

Application of Decomposition Method to PowerWorld Simulator for Facilitation of Load Flow Analysis

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Abstract- Power system analysis is generally done by power flow analysis. Various analysis methods have been developed but the enormous size and complicity of power systems calls for constant research into reducing the size and data handled per time. This work proposes a new and easier way of analysing power systems in which systems are analysed in bits before the separate results are combined by modelling to obtain the result of the whole system. This is done by exploring the possibility of synergy between PowerWorld software and a decomposition technique. Matlab was also engaged for numerical comparison of results. It is shown here that systems can be in parts without degrading the information required for important decisions.

Keywords- *Decomposition, Subnetworks, PowerWorld*

I. INTRODUCTION

The main of purpose of a power system is to deliver energy to consumers in a safe and efficient manner. In view of this, the importance of power system analysis cannot be overemphasized in successful planning and operation of power systems [1] [2] [3]. Lack of proper system analysis can lead to wrong decisions that can cause power systems to be unreliable, leading to negative impacts on the environment. Due to the increased size and complexity of power systems today, modern computers in many instances cannot cope with the analysis of the enormous power systems existing today. Supercomputers have been produced but very few are available to the majority of researchers and system analysts, so the need to reduce the size of the system handled per time is desirable. A method of decomposition known as Diakoptics proves to be a good tool in augmenting the computer performance [4].

The aim of this work is to demonstrate the possibility of carrying out Power system analysis using the PowerWorld software while employing the diakoptics approach. The approach adopted here involves establishing the relationship between power analysis results obtained from Matlab and those obtained from PowerWorld for a full 3-bus system. Analysis of a 5-bus system was then carried out as a whole for comparison and in parts PowerWorld and then a combination of PowerWorld and diakoptics. In earlier work, diakoptics has

been used in conjunction with Gauss-Seidel to solve large system.

II. OVERVIEW OF THE ANALYSIS METHODS

Power system analysis is a mathematical explanation of the working of real time power systems in successful generation, transmission and distribution of energy in an orderly manner [5]. Power-flow study uses simplified notation such as one-line diagram and per-unit system, and focuses on various aspects of ac power parameters, such as voltages, voltage angles, real power and reactive power [2]. Buses are classified according to which two out of the four quantities are specified [6]. Power systems are analysed in normal steady state operation. Load flow analysis materials are very common and so the equations which can be found in [7] [8], for example, are not repeated here but form the foundation of this analysis.

Many analysis procedures have been developed with a view to obtaining useful system information quicker. Combination of PowerWorld and diakoptics is a new step in this direction.

A. Powerworld

PowerWorld is interactive software designed to simulate high voltage power system operation on a time frame which varies from several minutes to several days. It contains a highly effective power flow analysis package which is capable of efficiently solving systems with very large number of buses [9]. It has an intuitive and user-friendly Graphical User Interface (GUI) and uses animated diagrams. There is also a *Model Explorer* which gives the necessary information.

B. Diakoptics

Diakoptics is a method of tearing networks into computationally smaller subsystems. Basically, in systems analysis, Diakoptics involves breaking a problem down into subproblems which can be solved independently before being joined back together to obtain an *exact* solution to the whole problem [10] [11]. Despite the fact that much of the work in the field of electrical networks can be accomplished by direct or iterative solutions, there are a number of problems for which the iterative method becomes difficult to use. Readily available computers do not usually have the characteristics required for a direct solution [12]

Modern computers are much faster than the ones used when Diakoptics was conceived, yet the speeds and storages of computers readily available cannot cope with the enormous size and complexity of power systems. Diakoptics therefore has a prospect that would enhance the effectiveness of a majority of computers. Also, supercomputers occupy very large spaces and until they can be made smaller, the smaller ones would still be carrying the day for a majority of researchers and analysts.

C. Analysis Procedure for Diakoptics

In Diakoptics, networks are subdivided but the solution is gotten directly by a number of definite steps without any approximations or iterations [6]. It is done by dividing the original network into a number of component networks so that each subnetwork is isolated from the rest of the system. The procedure is explained below by applying to the IEEE 5-bus test system in Fig. 5.

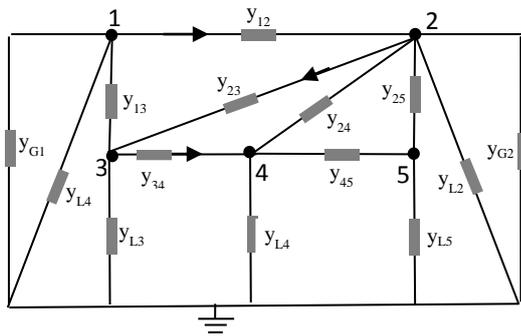


Figure 1. Admittance Diagram of a 5-bus network

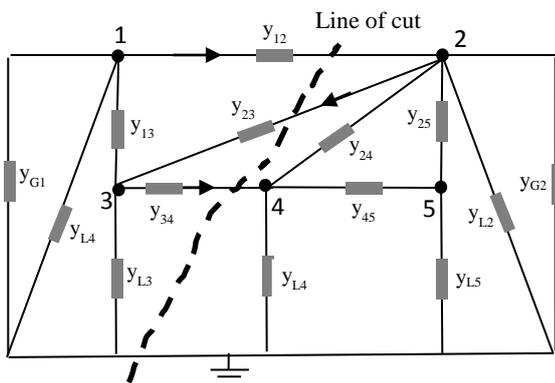


Figure 2. The Admittance diagram for the 5-bus system showing line of cut

Nodal voltage plays a very important role in the solutions of electrical networks. Here, nodal voltage analysis is used to explain Diakoptics procedure. Consider the network shown in Fig. 1 where the current sources I_a consisting of I_1, I_2, \dots, I_5 are known and the nodal voltages v_a consisting of v_1, v_2, \dots, v_5 are the unknowns. The subscripts 1-5 represent the nodes in the figure.

The aim of this analysis is to obtain a set of equations from which a solution of the unknown nodal voltages can be obtained by eliminating the additional unknowns. Broken lines Fig. 2 indicate the branches to be removed and arbitrary current directions are assigned to them. The removal of branch 12, 23 and 34 creates two independent subnetworks A and B, (Fig. 3). All parts including the equivalent current sources are referred to as the equivalent network. Also, all the removed branches together with the equivalent voltage sources are collectively referred to as the removed network and shown in Fig. 4.

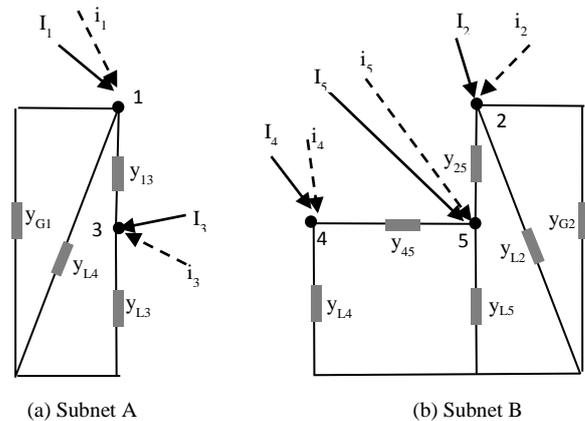


Figure 3. Subnetworks after tearing

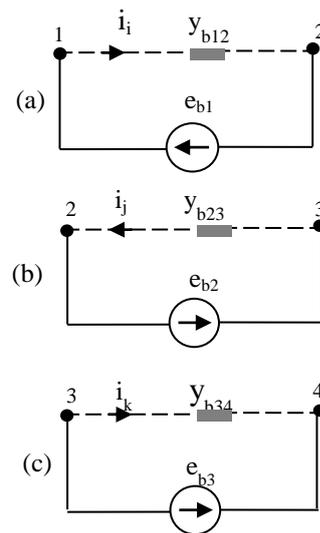


Figure 4. Removed network

$$\begin{bmatrix} Y_{13} & -Y_{13} \\ -Y_{13} & Y_{13} \end{bmatrix} \begin{bmatrix} V_{A1} \\ V_{A2} \end{bmatrix} = \begin{bmatrix} I_1 + i_1 \\ I_3 + i_3 \end{bmatrix} \quad (1a)$$

or

$$Y_B V_B = I_B + i_B \quad (1b)$$

$$\begin{bmatrix} (Y_{24} + Y_{45}) & -Y_{45} & -Y_{24} \\ -Y_{45} & (Y_{45} + Y_{25}) & -Y_{25} \\ -Y_{24} & -Y_{25} & (Y_{25} + Y_{24}) \end{bmatrix} \times \begin{bmatrix} V_4 \\ V_5 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_4 + i_4 \\ I_5 + 0 \\ I_2 + i_2 \end{bmatrix} \quad (2a)$$

$$Y_A V_A = I_A + i_A \quad (2b)$$

Neglecting generator admittances and bus admittances, the resulting matrix equations for the subnetworks are given in (1) and (2). The combined equations in the first three steps yield (3) for the complete network.

$$\begin{bmatrix} Y_A & \cdot \\ \cdot & Y_B \end{bmatrix} \begin{bmatrix} V_A \\ V_B \end{bmatrix} = \begin{bmatrix} I_A + i_A \\ I_B + i_B \end{bmatrix} \quad \text{or} \quad Y_m V_m = I_m + i_m \quad (3)$$

Y_m is a block diagonal matrix (BDM) comprising submatrices Y_A and Y_B .

The relationship between the hypothetical currents, I in Fig. 3 and the assumed branch currents i_b in all detached branches in Figs. 3 and 4 are expressed in (4).

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} i_i \\ i_j \\ i_k \end{bmatrix} \quad \text{or} \quad I = L_{mb} i_b \quad (4)$$

The hypothetical voltage sources, e_b , expressed in terms of nodal voltages V_m in (4) where K_{bm} is the same as $-L_{bm}^t$ in (4), therefore (5) can be rewritten as (6).

$$\begin{bmatrix} e_{b1} \\ e_{b2} \\ e_{b3} \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & -1 \\ 0 & -1 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ V_5 \end{bmatrix} \quad \text{or} \quad e_b = K_{bm} V_m \quad (5)$$

Therefore,

$$e_b = -L_{bm}^t V_m \quad (6)$$

The equations relating the voltages and currents of the removed branches are:

$$\begin{bmatrix} Z_{b1} & \cdot \\ \cdot & Z_{b2} \\ & & Z_{b3} \end{bmatrix} \begin{bmatrix} i_i \\ i_j \\ i_k \end{bmatrix} = \begin{bmatrix} e_{b1} \\ e_{b2} \\ e_{b3} \end{bmatrix} \quad \text{or} \quad Z_b i_b = e_b \quad (7)$$

Analysis of (1) to (5) yields (6) and (7) which are the *fundamental equations of diakoptics*. Rigorous derivation of the equations is shown in [1].

$$Z_b i_b = -L_{bm}^t V_m \quad (8)$$

$$Y_m V_m = I_m + L_{mb} i_b \quad (9)$$

By eliminating i_b in equations (6) and (7), the *final equation of solution* is obtained as (8). There is a saving in storage space because the need to invert the full true matrix, Y , of the original network is eliminated.

$$V_m = Y_m^{-1} I_m - Y_m^{-1} L_{mb} Z_b^{-1} L_{bm}^t Y_m^{-1} I_m \quad (10)$$

III. ANALYSIS OF THE 5-BUS SYSTEM

Analysis of a sample 3-bus system using MATLAB and PowerWorld gave the results in Table I. After comparing results to establish that the PowerWorld simulation gave similar results as the MATLAB computation for a 3-bus system, the IEEE 5-bus test system in Fig. 5 was analysed. This was necessary because MATLAB was used to recombine the solutions of torn subsystems.

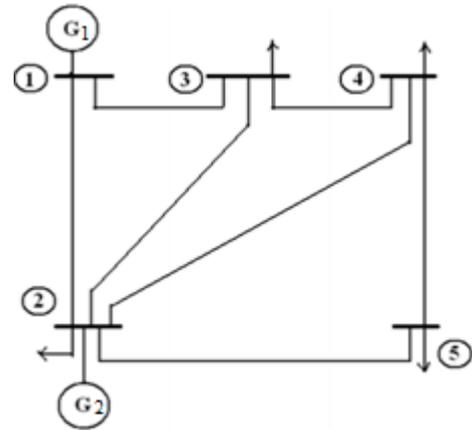


Figure 5. The 5-bus system to be analysed

PowerWorld was first used to analyse this 5-bus system as a whole (Fig. 6). The voltage of the slack bus (Bus 1) is given whereas the other buses are made to use a flat voltage start as can be seen from Table 5. Though powers were computed, the focus in this work is the voltage since other results depend on the calculated voltages.

TABLE I. THE 3-BUS SYSTEM RESULTS

Bus Code	PowerWorld results		MATLAB results	
	Per Unit Voltage	Angle (Degrees)	Per Unit Voltage	Angle (Degrees)
1	1.05000	0.00	1.05000	0.00
2	1.00000	-3.87	1.00000	-3.88
3	1.01118	-3.01	1.0013	-2.85

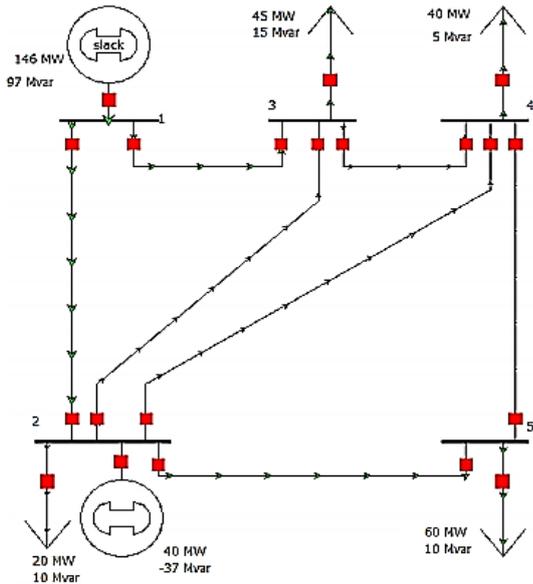


Figure 6. The 5-bus system after one-piece analysis using powerworld

TABLE II. RESULT OF ONE-PIECE ANALYSIS

Bus Code	One-piece analysis
	Voltage magnitude (pu)
1	1.06000
2	1.00000
3	0.97916
4	0.97572
5	0.96505

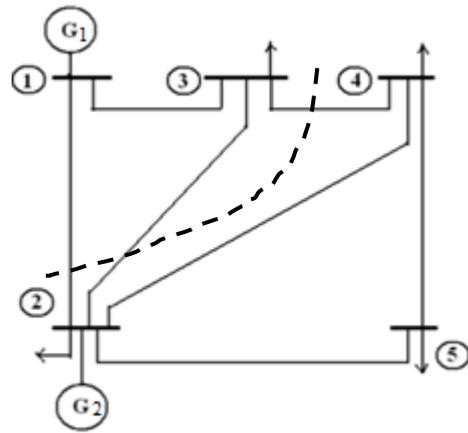


Figure 7. The 5-bus system showing line of cut

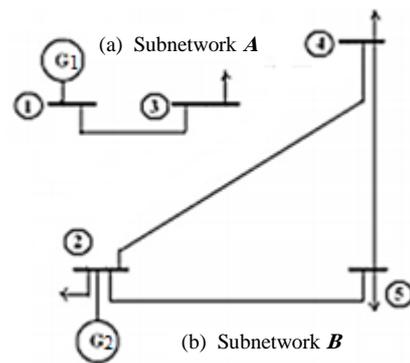


Figure 8. The system decomposed into two subnetworks

A. Results obtained after analysing systems as a whole

The one-piece analysis of the 5-bus system was done using PowerWorld. ‘One-piece’ here means analysing the system without decomposing. The resulting voltages are shown in Table I. Next, the system was torn into 2 subnetworks along the line shown in dotted lines in Fig. 7. Subnetwork A contains buses 1 and 3 and subnetwork B contains buses 2, 4 and 5. These 2 subnetworks were then simulated in PowerWorld illustrated in Fig. 5.

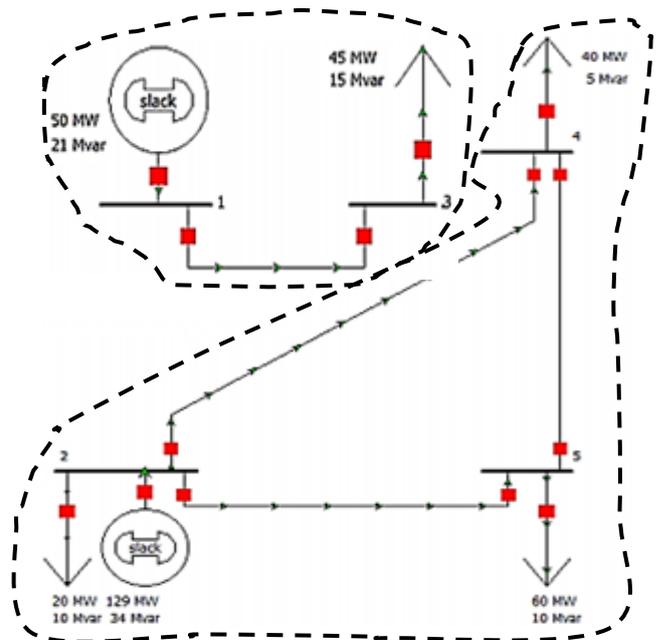


Figure 9. The two subnetworks after simulation with PowerWorld

After tearing the 5-bus system, two subnetworks were obtained (A and B). The first subnetwork contained only nodes 1 and 3 while the other subnetwork contained nodes 4, 5 and 2. Both subnetworks were simulated separately using PowerWorld and new voltage values were obtained. The admittance diagram for the 5-bus system was obtained as shown in Fig. 1.

IV. MODELLING OF SUBNETWORK SOLUTIONS

Connection matrices play a very important role in diakoptic analysis and indicate the relationship between subnetworks [12]. In any typical connection matrix, the number of rows is equal to the number of buses or nodes in the subnetwork and the number of columns is equal to the number of tearing branches. The numbers of columns in all subnetworks' connection matrices are equal but the rows depend on the number of buses. The matrices contain only +1, -1 and 0. The signs (+ and -) indicate the direction of current flow in the removed lines or branches. If a node was connected to a removed branch and the current direction is into the node, the entry in the connection matrix is +1 and if the flow is out of the node, the entry is -1. If a node was not connected to a removed branch, the entry in the connection matrix is 0. The connection matrices are normally equal to the number of subnetworks [13].

Following this procedure and based on Figs. 3 and 4, the connection matrices for subnetworks A and B are given in (11) and (12).

$$L_A = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & -1 \end{bmatrix} \quad (11)$$

$$L_B = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & -1 & 0 \end{bmatrix} \quad (12)$$

Next the diagonal admittance matrix of the removed branches is formed and shown in (13). The admittance matrices of the subnetworks were also formed as in (14) and (15).

$$Y_b = \begin{bmatrix} 5.00 + 15.00i & 0 & 0 \\ 0 & 1.67 + 5.0i & 0 \\ 0 & 0 & 10.00 + 30.00i \end{bmatrix} \quad (13)$$

$$Y_A = \begin{bmatrix} 1.2500 - 3.7250i & -1.2500 + 3.7500i \\ -1.2500 + 3.7500i & 1.2500 - 3.7250i \end{bmatrix} \quad (14)$$

$$Y_B = \begin{bmatrix} 2.9167 - 8.7050i & -1.2500 + 3.7500i & -1.6667 + 5.0000i \\ -1.2500 + 3.7500i & 3.7500 - 11.2100i & -2.5000 + 7.5000i \\ -1.6667 + 5.0000i & -2.5000 + 7.5000i & 4.1667 - 12.4650i \end{bmatrix} \quad (15)$$

Further analysis of the *equation of solution* in (10), yields the voltage matrix equations in (16).

$$\begin{bmatrix} V_A \\ V_B \end{bmatrix} = \begin{bmatrix} Y_A^{-1} + Y_A^{-1} L_A D^{-1} L_A^t Y_A^{-1} & Y_A^{-1} L_A D^{-1} L_B^t Y_B^{-1} \\ Y_B^{-1} L_B D^{-1} L_A^t Y_A^{-1} & Y_B^{-1} + Y_B^{-1} L_B D^{-1} L_B^t Y_B^{-1} \end{bmatrix} \begin{bmatrix} I_A \\ I_B \end{bmatrix} \quad (16)$$

Where D is defined in (17); all other symbols are as defined earlier.

$$D = -(Z_b + L^t Y_d^{-1} L) \quad (17)$$

From (6), e_b for the two subnetworks is given in (18) and further simplified to eliminate I_A and I_B as in (19) and (20).

$$\therefore e_{b(AB)} = (L_A^t Y_A^{-1} I_A + L_B^t Y_B^{-1} I_B) \quad (18)$$

$$e_{b(AB)} = (L_A^t Y_A^{-1} Y_A V_{A0} + L_B^t Y_B^{-1} Y_B V_{B0}) \quad (19)$$

$$\therefore e_{b(AB)} = (L_A^t V_{A0} + L_B^t V_{B0}) \quad (20)$$

where V_{A0} and V_{B0} are voltage vectors of the subnetworks computed when they are completely separated. $e_{b(AB)}$ is used to model the separate solutions of the subnetworks obtained from PowerWorld to yield the solution of the complete network. Table III shows the results of the two analyses. The same network was analysed using Newton-Raphson (N-R) and Gauss-Seidel (G-S) to validate the results obtained from the results proposed in this work. The differences between results of the two methods are also shown in Table III.

TABLE III. RESULTS FROM DIFFERENT METHODS

Bus Code	PowerWorld One-piece Analysis	Combined PowerWorld and Diakoptics Analysis	Disparity in results	Comparison of N-R and G-S
	Voltage magnitudes (pu)			
1	1.0600	1.0600	0	0
2	1.0000	1.0000	0	-0.0383
3	0.9792	0.9814	-0.0022	-0.0067
4	0.9757	0.9607	0.0150	-0.0096
5	0.9651	0.9596	0.0055	-0.0250

V. DISCUSSION

By comparing the results obtained from analysing the 5-bus system as a whole and from analysing the 5-bus system in parts i.e. through Diakoptics, it can be seen that though there are few differences between values, useful information can still be obtained from the proposed method while saving time and computer storage. Analysing the system using Newton-Raphson and Gauss-Seidel methods was just to show that results from iterative solutions often differ, though not with a large margin. This can be attributed to nonlinearity and approximations as the iterations are being performed.

VI. CONCLUSION

From the system analysed, the decomposition method known as diakoptics has proved to be a great tool for analysing power systems. It is shown here that, it can be combined with PowerWorld for quick analysis for planning purposes. However, this technique would be better appreciated when applied to large systems.

The method also offers the possibility of analysing subnetworks with different computer systems thereby making computation faster and less cumbersome. These results can then be combined together to give a single set of results. The method is not here proposed as to replace other methods of power system analysis but could be useful where other methods become inappropriate.

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