Large Signal and Small Signal Stability of Single Machine Infinite System using Dynamic Brake and Static Shunt Compensator

Balwinder Singh Surjan

Abstract— In this paper thyristor controlled dynamic brake and static shunt compensator controllers are employed to enhance the transient and small signal stability investigation stability of power system represented through Single Machine connected to Infinite Bus (SMIB). The Phillips-Heffron representation of SMIB system is also modified for reactive power inclusion. The controllers Power System Stabilizer (PSS), Static Shunt Compensator (SSC), Thyristor Controlled Dynamic Brake (TCDB) are tuned for the minimization of performance index. The results obtained here indicate explicitly that the coordinated operation of proposed controllers is effective in improving transient as well as small signal stability of the system.

Index Terms— ISE, PSS, SMIB, SSC, SVC, TCDB..

I. INTRODUCTION

Transient stability studies are limited to relatively short time intervals, typically 1sec or less. They are most often used to determine the stability of a single unit or plant during the initial period of high stress immediately following a nearby fault. Traditionally, transient stability studies have utilized classical generator models, but modern practice is to represent generators, excitation systems, and speed-governing systems in detail. Braking resistors, Short-circuit current limiters, turbine fast valving may be employed to maintain large disturbance stability.

The dynamic braking resistor has been known to be a useful tool in stabilizing power systems following large disturbances in the system. The braking resistor can be viewed as fast load injection to absorb excess transient energy of an area caused by a large disturbance. It has generally been studies as a shunt resistor load connected at a generator site and its energy absorbing capacity is limited by the maximum temperature rise of the braking resistor material [1-3].

Where as Small signal stability is of vital importance to circumvent occurrence major system failure. Small signal are the oscillation associated in the frequency range of 0.2 to 2.5Hz. These low frequency oscillations may be confined to a group of machines or they may be between two or more machine groups or they may propagate between interareas. The frequency of oscillations slides towards lower range as the system inertia adds up. Low frequency oscillations (LFO) are detrimental to the goals of maximum power transfer and power system security. These are generator rotor angle oscillations having a frequency between 0.1 to 2.5Hz. The small signal oscillations are divided into three categories [4], [5], (a) local mode of oscillations with frequency range from 0.5 to 2.5 Hz, (b) intermachine mode of oscillation with frequency range from 0.3 to 1.0Hz, (c) inter-area or global mode of oscillations with frequency range from 0.1 to 0.6 Hz [6,7].

In many power systems constrained by stability the limiting factors are not first swing stability but the damping of system oscillations. The traditional method used to increase the damping of a power system is by adding PSS in the excitation system of generator [8]. Application of PSS has been one of the first measures to enhance the damping of power swings. With increasing transmission line loading long over distances, the use of conventional PSS might in some cases, not provide sufficient damping for inter-area power swings [9].

Dynamic braking resistors are in use in the USA, Japan and USSR. The Peace River System, the Four Corner Plant of the Arizona Public Service Company and the Bonneville Power Administration in North America have experience using braking resistors. Normally, switching of the resistors in these installations is done on the basis of open loop, predetermined strategies. A number of theoretical and Computer studies on braking resistor switching strategies are reported in literature [3].

With the advanced technologies in power electronic devices, such as thyristor switches, has been used to improve at power system stability, and capacity to transfer power. Switch control of a braking resistor is one of the effective methods to absorb the excessive energy caused by system disturbances and provides stability enhancement [1,2,9,10]. In the reference [11] transient stability investigation is presented using thyristor controlled braking resistor, which connected across the terminals of three-phase controlled rectifier bridge

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It has generally been studies as a shunt resistor load connected at a generator site and its energy absorbing capacity is limited by the maximum temperature rise of the braking resistor material [10]-[12]. Normally, switching of the resistors in these installations is done on the basis of open loop, predetermined strategies. A number of theoretical and Computer studies on braking resistor switching strategies are reported in literature [12].

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Dynamic voltage support and reactive power compensation have been long recognized as a very significant measure to improve the performance of electric power systems. The rapid advances in the power electronics area have made it both practical and economic to design powerful thyristor controlled reactive power compensators (SVC). The primary purpose of SVC application is to maintain bus voltage at near a constant level. In addition SVC may improve transient stability by dynamically supporting the voltage at key points and steady state stability by helping to increase swing oscillation damping [16-18]. Effectiveness of SVC is dependent on its location, and load characteristics. It becomes more effective for controlling power swings at higher levels of power transfer.

In this paper Thyristor controlled resistive brake and static shunt compensator are coordinated for the large disturbance as well as small signal stability investigation of SMIB system. The performance of the systems studied is based on minimum integral squared error. The performance of the controllers has been compared for the large disturbance and small signal disturbance as well. The system for small signal stability has been linearized and modified to include reactive power effects.

II. POWER SYSTEM AND CONTROLLERS UNDER STUDY

A. Modeling of Thyristor Controlled Dynamic Brake [12-17]

Thyristor controlled Dynamic Brake (TCDB) may be visualized as a load connected at generator terminals. The accelerating power dissipated across the resistor can be varied as a function of triggering angle. The accelerating power dissipated across the braking resistor as a function of triggering angle is given below

$$P_d = \frac{1}{R_B}\left[K\sqrt{2}V_t\cos(\alpha)\right]^2 \quad (1)$$

where, α is the triggering angle of the thyristor, V_t is the terminal voltage of the generator, and R_B is the braking resistor. K is the value of constant depending upon the type of thyristor device used. The value of triggering angle is a dependent upon the generator rotor speed.

The angular rotor speed signal may be converted to the electrical signal by using transducer. The signal conditioning that is its amplification, signal blocking during deceleration interval, etc., is accounted into the measuring block. The measured signal is fed to the signal washout block. The function of which is to block the signal during steady state, and to washout any drift in the signal because of circuit elements.

B. Modeling of Static Shunt Compensator

The proposed Static Shunt Compensator (SSC) comprises of a fixed capacitor and a thyristor controlled variable reactor (FC-TCR) connected in parallel at the generator terminals [18-20]. To limit the harmonics entering the system, some of the fixed capacitors are connected as series tuned filters. The maximum capacitive var output is available when TCR is switched off (α=0). TCR is phase controlled by controlling the firing angle α in the range from 90˚ to 180˚. The instantaneous current of TCR over half a cycle is given below [11, 21].

$$i_{TCR} = \frac{\sqrt{2}V_t}{X_L}\left(\cos\alpha - \cos(\omega t)\right),\ \alpha > \omega t > (\alpha+\sigma)$$
$$= 0, \qquad (\alpha+\sigma) > \omega t > (\alpha+\pi) \quad (2)$$

where, V is the rms value of generator terminal voltage , X_L is the fundamental frequency reactance of the reactor, α is the delay angle , σ is the conduction angle. The fundamental frequency component of the current may be written as

$$I_1 = V_t B_{TCR}(\sigma), \quad (3)$$

where, $B_{TCR}(\sigma) = B_L \frac{\sigma - \sin(\sigma)}{\pi}$. $B_L = \frac{1}{X_L}$ is the constant susceptance of the reactor at the fundamental frequency, and $\sigma = 2(\pi-\alpha)$. B_{TCR} is the variable susceptance of the TCR, which is a function of triggering angle. B_{TCR} varies from 0 to B_L as α is decreased from π to $\frac{\pi}{2}$. The net reactive power of absorbed or supplied by the SSC is given by the difference of reactive powers of TCR inductor and fixed capacitor, as given below

$$Q_{SSC} = V_t^2 B_L\left[2 - \frac{2\alpha}{\pi} + \frac{\sin 2\alpha}{\pi}\right] - V_t^2 B_C. \quad (4)$$

The control of the SSC is a function of deviation of synchronous generator terminal voltage. The SSC behaves as a capacitor or reactor depending upon triggering angle α of TCR. The firing angle control of TCR involves measuring and signal conditioning, signal washout, the pulse generation circuit, time delay circuits.

C. Modeling of SMIB System

The differential equations of SMIB system equipped with static exciter incorporated with TCDB and SSC controller are given as [6, 7, 21]

$$\frac{d\delta}{dt} = (\omega - \omega_s) \quad (5)$$

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$$\frac{d\omega}{dt}=\left(\frac{\omega_s}{2H}\right)\left[T_m-\left(T_e+T_{TCDB}\right)-D(\omega-\omega_s)\right] \quad (6)$$

$$\frac{dE_q'}{dt}=\left(\frac{1}{T_{do}'}\right)\left[-E_q'+(x_d-x_d')[(Q_G-Q_{ssc})-E_q' i_q]\frac{1}{E_d'}+E_{fd}\right] \quad (7)$$

$$\frac{dE_{fd}}{dt}=\left(\frac{1}{T_A}\right)\left[-E_{fd}+K_A\left(V_{REF}-V_R\right)\right] \quad (8)$$

$$\frac{dV_R}{dt}=\left(\frac{1}{T_R}\right)\left[V_t-V_R\right] \quad (9)$$

The related algebraic equations are

$$T_e=E_q' i_q+E_d' i_d+(x_d'-x_q')i_d i_q \quad (10)$$

$$Q_G=E_q' i_q+E_d' i_d, \quad (11)$$

$$V_q=E_q'+x_d' i_d-r_a i_q$$
$$V_d=E_d'-x_q' i_q-r_a i_d \quad (12)$$

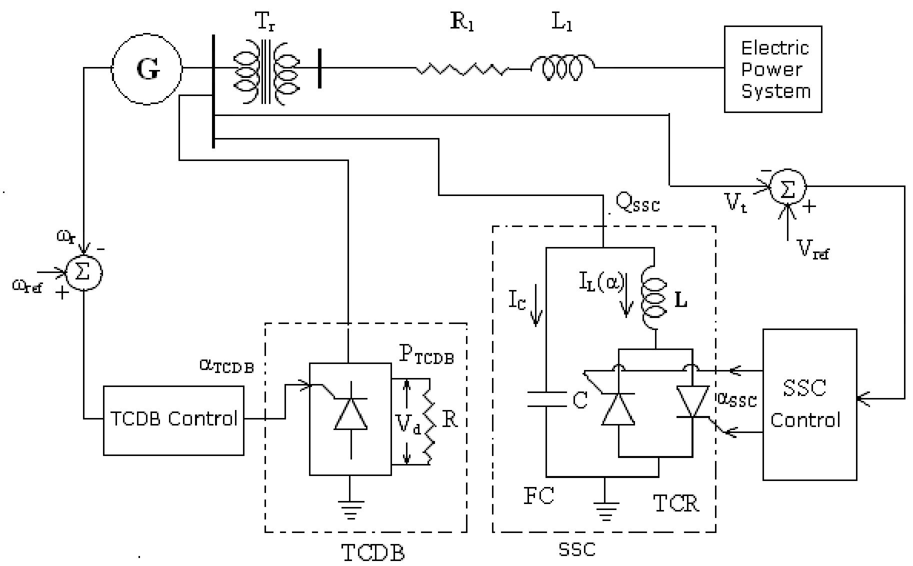
$$V_t^2=V_q^2+V_d^2 \quad (13)$$

III. PROBLEM FORMULATION

A. Problem Formulation

In the present study the controller parameters, except control loop gains, are predetermined or approximated from the literature referred. The controller gains are determined through error and trial method subjected to the minimum value of objective function. The system disturbance is a three-phase short-circuit to the ground, which is cleared after some cycle of supply frequency. For the small signal stability investigation an unit pulse load variation applied at the generator terminals. The controllers are at located at the generator terminals and tuned to achieve maximum improvement in transient stability of the representative power system networks. The schematic diagram of the system studied is shown in Fig. 1, below. The various system data has been tabulated in Table I-III.

The system data, for the stability study and enhancement under both disturbance conditions, has been same. The transient study is carried with non-linear system equations whereas small signal study has been performed after linearizing the system equations.



Schematic Diagram of Static Shunt Compensator and Thyristor Controlled Dynamic Brake

Fig. 1. Schematic diagram for location of SSC and TCDB.

TABLE I
DATA FOR THE SMIB SYSTEM [21]

Inertia Constant, H	3.66 MW-s/MVA
Rated MVA	1280
Rated KV	22
Power Factor (lag)	0.95
X_d	2.02
X_d'	0.358
X_q	1.86
R_S	0.0019
T_{do}'	9.1
K_A	50
T_A	0.02

Re	0.0
Xe	0.4

Table. II Bus Data

Bus No	Bus No	Resistance p.u.	Reactance p.u.
1	3	0.000	0.50
2	3	0.000	0.45
3	1	0.000	0.95

Table III Line Data

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Bus No	Voltage p.u.	Angle (degrees)	P_G p.u.	Q_G p.u.
1	0.9008	0	0	0
2	1	28.34	0.9	0.436
3	0.928	20.34	0	0

B. Objective Function

In this paper, an Integral of Squared of the Error (ISE) has been taken as objective function. The objective function is defined as follows:

$$J = \int_0^{t_{sim}} (\delta_i - \delta_{final}) dt \tag{14}$$

Where, δ_i, δ_{final} are the instantaneous, final values of the generator angle respectively, and t_{sim} is the simulation time. Various combinations of controllers considered are tuned for the minimum magnitude of Integral of Squared Error (ISE) in the generator rotor angle.

IV. TEST SYSTEMS AND RESULTS

The effectiveness of the proposed controllers in the present study has been investigated with the SMIB system shown in Fig. A.1 having data given in Table I.

A. Large Disturbenace:

The test systems are subjected to large disturbances in terms of three phases to ground fault of duration 0.06sec in the middle of one of the parallel lines is incepted at 0.05sec. as shown in single line diagrams. The results obtained are presented in the following subsections. The system is restored to pre-fault configuration after 0.13sec. the response of the system is shown in Fig. A.2 to Fig. A.4. The magnitude of performance index J for different combinations of controllers is tabulated below.

Table IV. The Controller Performance Index for Large Disturbance

Controllers	J = ISE
No controller	0.0299
PSS only	0.0344
TCDB only	0.0017
SSC only	0.0305
PSS and TCDB	0.0012
PSS and SSC	0.0599
TCDB and SSC	0.000177
PSS, TCDB and SSC	0.000258

B. Small Signal Disturbance

The relevant data of SMIB system for the small signal stability investigation is reproduced from the reference [6]. The generator and external network data is given in Table I. The constants in per unit for Modified form of Heffron-Phillips model of SMIB Test system are given in Table II. The response of the SMIB system obtained for unit impulse rotor angle variation applied at the simulation time t=0.0 seconds. The variation of system parameters as a function of time is shown in Fig. A.5 to Fig. A.8. The effectiveness of different controllers individually and as a possible combinations may be observed from these curves. The presence of TCBR improves the system performance by reducing the ISE value from 0.2231 to 0.1997 and settling time from 3.005 to 1.607 seconds. The presence of SRPC improves the system performance by reducing the ISE from 0.2231 to 0.1979 and settling time from 3.005 to 2.600 seconds. The controller combination of TCBR and SRPC further improves the system performance by reducing ISE value from 0.2231 to 0.1754 and settling time from 3.005 to 1.441 seconds. The variation of ISE for different controllers is also shown in Fig. A.7.

TABLE V - MODIFIED HEFFRON-PHILLIPS SMIB SYSTEM CONSTANTS

K_1	1.0307	K_2	1.242	K_3	0.313
K_4	1.9651	K_5	-0.101	K_6	0.362
K_7	0.1749	K_8	1.346	K_9	0.189
K_{10}	-0.9531	K_{11}	-5.339	K_{12}	2.260
K_{13}	0.000	K_{14}	-1.273	----	-----

Table VI The Controller Performance Index For Small Signal Disturbance

Controller	J = ISE
TGR	0.7344
PSS	0.1364
TCDB	0.2503
SSC	0.5902
PSS, TCDB	0.1325
PSS, SSC	0.1334
TCDB, SSC	0.2432
PSS, SSC, TCDB	0.1257
PSS, TCDB, SSC	0.1268

V. CONCLUSION

From the results obtained in the present paper it may be concluded that the coordinated tuning of the controllers renders in improvement of transient stability as well as small signal stability of the power systems. From the results it may also be observed that TCDB controls the peak of the transients and SSC improves the steady state error of the system response without affecting the overshoots. The comparison of performance index reveals that proposed controller comprising of TCDB and SSC renders minimum value of ISE performance index. The minimum value of ISE has been obtained for TCDB and SSC for large disturbance and for small disturbance with PSS, TCDB and SSC controller combinations. The maximum value of ISE has been obtained for PSS and SSC for large disturbance and for small disturbance with TGR. From the graphical results it is observed that the other parameters such as peak overshoot, settling time, rise time are also improved in the presence of various combinations of controllers.

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Appendix-A SMIB System Data and Response

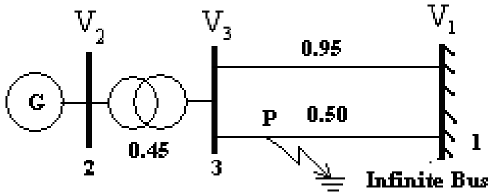

Fig. A.1 One-Line Diagram of SMIB System

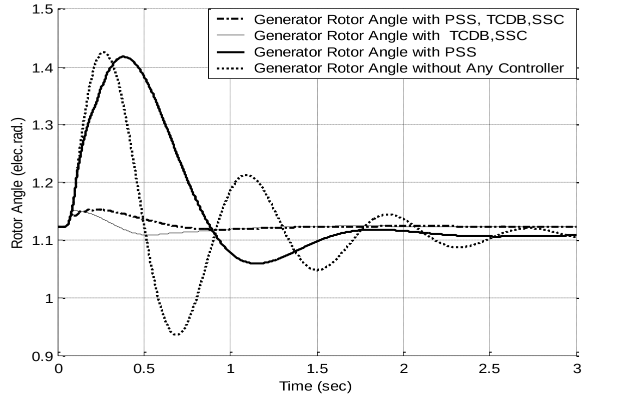

Fig. A.2. Generator rotor angle of SMIB System for different combinations of controllers.

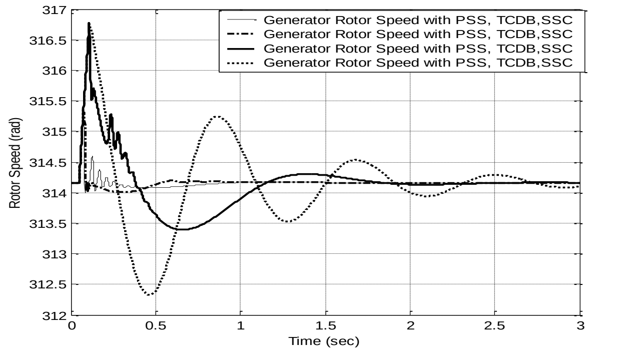

Fig. A.3. Generator rotor speed of SMIB System for different combinations of controllers.

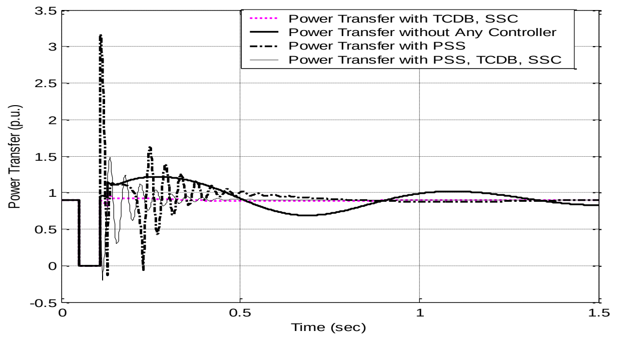

Fig. A.4. Electrical Power Transfer SMIB System for different combinations of controllers.

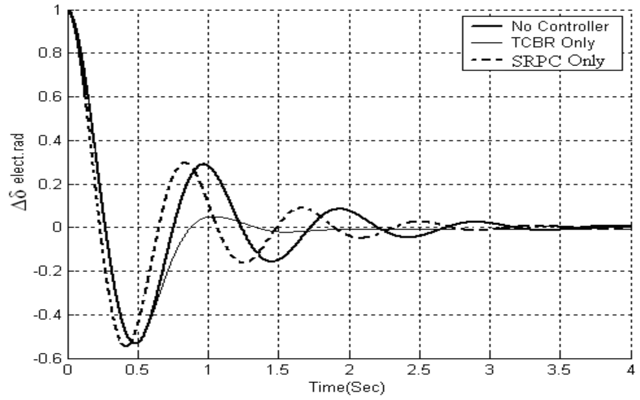

Fig. A.5. Deviation of generator rotor angle with individual tuned Controller .

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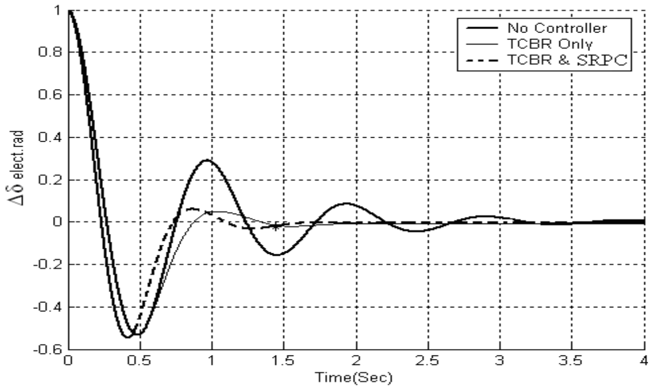

Fig.A.6. Deviation of generator rotor angle with TCBR only And SRPC tuned in the presence of tuned TCBR

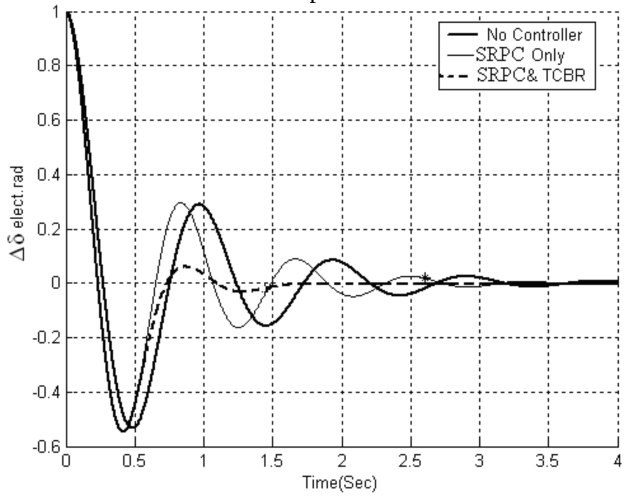

Fig.A.7. Deviation of generator rotor angle with SRPC only and TCBR tuned in the presence of tuned SRPC.

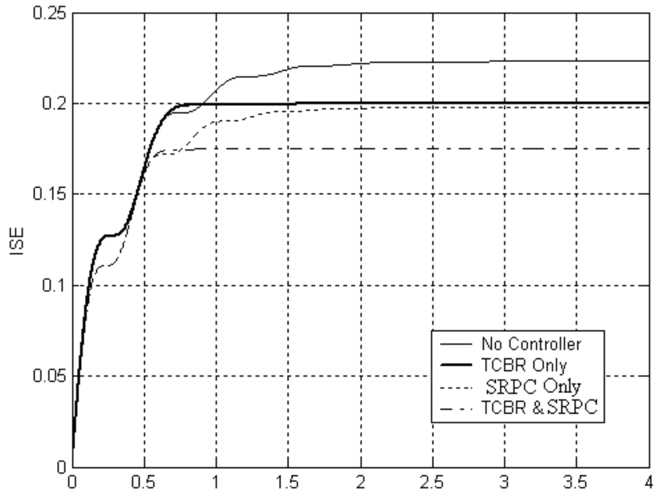

Fig.A.8. Variation of ISE with different tuned controllers.

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