International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

Analysis and Design of Power System with Excitation and Stabilizer Controllers

Vimala Devi V
Department of EEE
CVR College of Engineering
Hyderabad, INDIA

Dr. K. Dhanvanthri, Prof., Emeritus
Department of EEE
CVR College of Engineering
Hyderabad, INDIA

***Abstract*—Power system with single machine infinite bus configuration has been analyzed including the effects of excitation and stabilizer controls. This analysis gives the block diagram representation of single machine infinite bus system (SMIB) which in turn gives its system matrix. This model has been enhanced to include the effects of power system stabilizer (PSS) which improves the performance of a power system by providing the extra damping required to suppress the oscillations. A generalized program has been developed in this work which gives the effects of all the above and also gives the desired values of synchronizing and damping torques which are essential for the operation of power system.**

Keywords—Synchronous Generator; Excitation system; PSS; SMIB; Synchronizing torque; Damping torque.

I. INTRODUCTION

Synchronous generator is the most important element of the electrical power system because of its mechanical to electrical energy conversion. This transformation is possible only if the excitation to the generator exists. Excitation of generator also effects the generator output values i.e., voltage and reactive power. This means the excitation control is actually the regulation of output energy of generator, thereby the entire electrical power system stability. The graphical representation of synchronous generator stability by P-Q diagram is shown below (Fig.1).

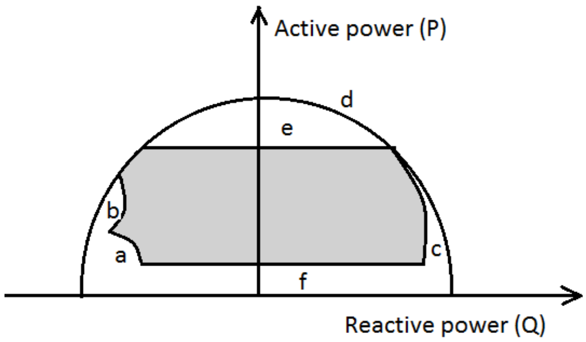

Figure 1: P-Q diagram of Synchronous Generator

The operating point of synchronous generator must be inside the shaded area formed by minimum excitation current required (curve a),stability limit (curve b), maximum excitation current (curve c),maximum armature current (curve d), maximum and minimum turbine power (curve e and f) respectively.

II. EXCITATION SYSTEM

Excitation system provides the excitation current required for synchronous generator which consists of automatic voltage regulator (AVR), exciter, measuring element, power system stabilizer (PSS), limitation and protection unit (Fig. 2).

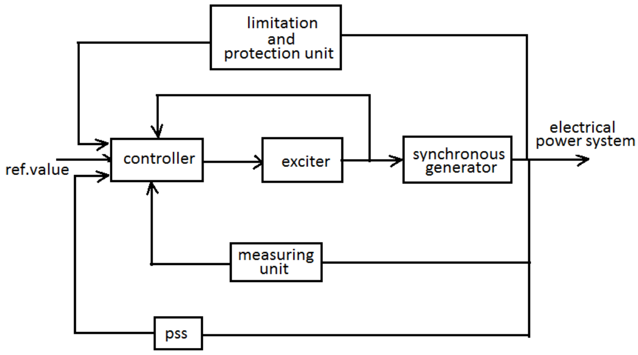

Figure 2: Block diagram of excitation system control of synchronous generator

Exciter is the source of electrical power for the synchronous generator field windings, provided by a separate DC generator. This exciter is controlled by automatic voltage Regulator(AVR). AVR is very effective during steady state operation, but it may have negative effects on damping torque in case of sudden disturbances because it forces the field current changes in the generator. These negative effects of AVR may be reduced by introducing power system stabilizer which produces an additional control and compensates the oscillations in the voltage. Required range of frequencies for PSS to produce phase compensation lies between 0.1 - 2.0Hz. and insufficient damping of oscillations may limit the power transmission. Input quantities of PSS may be speed deviation, transient emf, and generator current. To get optimal regulation, any two quantities of the above mentioned can be chosen.

Measuring elements are used to obtain the input values of excitation system. Generator armature voltage is continuously measured whereas armature current, exciter current and voltage may be optional.

Limitation and protection unit contains large number of circuits which ensures that certain physical values are limited. (e.g. generator armature voltage and excitation current etc.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

III. Single Machine Infinite Bus System

Single machine infinite bus system (SMIB) consists of a generator connected radially to a large system through a long transmission line. The single line diagram of a typical power system and its equivalent circuit are as shown in figure 3.

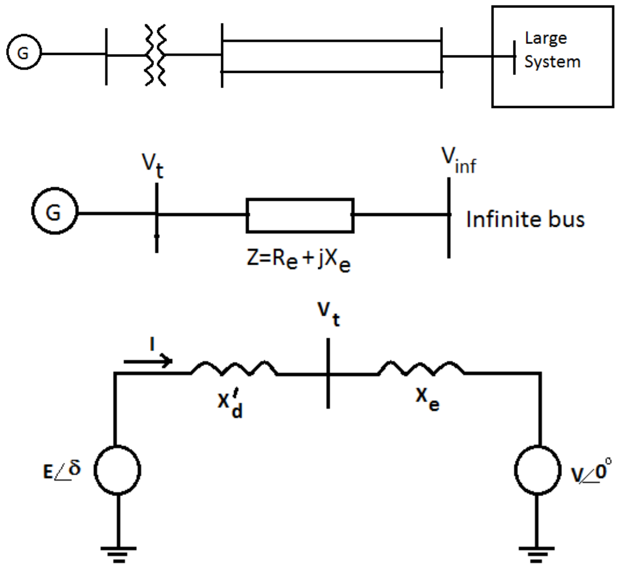

Figure 3: Equivalent circuit of SMIB

The state variable representation of considered SMIB is:

$$\begin{bmatrix} \Delta\dot{\omega} \\ \Delta\dot{\delta} \end{bmatrix} = \begin{bmatrix} -(K_D/2H) & -(K_s/2H) \\ \omega_s & 0 \end{bmatrix} \begin{bmatrix} \Delta\omega \\ \Delta\delta \end{bmatrix} + \begin{bmatrix} \Delta T_m/2H \\ 0 \end{bmatrix} \quad (1)$$

The state matrix A depends on K_D, H, X_T and Initial value of E and δ, E_0 and δ_0.

$$\xi = \frac{1}{2}\frac{K_D}{\sqrt{K_s 2H\,\omega_s}} \quad (2)$$

From equation(2) we can observe that,

- As the synchronizing coefficient increases the natural frequency of rotor oscillations increases and the damping ratio decrease.
- As the damping coefficient increases damping ratio also increases.
- As the inertia constant increases natural frequency and damping ratio decreases.

A. *Effect of Excitation system without PSS on SMIB*

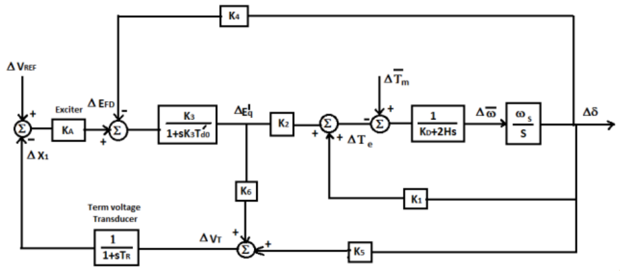

Figure 4: SMIB with Effect of Excitation

Voltage E_{FD} can be varied by the excitation system when the main generator terminal voltage deviates from the reference set point. The considered excitation system can be controlled by the constants K_1 to K_6. Optimum values of K_1 to K_6 defines the stability of SMIB system. The constants K_1 through K_4 are usually positive. The constant K_5 can be positive or negative. K_5 is negative for high external reactance and high generator outputs. The synchronizing torque Te depends on the value of these constants. The equation of Te is given in equation (3).

$$[\Delta T_e] = \frac{-K_2K_3(K_4+K_5K_A)}{1+K_3K_6K_A}\Delta\delta \quad (3)$$

If K_5 is negative, then the torque is purely synchronizing and negative. If $K_4+K_5K_A = 0$, then the constant K_4 represents the demagnetizing effect of armature reaction. The gain of the excitation system just to overcome the armature reaction is given by,

$$K_A = -K_4/K_5 \quad (4)$$

Because of negative value of K_5, AVR introduces a negative damping and positive synchronizing torque component.

B. *Effect of PSS on SMIB*

Hence it may not always be possible to set the exciter to provide sufficient synchronizing and damping torques. Under such conditions, supplementary control through power system stabilizer is resorted to provide positive damping. Its effect can be neutralised by superimposing a sufficient positive damping torque on it. This can be produced by feeding back the speed deviation from synchronous speed signal at the excitation system input after providing to it appropriate gain and phase advance for the range of expected rotor oscillation frequencies. The amount of gain and advance to be provided depend on the net positive damping required and the phase characteristics of the exciter - generator composite transfer function respectively. The required gain and phase advance characteristics to the speed deviation signal are provided by the PSS. The basic function of PSS is to introduce Positive damping to rotor oscillations by controlling the excitation using auxiliary stabilizing signal such as the speed deviation. The block diagram including the PSS with speed deviation as the stabilizing signal is shown below.

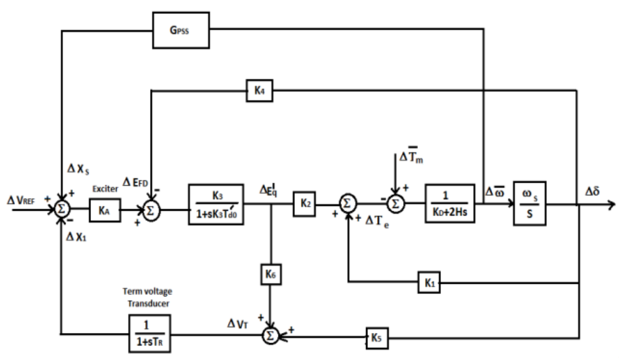

Figure 5: SMIB with Excitation system and Power system stabilizer

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

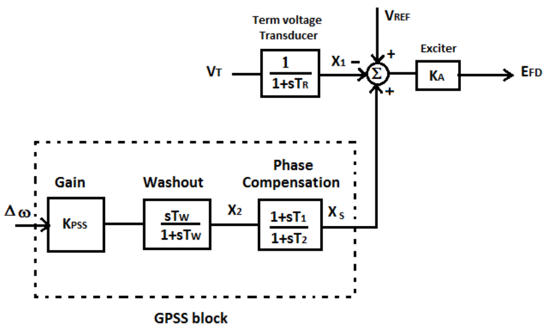

Figure 6: Block diagram of excitation system with PSS

Phase compensation is required for a frequency range of 0.1 - 2.0Hz. The phase lead provided is a compromised value to ensure satisfactory operation for different operating conditions. To prevent negative synchronizing torque component, the phase lag between exciter input and electrical torque is undercompensated.

The signal washout block is a high -pass filter to let in rotor oscillation without magnitude reduction. It prevents steady changes in speed modifying terminal voltage and ensures that the PSS responds only to changes in speed. the value of the washout time constant T_W is between 1 to 20 seconds. The lower limit of the time constant is based on time required to let stabilizing signals in unchanged for frequency range of interest and higher limit is based on the requirement that it should not cause undesirable generator voltage excursions during islanding conditions. On the whole, PSS should improve overall stability of the system.

The state variable representation of PSS variables is given by equation (5).

$$\begin{bmatrix} \dot{\Delta\omega} \\ \dot{\Delta\delta} \\ \dot{\Delta E_q'} \\ \dot{\Delta X_1} \\ \dot{\Delta X_2} \\ \dot{\Delta X_s} \end{bmatrix} = \begin{bmatrix} -K_D/2H & -K_1/2H & -K_2/2H & 0 & 0 & 0 \\ \omega_s & 0 & 0 & 0 & 0 & 0 \\ 0 & -K_4/T_{d0}' & -1/K_3T_{d0}' & -K_A/T_{d0}' & 0 & K_A/T_{d0}' \\ 0 & K_5/T_R & K_6/T_R & -1/T_R & 0 & 0 \\ a & b & c & 0 & -1/T_w & 0 \\ aT_1/T_2 & bT_1/T_2 & cT_1/T_2 & 0 & d & -1/T_2 \end{bmatrix} \begin{bmatrix} \Delta\omega \\ \Delta\delta \\ \Delta E_q' \\ \Delta X_1 \\ \Delta X_2 \\ \Delta X_s \end{bmatrix} + \begin{bmatrix} \Delta T_m/2H \\ 0 \\ (K_A/T_{d0}')\Delta V_{REF} \\ 0 \\ (K_{PSS}/2H')\Delta T_m \\ (K_{PSS}/2H')\Delta T_m * (T_1/T_2) \end{bmatrix} \quad (5)$$

From the above 6x6 coefficient matrix eigen values of the SMIB can be obtained.

IV. RESULTS

As an illustration, a typical SMIB is considered in this work With the following data and important highlights are Provided.

System data:

Generator: 588MVA, 500MW, 21KV, 50Hz

R_a = 0.0023, X_d = 2.35, X_q = 2.15

Step-up Transformer: leakage reactance = j0.15

Transmission line: X_{pos} = j1.0

All reactances in p.u. on 588MVA

Initial Operating Conditions:

Active power of the generator P = 0.85 p.u.

Reactive power output Q = 0.52 p.u.

Terminal Voltage of the Generator V_t = 1.0 p.u.

The parameters for stabilizer are

KPSS=9.5;T_w= 1.4; T_1=0.154; T_2=0.0335

In this work, a versatile computer program has been developed highlighting the various vital points. The developed program gives the values of constants K_1 to K_6. Using these values, the program developed computed the system matrix which in turn gives Eigen Values.

A. Value of constants and eigen values for operating coondition(0.85+j0.52)

K_1 = 0.6832, K_2 = 0.9422, K_3 = 0.3010, K_4 = 1.9757
K_5 = -0.1101, K_6 = 0.5450
Eigen values:
-35.9615, -1.0271+j5.6528, -1.0271-j5.6528, -0.7444,
-21.1793+j23.1359, -21.1793-j23.1359.
For the chosen values, it has been observed that the
Value of K_5 is negative.

The effect of AVR is to increase the synchronizing torque and decrease the damping torque which results in instability. To compensate this, use of power system stabilizer gave positive synchronizing torque and positive damping torque for the chosen values of stabilizing parameters.

V. CONCLUSION

A very versatile computer program has been developed and used in this work which computes the Eigen values for a chosen SMIB system. The Constants K_1 to K_6 which are required for the analysis can be obtained using this developed program which further can be used to obtain the system Eigen Values for selected parameters. For a particular set of chosen system data, it has been observed that with only AVR, synchronizing torque increases but damping torque decreases. Addition of Power system stabilizer to the chosen SMIB system gave both the above torques positive which gives better performance for chosen parameters.

Though typical values are used in this work to highlight salient points, the developed program is very general and can be used to analyze any SMIB system with any chosen AVR and PSS parameters to get any desired results

VI. REFERENCES

1. Computer Methods in power System Analysis- Stagg & El-Abiad- MCGraw Hill.
2. Power System Stability and Control- Kundur.P; McGraw Hill.
3. Power System Dynamics- R. Ramanujam, PHI Learning PVT Ltd.