Effect Of Nonlinearitiy On Dynamic Stability Of A Single Machine Infinite Bus System

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Abstract – Electrical power system is a huge complex system consists of the components needed for generation, transmission and large scale distribution of electrical energy. Generating station and distribution system are connected through transmission lines, which also connect one power system to another. A distribution system connects all the loads in a particular area to the transmission lines. The system must be able to meet the continually changing load demand for active and reactive power.

Power system stability may be defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions. In power system stability, synchronous machine has great importance and receives increasing attention. By using the modern voltage regulators and excitation systems with fast speed of response and high ceiling voltage can be used to improve the transient stability by increasing the synchronizing torque of the machine, their effects on the damping torque are rather small.

Generating system equipped with modern fast acting static excitation systems with larger percentage of generating capacity, excitation system had an impact on dynamic stability (small signal response) of power system.

To analyze the small-signal stability of the single system connected to a large system through transmission lines system which is a single machine infinite bus system is extended by considering single Kaplan turbine-generator with exciter and governor in a low head -hydro power plant connected to local load and an infinite bus for the study. Nonlinearity has been considered in this work as it is inherently present in the system, and the nonlinearity considered is governor dead band. Turbine-governor dead bands are found due to backlash in the linkage connecting the piston to the shaft. Backlash is the nonlinearity which causes governor dead band tending to produce continuous sinusoidal oscillations. The dual regulation of hydro-turbine is incorporated through the operation of both wicket gate and runner blade. The results of extended single machine infinite bus system are plotted for speed deviation and successfully analysed using Matlab simulink program.

Keywords–Power system stability, SMIB, Kaplan turbine, Nonlinearity.

I.INTRODUCTION

Electric power system varies in size and structural components. Synchronous machine is used to power generation. Industrial loads are three-phase; single phase residential and commercial loads are distributed equally form a three phase system. Power system stability can be defined as “if the oscillatory response of a power system during the transient period following a disturbance is damped and the system settles in a finite time to a new steady operating condition, we say the system is stable. If the system is not stable, it is considered unstable.The power system is a highly non linear system whose dynamic response is influenced by a wide array of devices with different response rates and characteristics. The power system instability of interconnecting system depends on rotor angle instability and voltage instability.

II. SINGLE MACHINE INFINITE BUS SYSTEM

For small-signal stability analysis, dynamic modeling is required for the major components of the power system. Consider a single machine system as shown in fig1, neglecting damper windings both in the d and q axis. Also the armature resistance of the machine is neglected and the excitation system represented by a single time constant of the system is shown in fig1.

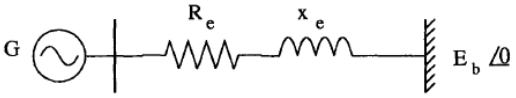

Fig 1 : A Single Machine Power System Model.

III. MODIFIED HEFFRON-PHILLIPS MODEL

The standard Heffron- Phillips model can be obtained by linearizing the system equations around an operating condition. From fig1 the following equations are obtained. The development of the model is explained in [].

$$E_q^{'} + X_d^{'} i_d = V_q \qquad (1)$$

$$-xqiq = Vd \qquad (2)$$

Here q and d refers to the q and d axis respectively. The complex voltage can be expressed as

$$V_q + jV_d = (V_q + jV_d)e^{j\delta} = (i_q + ji_d)(R_e + jX_e)e^{j\delta} + E_b\angle 0$$

$$V_q + jV_d = (i_q + ji_d)(R_e + jX_e) + E_b e^{-j\delta} \qquad (3)$$

Separating Real and Imaginary parts of eq(3) can be expressed as

$$V_q = R_e i_q - X_e i_d + E_b \cos\delta \qquad (4)$$

$$V_d = R_e i_d - X_e i_q - E_b \sin\delta \qquad (5)$$

Substituting(4) and (5) in (1) and (2) gives

$$\begin{pmatrix} (X_d^{'} + X_e) & -R_e \\ -R_e & -(X_q + X_e) \end{pmatrix}\begin{pmatrix} i_d \\ i_q \end{pmatrix} = \begin{pmatrix} E_b \cos\delta - E_q^{'} \\ -E_b \sin\delta \end{pmatrix}$$

(6)

The system mechanical equations, electrical equations and eqn.(6) are linearized as in [] to obtain the following modified K-constants.

$$K_1 = \frac{E_b E_{qo} \cos\delta_o}{(X_e + X_q)} + \frac{(X_q - X_d\,')}{(X_e + X_d\,')} E_b i_{qo} \sin\delta_o$$

$$K_2 = \frac{(X_e + X_q)}{(X_e + X_d^{'})} i_{qo}\,;$$

$$K_3 = \frac{(X_e + X_d^{'})}{(X_e + X_d)}\,;$$

$$K_4 = \frac{(X_d - X_d^{'})}{(X_e + X_d^{'})} E_b \sin\delta_o\,;$$

$$K_5 = \frac{-X_q V_{do} E_b \cos\delta_o}{(X_e + X_q)V_{to}} - \frac{X_d^{'} V_{qo} E_b \sin\delta_0}{(X_e + X_d\,')V_{to}}\,;$$

$$K_6 = \left(\frac{V_{qo}}{V_{to}}\right)\frac{X_e}{(X_e + X_d\,')}$$

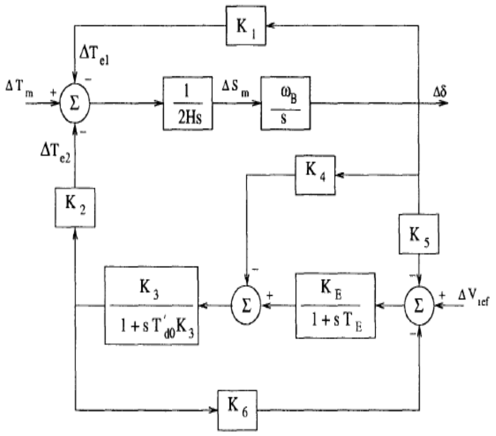

Fig 2: Modified block diagram of SMIB with Heffron-Phillips constants.

IV: EXTENDED SMIB

Single Machine Infinite Bus System is extended to dual regulation of low-head power plant with wicket gate opening and runner blade position for controlling the water pressure. The generation of hydroelectric power is accomplished by means of hydraulic turbines that are directly connected to synchronous generators. Kaplan turbine shown in figure 3 was an evaluation of the Francis turbine.

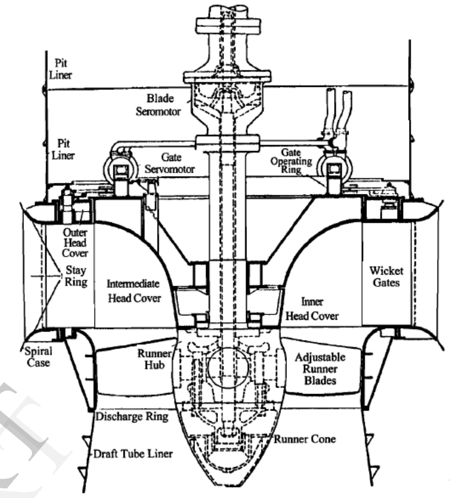

Fig 3: Kaplan Propeller Turbine

This design has the advantage of fairly high efficiency over a wide range of head and wicket gate settings. Adjustments of wicket gate setting and blade angle can both be made with the unit running. This permits optimization of turbine efficiency over a wide range of head and load conditions.

V.MODELING OF EXTENDED SMIB

The hydraulic flow in the penstock is modelled with the assumption of inelastic water column effect. The stiff water hammer equation can be expressed as

$$\frac{dh}{dt} = -T_w \frac{dw}{dt} \qquad (7)$$

The turbine flow q and torque m in case of Kaplan turbine are nonlinear functions of head h, wicket gate opening z, machine speed wand runner blade position θ.

The corresponding servomotor equations are described as

$$\frac{dz}{dt} = (U_{gov} - Z)/T_{gv} \qquad (8)$$

$$\frac{d\theta}{dt} = (U_{gov} - \theta)/T_r;$$

Where T_{gv} and T_{rb} are wicket gate and runner blade servomotor constants respectively.

The dynamic characteristics of the extended SMIB system are expressed in terms of constants K_1 to K_9. The constants K_7, K_8, K_9 are due to head h, wicket gate opening z, machine speed w and runner blade position ϴ and their equations are given by;

$$K_7 = T_7 - (T_3 T_5)/T_1; \qquad (9)$$

$$K_8 = T_6 - (T_2 T_5)/T_1; \qquad (10)$$

$$K_9 = T_8 - (T_4 T_5)/T_1; \qquad (11)$$

VI: NONLINEAR TURBINE MODEL

The primary function of a governor is to control speed and /or load. Here we discuss the special requirements of governing hydraulic turbines, their physical structure and modelling in system studies. For a stable parallel operation of multiple units, the speed governor is provided with the droop characteristic. The purpose of droop is to ensure equitable load sharing between generating units. For a stable control performance, a large transient droop with a long setting time is required. This is accomplished by the provision of a rate feed back or transient gain reduction compensation as shown in fig (4).

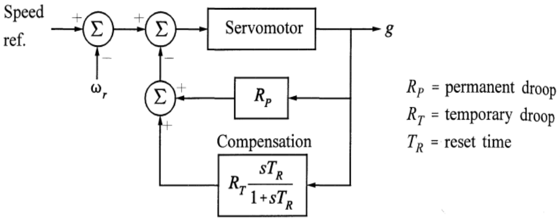

Fig4: Governor with transient droop compensation

The governor model as shown in fig 5 has provision for representing the effect of dead bands.

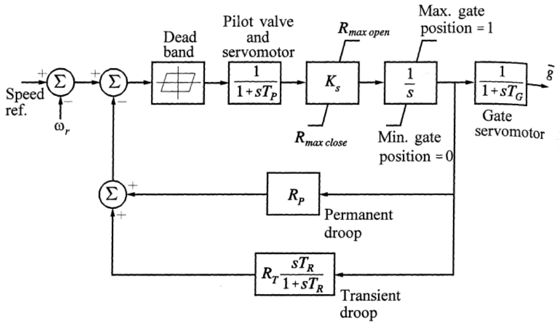

Fig 5: Model of governor for hydraulic turbines.

VII: SIMULATION RESULTS

The results are obtained using MATLAB-SIMULINK software for the block diagrams shown below at different operating conditions.

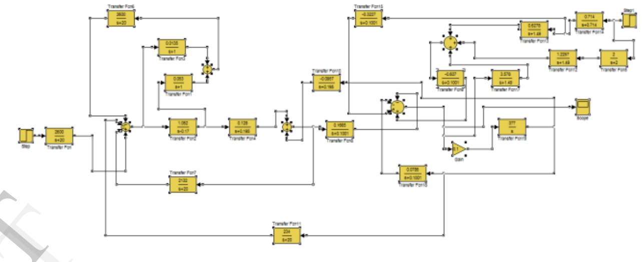

fig 6 : Simulink block diagram of extended SMIB without nonlinearity for operating point p=1.0 and q=1.0

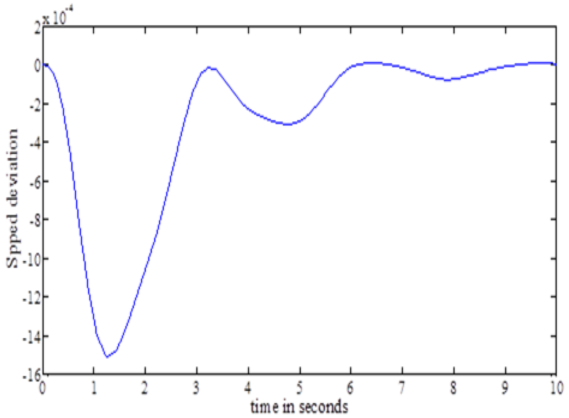

Fig 6.1 : Simulation results for extended SMIB without nonlinearity for operating point p=1.0 and q=0

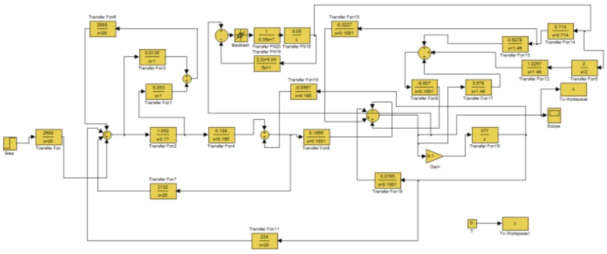

Fig 6.2 : Simulation block diagram for extended SMIB with nonlinearity for operating point p=1.0 and q=0

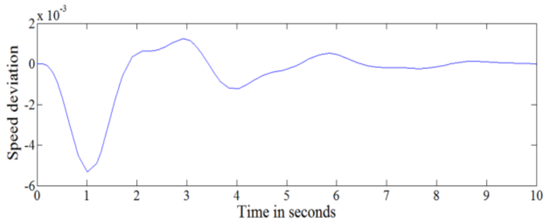

Fig 6.3 : Simulation results for extended SMIB with nonlinearity for operating point p=1 and q=0

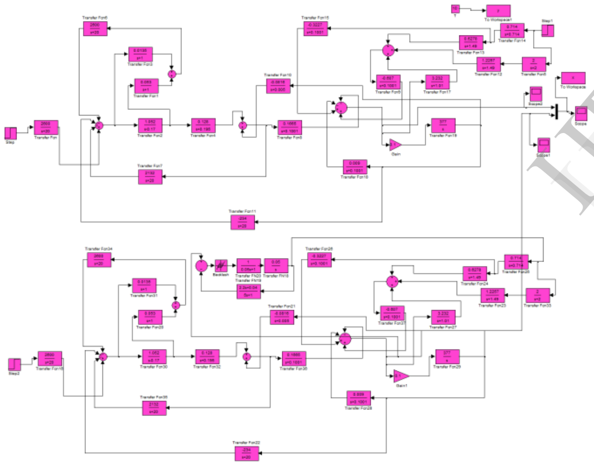

Fig 6.4 : simulation block diagram for extended SMIB with and without nonlinearity fro operating point p=1.0 and q=0

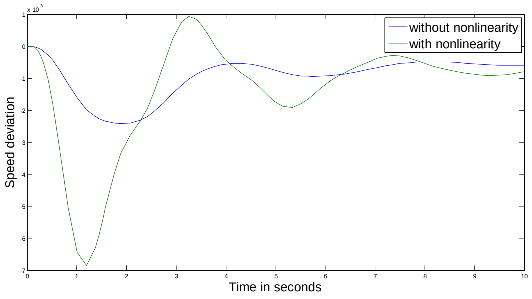

fig 6.5 : Simulation block diagram results for an extended SMIB with and without nonlinearity for operating point p=1.0 and q=0

VIII: CONCLUSIONS

Dual regulation of extended low hydro power plant is achieved by controlling both wicket opening and runner blade position which is connected to SMIB. Turbine governor dead band is considered which is inherently present in the system which is found due to backlash in the linkage connecting the piston to the shaft. From the step responses it has been observed that the speed deviation settling time is increased for an extended SMIB with the inherent backlash nonlinearity is considered. From the step responses of two operating points of extended SMIB it can be observed that the dynamic stability is affected.

Table 1: Data considered for Extended SMIB for an operating point p=1.0 and q=1.0

Table 2 : Settling time with and without nonlinearity for an opearting point.

Operating point	Settling Time without nonlinearity	Settling Time with nonlinearity
P=1 and q=0	8.99sec	15 sec

IX: REFERENCES

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T_a=0.05	T_{do}' =7.76	G+jB= 0.248+j0.262	R_t =0.4
Tgv=0.5	K_A=130	V_{d0}=1.34	T_r = 5.0
V_t =1.05	D=0	K_f = 1.0	T_w=2.23
δ_0=65.1	M=9.6	I_{d0}=0.40	T_1= 0.30
X_q=057	ω_0=377.17	T_p=0.05	T_2 =0.82
X_d= 1.6	T_a,T_e=0.05,0.05	K_s= 5.0	T_3 =0.038
X_d' =0.32	K_1 =0.55, K_2 =1.16, K_3 =0.66, K_4 =0.67, K_5 = -0.99, K_6=0.82	T_g= 0.2	T_4 =0.42
K_e=1.0	R+jX= -0.34+j0.926	R_p=0.04	T_5 = 1.276