Study of Power System Transient Stability with Simulink

Ramnarayan Patel, T.S. Bhatti and D.P. Kothari

***Abstract*--Simulink is advanced software by the Math Works Inc., which is increasingly being used as a basic building block in many areas of research. It has proven to be a powerful simulation tool in the study of power system dynamics. In this paper, we have taken a multi-machine system example, to demonstrate the features and scope of a Simulink based model for transient stability analysis. An integral and self-sufficient model has been illustrated with its complete details.**

***Index terms--* Matlab, Simulation, Simulink, Transient stability**

I. INTRODUCTION

Stability of power system has been and continues to be of major concern in system operation. Modern electrical power systems have grown to a large complexity due to increasing interconnections, installation of large generating units and extra high voltage tie-lines etc. Transient stability is the ability of the system to maintain synchronism when subjected to a severe transient disturbance, such as a fault on transmission facilities, sudden loss of generation, or loss of a large load. The system response to such disturbances involves large excursions of generator rotor angles, power flows, bus voltages, and other system variables. It is important that, while steady-state stability is a function only of operating condition, transient stability is a function of both the operating condition and the disturbance(s) [1]. This complicates the analysis of transient stability considerably. Repeated analysis is required for different disturbances that are to be considered. In the transient stability studies, frequently considered disturbances are the short circuits of different types. Out of these, normally the three-phase short circuit at the generator bus is the most severe type, as it causes maximum acceleration of the connected machine [2].

Historically, simulation of transient phenomena related to power systems has been carried on using the electromagnetic transients program (EMTP) [3] or one of its variants, such as the alternative transient program (ATP) or electromagnetic transients for dc (EMTDC), which are all based on the trapezoidal integration rule and the nodal approach. SPICE is a general-purpose circuit simulation program which was developed at the University of California, Berkeley [4]. SPICE is mainly applied to simulate electronic and electrical circuits for different analyses, including dc, ac, transient, zero pole, distortion, sensitivity, and noise. The simulation of control systems in PSPICE A/D (a commercial version of SPICE by MicroSim) is facilitated by using the analog behavioral modeling (ABM) blocks. However, there are no specific models for power systems and drives, such as electrical machines, circuit breakers, surge arresters, thyristors, etc. To simulate a power system, the user has to build the needed models using SPICE primitives and basic elements, so the simulation setup can be highly time consuming.

Simulink is an interactive environment for modeling, analyzing, and simulating a wide variety of dynamic systems. Simulink provides a graphical user interface for constructing block diagram models using "drag and drop" operations [5]. A system is configured in terms of block diagram representation from a library of standard components. A system in block diagram representation is built easily and the simulation results are displayed quickly. Simulation algorithms and parameters can be changed in the middle of a simulation with intuitive results, thus providing the user with a ready access learning tool for simulating many of the operational problems found in the real world. Simulink is particularly useful for studying the effects of non-linearity on the behavior of the system, and as such, is also an ideal research tool. The key features of Simulink are [6]:

- Interactive simulations with live display.
- A comprehensive block library for creating linear, nonlinear, discrete or hybrid multi-input/output systems.
- Seven integration methods for fixed-step, variable-step and stiff systems.
- Unlimited hierarchical model structure.
- Scalar and vector connections.
- Mask facility for creating custom blocks and block libraries.

The user can also derive many features and in-built components from various Blocksets and Toolboxes [7]. The user has access to numerous design and analysis tools provided in Matlab and it's toolboxes.

Use of Simulink is rapidly growing in many areas of research work and so also in the study of power system dynamics [8]-[10]. In this paper we have demonstrated a simplified, yet an effective approach to study the transient stability performance of a multi-machine power system, with Simulink as a tool.

II. ILLUSTRATIVE SYSTEM EXAMPLE

A 4-generator 6-bus example of Fig. 1 is considered in the present study. The system data are given in [11]. The disturbance initiating the transient is a three phase-fault occurring near bus 3 at the corresponding end of line 3-4. The fault is cleared by opening of line 3-4. The system, while small, is large enough to be nontrivial and thus permits the illustration of a number of stability concepts and results.

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III. SYSTEM MODELING

The complete system has been represented in terms of Simulink blocks in a single integral model. It is self - explanatory with the mathematical model given below. One of the most important features of a model in Simulink is its tremendous interactive capacity. It makes the display of a signal at any point readily available, all one has to do is to add a Scope block there or an output port alternatively. Giving a feedback signal is also as easy as drawing a line. A parameter within any block can be controlled from Matlab command line or through an m-file program. This is particularly useful for transient stability study as the power system configurations differ before fault, during and after fault. Loading conditions and control measures can also be implemented accordingly.

1) Mathematical Modeling

Once the Y matrix for each network condition (pre-fault, during and after fault) is calculated, we can eliminate all the nodes except for the internal generator nodes and obtain the Y matrix for the reduced network. The reduction can be achieved by matrix operation with the fact in mind that all the nodes have zero injection currents except for the internal generator nodes. In the power system with n generators, the nodal equation can be written as:

$$\begin{bmatrix} I_n \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nr} \\ Y_{rn} & Y_{rr} \end{bmatrix} \begin{bmatrix} V_n \\ V_r \end{bmatrix} \qquad ...(1)$$

Where the subscript n is used to denote generator nodes and the subscript r is used for the remaining nodes.

Using (1), we eliminate V_r to find,

$$I_n = (Y_{nn} - Y_{nr} Y_{rr}^{-1} Y_{rn}) V_n \qquad ...(2)$$

Thus the desired reduced matrix can be written as follows,

$$Y_R = (Y_{nn} - Y_{nr} Y_{rr}^{-1} Y_{rn}) \qquad ...(3)$$

It has dimensions (n x n) where n is the number of generators. Note that the network reduction illustrated by (1) to (3) is a convenient analytical technique that can be used only when the loads are treated as constant impedances.

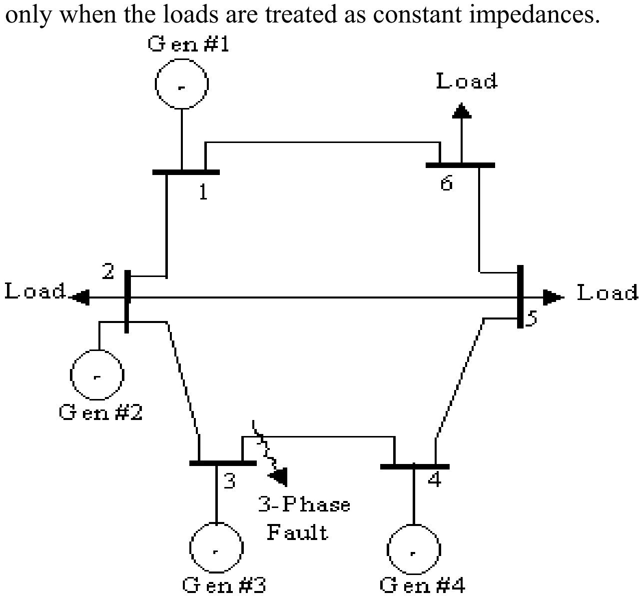

Fig. 1. Line diagram of the example power system

Now, the complex power into the network at node i, which is the electrical power output of machine i, is given by,

$$P_i + jQ_i = E_i * .I_i \qquad ...(4)$$

Where E_i is generator internal voltage and I_i is the node current.

Furthermore,

$$I_i = \sum_{j=1}^{n} E_j Y_{ij} \qquad ...(5)$$

Where n is the number of generators in the system. Note that the elements Y_{ij} in the above equation are the elements of the reduced matrices found by using (3) above. The value of these elements will change as the network changes from before fault to during fault and after the fault is cleared. The equations of motion are then given by,

$$\frac{2H_i}{\varpi_R} \frac{d\varpi_i}{dt} + D_i \varpi_i = P_{mi} - P_i \qquad ...(6)$$

and

$$\frac{d\delta_i}{dt} = \varpi_i - \varpi_R \qquad i = 1, 2, ..., n \qquad ...(7)$$

Where,

H_i = Inertia constant of the machine

ω_R = Rated angular speed

D_i = Damping coefficient

P_{mi} = Mechanical power input to the generator and

δ_i = Rotor angular position

It should be noted that prior to the disturbance (at $t = 0^-$) $P_{mi0} = P_{i0}$; which indicates the steady state.

The dynamics of the generator internal voltage is governed by,

$$T'_{doi} \frac{dE_i}{dt} = E_{fdi} - E_i - (X_{di} - X'_{di}) i_{di} \qquad ..(8)$$

The symbols used here have their standard meaning.

2) Simulink Model

The complete 4-generator system has been simulated as a single integral model in Simulink. The mathematical model given above, give the transfer function of the different blocks. Fig. 2 shows the section of the complete block diagram relevant to generator #3. The simulation of the other generators in the system will be exactly in the similar fashion, with their corresponding values. Subsystem1 in Fig. 2 is meant to calculate the value of node current at the point of generator terminal. Fig. 3 shows the details inside the subsystem.

The other components of the model such as the governor, turbine and excitation system are modeled similarly; the internal details are not given here due to space constraints. The reader can refer to [1] and [12].

The model facilitates the choice of simulation parameters, such as start and stop times, type of solver, step sizes, tolerance and output options etc. The execution can be done either directly or from Matlab command line or through a Matlab m-file program.

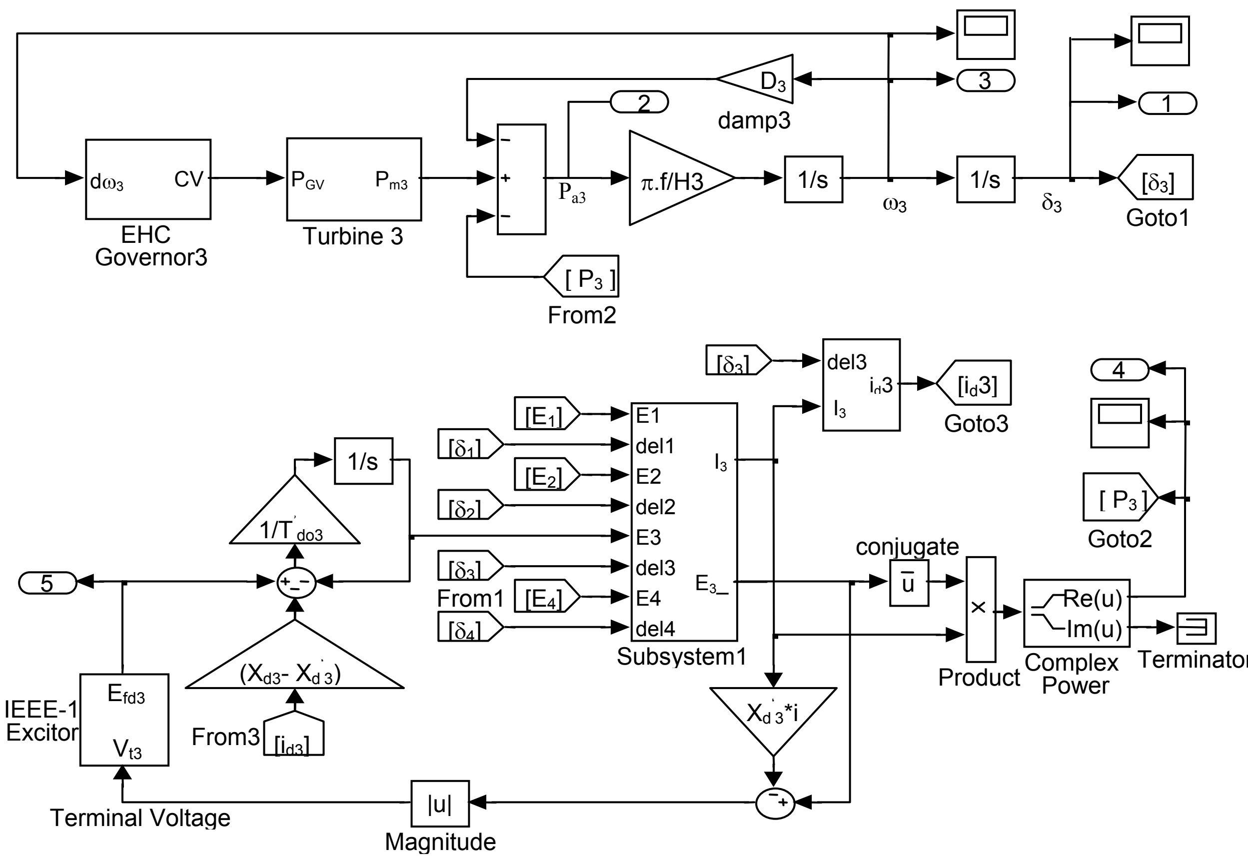

Fig. 2. The Simulink model of the generator no. 3 in the 4-generator system example

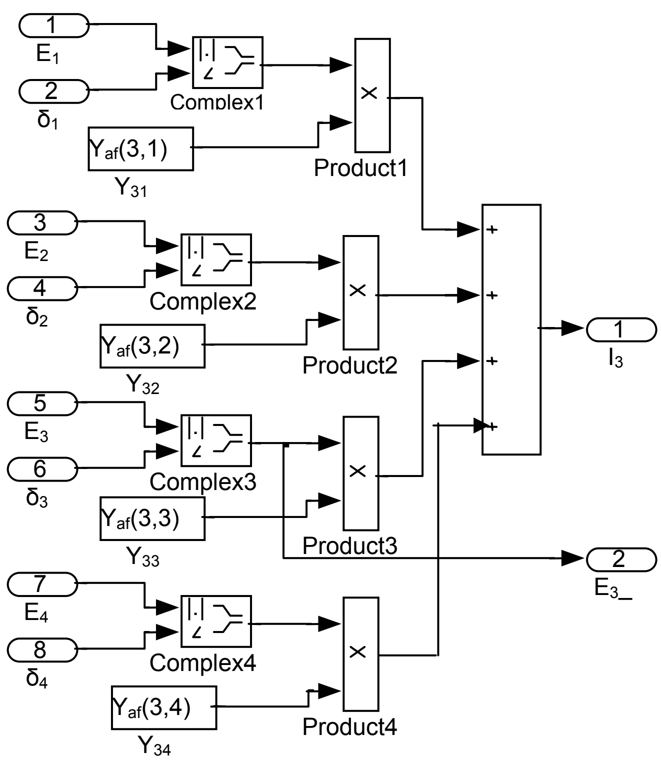

Fig.3. Computation of the node current by subsystem1

IV. Simulation Results

System responses are given for different values of fault clearing time (F.C.T.). The generator under study is the generator #3, since the fault is close to this terminal. Figures 4, 5 and 6 show the variation in generator angle, accelerating power of the generator and generator angular speed deviation respectively. The output ports 1,2 and 3 in Fig. 2 give the corresponding values of these system responses. Alternatively, we can also observe these responses through the scope blocks connected to the corresponding point. Thus, the Simulink facilitates fast computation and ready access to any desired variable in a system study. The results show that the example system is stable for F.C.T. = 0.25 sec. With increasing value of F.C.T., the rotor angle swing increases as shown in Fig. 7 for F.C.T. = 0.27 sec. At this point the system is critically stable. The system becomes unstable for F.C.T. = 0.28, as shown in Fig. 8. Fig. 9 shows the angular speed deviation for the same case. The increased rotor angle swing also results in a wide fluctuation of generator terminal voltage. The generator terminal voltage variations under stable and unstable system conditions are shown in Fig. 10.

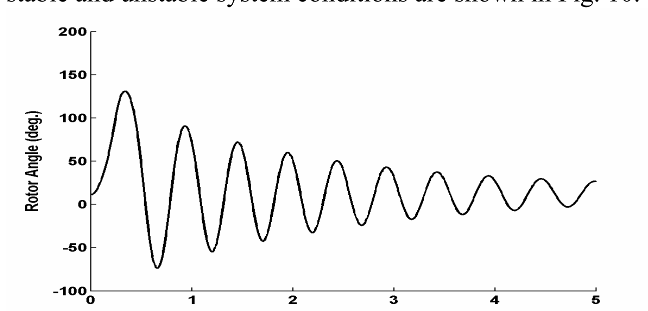

Fig. 4. Rotor angle variation (gen. #3) for F.C.T. = 0.25 sec., the stable system.

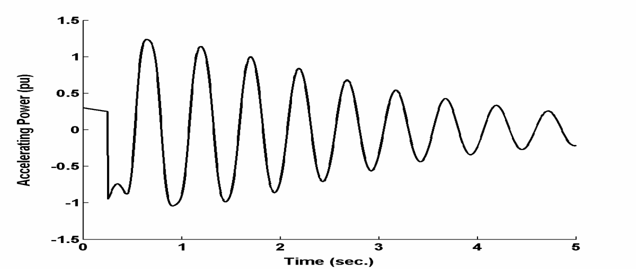

Fig. 5. Accelerating power of the generator, F.C.T. = 0.25 sec.

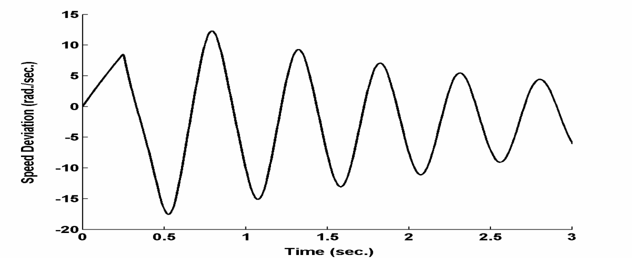

Fig. 6. Angular speed deviation (gen. #3), F.C.T. = 0.25 sec.

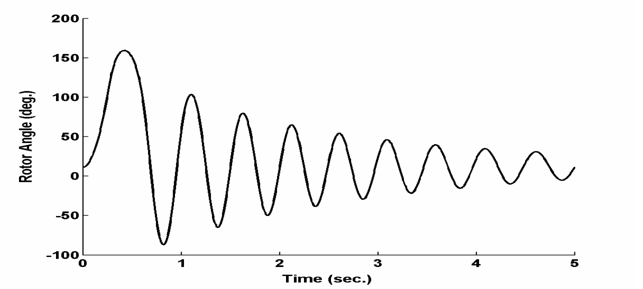

Fig. 7. Rotor angle variation (gen. #3) for F.C.T. = 0.27 sec.; system critically stable.

Thus a simple model based on Simulink, is very well suited for analyzing the transient stability performance of a power system under any system condition. The same model can also be extended to incorporate a more generic case with larger number of generators.

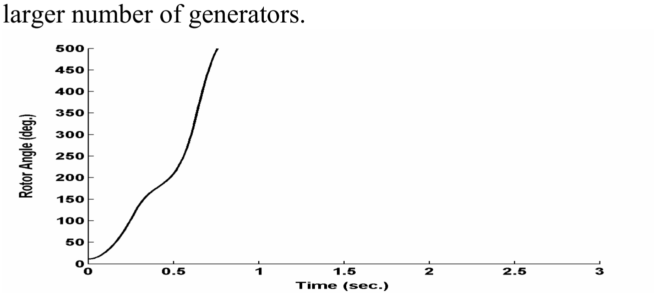

Fig. 8. Rotor angle variation (gen. #3) for F.C.T. = 0.28 sec.; system unstable.

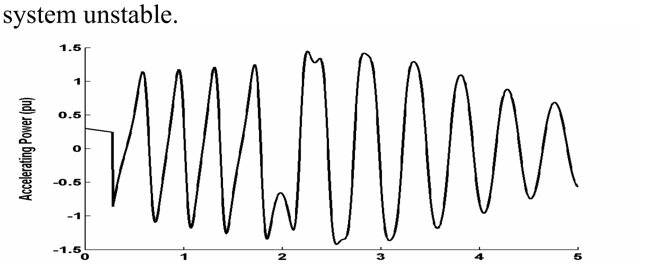

Fig. 9. Accelerating power of the generator, F.C.T. = 0.28 sec.

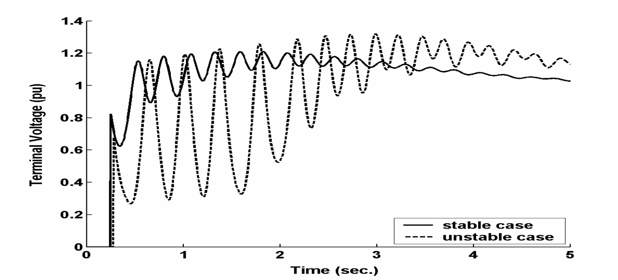

Fig. 10. Generator terminal voltage variation for the stable (F.C.T. = 0.25 sec.) and unstable (F.C.T. = 0.28 sec.) cases.

V. CONCLUSIONS

A complete model for transient stability study of a multi-machine power system was developed using Simulink. It is basically a transfer function & block diagram representation of the system equations. A variety of component blocks are readily available in various Simulink libraries and also in other compatible Blocksets and Toolboxes. A Simulink model is not only best suited for an analytical study of a typical generating system network, but it can also incorporate the state of the art tools for a detailed study and parameter optimization. A Simulink model is very user-friendly, with tremendous interactive capacity and unlimited hierarchical model structure. Typically, for a transient stability study the model facilitates fast and precise solution of nonlinear differential equations viz. the swing equation. The user can easily select the solver type, step sizes, tolerance, simulation period, output options etc. with the help of an appropriate menu from within the Simulink. Any parameter within any block or subsystem of the model can be easily modified through simple Matlab commands to suit the changes in the original network due to a fault or a corrective action.

VI. REFERENCES

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