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DEVELOPMENT OF PARALLEL ALGORITHMS FOR ELECTRICAL POWER MANAGEMENT IN SPACE APPLICATIONS

Final Report

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ABSTRACT

This paper is concerned with the application of parallel techniques for electrical power system analysis. The Newton-Raphson method of load flow analysis was used along with the decomposition-coordination technique to perform load flow analysis. The decomposition-coordination technique enables tasks to be performed in parallel by partitioning the electrical power system into independent local problems. Each independent local problem represents a portion of the total electrical power system on which a load flow analysis can be preformed. The load flow analysis is preformed on these partitioned elements by using the Newton-Raphson load flow method. These independent local problems will produce results for voltage and power which can then be passed to the coordinator portion of the solution procedure. The coordinator problem uses the results of the local problems to determine if any correction is needed on the local problems. The coordinator problem is also solved by an iterative method much like the local problem. The iterative method for the coordination problem will also be the Newton-Raphson method. Therefore, each iteration at the coordination level will result in new values for the local problems. The local problems will have to be solved again along with the coordinator problem until some convergence conditions are met.

INTRODUCTION

This paper will use the decomposition-coordination technique which enables task to be performed in parallel when solving sets of nonlinear equations(1, 4, 5, 6). Sets of nonlinear equations occur when performing a load flow analysis on an electrical power system(3, 7, 8). Load flow is the solution of an electrical network that gives the values of currents, voltages, and power flows at every bus (node) in the electrical power system(3, 7, 8). In the load flow problem nonlinear relationships between voltage and power occur at each bus(3, 7, 8). The values of the voltage and power must be solved for at each bus so that the response of the electrical power system can be determined. With the increase in the size of new proposed space based electrical power systems, it will become necessary to have very fast simulation (solution) of these systems. Very fast simulation of the electrical power system will aid in the evaluation of the system performance by decreasing the speed of calculations(1, 3, 4, 6, 7, 8).

LOAD FLOW ANALYSIS

The Newton-Raphson method for preforming the load flow calculation was used(2, 3, 7, 8). Taylor series expansion for a function of two or more variables is the basis of the Newton-Raphson method. Partial derivatives of order greater than 1 are neglected in the series terms of the Taylor series expansion. The Newton-Raphson method was used because it calculates corrections while taking into account all other interactions. The number of iterations required by the Newton-Raphson method using bus admittances is practically independent of the number of buses(3, 7, 8). For these reasons shorter computer time for a solution of the load flow problem could occur when analyzing large electrical power systems(3, 7, 8).

The solution of the load flow problem is initiated by assuming voltage values for all buses execpt the slack bus(3, 7, 8). The slack bus is the point at which the voltage is specified and remains fixed. The voltage at the slack bus is fixed because the net power flow of the system cannot be fixed in advance until the load flow study is complete(3, 7, 8). The power calculation at the slack bus supplies the difference between the specified real power

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into the system at the other buses and the total system output plus losses(3, 7, 8). The Newton-Raphson method for load flow analysis will be used to solve the load flow problem at the local and coordinator problem levels(2, 3, 7, 8).

DECOMPOSITION-COORDINATION METHOD

The decomposition-coordination method enables tasks to be preformed in parallel by partitioning the electrical power system into independent local problems(1, 4, 6). The power system presented in Figure 1 was solved by defining three local problems and a coordinator problem(1, 4, 6).

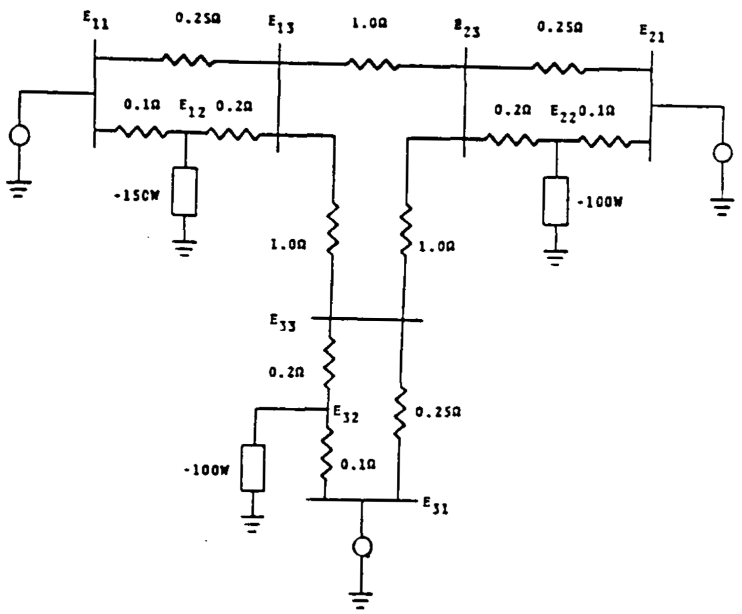

FIGURE 1.-CIRCUIT DIAGRAM OF POWER SYSTEM TO BE ANALYZED.

The local problems were solved by the Newton-Raphson procedure (1, 2, 3, 4, 6, 7, 8):

$$v_i^{n+1} = v_i^n - \left[\frac{\partial F_i(p_i, v_i)}{\partial v_i} \bigg|_{v_i = v_i^n} \right]^{-1} F_i(p_i^n, v_i) \qquad .(1)$$

Starting with an initial guess for the voltage, equation (1) was used successively until convergence was achieved(1, 2, 3, 4, 6, 7, 8). Convergence is achievied when the power equations are in balance at each bus(3, 7, 8). This is represented by the following equation:

$$F_i\ (p_i,\ v_i) = 0 \qquad .(2)$$

The system of equations which describe the three local problems are given in Table 1.

TABLE 1.-LOCAL PROBLEM EQUATIONS.

$$F(P_{11},V_{11}) = -P_{11} + 14E_{11}^2 - 10E_{11}E_{12} - 4E_{11}E_{13} = 0$$

$$F(P_{12},V_{12}) = -P_{12} - 10E_{11}E_{12} + 15E_{12}^2 - 5E_{12}E_{13} = 0$$

$$F(P_{13},V_{13}) = -P_{13} - 4E_{11}E_{13} - 5E_{12}E_{13} + 9E_{13}^2 = 0$$

$$F(P_{13},V_{13}) = -P_{13} + 2E_{13}^2 - E_{13}E_{23} - E_{13}E_{33} = 0$$

$$F(P_{23},V_{23}) = -P_{23} - E_{12}E_{23} + 2E_{23}^2 - E_{23}E_{33} = 0$$

$$F(P_{33},V_{33}) = -P_{33} - E_{13}E_{33} - E_{23}E_{33} + 2E_{33}^2 = 0$$

$$F(P_{21},V_{21}) = -P_{21} + 14E_{21}^2 - 10E_{21}E_{22} - 4E_{21}E_{23} = 0$$

$$F(P_{22},V_{22}) = -P_{22} - 10E_{21}E_{22} + 15E_{22}^2 - 5E_{22}E_{23} = 0$$

$$F(P_{23},V_{23}) = -P_{23} - 4E_{21}E_{23} - 5E_{22}E_{23} + 9E_{23}^2 = 0$$

The solution for the local problems are usually not available in an explicit form. Therefore, the coordinator problem must be solved iteratively. This implies that for each iteration at the coordinator level, new values for the input to the local problem will result(1, 4, 6).

The Newton-Raphson procedure was also used for the solution of the coordinator problem:

$$v_k^{m+1} = v_k^m - \left[\frac{\partial F_k(p_k, v_k)}{\partial v_k} \bigg|_{v_k = v_k^m} \right]^{-1} F_k(p_k^m, v_k) \qquad .(3)$$

Starting with an initial guess for the voltage (these values should come from the last solution of the local problem), equation (3) was used successively until convergence was achieved(1, 2, 3, 4, 6, 7, 8). Convergence is achieved just like that of the local problem when the power equations balance to zero (or within a preset error). This is represented by the following equations:

$$F_k\ (p_k, v_k) = 0 \qquad .(4)$$

The equations which describe the coordinator problem are given in Table 2.

TABLE 2.-COORDINATOR PROBLEM EQUATIONS.

$$F(P_{31}, V_{31}) = -P_{31} + 14E_{31}^2 - 10E_{31}E_{32} - 4E_{31}E_{33} = 0$$

$$F(P_{32}, V_{32}) = -P_{32} - 10E_{31}E_{32} + 15E_{32}^2 - 5E_{32}E_{33} = 0$$

$$F(P_{33}, V_{33}) = -P_{33} - 4E_{31}E_{33} - 5E_{32}E_{33} + 9E_{33}^2 = 0$$

EXAMPLE SOLUTION AND RESULTS

To solve the load flow problem of Figure 1 the local and coordinator problems of Table 1 and 2 were first solved by the following process:

1. There were three local problems designated and slack buses were assigned(given Table 3).

2. The local problems were then solved to determine what value of voltage and power must be present at the buses of each local system to meet the load requirement of each local problem.

3. The coordinator problem was then solved by assigning a slack bus(given Table 3) and using the most recent values of the voltage and power from the local problem.

This process was continued until the local and coordinator problems converged on a value of voltage for all buses. The results of this process are given in Table 3.

TABLE 3.-SOLUTION OF THE LOAD FLOW PROBLEM FOR FIGURE 1.

Local Problem Iteration 1.

Bus	Power	Voltage	Bus	Power	Voltage	Bus	Power	Voltage
11	120.000	30.588	13	-30.579	30.303	21	120.000	30.738
12	-150.000	30.228	23	20.017	30.595	22	-100.000	30.440
13	30.579	30.500*	33	11.213	30.500*	23	- 20.017	30.500*

Coordinator Problem Iteration 1.

Bus	Power	Voltage
31	112.051	30.500*
32	-100.000	30.212
33	- 11.213	30.299

Local Problem Iteration 2.

Bus	Power	Voltage	Bus	Power	Voltage	Bus	Power	Voltage
11	120.000	30.388	13	-31.703	29.797	21	120.000	30.828
12	-150.000	30.026	23	18.874	30.359	22	-100.000	30.532
13	31.703	30.303*	33	13.399	30.299*	23	- 18.874	30.595*

Coordinator Problem Iteration 2.

Bus	Power	Voltage
31	114.446	30.500*
32	-100.000	30.209
33	- 13.399	30.289

Local Problem Iteration 3.

Bus	Power	Voltage	Bus	Power	Voltage	Bus	Power	Voltage
11	120.000	29.882	13	-31.763	29.785	21	120.000	30.534
12	-150.000	29.515	23	18.877	30.348	22	-100.000	30.235
13	31.763	29.797*	33	13.458	30.289*	23	- 18.877	30.299*

Coordinator Problem Iteration 3.

Bus	Power	Voltage
31	114.507	30.500*
32	-100.000	30.208
33	- 13.458	30.288

Local Problem Iteration 4.

Bus	Power	Voltage	Bus	Power	Voltage	Bus	Power	Voltage
11	120.000	29.871	13	-31.765	29.785	21	120.000	30.583
12	-150.000	29.503	23	18.880	30.348	22	-100.000	30.284
13	31.765	29.785*	33	13.449	30.289*	23	- 18.889	30.348*

Coordinator Problem Iteration 4.

Bus	Power	Voltage
31	114.498	30.500*
23	-100.000	30.209
33	- 13.449	30.289

*Slack Bus

As can be seen from the results of Table 3 convergence of the values of voltage and power have occured to within an error of 0.01. To continue this solution procedure for 1 more iteration will result in convergence at errors of less then 0.001 for the voltage and power.

CONCLUSION

This research used the decomposition-coordination technique along with the Newton-Raphson method to preform load flow analysis. It has been shown that parallel techniques can be used to solve standard power system problems. The solution procedure required the formulation of a set of local problems which could be run in parallel. The results of these local problems were then passed to the coordinator problem to determine if any correction is needed to the local problem. This process was continued until convergence conditions were met.

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