Chapter FOUR

TRANSENT STABILITY INVESTIGATIONS OF SYNCHRONOUS GENERATOR EQUIPPED WITH STATIC EXCITATION SYSTEM

INTRODUCTION

In this chapter, a digital computer program developed by the author to investigate the transient stability of a synchronous generator equipped with a static excitation system is given. Results of investigations obtained by the author with respect to a typical hydro system pertaining to various aspects of static excitation system are discussed. For all the investigations carried out the tuning of the power system stabilizer corresponded to the initial conditions of the system prior to the fault assuring its best steady-state stability.

4.1 DEVELOPMENT OF DIGITAL COMPUTER PROGRAM TO INVESTIGATE THE TRANSIENT STABILITY OF A SYNCHRONOUS GENERATOR WITH STATIC EXCITATION

As a first step in the development of the proposed program, a mathematical model valid for large disturbances is obtained. The schematic diagram of the system considered is shown in Fig 4.1. The block diagrams of various system elements for both the types of generators are given in Figs 4.2 to 4.5.

4.1.1 Synchronous Generator

Park’s model describing the dynamic behaviour of a synchronous generator in per unit form is given by the following equations

Direct-axis flux linkage

\[ \psi_d = X_{fd} I + X_{ad} I - X_{kd} I, \]  
(4.1.1)

\[ \psi_d = X_{ad} I + X_{kd} I - X_{dd} I, \]  
(4.1.2)

\[ \psi_{kd} = X_{ad} I + X_{kd} I - X_{dd} I. \]  
(4.1.3)
Fig 4.1 Schematic Diagram of the system considered
Fig 4.2 Static Excitation system of type ST1

Fig 4.3 Static Excitation with modified representation
Auxiliary channel can act either as an integrator or a differentiator.
Fig. 4.5(a) General model for steam turbine with speed governing system

Fig. 4.5(b) General model for hydro turbine with speed governing system

Fig. 4.5(c) Modified representation of turbine governor system of steam generator

Fig. 4.5(d) Modified representation of turbine governor system of hydro generators
Quadrature-axis flux linkage

\[ \psi_q = X_{aq} I_q - X_{kq} I_k \quad (4.1.4) \]

\[ \psi_{dq} = X_{kkq} I_k - X_{aq} I_q \quad (4.1.5) \]

Direct-axis voltages

\[ E_{fd} = \left(1/\omega_R \right) A \psi_{fd} + r_{fd} I_{fd} \quad (4.1.6) \]

\[ V_d = \left(1/\omega_R \right) A \psi_d - r_{a} I_{a} - \omega \psi_{q} \quad (4.1.7) \]

\[ 0 = \left(1/\omega_R \right) A \psi_{kd} + r_{kd} I_{kd} \quad (4.1.8) \]

Quadrature-axis voltage

\[ V_q = \left(1/\omega_R \right) A \psi_{q} - r_{a} I_{a} - \omega \psi_{d} \quad (4.1.9) \]

\[ 0 = \left(1/\omega_R \right) A \psi_{kq} + r_{kq} I_{kq} \quad (4.1.10) \]

The per unit system chosen is such that all per-unit mutual inductances between rotor and stator circuits in each axis are equal to one another. On this basis, the following relations between self, mutual and leakage reactances pertain:

\[ X_{ffd} = X_{ad} + X_{fl} \quad (4.1.11) \]

\[ X_d = X_{ad} + X_{a} \quad (4.1.12) \]

\[ X_{kkd} = X_{ad} + X_{kd} \quad (4.1.13) \]

\[ X_{aq} = X_{aq} + X_{a} \quad (4.1.14) \]

\[ X_{kkq} = X_{aq} + X_{kq} \quad (4.1.15) \]

Saturation is neglected in the machine and balanced condition is assumed.
The swing equation governing the electromechanical behaviour of synchronous generator is given by

\[ \frac{2H}{R} \frac{d^2 \delta}{dt^2} + \frac{K}{R} \frac{d \delta}{dt} = P_T - P_E \]  

(4.1.16)

Rewriting it in the form of two first order linear differential equations, one gets

\[ \delta = \frac{\omega}{R} \omega_r \]  

(4.1.17)

\[ \omega_r = \frac{1}{(2H).R}(P_T - P_E - K \omega) \]  

(4.1.18)

where

- \( \omega_R \) = Rated speed of generator in radians per second; (This speed is also taken as base value of speed)
- \( \omega_o \) = Rated speed of generator in per unit having a value of 1;
- \( \omega \) = Instantaneous speed of generator in per unit
- \( \omega_r \) = \( \omega - \omega_o \), relative speed of generator with respect to a synchronously rotating reference axis in per unit;
- \( P_T \) = Power input to generator by the turbine in per unit;
- \( P_E \) = Electromagnetic power transmitted from generator rotor to stator in per unit;
- = Generator output power + stator copper loss - transient power appearing due to change in electromagnetic energy accumulation in the inductance of stator circuits

\[ = P + I_R^2 G_a - \left( I_d s \psi_d + I_q s \psi_q \right) / \omega_R \]  

(4.1.19)
P = V_I + V_I; (4.1.20)

\[ I_G = \left( \frac{I^2_q + I^2_d}{d_q} \right)^\frac{1}{2} \quad (4.1.21) \]

4.1.2 Static Excitation System

The static excitation system of type ST1 considered here with lag lead network [1] is shown in Fig 4.2. In order that its governing equations could be written in the form of first order differential equations its block diagram model is redrawn as shown in Fig 4.3, where

\[ T' = \frac{(T - T_c)}{T} \quad (4.1.22) \]

From this figure, the governing equations are

\[ V_5 = \frac{(T'_b / T)}{V_5} - \frac{(1/T)}{V_5} \quad (4.1.23) \]

\[ E_{fd} = \frac{(K / T)}{A} \cdot \left( \frac{T / T}{C} \right) V - \frac{(K / T)}{A} V - \left( \frac{1}{T} \right) E_{fd} \quad (4.1.24) \]

\[ V_r = V_{ref} - V_t - V_s \quad (4.1.25) \]

provided

\[ E_{fdmin} \leq E_{fd} \leq E_{fdmax} \quad (4.1.26) \]

\[ V_{rmin} \leq V_r \leq V_{rmax} \quad (4.1.27) \]

4.1.3 Power System Stabilizer

The large signal block diagram model of a two channel power system stabilizer with electric power P as its input signal is shown in Fig 4.4. In this model, some intermediate signals are also shown. The auxiliary channel has two possibilities, either to act as integrating channel i.e.

\[ W_X = \frac{1}{1 + s T_3} \quad (4.1.28) \]
or to act as a differentiating channel i.e.

$$ W_X = \frac{(sT_3)}{1 + sT_3} $$

(4.1.29)

The governing equations of the power system stabilizer for large signal response are given by

$$ \dot{V}_1 = \frac{1}{T_1} P - \bigg(\frac{1}{T_1}\bigg) V_1 $$

(4.1.30)

$$ \dot{V}_2 = \dot{V}_1 - \bigg(\frac{1}{T_2}\bigg) V_2 $$

(4.1.31)

either

$$ \dot{V}_3 = \bigg(\frac{1}{T_3}\bigg) V_2 - \bigg(\frac{1}{T_3}\bigg) V_3 $$

(Integrating)

(4.1.32)

or

$$ \dot{V}_3 = \dot{V}_2 - \bigg(\frac{1}{T_3}\bigg) V_3 $$

(Differenting)

(4.3.2/a)

$$ V_s = K_1 V_2 + K_2 V_3 $$

(4.1.33)

provided

$$ V_{smin} \leq V_s \leq V_{smax} $$

(4.1.34)

4.1.4 Turbine-Governor System

The large signal models of turbine-governor system for steam and hydro units are shown in Figs 4.5(a) and 4.5(b) respectively. These figures may be drawn to facilitate the formation of mathematical model as shown in Figs 4.5(c) and 4.5(d). The equations governing the dynamic behaviour of turbine and its speed governing system under large disturbances are then

$$ \dot{P}_1 = K_{G1} \bigg(\frac{T_{G2}}{T_{G1}}\bigg) \omega + K_{G2} \bigg(\frac{1}{T_{G1}}\bigg) \omega - \bigg(\frac{1}{T_{G1}}\bigg) P_1 $$

(4.1.35)

$$ \dot{P}_{GV} = \bigg(\frac{1}{T_{G3}}\bigg) \left( P_1 - P_3 \right) - \bigg(\frac{1}{T_{G3}}\bigg) P_{GV} $$

(4.1.36)
\[ P_{T} = P + \left( \frac{1}{T} \right) G_{V} G_{4} P - \left( \frac{1}{T} \right) G_{V} T \]  \hspace{1cm} \text{(4.1.37)}

\[ P_{T_{\text{min}}} < P < P_{T_{\text{max}}} \]  \hspace{1cm} \text{(4.1.38)}

The equations (4.1.35) to (4.1.38) are applicable for steam as well as hydro systems with the differences pointed out as follows:

For steam system

\[ P_{\text{down}} < P < P_{\text{up}} ; \]  \hspace{1cm} \text{(4.1.39)}

\[ T_{G2} = 0 \quad \text{For units without steam feedback;} \]  \hspace{1cm} \text{(4.1.40)}

\[ F = \text{Per unit shaft output ahead of reheater.} \]

For hydro system

\[ F = -2.0 ; \]  \hspace{1cm} \text{(4.1.41)}

\[ T_{G4} = \text{One half of the water starting time constant.} \]

The other symbols are already defined.

4.1.5 Transmission System

The synchronous generator is connected to infinite bus through a transformer and double circuit transmission line without any local load on the station bus as shown in Fig 4.1. The infinite bus voltage vector is taken as reference for obtaining rotor swings and the generator terminal voltage vector is governed by the relation

\[ v_{t} = V + i_{G} \cdot \omega_{e}, \]  \hspace{1cm} \text{(4.1.42)}

where the terminal current \( i_{G} \) required for connection with the network expressed in equation (4.1.42) is obtained from
whereas, $\psi_d$, $\psi_q$, $\psi_{ad}$, and $\psi_{aq}$ are obtained by carrying out the numerical integration of generator differential equations.

4.1.6 Complete System Model Governing Time Response of the System due to Large Disturbances.

The complete model of one machine - infinite bus system governing its dynamic behaviour when subjected to large disturbances is obtained by combining the equations (4.1.1) to (4.1.44) and rearranging these as follows:

**DIFFERENTIAL EQUATIONS**

**Synchronous Generator**

\[ \delta = \omega - \omega_r \]  
\[ \omega_r = \frac{1}{2H} (P_T - P - K \omega) \]  
\[ \psi_{fd} = \omega_{R} \left[ E_{fd} - \left( \frac{r_{fd}}{X_{f,k}} \right) (\psi_{ad} - \psi_{fd}) \right] \]  
\[ \psi_d = \omega_r \left[ V + \left( \frac{r}{X_{a,k}} \right) (\psi_{ad} - \psi_d) + \omega \psi_q \right] \]  
\[ \psi_{kd} = -\omega_{R} \left( \frac{r_{kd}}{X_{kd,k}} \right) (\psi_{ad} - \psi_{kd}) \]  
\[ \psi_{q} = \omega_{R} \left[ V + \left( \frac{r}{X_{a,k}} \right) (\psi_{aq} - \psi_q) - \omega \psi_d \right] \]  
\[ \psi_{kq} = -\omega_{R} \left( \frac{r_{kq}}{X_{kq,k}} \right) (\psi_{aq} - \psi_{kq}) \]

**Static Excitation System**

\[ V_5 = \left( \frac{T_r}{T_b} \right) V - \left( \frac{1}{T_b} \right) V \]  
\[ E_{fd} = \left( \frac{K_i}{T_b} \right) \left( \frac{T_r}{T_b} \right) V + \left( \frac{K_i}{T_A} \right) V - \left( \frac{1}{T_A} \right) E_{fd} \]
Power System Stabilizer

\[ V_1 = \frac{1}{T_1} P - \frac{1}{T_1} V_1 \]  
\[ V_2 = V_1 - \frac{1}{T_2} V_2 \]  

either \[ V_3 = \frac{1}{T_3} V_2 - \frac{1}{T_3} V_3 \] (Integrating element)  

or \[ V_3 = V_2 - \frac{1}{T_3} V_3 \] (Differentiating element)

Turbine-Governor System

\[ P_{1} = K_{G} \left( \frac{T_{1}}{T_{p}} \right) \omega_{r} + K_{G} \left( \frac{1}{T_{G1}} \right) \omega_{r} - \frac{1}{T_{G1}} P_{1} \]  
\[ P_{GV} = \left( \frac{1}{T_{G3}} \right) \left( P_{1} - P_{GV} \right) - \frac{1}{T_{G4}} P_{GV} \]  
\[ P_{T} = P_{GV} + \left( \frac{1}{T_{G4}} \right) P_{GV} - \frac{1}{T_{G4}} P_{GV} \]  

ALGEBRAIC EQUATIONS

Synchronous Generator

\[ \psi_{fd} = \frac{X_{fd} I}{f_{fd}} + X_{ad} k_{d} - X_{ad} I \]  
\[ \psi_{d} = X_{ad} f_{d} + X_{ad} k_{d} - X_{d} I \]  
\[ \psi_{kd} = X_{ad} f_{d} + X_{kd} k_{d} - X_{ad} I \]  
\[ \psi_{q} = X_{aq} k_{q} - X_{q} I \]  
\[ \psi_{kq} = X_{kq} k_{q} - X_{q} I \]  
\[ \psi_{ad} = \frac{1}{\beta_{1}} \left( \frac{\psi_{fd}}{a_{f}} + \frac{\psi_{fd}}{f_{d}} + \frac{\psi_{kd}}{k_{d}} \right) \]  
\[ \psi_{aq} = \frac{1}{\beta_{2}} \left( \frac{\psi_{q}}{a_{q}} + \frac{\psi_{kq}}{k_{q}} \right) \]
\[ e_{1} = \frac{1}{X_{k_{d}}} + \frac{1}{X_{a_{q}}} + \frac{1}{X_{a_{q}}} + \frac{1}{X_{k_{q}}} \]  
\[ e_{2} = \frac{1}{X_{a_{q}}} + \frac{1}{X_{a_{q}}} + \frac{1}{X_{k_{q}}} \]  
\[ E_{f_{d}} = V_{x} \frac{X}{f_{d}} \]  
\[ P = V_{d} I_{d} + V_{q} I_{q} \]  
\[ I_{G} = \frac{(I_{d}^{2} + I_{q}^{2})^{1/2}}{} \]  

**Static Excitation System**

\[ V_{r} = V_{r}^{\text{ref}} - V_{r} - V_{r}^{s} \]  

**Power System Stabilizer**

\[ V_{s} = K_{p} V_{s} + K_{p}^{2} X_{s} \]  

**Transmission System**

\[ V_{t} = V_{t}^{*} + \frac{f_{e}}{G_{e}} \]  

\[ I_{d} = \frac{1}{X_{a_{q}}} \left( \psi_{a_{q}} - \psi_{d} \right) \]  

\[ I_{q} = \frac{1}{X_{a_{q}}} \left( \psi_{a_{q}} - \psi_{q} \right) \]  

**Constraints on System Variables**

**Synchronous Generator**

i. Saturation is neglected in the generator;

ii. Only symmetrical fault is considered for time response of the system;
Static Excitation System

i. \[ E_{\text{fdmin}} \leq E_{\text{fd}} \leq E_{\text{fdmax}} \]  
\hspace{1cm} (4.1.84)

ii. \[ V_{\text{rmin}} \leq V_{\text{r}} \leq V_{\text{rmax}} \]
\hspace{1cm} (4.1.85)

Power System Stabilizer

i. \[ V_{\text{smin}} \leq V_{\text{s}} \leq V_{\text{smax}} \]
\hspace{1cm} (4.1.86)

Turbine-Governor System

For Steam System

i. \[ P_{\text{down}} \leq P \leq P_{\text{up}} \]
\hspace{1cm} (4.1.87)

ii. \[ T_{G2} = 0 \], for units without steam feedback , 
\hspace{1cm} (4.1.88)

iii. \[ F = \text{per unit shaft output ahead of reheater} \], 
\hspace{1cm} (4.1.89)

iv. \[ T_{G3} = \text{is the sum of servomotor time constant and} \]
\hspace{1cm} \text{steam valve bowl time constant;} 
\hspace{1cm}

For hydro system

v. \[ F = -2.0 \], 
\hspace{1cm} (4.1.90)

vi. \[ T_{G4} = \text{One half of water starting time constant;} \] 
\hspace{1cm} (4.1.91)

For both types of systems

vii. \[ P_{\text{Tmin}} \leq P_{\text{GV}} \leq P_{\text{Tmax}} \] 
\hspace{1cm} (4.1.92)
4.1.7 Solution Technique and Digital Computer Program

In the process of computations, voltages $V_d$ and $V_q$ which result from network constraints (4.1.81) and appear as non-integrable variables in machine differential equations are considered as the input quantities for the solution of machine differential equations, whereas currents $I_d$ and $I_q$ are looked upon as their output quantities.

Fourth-order Runge-Kutta method of numerical integration is adopted to compute the solution of differential equations (4.1.51) to (4.1.65) together with algebraic equations (4.1.66) to (4.1.83) keeping in view the constraints on system variables as given by equations (4.1.84) to (4.1.92).

The digital computer program has been developed to obtain the solution of the system of equations (4.1.51) to (4.1.92) in the form of time response of the system due to large disturbances.

4.2 SYSTEM CONSIDERED FOR INVESTIGATIONS

The power system, considered here [5] consists of a hydro generator connected to infinite bus through a transformer and a transmission time as shown in Fig 4.1. The generator is equipped with static excitation system of type ST1.

The parameters relating to the initial operating conditions in per unit (on 100 MVA base) are given below:

**Synchronous Generator**

Rated output = 131 MVA,

$H = 4.584$, MW-sec/MVA

$X_{a_b} = 0.206$

$X_d = 0.771$, $X'_d = 0.275$, $X^*_d = 0.252$, $X^*_q = 0.435$, $X'_q = 0.434$, $X^*_q = 0.252$, $r_a = 0.0031$

$T''_{do} = 0.03$ sec, $T''_q = 0.03$ sec;
Static Excitation System

$K_A = 50$ p.u. change in excitation voltage/p.u. change in terminal voltage.

$T_A = 0.01$ sec, $T_C = 1.0$ sec, $T_B = 10.0$ sec;

Power System Stabilizer

$T_1 = 0.03$ sec, $T_2 = $ To be determined, $T_3 = $ Appropriate value,

$K_P = $ To be determined, $K_D = $ Need not be specified;

Turbine-Governor System

$K_G = 20$,

$T_{G1} = 27.5$ sec, $T_{G2} = 3.24$

$T_{G3} = 0.5$ sec, $T_{G4} = 0.52$ sec

$F = -20$, $\omega_o = 314.16$ radian/sec;

Transmission System

$r_L = 0.0100$, $x_L = 0.0850$ (Each line)

$X_T = 0.0576$.

The initial operating condition is given by

Generator Power output = 118 MW

Power factor = 0.91

Infinite bus voltage = 1.00
The large disturbance initiating the transient is a three-phase fault occurring on one of the two transmission lines near the station bus. The fault is cleared in 0.16 second by opening the faulted line.

4.3 EFFECT OF CEILING VOLTAGE

As an aid to transient stability, the desirable excitation system characteristics are a fast speed of response and a high ceiling voltage. With the help of fast transient forcing of excitation and the boost of machine internal flux, the electrical output of the machine may be increased during the first swing compared to the results obtainable with a slow exciter. This reduces the accelerating power and results in improved transient performance [5].

Modern excitation systems like static excitation systems can be effective in two ways: in reducing the severity of machine swings when subjected to large impacts by reducing the magnitude of the first swing and by ensuring that the subsequent swings are smaller than the first. The latter is an important consideration in present-day large interconnected power systems. Situations may be encountered where various modes of oscillations reinforce each other during later swings, which along with the inherent weak system damping can cause transient instability after the first swing. With the proper stabilization schemes a modern excitation system such as static excitation system can be very effective in damping out such fatal swings in a multimachine environment [5].

For large disturbances the assumption of linear analysis is not valid. However, the power system stabilizer should be helpful in damping oscillations caused by large disturbances and help the system to return to normal steady-state condition speedily. Since the initial rotor swing is largely an inertial response to the accelerating torque in the rotor the stabilizer is likely to have little effect on the first swing [5].

ILLUSTRATIVE EXAMPLE

The numerical example considered for investigating the effect of ceiling values on the damping of swings due to large disturbances with and without a power system stabilizer is same as the given in section 4.2.
The computations are carried out with the help of the digital computer program developed in section 4.1. The results are brought out in Figs 4.6(a) to 4.6(c) and Figs 4.7(a) to 4.7(c). Figs 4.6(a) to 4.6(c) indicate the time response without power system stabilizer, whereas Figs 4.7(a) to 4.7(c) are obtained when the power system stabilizer is in action.

From Fig 4.6(b) it is clear that the \( E_{fd} \) remains constant for the first swing in case the ceiling value is 2.5. The corresponding swing curve in Fig 4.6(a) is the best damped and has the minimum settling time. Whereas, in case the stabilizer is in action the \( E_{fd} \) is almost constant for the first swing when the ceiling value is 2.0 as shown in Fig. 4.7(b). The corresponding swing curve in Fig 4.7(a) has also the best damped response. For comparison sake the swing curves of both these cases are plotted in Fig 4.8. It may be seen from Fig 4.8 that when power system stabilizer is provided a better damping of swing curves is obtained with a lesser ceiling value for \( E_{fd} \) \( (E_{fdmax} = 2.00 \text{ p.u.}) \) compared to the best damping case when power system stabilizer is out of action \( (E_{fdmax} = 2.5 \text{ p.u.}) \).

### 4.4 EFFECT OF RELAY FORCING

When the fault occurs on the system there is a sharp drop in voltage at all points in the system. The magnitude of this drop is a measure of the electrical proximity of the fault and its potential effect on the transient stability of the machine [6]. If it happens to be near the terminals of a synchronous generator its terminal voltage will collapse instantly thus requiring the forcing of excitation to the ceiling value for the duration till the terminal voltage recovery takes place. During this period which precedes immediately after the fault the power system stabilizer is not as effective in damping the oscillations as relay forcing. In case the forcing of excitation at the ceiling can be achieved by the power system stabilizer on its own, then the relay forcing is not necessary. If the power system stabilizer is unable to maintain the exciter voltage at its ceiling value before the terminal voltage recovery is made to the normal value relay forcing of exciter voltage will have to be resorted to. Once the control of the initial swing is achieved through appropriate relay forcing then the damping of subsequent swings may be entrusted to the power system stabilizer.
Fig 4.6(b) $E_{fd}$ variation with different ceiling values without power system stabilizer
Fig 4.6(c) $V_t$ variation with different ceiling values without power system stabilizer.
Fig 4.7(a) Transient swings with different ceiling values with power system stabilizer
Ceiling value

Fig 4.7(b) variation with different ceiling values with power system stabilizer
Fig 4.7(c) $V_t$ variation with different ceiling values with power system stabilizer.
Fig 4.8 Effect of ceiling values on transient swings with and without power system stabilizer—comparison.
Fig 4.9(a) to 4.9(c) show the variation of $\delta$ vs $t$, $E_{fd}$ vs $t$, and $V$ vs $t$ respectively when relay forcing is present but power system stabilizer is not in action. Fig 4.10(a) to 4.10(c) show corresponding variations in case when alongwith relay forcing power system stabilizer is in action. Fig 4.11 shows the swing curves for four cases as indicated. The results shown in Figs 4.9, 4.10 and 4.11 support the observations made above that the relay forcing combined with power system stabilizer improves the damping capabilities of the static excitation system.

4.5 EFFECT OF TURBINE REGULATION

There are two primary control systems associated with the stability of synchronous generator [5]. The first is the excitation system that controls the terminal voltage. It may be noted that the excitation system also plays an important role in controlling the machine rotor oscillations since it affects the electrical power output of the generator during oscillations. The second control system is the speed control mechanism of turbine that monitors the shaft speed and controls the mechanical power output of the turbine.

The results of investigations concerning the effect of turbine regulation on the transient stability are brought out in Fig 4.12 corresponding to the cases when power system stabilizer is in action and out of action. The system considered in the above illustrative example is given in section 4.2.

It may be seen from Fig 4.12 that the actual swings of the synchronous machine with speed governor mechanism action taken into account are marginally higher in amplitude than the swing curves computed with constant turbine power. However, this slight deviation in the swing curves occurs only after 1.7 second which is the approximate time required for the turbine to react on the system disturbance. The above computations were made without power system stabilizer. The swing curves obtained with power system stabilizer are shown in Fig 4.12 by lines with circles. It may be seen that the effect of turbine regulation on the swings is similar in this case also. However, with power system stabilizer present irrespective of turbine regulation the damping achieved during the later part of the oscillations remains the same.
Fig 4.9(a) Transient swings with different ceiling values when field forcing is adopted without power system stabilizer
Fig 4.9(b) $E_{fd}$ variation with different ceiling values when field forcing is adopted without power system stabilizer.
Fig 4.9(c) Variation with different ceiling values when field forcing is adopted with power system stabilizer
Ceiling value

2.0
2.5
3.0
4.0
Field forcing = 0.3 sec

Fig 4.10(a) Transient swings with different ceiling values when field forcing is adopted with power system stabilizer
Fig 4.10(b) Variation with different ceiling values when field forcing is adopted with power system stabilizer.
Fig 4.10(c) V variation with different ceiling values when field forcing is adopted with power system stabilizer
Fig 4.11 Comparison of transient swings with various combinations of field forcing, ceiling values, with and without power system stabilizer
Fig 4.12 Effect of turbine regulation on transient swings with and without power system stabilizer.

With out stabilizer
P_T = P_T0

With stabilizer
P_T = P_T0

Turbine governor system represented in detail
CONCLUSIONS

In this chapter, a digital computer program is developed to investigate transient stability of the synchronous generator equipped with static excitation system where all the power system elements such as synchronous generator, static exciter, transient gain reduction unit, power system stabilizer, et cetera are represented in full details.

Investigations are made to show the effect of exciter ceiling voltage and relay forcing of exciter voltage on the rotor swings. Two cases are investigated namely with and without power system stabilizer in action for the system given in section 4.2.

It was noticed that without relay forcing and without power system stabilizer in action the ceiling value which enables the excitation to hold to its positive maximum upto the duration of first swing provides maximum possible damping of the oscillations. Identical results are obtained in case the power system stabilizer is in action with a difference that a lower ceiling value for the exciter voltage is sufficient to achieve the maximum possible damping in this case.

While studying the effect of relay forcing it is found that the forcing of exciter voltage upto the duration of first swing helps in both cases i.e. with and without power system stabilizer in reducing the amplitude of rotor swings. The field forcing with appropriate ceiling value and duration of forcing combined with power system stabilizer improves the damping capabilities of the static excitation system.

Turbine regulation has marginally affected the amplitude of latter swings. Compared to the case when the turbine power is assumed constant the amplitude of swings are slightly higher in this case.
REFERENCES


