

Effect of Alternator's Inertia Constant 'H' on Small Signal Oscillations in Power System

¹Ayesha Firdaus and ²Anwaruddin Anwar

^{1,2}*Department of Electrical Engineering,
Aligarh Muslim University, Aligarh, U.P*

Abstract

A Power System consists of the generating machines and transmission network in which the generating machine includes turbine, alternator and excitation system. Every synchronous generator has rotating rotor which has some inertia that depends upon the stored rotating energy in the system. There are various types of disturbances which are occurring on the power system. A stable power system should be designed such that it can withstand with the disturbances and remain in synchronism. The dynamic or small signal stability of an interconnected power system is its ability to return to normal or stable operation after subjected to some form of small disturbances. Dynamic instability is more probable than steady state instability. Small disturbances such as variations in loading, changes in turbine speed etc. which are small enough not to cause the system to lose synchronism but do excite the system into the state of natural oscillations. Machine inertia significantly affects the rate of rise and fall of system frequency. This paper discusses the effect of variation in machine inertia on the frequency of rotor oscillations. A Single machine infinite bus (SMIB) system is taken as the test system and its Eigen values are obtained by changing machine inertia constant.

Keywords: Inertia Constant, SMIB, Small Signal Stability.

1. Introduction

F.P. Demello and C. Concordia were the first to study the effect of excitation system on stability of synchronous machine [1]. It was observed that with a continuously acting voltage regulator, low frequency oscillations occur in electrical output voltage

and electrical torque of synchronous machine. In the absence of sufficient damping the rotor angle keeps on increasing and finally machine trips. This is termed as small signal stability problem. [2, 3] represents practical studies where a problem of small signal stability was observed. The oscillations may be local to a single generator or generating plant, or they may involve a number of generators widely separated geographically.

The frequency of rotor oscillations is very much affected by the size of the generator and its inertia. This paper discusses the effect of rotor Inertia constant on the frequency of small signal oscillations of a Single Machine Infinite Bus System (SMIB). The paper is organized as follows: Section II presents the basic modeling of SMIB system used in this paper. Simulink model is prepared based on the mathematical modeling. Section III gives the basic idea about the Inertia constant and its definition. Section IV and V presents the results obtained and discussion on the results. Finally section VI gives the conclusion.

2. SMIB System

For the purpose of stability analysis, a Single Machine Infinite Bus system is taken in which the machine can be represented by any of the three models Classical, simplified and detailed [4]. A classical model includes only second order differential equation associated with the rotor dynamics of the machine. A simplified model includes the effect of the rotor dynamics along with the effect of synchronous machine field circuit dynamics and Excitation system. And the detailed model of the machine includes the machine amortisseurs also. Since the disturbance under study is of 0.2 Hz to 2 Hz, so the mathematical equations describing various effects can be linearized around an equilibrium point.

Fig. 1 shows a general SMIB system configuration with a generating unit and transmission line. In this paper, simplified model of the machine is considered. The complete state space model is given by

$$\begin{bmatrix} \Delta \dot{\omega}_r \\ \Delta \dot{\delta} \\ \Delta \dot{\psi}_{fd} \\ \Delta \dot{v}_1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & 0 & 0 & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \Delta \omega_r \\ \Delta \delta \\ \Delta \psi_{fd} \\ \Delta v_1 \end{bmatrix} + \begin{bmatrix} b_1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \Delta T_m \quad (1)$$

The elements of state matrix are explicit functions of system parameters. The above model includes the effect of synchronous machine field circuit dynamics, field flux linkage variation, and excitation system. The expressions for a_{42} , a_{43} , a_{44} are given as

$$a_{11} = -K_d/2H \quad a_{12} = -K_1/2H \quad a_{13} = -K_2/2H \quad a_{42} = K_5/T_r \quad a_{43} = K_6/T_r \\ a_{44} = 1/T_r$$

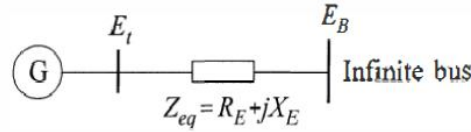


Fig. 1: SMIB system.

Where K_d is the damping coefficient, H is the inertia constant of the generator and K_1, K_2, K_5, K_6 are functions of initial operating parameters of machine like initial machine speed, initial rotor angle, initial currents along d and q axis and the initial values of d and q axis flux. Similarly the other matrix elements are the functions of machine parameters.

It was established in [5] that for small signal stability analysis of SMIB system it is useful to represent the above developed model in block diagram form. Fig. 2 represents the block diagram for the SMIB system with torque angle relationship.

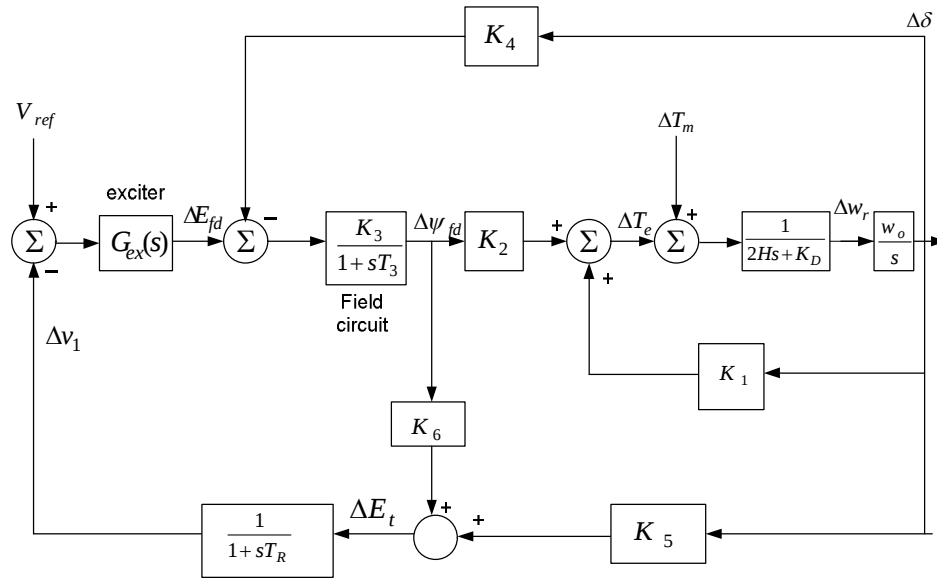


Fig. 2: Block diagram of SMIB system with exciter.

3. Inertia Constant

The dynamics of the rotor is defined by the second order swing equation of the synchronous which is a non linear differential equation and is given by-

$$\frac{GH}{\pi f} \frac{d^2 \delta}{dt^2} = P_m - P_e \text{ MW} \quad (3)$$

Where

G is the MVA rating of the machine, H is the inertia constant

In the given swing equation, the damping term is ignored because of the fact that the torque of the damper winding is ignored.

Inertia constant H is defined by-

$$H = \frac{\text{Stored Kinetic Energy in mega joules at Synchronous speed}}{\text{Machine rating in MVA}} \text{ MJ/MVA} \quad (4)$$

The inertia constant H has a characteristic value or a range of values for each class of machines. It is observed that turbo generators have larger inertia constant than hydro generators.

4. Eigen Value Analysis

After the Linearization of system equations the system can be described as

$$\Delta x' = A\Delta x + B\Delta u \quad (5)$$

Where A is called system matrix.

$$\det(sI - A) = 0 \quad (6)$$

Eq. (6) is called characteristics equation and the roots of it is called Eigen values. Eq. [6] gives the Lyapunov's first method for determining the system stability as

When the Eigen values have real negative parts the original system is asymptotically stable.

When at least one of the Eigen values has positive real part the system is unstable.

Table 1: Effect of Change in inertia constant on Eigen values

Inertia Constant (H)	Open loop Complex Eigen Values	Frequency of rotor oscillations (Hz)
2	$0.7648 \pm 9.3999i$	1.495
3	$0.5685 \pm 7.7807i$	1.239
3.5 (base case)	$0.5042 \pm 7.2359i$	1.152
4	$0.4532 \pm 6.7927i$	1.082
6	$0.3229 \pm 5.5971i$	0.891
8	$0.2511 \pm 4.8718i$	0.776

- Due to the presence of AVR, the system is unstable which is also seen from the given Eigen values as the real part is positive.

5. Simulation and Results

Based on the block diagram of SMIB with exciter given in Fig. 2, real time simulation is done in MATLAB/SIMULINK environment. Results obtained for variation in rotor speed (for $K_d=0$) fig. 3. Simulation is run for 10 sec and non adaptive algorithm is used for obtaining the characteristics with maximum step size of 0.01 and relative tolerance of 0.001. Following inferences can be derived from the obtained characteristics.

- From the fig 3, it has been observed that the SMIB system is unstable in nature having increasing response with negative damping ratio.
- From the table 1, it is seen that on increasing the system inertia constant, the frequency of oscillations of rotor decreases.

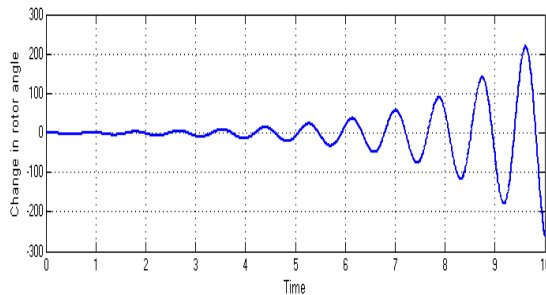


Fig. 3: Variation in rotor speed with time

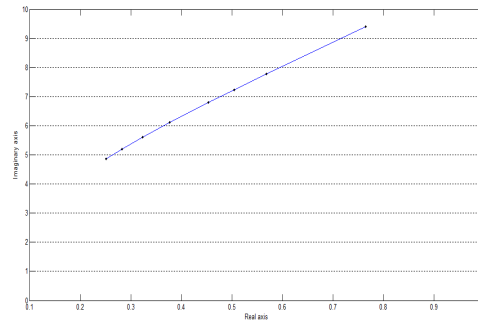


Fig. 4: Effect of change in H on rotor oscillation

6. Conclusion

From fig.4 and table 1 it is evident that frequency of rotor oscillations is inversely proportional to the system inertia. This result is in accordance with the basic physics of rotating mass. Moreover, system with higher inertia should be more stable as compared to the system with lighter mass. This is clear from the damping of rotor oscillations mode in fig 4. Since the stability analysis is based on the linearized equations so some kind of error must be there in the results. The error can be reduced by using Stability analysis technique developed for nonlinear systems.

References

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Appendix

For the purpose of Simulation of SMIB system given in fig. 2, we take following data,

Machine parameters:

2220 MVA, 24Kv synchronous machine parameters
on rated power and rated voltage per unit base,

$$X_d = 1.81 \text{ pu } X_q = 1.76 \text{ pu}$$

$$R_a = 0.003 \text{ pu } T'_{d0} = 8.0 \text{ s}$$

Excitation system parameters:

$$K_a = 200, T_a = 0.02 \text{ s}$$

$$G_{ex}(s) = 200.0$$

$$X'_d = 0.3 \text{ pu } X_l = 0.16 \text{ pu}$$

$$H = 3.5 \text{ MW-s/MVA}$$