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FAST TRANSIENT STABILITY SIMULATION OF LARGE SCALE POWER SYSTEMS

SREERAMA KUMAR. R
Electrical Engg. Dept.
REC Calicut-673601
Kerala, India

RAMANUJAM. R
IDEA (P) Ltd.
Bangalore
India

KHINCHA. H. P JENKINS. L
Electrical Engg. Dept.
IISc Bangalore-560012
India

ABSTRACT - This paper describes a computationally efficient algorithm for transient stability simulation of large scale power system dynamics. The simultaneous implicit approach proposed by H. W. Dommel and N. Sato [1] has become the state-of-the -arc technique for production grade transient stability simulation programs. This paper proposes certain modifications to the Dommel-Sato method with which significant improvement in computational efficiency could be achieved. Preliminary investigations on a standard test syscem and on a large practical system indicate that the number of network solutions required for convergence per time step can be reduced at least by half. This algorithm finds potential application in real time simulation of generator dynamics for operator training.

Principal Symbols

- d, q : used as suffixes denotes Park's Coordinates
- E : general symbol for internal voltages of machines (phasor)
- P : generator power output
- P_m : mechanical power
- δ : position of q-axis with respect to network reference for phasor solution
- θ : terminal voltage angle
- W : angular frequency
- W_o : synchronous angular frequency
- M : inertia constant
- h : step size for numerical integration
- p : differential operator

1. INTRODUCTION

The problem of transient stability simulation can be considered as one of solving a system of algebraic equations

$$g([x],[y]) = 0 \tag{1}$$

together with a system of differential equations [1]

$$P[y] = f([x_A],[y],t) \tag{2}$$

The algebraic equations describe the steady state behaviour of the network, which includes loads and synchronous machines. The

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differential equations describe the dynamic behaviour of the machines and their associated control systems. The vector [x] consists of the nodal voltages of the network and the generator terminal voltages and currents. The vector [y] consists of the synchronous machine rotor angles and speeds, voltages proportional to the rotor winding flux linkages and the state variables of the excitation and governor systems. The vector $[x_A]$ is a subset of [x], and consists of only synchronous machine terminal voltages and currents. In the Dommel-Sato method, the differential equations are discretized using trapezoidal rule, and are combined with the algebraic equations to yield a matrix equation

$$[Y][V] = [I] \tag{3}$$

The elements of [I] are non-zero only for generator nodes, and are functions of modified internal voltages. The computation of [I] depends on the Norton representation of generators. At each time step, equation (3) is solved iteratively for [V], along with the differential equation for the rotor swing. In the Dommel-Sato algorithm, the major part of the total computing time is consumed by the number of iterations per time step for solution of equation (3). An algorithm to minimize these iterations is described in the following section.

2. PROPOSED ALGORITHM

The basic structure of the proposed algorithm is the same as that described in [1]. The reduction in the number of network solutions per time step is obtained by a two-tier approach. In this algorithm, first, a coarse convergence is obtained for rotor angle (δ), with the terminal voltage being initially held constant at the value obtained in the previous step. The final convergence is obtained through iterations using the triangularized admittance matrix, and the converged values of rotor angles.

The initial conditions for transient stability simulation are obtained from load flow analysis. Then the basic computations are performed as follows:

i. Initialize the synchronous machine variables.

ii. Form the bus admittance matrix [Y], and triangularize it.

iii. Predict rotor angles for all generators using the formula [1]

$$\delta(t) = 2\delta(t-h)-\delta(t-2h)+(h^2/M)(P_m - P(t-h)) \quad (4)$$

iv. Correct the machine rotor angles using the equation

$$\delta(t) = \delta(t)+\Delta\delta \quad (5)$$

The solution of swing equation is used as the rotor angle corrector. The equations for rotor acceleration and swing are

$$MpW = P_m-P \quad (6)$$

$$p\delta = W-W_o \quad (7)$$

Assuming that the real power (P) and rotor angular frequency (W) vary linearly over time step, and using Newton's method [2], $\Delta\delta$ can be obtained as [3]

$$\Delta\delta = \frac{(-E_q'|V|)/X_d')Sin(\delta-\Theta)-(6M/h^2)\delta+\beta}{(E_q'|V|)/X_d')Cos(\delta-\Theta)+(6M/h^2)} \quad (8)$$

where

$$\beta = (6M/h^2)(\delta(t)+(6M/h)(W(t)-W_o)) + 3P_m - 2P(t) \quad (9)$$

v. Check for rotor angle convergence. If convergence **has** not been obtained, with the latest values of the rotor angles, return to step (iv).

vi. Form the current injection vector [I] using the converged values of rotor angles.

vii.. Solve equation (3) for [V].

viii. Check for saliency convergence, by comparing the magnitudes of generator terminal voltages with their earlier values. If convergence has not been obtained, with the latest values of the generator terminal voltages, return to step (iv).

It can be observed that the coarse convergence for rotor angle is obtained in the loop iv-v-iv. The significant point is that the computationally intensive network solutions. are avoided in getting rotor angle convergence. Further this loop execution is quite fast, as it involves multiplication/ division-addition operations, and is confined to generator nodes only.

3. SIMULATION RESULTS

The performance of the proposed algorithm has been tested on two systems, **viz.**,(i) the nine bus, three generator standard test system proposed by Western System Coordinating Council (**WSCC**) [4], and (ii) a 122 bus, 154 branch, 14 generator practical Indian power system [3]. The results obtained are compared against that obtained with a production grade program based on Dommel-Sato method.

In the test on the **WSCC** system, the disturbance simulated was a three-phase fault on bus 7 at time t = 0.0 seconds, with the fault being cleared after five cycles of 60 Hz, by opening line 5-7. In this experiment, generator 2, being nearest to the fault, was represented by variable voltages behind transient reactances, and the remaining generators by the classical model. The step size of numerical integration was one cycle. The tolerance for angle was chosen as 0.0001 radian, and that for voltage magnitude as 0.01 per unit. It is observed that with the Dommel-Sato method, the maximum number of network solutions per time step is four, and that with the proposed algorithm is two. Fig.1 shows the relative swing between generator 2 and generator 1, from which it can be inferred that the results obtained by these methods are indistinguishable.

In the test on the Indian system, the disturbance simulated was a three-phase fault on bus 17 at t = 0.0 seconds with the fault being cleared after 5 cycles of 50 Hz. In this experiment, generators 10, 11 and 13 were represented by classical model, and the remaining generators by variable internal voltages behind transient reactances. The step size was 1 cycle. The tolerance for angle and voltage magnitude were the same as in the previous experiment. It was observed that with the Dommel-Sato method, the total number of network solutions for ten seconds was **1484,** and that with the proposed algorithm was only 514. Fig.2 shows the relative swing between generator **9** (which is the one nearest to the fault) and generator **1,** from which it can be inferred that the results obtained by these methods match closely.

4. CONCLUSIONS

In this paper, an algorithm for fast simulation of large scale power system dynamics is presented. The results of experiments on a standard test system, and on an Indian system indicate that with the proposed algorithm, considerable reduction in computation time could be achieved without affecting the accuracy appreciably. This feature of the algorithm makes it a potential candidate for real time applications.

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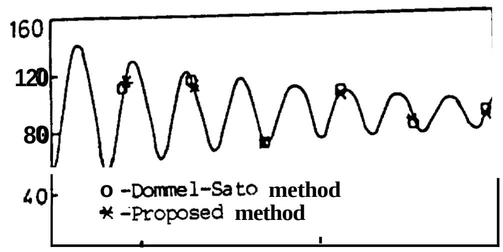

Fig. 1 Relative swing between Gen. 2 and Gen. 1 in degrees - WSCC system

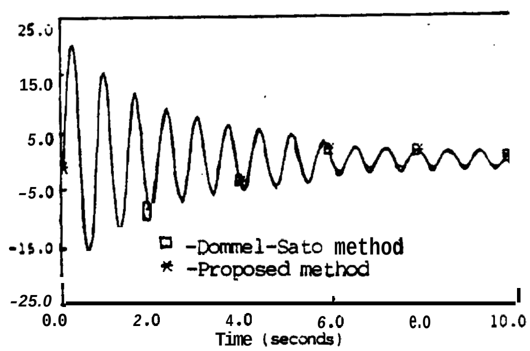

Fig. 2. Relative swing between Gen. 9 and Gen. 1 in degrees - Practical System