# A Transient Stability Simulation Package(TSSP) for Teaching and Research Purposes

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***Abstract*—This paper describes a simulation package for performing transient stability study of a power system. The package includes four parts which are a fast decoupled load flow program, a short circuit calculation program, a transient simulation program and a plotting program. The simulation program consists of a coordinator and many modules, each of which simulates a power component, a controller or a physical process. Simulated results can be displayed on the screen by identifying the components and variables. The package is rich in providing modules for nonlinear representations of power components, though user-defined modules can also be easily interfaced into the package. The three data files are designed in such a way that maximum convenience in data preparation is achieved. The package can be used for teaching and doing research related to power system dynamics and control. Application examples and experience gained with the use of the package are discussed.**

## I. Introduction

Time domain simulation of power system stability has been a classical tool for various purposes of studies and popular for decades [1,2,3,4]. Various large scale simulation packages such as the EPRI-ETMST (Extended Transient/Mid Term Stability Program) and the PTI-PSS/E (Power System Simulation/E Program) are in wide use. A number of educational softwares are also reported in the literature [5,6,7,8].

It is felt that every simulation package has its own advantages and shortcomings. A package available to one may not have all the features and flexibility that one wants for either education or research purpose. The possibility of changing the capability of the package is often limited if not impossible. During the last two years, we have felt the urgent need of a package that has the capability of fulfilling most requirements in both teaching and research. In answering this call, a transient stability simulation package implemented on an IBM PC has been developed at the University of Saskatchewan. This package has been utilized to perform stability studies of the WSCC system [9] and the New England Test system. A classroom project associated with a power system modeling and control course using the WSCC system is discussed. As a research tool, the package has also been used to conduct a stability investigation of a longitudinal power system having 69 buses and 12-machines [10]. The results of this research are briefly discussed in this paper.

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The following is a list of tasks that can be performed using the TSSP:

1) Machine modeling of varying complexity
2) Transient simulation of induction motors
3) Modeling of symmetrical and asymmetrical disturbances
4) Various load modeling
5) Modeling of AVR, AGC and PSS
6) Interfacing of user-defined modules
7) Load flow studies
8) Short circuit calculations

## II. Computer Requirements

The package is written in the FORTRAN language and run on an IBM compatible PC. A minimum of 410K conventional memory is required to conduct a stability study for a power system of 100 buses. A CGA, EGA or VGA graphics card is also required to run the plotting program. A hard disk should be used if it is required to store a large amount of numerical results from simulation.

The purpose of the package is to provide researchers and university students easy and wide access of it through personal computer while retaining the capability of modeling power components with desired complexity. The only limitation to the application of the package is imposed by the PC, not by the package itself. That limitation is the size of the system to be studied. A small to medium sized system can be handled on the PC.

## III. Modeling Description

The transient behavior of a power system component or a controller is modeled by a set of first order differential equations. Based on the implicit integration method [11], this set of differential equations can be simulated by

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building a block diagram with integrators and DC gains. Each such block diagram forms an independent module to be called upon by the coordinator in the TSSP.

The TSSP has modules for four different synchronous machine models [12], one induction motor model [13], all the current IEEE recommended excitation system models [14], speed governing and turbine system models [15] and the standard power system stabilizer model [14]. Different load models can also be included [16]. For teaching purposes, these modules are sufficient for students to do their course related project assignments at graduate level. For conducting research, more modules are available or can be written and easily interfaced to the simulation package. Descriptions of the models available in the TSSP as well as user-defined modules that can be interfaced into the package are given in this section.

### *III. 1 Synchronous Machine*

A synchronous machine can be modeled in varying complexity. Adequate and accurate modeling of system disturbances requires that subtransient phenomena of a machine be modeled. With the transformer voltages in the stator equations and the subtransient saliency being neglected, a fifth order representation of the synchronous machine can fulfill these requirements for disturbances including those in which the machine may momentarily fall out of step. Further detailed modeling is not worthwhile as the computation effort increases rapidly, however, the gain in terms of accuracy is very little [12].

Four machine representations and a large machine modeled as an infinite bus can be simulated in the TSSP. An induction motor is modeled by a first order differential equation of the transient complex voltage proportional to the rotor flux-linkage. Each model is designated by a one-digit identifying number as illustrated in Table I.

The differential equations describing the two-axis subtransient model of a synchronous generator are given by (A.1)-(A.5) in Appendix A. The block diagram for this model is also included in that appendix. Generator saturation has been taken into account by approximating the open circuit curve of the generator terminal voltage as an exponential function [9] and by modifying the reactances $x_{ad}$, $x_{aq}$ and the three time constants according to (A.6)-(A.10), respectively. Detailed derivation of these equations are given in [19].

### *III. 2 Excitation, Speed Governing and Turbine Systems*

Any excitation, speed governing and turbine system including their non-linearities can be modeled in the TSSP. Available excitation modules are those for all the current IEEE recommended excitation models. All the current hydro as well as steam turbine and speed governing systems recommended by IEEE are also incorporated in the TSSP. Each module is designated by a two- or three-digit model identifying number as shown in Table I.

### *III. 3 Power System Stabilizer*

One IEEE standard PSS model is incorporated in the TSSP. Different input signals can be chosen by specifying the signal identifying numbers as listed in Table I.

TABLE I
MODULE IDENTIFYING NUMBERS IN THE TSSP

| Generator | AVR | AGC | PSS |
|---|---|---|---|
| 0 - Infinite-bus | 11 - DC 1 | 211 - Fig. 7(A)* | 313 - IEEE |
| | 12 - DC 2 | 212 - Fig. 7(B)* | |
| 1 - Classic | 13 - DC 3 | 213 - Fig. 7(C)* | Input identifier: |
| | | 214 - Fig. 7(D)* | 1 - Deviation of speed |
| 2 - E'q | 21 - AC 1 | 215 - Fig. 7(E)* | 2 - Deviation of terminal frequency |
| | 22 - AC 2 | 216 - Fig. 7(F)* | |
| 3 - E'd, E'q | 23 - AC 3 | | 3 - Electrical power |
| | 24 - AC 4 | 221 - Hydro 1 | 4 - Accelerating power |
| 4 - E"d, E"q | | 222 - Hydro 2 | 5 - Deviation of terminal voltage |
| | 31 - ST 1 | | |
| -1 - Induction motor | 32 - ST 2 | | |
| | 33 - ST 3 | | |
| | 51 - 55 User defined | 231 - 235 User defined | 321 - 325 User - defined modules |

* Fig. 7(A) ~ Fig. 7(F) in [15].

### *III. 4 Disturbances*

Special attention is given to the modeling of various disturbances, as they are significant in influencing the stability of a system. To conduct a stability study, a disturbance, small or large, symmetrical or asymmetrical, must be created and applied to the system under study. The common practice is that a symmetrical disturbance such as a three-phase fault is used as the most severe disturbance under certain operating conditions. The stability margin obtained under such a fault is quite conservative and pessimistic. Moreover, the frequency of occurrence of such disturbance is much lower than that of asymmetrical ones such as the single-phase fault. Therefore, it is desirable to conduct transient stability investigations under asymmetrical disturbances at both stages: planning and operation.

The exact solution of a three-phase network under asymmetrical fault can be carried out by a three-phase stability program, where the symmetrical component method is employed to resolve the disturbed system into three symmetrical three-phase systems. Thus the system size is equivalently two times larger and the total computation will increase up to three times. On the other hand, it is understood that the average braking torque produced by the reaction of the two magnetic fields, one produced by the negative sequence current and the other by the rotor winding current, is approximately zero, and that zero sequence currents yield a zero compound torque, too. Therefore, only the positive sequence quantities are needed to be taken into account during a transient process. However, the negative and zero sequence networks should be incorporated in computing the positive sequence quantities.

Presently, the TSSP is capable of modeling the following disturbances. Provision is made to allow the inclusion of fault and/or grounding impedance.

1) Three phase to ground
2) One phase to ground
3) Two phase to ground
4) Phase to phase
5) One phase open
6) Two phases open

### *III. 5 Load Representations, Network Model and Its Interface with Machine Models*

Various load models can be simulated as long as their representations are known. Specifically, a large induction motor is simulated by its transient model [13]. Other loads can be represented by a variety of models [16]. Exact simulation of load requires that at each time step, a load flow study be carried out in order to obtain the accurate bus voltage. This will increase the computation effort to an unacceptable extent. In the TSSP, a mechanism is designed to calculate new operating points by the fast decoupled load flow program only at the instant when a disturbance happens. At other times, the bus voltage as computed in the latest load flow study is used in load representation.

The network is modeled by lumped parameters, as used in a load flow program. The positive, negative and zero sequence impedances of power apparatus are needed to assemble the three sequence admittance matrices. Interface between network and machine models is accomplished by utilizing an iterative procedure of subtransient and transient saliency [2].

### *III. 6 User-Defined Modules*

If the module of a controller is not available in the TSSP, such a module can be developed by building its block diagram with integrators and DC gains, and then programming it. The name of a user-defined module is the name of the controller to be modeled, for instance, AVR, plus the identifying number of it as given in Table I. A variable is required to correspond the controller module to a machine on which the controller is installed. The parameters of the controller are passed to the coordinator through the data file *mach.inp*. A sample module is provided with the TSSP to assist the user to develop his/her user-defined module. Detailed programming procedure is given in [17].

## IV. Data Files and Program Structure

A maximum of three input data files are needed to perform a transient stability simulation. Each data file consists of a number of data blocks. In each block, data items are entered as a record in free format with a comma between items. A dash line (/) signifies the end of a record. Proceeding each block, there are comments and definitions specifying what data are to be entered and how. Any length of comments can be added into the files as long as a (!) precedes each comment line.

Data file *pqlf.inp* contains all the information required to perform a load flow study. It also provides the freedom to use different system base MVA, per unit or nominal unit system. Data file *ntwk.inp* contains fault information, sequence network parameters and branch incidence of the zero sequence network. Data file *mach.inp* contains parameters for machine, excitation system (AVR), speed governor and turbine system (AGC) and power system stabilizer (PSS) in four blocks. Each controller is identified in the corresponding block by its machine number. If a controller is absent from a machine, a record 888/ is entered to signify this fact.

Three sample data files are provided in the TSSP. The user can create his/her own data files by copying and modifying them with a DOS editor or any word procssor according to the system under study. Any error in the data files will be automatically detected and located when the programs are started. The format of the data files is designed to provide maximum flexibility and minimize frustration in data input. This design was inspired after experiencing the "sophisticated" and "non user-friendly" data input in EMTP [18].

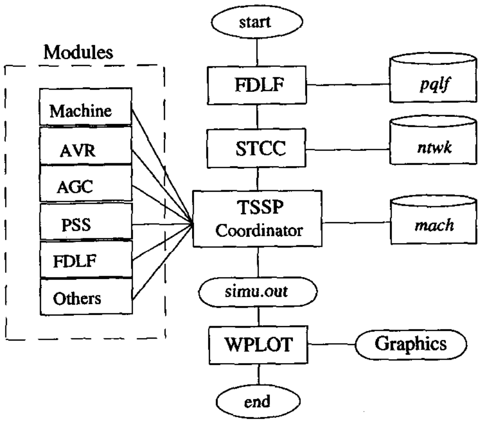


Fig. 1. Overall structure of the TSSP

The overall structure of the package is shown in Fig. 1. To initialize TSSP, the fast decoupled load flow (FDLF) is run first. Then the short circuit calculation (STCC) program is executed. The results of the two runs are passed onto the TSSP coordinator internally. Finally the transient simulation program (TSSP) is run. The end result of a simulation is stored in the file *simu.out*. A data sorting and plotting program (WPLOT) can be employed to plot a maximum of five curves on one screen and up to fifteen variables can be sorted out at a time. The sorted data is stored in a file specified by the user when the plot program is started and can be further utilized by other applications.

## V. TSSP AS A TEACHING AID

As the TSSP can be easily accessed by students, the package can be utilized as a supplementary tool in classroom instruction on power engineering courses such as power system analysis, stability and control at both undergraduate and graduate levels. One specific example of application of the TSSP as a teaching aid for the graduate course POWER SYSTEM MODELING & CONTROL offered at the University of Saskatchewan is presented.

There are two major projects associated with this course. One is on steady state stability study, including eigenanalysis, sensitivity study and swing mode identification (not covered here). The other is on transient stability study, which is the subject of this section. The prerequisites of the course are POWER SYSTEM I & II and CONTROL SYSTEM I & II offered at the undergraduate level.

The project is to perform a transient stability study of the WSCC simplified three machine system [9], as shown in Fig. 2. The system has three generators, three loads and nine buses. The advantage of using this small system is that it is less complicated and partial hand calculations are possible, if required. The project is divided into four assignments (Assign.): load flow study, short circuit calculation, transient stability simulation and PSS design. To encourage independent investigation, each student can be given different system and power component parameters. The first two assignments will take three weeks, and each of the last two assignments will take four weeks. Two separate reports describing the simulated results are required. The weighting of the project can be 15% towards the course grade.

### *Assign. 1: Load Flow Studies*

The students are encouraged to read the user's manual [17] before starting. Then, they can create their own input data file *pqlf.inp* by copying and modifying the sample file *pqlfsam.inp* according to the given parameters. A few runs of the FDLF program may be necessary to debug the errors if any in the input file. This error detection and location information is found in the output file *fdlf.out* produced by the program.

The objective of this assignment is to get started as well as to prepare for short circuit calculation and stability study that follows. The report of this part should include the input data file and load flow results contained in the file *fdlf.out*. Analysis of the voltage profiles of the system under different operating conditions and voltage control methods may also be included in the report.

### *Assign. 2: Short Circuit Calculations*

The objective of this assignment is to encourage the students to review the symmetrical component theory, to manually construct the admittance matrices of the sequence networks and to create the data file *ntwk.inp* by copying and modifying the sample file *ntwksam.inp*. At least three types of faults, three-phase fault, two-phase to ground fault and single-phase to ground fault, should be studied. Different fault sequences may be assumed. Results from hand calculations can be checked with those from the output file *stcc.out* obtained by executing the STCC program. The results of this part are combined with the report from the first assignment.

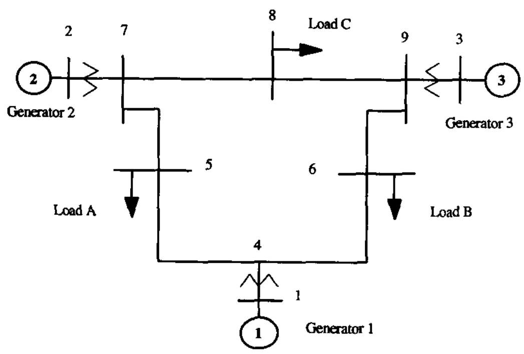


Fig. 2. Single line diagram of the 3-machine system

### *Assign. 3: Transient Stability Simulations*

In this assignment, each student can be given a different combination of generator, AVR and governor models. The initial operating condition of the system is determined from the load flow study. Fault sequence of simulation is imported from the short circuit program. To run the TSSP simulation program, the data file, *mach.inp*, must be established. It is desirable to check whether the default time step length copied from the sample file *machsam.inp* is suitable for the system under study.

In this part of the project, the following aspects are to be studied. After each simulation, results should be plotted by using the WPLOT program and interpreted accordingly.

1) Effect of different generator and AVR models
2) Functioning of speed governing and turbine system during transients
3) Voltage response as affected by AVR
4) Effect of PSS
5) Effect of three-phase auto-reclosure
6) Effect of single-phase auto-reclosure
7) Repeat of 5) and 6) when the transmission lines from buses 7-9 are replaced by double circuit lines with a fault on one of these lines

### *Assign. 4: PSS Design*

The objective of this assignment is to provide the students with an opportunity to stabilize the system by their own newly designed power system stabilizers (PSSs). A design procedure for multimachine system should be used. At least two types of PSSs, one using speed difference as input signal and the other using net accelerating power as input, should be designed and tested by putting them into service in the system. To do this part of the project, the students are required to perform eigenanalysis of the system and compute the compensation angle of the electrical loop of each generator. The best PSS gain can be determined using the procedure as discussed in class.

A complete report with graphics of the last two assignments in the form of an IEEE paper should be prepared. The requirement of presenting the report this way provides the students with an opportunity to experience technical paper writing, which can be very valuable in their later research.

## VI. TSSP AS A RESEARCH TOOL

The package can be utilized in research related to power system transient stability and control. Presented in this section is the stability investigation of a power system which is of longitudinal structure and exists in northern Saskatchewan, Canada.

The system has 69 buses, 12 hydro generators and 850 kilometers of transmission lines. A simplified single line diagram of the system is shown in Fig. 3. As all the excitation systems and the PSSs used in this system are not IEEE standard models, user-defined modules were developed when applying the TSSP software. Specifically, three exciter modules, i.e., DC type 2 modified (EXDC2B), SCRX (see Appendix B) and SCRXIL (SRCX with maximum field current limitation), and two PSS modules, i.e., IEEEST and IEEESN, were created [19].

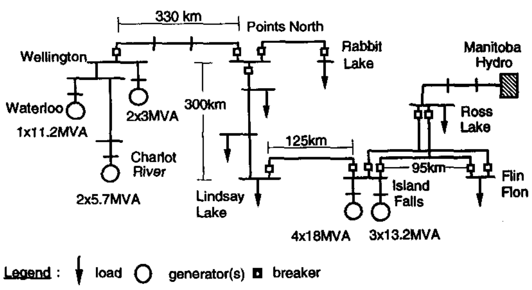


Fig. 3. Single line diagram of Athabasca-Points North system

As the remote hydro generation has to be transmitted over the long and weak transmission line, the system experiences low frequency oscillations under system contingency. Though, the system is stable under common outages with the existing PSSs, it was desired to propose and test different but more effective PSSs to enhance the system's transient stability.

A coordinated PSS design procedure is proposed in [10]. It is based on the central oscillation frequency of a coherent generation group and a lead/lag time constant spread. A PSS such designed is found very effective. To achieve even better PSS performance, communication of the PSS input signals among a coherent generation group can be introduced.

The following simulations are intended to domonstrate the effectiveness of different PSSs. Consider that there is a three phase to ground (3LG) fault on the line from Island Falls to Lindsay Lake for a duration of 6 cycles and the fault is cleared by opening the faulted line. No reclosure is available. The stability of the northern part of the system depends on how much power is being transferred from Island Falls to Points North station at the time of disturbance. The rest of the system can be saved under the outage. Figure 4 shows the responses of speed difference of generator #1 at Island Falls with the existing and proposed PSSs, respectively. The other six generators at the plant behave similar to generator #1.

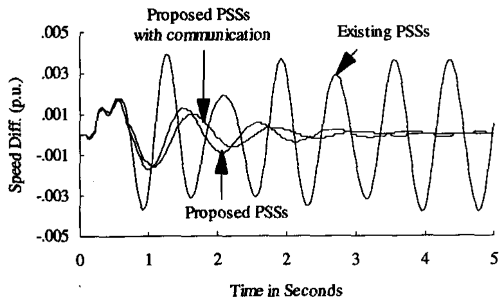


Fig. 4. Responses of speed difference of generator #1 following the 3LG fault on the line from Island Falls to Lindsay Lake.

## VII. EXPERIENCE WITH THE TSSP

Experience gained so far with the use of the TSSP has been positive and encouraging. Implemented on the low cost PC, the package provides students and researchers with easy access. Its capability of interfacing user-defined modules has largely enhanced its flexibility to suit the users' needs. It is no longer necessary to spend much time on data file editing and error finding because of the very user-friendly data files and error-detecting functions in the TSSP. With the aid of the package in doing assignments and other homework, students feel more confident in their ability to solve more complicated problems of power engineering. The freedom given to the students to choose certain parameters, operating conditions, fault sequences and different power component models for the system inspires them to do more research while doing the project, in order to make sure that their assumptions make sense and that their interpretations of the obtained results are consistent with the assumed conditions.

It is planned to use this package for a senior undergraduates course, POWER SYSTEM II. At the same time, further improvement of the package will be undertaken, if necessary, as more experience is gained in the use of the package.

## VIII. Conclusions

This paper presents a transient stability simulation package (TSSP), implemented on an IBM PC, for teaching and research purposes. The structure, database and modeling aspects of the package are covered. Examples are given on the application of the software.

The package can be used by students at both senior undergraduate and graduate levels to do project assignments on power system analysis, modeling and control. Its graphic display capability can assist students to have more intuitive appreciation of the transient behavior of the various power components during disturbances. The analysis and interpretation of the simulated results are facilitated also by the graphic plotting utility. The package can also be used to perform transient stability simulation of up to medium-sized power systems for research purposes. The PC version of the software is available through the authors of this paper.

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## Appendix A: A Fifth Order Machine Model

Assuming that positive stator currents $i_d$ and $i_q$ are generated currents, positive rotor currents $i_f$, $i_D$, and $i_Q$ flow into the machine, where *d, q, f, D* and *Q* denote the direct-axis winding, quadtrature-axis winding, the field winding, the direct-axis and quadtrature-axis damper windings, respectively. The differential equations related to the rotor windings are given below [19]:

$$\dot{E}_q' = \frac{1}{\tau_{do}'}\left\{kE_{fd} - E_q' - \left(x_d - x_d'\right)i_d\right\} \tag{A.1}$$

$$\dot{E}_{sum} = \frac{1}{\tau_{do}''}\left\{-E_{sum} - \left(x_d' - x_d''\right)i_d\right\} \tag{A.2}$$

$$\dot{E}_d'' = \frac{1}{\tau_{qo}''}\left\{-E_d'' + \left(x_q - x_q''\right)i_q\right\} \tag{A.3}$$

where $E_q', E_q''$ are the transient and subtransient voltages of the q-axis, $E_d''$ is the subtransient voltage of the d-axis, and $E_{sum}$ = $E_q'' - E_q'$. A block diagram for this model is shown in Fig. A.1.

The differential equations describing machine motion are given by

$$\dot{\omega} = \{T_m - T_e - D(\omega - 1)\}/2H \qquad (A.4)$$

$$\dot{\delta} = \omega_o(\omega - 1) \qquad (A.5)$$

where $H$ is the machine inertia constant in second and $\omega_o$ is the synchronous speed of the machine in radian per second.

Saturation can be taken into account by modifying the reactances $x_{ad}$ and $x_{aq}$ according to machine saturations at 1.0 pu and 1.2 pu terminal voltage which usually are known from manufacturer. There are several algorithms to realize this modification [9,19]. An iterative procedure is employed in the TSSP. At the same time, the corresponding time constants must also be modified.

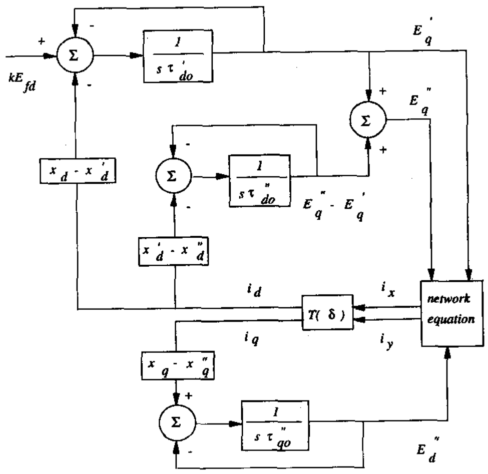


Fig. A.1. Block diagram for the fifth order generator model

Saturated reactances are modified by

$$x_{ad} = kx_{ad}^{(0)} \qquad (A.6)$$

$$x_{ad} = kx_{ad}^{(0)} \qquad (A.7)$$

Saturated time constants are given by [19]:

$$\tau'_{do} = \tau'^{(0)}_{do}\left\{k + (1-k)\frac{x'_d - x_l}{x_d^{(0)} - x_l}\right\} \qquad (A.8)$$

$$\tau''_{do} = \tau''^{(0)}_{do}\left\{k + (1-k)\frac{x''_d - x_l}{x_d^{(0)} - x_l}\right\} \qquad (A.9)$$

$$\tau''_{qo} = \tau''^{(0)}_{qo}\left\{k + (1-k)\frac{x''_q - x_l}{x_q^{(0)} - x_l}\right\} \qquad (A.10)$$

where the superscript (0) indicates unsaturated values, and $k$ is the saturation factor. Other symbols are conventional.

## Appendix B: Modeling Of Fast Exciter SCRX

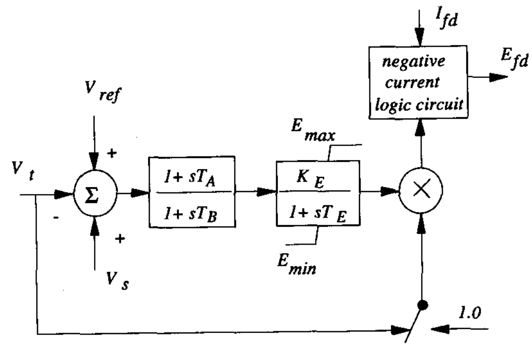


Fig. B.1. Block diagram for SCRX exciter

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