Compared all the results in Figure 2, 3 and 4, its proved that the results from iteration method and PSCAD method are quite similar, however the PSCAD simulation results of power flow solution is faster as compared to the conventional methods. The test results have proved that the load flow program is capable of handling the power flow computations of different power systems with high accuracy and at high solution speeds.

TABLE III.
COMPARISON RESULTS BETWEEN MATLAB AND PSCAD

Line		Power at bus & line flow By using Matlab			Power at bus & line flow by using PSCAD		
from	to	MW	Mvar	MVA	MW	Mvar	MVA

1	2	177.7	-22.1	179.1	177.8	-21.5	179.1
	3	83.2	5.1	83.4	83.2	5.2	83.4
2	1	-172.3	32.7	175.4	-171.9	32.6	175.0
	4	45.7	2.7	45.8	45.6	2.7	45.7
	5	83.0	1.7	83.0	82.8	1.7	82.9
	6	61.9	-1.0	61.9	61.6	-1.0	61.6
3	1	-80.4	2.0	80.4	-80.4	2.0	80.4
	4	78.0	-3.1	78.1	77.9	-3.0	78.0
4	2	-44.6	-3.2	44.7	-44.6	-3.2	44.7
	3	-77.3	4.4	77.4	-76.8	4.4	77.0
	6	70.1	-17.6	72.3	70.1	-17.6	72.3
	12	44.1	14.6	46.5	44.3	15.4	46.9
5	2	-80.0	6.5	80.3	-78.9	6.4	79.2
	7	-14.2	10.5	17.6	-14.1	10.4	17.5
6	2	-59.9	3.2	59.9	-59.5	3.2	59.6
	4	-69.5	18.8	72.0	-69.5	18.8	72.0
	7	37.5	-1.9	37.6	37.5	-1.9	37.6
	8	29.5	-3.7	29.8	29.6	-3.7	29.6
	9	27.7	-7.3	28.7	27.5	-7.2	28.4
	10	15.8	0.7	15.8	15.9	0.7	15.9
	28	18.8	-9.6	21.1	18.9	-9.6	21.2
7	5	14.4	-12.2	18.8	14.3	-12.1	18.8
	6	-37.2	1.3	37.2	-37.2	1.3	37.2
8	6	-29.4	3.2	29.6	-26.4	3.1	26.5
	28	-0.6	-2.4	2.4	-0.6	-2.3	2.4
9	6	-27.7	8.9	29.1	-26.7	8.9	28.1
	11	0.0	-15.7	15.7	0.0	-15.7	15.7
	10	27.7	6.7	28.5	27.7	6.7	28.5
	6	-15.8	0.6	15.8	-15.8	0.6	15.8
10	9	-27.7	-5.9	28.4	-27.8	-5.9	28.4
	20	9.0	3.6	9.7	8.9	3.6	9.7
	17	5.3	4.4	6.9	5.3	4.5	6.9
	21	15.7	9.8	18.6	15.7	9.8	18.5
	22	7.6	4.5	8.8	7.6	4.5	8.8
	11	9	0.0	16.1	16.1	-0.0029	16.1
12	4	-44.1	-9.9	45.2	-43.7	-9.9	44.8
	13	0.0	-10.3	10.3	0.0	-10.4	10.4
	14	7.9	2.4	8.2	7.9	2.5	8.2
	15	17.9	7.0	19.2	17.8	6.7	19.1
	16	1.6	0.7	1.7	1.6	0.7	1.8
13	12	0.0	10.4	10.4	0.0	10.5	10.5
14	12	-7.2	-3.3	7.9	-7.2	-3.3	7.9
	15	1.6	0.7	1.7	1.6	0.7	1.8
15	12	-17.6	-6.5	18.8	-17.7	-6.6	18.9
	14	-1.6	-0.7	1.7	-1.6	-0.7	1.7
	18	6.0	1.7	6.3	6.0	1.8	6.3
	23	5.0	3.0	5.8	5.0	3.0	5.8

16	12	-7.2	-3.3	7.9	-7.2	-3.3	7.9
	17	3.7	1.4	3.9	3.7	1.4	3.9
17	16	-3.6	-1.4	3.9	-3.6	-1.4	3.9
	10	-5.3	-4.4	6.9	-5.3	-4.2	6.8
18	15	-6.0	-1.7	6.2	-6.0	-1.7	6.2
	19	2.8	0.8	2.9	2.8	0.8	2.9
19	18	-2.8	-0.8	2.9	-2.8	-0.8	2.9
	20	-6.7	-2.7	7.2	-6.0	-2.6	7.3
20	19	6.7	2.7	7.2	6.8	2.8	7.4
	10	-8.9	-3.4	9.6	-9.0	-3.4	9.6
21	10	-15.6	-9.6	18.3	-15.6	-9.6	18.3
	22	-1.8	-1.6	2.5	-1.9	-1.6	2.5
22	10	-7.5	-4.4	8.7	-7.5	-4.4	8.7
	21	1.9	1.6	2.5	1.9	1.6	2.5
23	24	5.6	2.8	6.3	5.7	2.8	6.3
	15	-5.0	-2.9	5.8	-5.0	-3.0	5.8
24	24	1.8	1.3	2.2	1.8	1.3	2.2
	22	-5.6	-2.7	6.2	-5.6	-2.7	6.2
	23	-1.8	-1.3	2.2	-1.8	-1.3	2.2
25	25	-1.3	1.6	2.1	-1.3	1.6	2.1
	24	1.3	-1.6	2.1	1.4	-1.6	2.1
	26	3.5	2.4	4.2	3.6	2.4	4.3
	27	-4.9	-0.8	4.9	-4.9	-0.8	5.0
27	25	-3.5	-2.3	4.2	-3.5	-2.4	4.2
	25	4.9	0.8	5.0	4.9	0.8	5.0
	28	-18.2	-4.2	18.7	-18.2	-4.2	18.7
	29	6.2	1.7	6.4	6.1	1.7	6.4
28	30	7.1	1.7	7.3	7.1	1.7	7.3
	27	18.2	5.5	19.0	18.1	5.4	18.9
	8	0.6	-2.0	2.1	0.6	-2.0	2.1
	6	-18.8	-3.5	19.1	-18.9	-3.6	19.2
29	27	-6.1	-1.5	6.3	-6.1	-1.5	6.3
	30	3.7	0.6	3.8	3.7	0.6	3.8
30	27	-6.9	-1.4	7.1	-7.0	-1.4	7.1
	29	-3.7	-0.5	3.7	-3.7	-0.5	3.7

Compared all the result in Table 3, it proved that the results from iteration method and PSCAD method are quite same. Using PSCAD simulation the computation of power flow solution is fast compared with the conventional methods. The test results have proved that the load flow program is capable of handling the power flow computations of different power systems with high accuracy and at high solution speeds.

From Figure 2 to Figure 4, the error between calculations using Matlab and PSCAD in the range of 5%. It means that, PSCAD is applicable for computing the power flow solution with acceptable errors. From Figure 2, the maximum errors are 5.26316% which are at bus 25 to 24 and bus 28 to 8. The min error are 0% which are from bus 3 to 1, 4 to 6, 7 to 6, 8 to 28, 16 to 17, 21 to 10, 24 to 25 and 30 to 29.

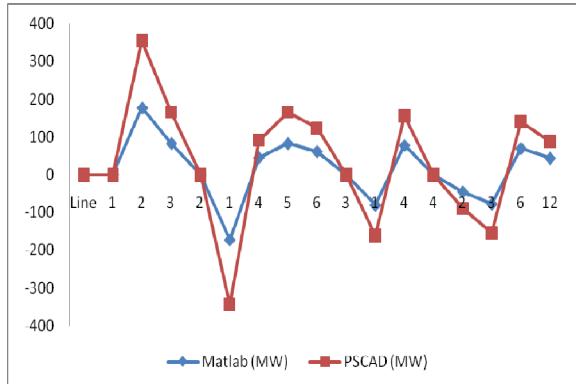


Figure 2. Comparison results real power (P) between Matlab and PSCAD

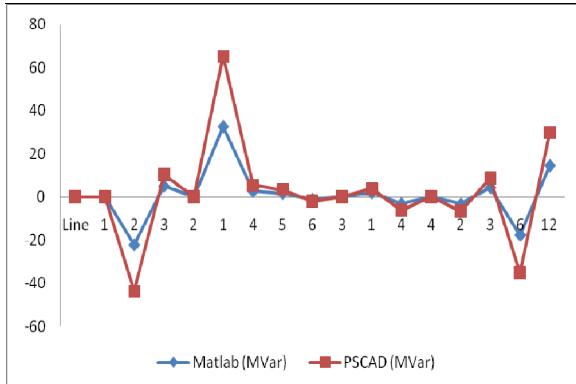


Figure 3. Comparison results reactive power (Q) between Matlab and PSCAD

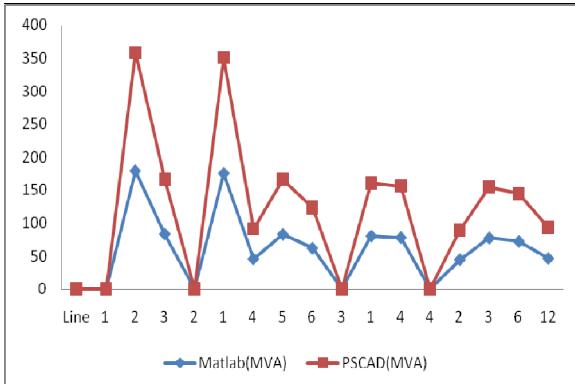


Figure 4. Comparison results apparent power (S) between Matlab and PSCAD

In Table 4, the maximum error is 5.35995% at bus 4 to bus 12, while the minimum error still 0% which are from bus 3 to 1, 4 to 6, 9 to 10, 16 to 17, 21 to 10, 24 to 25, 25 to 27 and 30 to 29. Refer to Figure 4, the maximum error occur at bus 9 to 6 with the value of 3.3418%. The value is lower compared than the result for real power and reactive power in Figure 2 and Figure 3. The minimum error still 0 value.

Using PSCAD, the real and reactive power levels of the generators and loads can be changed. It is also able to set the power levels of this component by zones and areas. These important characteristics ensure that the user can conveniently adjust the network's power generation.

Besides, computation in the power flow study resulting fast and better estimate of power flow of the system.

PSCAD software also can do the load flow computation either directly using the raw data or the schematic diagram. Furthermore, PSCAD program can perform the power flow computations of all the independent subsystems in a power system simultaneously. It produced the power flow information on each subsystem.

TABLE IV
MAXIMUM ERROR BETWEEN MATLAB AND PSCAD

Line		Maximum Error (%)		
From	To	Real Power (P) MW (%)	Reactive Power (Q) MW (%)	Apparent Power (S) MW (%)
25	24	5.26316	-	
28	8	5.26316	-	-
4	12	-	5.35995	-
9	6	-	-	3.3418

V. CONCLUSION

The development simulator tool models using PSCAD/EMTDC software can be applied to solve power flow solution system. These models have been used to study and analyze the power flow parameter such as generator bus, load bus, slack bus, impedance at transmission line and transformers. Besides, the simulator tool was developed by incorporating each bus. In order to analyze power flow in this power system, all parameter was set according to IEEE approved. All the result from PSCAD was more accurate compared to the theory of iteration method. In power system studies, the PSCAD simulation is the best providing quick and economical results of high accuracy. Better economy in power flow calculation; therefore rely primarily on high speed and economical computers as well as accurate and efficient computer aided software. The proposed analysis of power flow solution also can be applied to industry and world wide used. In addition, PSCAD method still needs to be explored and improve for better application.

REFERENCES

- [1] K.W. Louie, A. Wang, P. Wilson and P. Buchanan, "A newly built power flow program in PSCAD/EMTDC for electric power system studies", *IEEE Proc. Power System Technology (PowerCon 2004)*, Vol. 2, pp 1502-1507, Nov 2004.
- [2] S.J. Chapman, "Electric Machinery and Power System Fundamentals", Mc Graw Hill, USA, 2002.
- [3] F. de Leon and A. Semlyen, "Iterative Solvers in the Newton power flow problem", *IEE Proc on Generation, Transmission and Distribution*, Vol. 149, pp 479-484, July 2002.
- [4] H. Saadat, "Power System Analysis", Mc Graw Hill, Singapore, 2004.
- [5] J. H.Teng, " A modified Gauss-Seidal algorithm of three -phase power flow analysis in distribution networks", *International Journal of Electrical Power & Energy Systems*, Volume 24, pp 97-102, February 2002.
- [6] J.B. Ward and H.W. Hale, "Digital Computer Solution of Power Flow Problems", *IEEE Journal on Power Apparatus and Systems, Part III. Transactions of the American Institute of Electrical Engineers*, Vol. 75, pp 398-404, Jan 1956.