Load Frequency Control of Multi Area Power System with Super Conducting Magnetic Energy Storage

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Abstract— This paper describes the Load Frequency Control (LFC) of interconnected reheat thermal system using Conventional PI Controller with SMES. The conventional proportional integral controller reduces the settling time error of the system. But it is slow and is less efficient in handling the system non-linearity like Governor Dead Band (GDB) and Generation Rate Constraint (GRC). The purpose of the AGC is to balance the total system generation against system load and losses so that the desired frequency and power interchange with neighboring systems are maintained. The automatic generation control performances have been compared with the conventional proportional integral controller and smes unit for the two-area interconnected power system considering non-linearties. Integral square error (ISE) technique is used to find the optimum integral gain. System performance is examined considering 1% step load perturbation in either area of the system. The simulation results concludes that, smes unit has better dynamic response than conventional controller, i.e. quick in operation, reduced steady state error magnitude and minimized transient frequency oscillation.

Keywords: Area Control Error (ACE), Fuzzy Logic Controller (FLC), Governor Dead Band (GDB), Generation Rate Constraint (GRC), Load-Frequency Control (LFC), Superconducting Magnetic Energy Storage (SMES)

I. INTRODUCTION

In an electrical power generation, there are plenty of concepts to be brought under discussion. The most significant factor is the concept of load frequency control. Load is actually a device that taps energy from the network. A severe stress in the system results in an imbalance between generation and load which seriously degrades the power system performance and requires considerable attention in the power system frequency control issues. The unsuppressed frequency deviation will deteriorate the performance of the equipment, degrading the performance of the transmission line capacities and can interfere with the system protection leading to an unstable condition of power system. Frequency oscillations may experience a severe stability problem in power systems which occur as a consequence of uncertainties

In most of the automatic generation control studies, the effect of the governor dead band and generation rate constraint are neglected for simplicity [13]. But for a realistic analysis of the performance of the system, these should be included as they have considerable effects on the amplitude and settling time of the oscillations. The load on the power system is seldom constant. It varies from time to time due to uncertain demands of the consumers. When there is any change in voltage beyond the permissible value, it leads to load fluctuation causing system disturbances which results in the change of desired frequency value [5]. Thus a load frequency control mechanism is employed to match the maximum demands. The difference of the signal is fed to the integrator and it is given to the speed changer which generates the reference speed for the governor [11]. Here, the tie line power is maintained constant. The real idea of the system is, to maintain the frequency and tie line power within the pre-specified limits.

This paper employs conventional control strategies using proportional integral gain ‘PI’ controller before the summing point of the governor. The ‘PI’ controller provides zero steady state frequency deviation, when it is tuned to an appropriate gain value. The gain value is optimised using a very suitable method called the Integral Square Error (ISE) method [8]. But this conventional method exhibits bit poor dynamic performance. Also the effect of non-linearities on LFC has a serious effect which may cause the system limiting cycling with periods of 30 to 90 seconds [16]. To solve this problem, superconducting magnetic energy storage (SMES), which is capable of controlling active and reactive power simultaneously, has been proposed as one of the most effective stabilizers of inter-area power oscillations. The stability of the inter-area oscillation mode is deteriorated by the heavy load condition in tie-lines especially due to the electric power exchange. Superconducting energy storage systems (SMES) represent a fascinating prospective FACTS technology as they can generate absorb active and reactive power in rapid response to power system requirements [10,14].

II. SYSTEM INVESTIGATED

The detailed block diagram modeling of two area thermal power system, for load frequency control, investigated in this study is shown in figure (1) [4]. Here, area 1 and 2 comprising reheat thermal system with governor dead Band and generation rate constraint non-linearities. Matlab version 7.3 has been used to obtain dynamic response such as frequency deviation in area 1 (ΔF1), area 2 (ΔF2) and tie line power deviation (ΔPtie) for 1% step load perturbation in either area of the system. The system has been designed for nominal frequency. Proper assumptions and approximations are made to linearize the mathematical equations which describe the system and transfer function model. The main idea of using this smes unit is to improve the dynamic performance of the system to an effective level even at the inclusion of non-linearities. The area control error is used to control the smes, when both the load and smes are connected in parallel at the generator terminal.

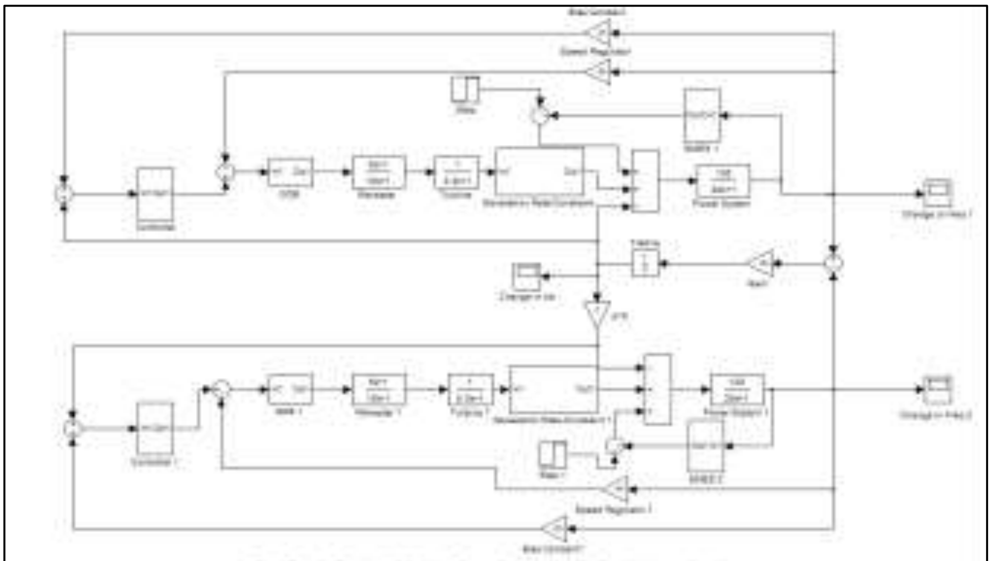

Fig. 1 Transfer Function of Multi Area Power System with Smes Considering non linearities

A. *Reheat Turbine*

In steam turbine, water is transformed into steam of high temperature and pressure in the steam generator. The heat source for the boiler supplying the steam may be a nuclear reactor or a furnace fired by fossil fuel. Steam turbines with the variety of configuration have been built depending on unit size and steam conditions [7]. They consist of two or more turbine sections or cylinder coupled in series. Each turbine section consist of a set of moving blades are called buckets. The stationary vanes, referred to as nozzle sections, forms nozzles or passages in which steam is accelerated to high velocity. The kinetic energy of this high velocity steam is converted into shaft torque by the buckets. Depending on the turbine configuration, fossil fueled units consist of high pressure (HP), intermediate pressure (IP), low pressure (LP) turbine sections. They may be of either reheat type or non reheat type. In this paper we are considering single stage reheat type thermal system. In a reheat type turbine, the steam upon leaving the HP section returns to the boiler, where it is passed through a reheater before returning to the IP section. Reheater improves efficiency. The nonreheat steam turbine gives a fast exponential response. The reheat turbine gives a fast response component due to the HP stage and a much slower LP component due to the reheat delay.

B. *Governor Dead Band*

Governor Dead Band (GDB) is defined as the total magnitude of a sustained speed change within which there is no resulting change in valve position. The Backlash non linearity tends to produce a continuous sinusoidal oscillation with a natural period of about 2s. The speed governor dead band has significant effect on the dynamic performance of load frequency control system [6]. Describing function approach is used to incorporate the governor dead band non-linearity. The hysteresis type of non-linearities is expressed as,

$$y = F(x\ \dot{x}) \text{ rather than as } y = F(x) \qquad (1)$$

To solve the non-linear problem, it is necessary to make the basic assumption that the variable x, appearing in the above equation is sufficiently close to a sinusoidal equation, that is,

$$x = A\sin \omega0\ t \qquad (2)$$

where, A is amplitude of oscillation
ω0 is frequency of oscillations
ω0 = 2π f0

As the variable function is complex and periodic function of time, it can be developed in a Fourier series as follows, [12]

$$F(x\ \dot{x}) = F0 + N1\ x + N2\ /\omega0\ \ \dot{x} + \ldots\ldots \qquad (3)$$

As the backlash nonlinearity is symmetrical about the origin, F0 is zero. From the above equation, for simplification, neglect higher order terms, the Fourier co-efficients are derived as N1=0.8 & N2=-0.2. By substituting the values in equation (3) the transfer function for GDB is expressed as follows,

$$F(x\ \dot{x}) = 0.8x - 0.2\dot{x}/\pi \qquad (4)$$

C. *Generation Rate Constraint*

In practice, there exists a maximum limit on the rate of change in the generating power. For thermal system a generating rate limitation of 0.1 p.u MW per minute is considered, [1,9] i.e.

$$\dot{P}g \leq 0.1 \text{ p.u.MW /min} = 0.0017 \text{ p.u.MW / s} \qquad (5)$$

III. CONVENTIONAL CONTROLLER

To achieve better dynamic performance and to provide accuracy, Proportional Integral (PI) controller is adopted. The main idea of implementing PI controller is to actuate the load reference point until the frequency deviation becomes zero. Integral controller provides zero steady state frequency deviation and proportional controller reduce the overshoot [2].

The load frequency controller is based upon tie line bias control where each area tends to reduce the Area Control Error (ACE) to zero. Literature survey shows that many utilities such as frequency control and voltage control use PI controller to achieve improved dynamic performance [15]. The task of load frequency controller is to generate a control signal (u) that maintains dynamic parameter at predetermined values. The control signals can be written as,

$$u1\ Kp\ \ ACE1\ \ \ Ki\ \ \ ACE1dt \qquad (6)$$

$$u2 \; K p \;\; ACE2 \;\; Ki \;\; ACE2 \, dt \qquad (7)$$

where, Kp and KI are proportional and integral gains, respectively. For conventional PI controller, the gain Kp and KI has been optimized using Integral Square Error (ISE) criterion. For ISE technique, the objective function used is,

$$J \;\; (\;\; F1F2Ptie \;)dt \qquad (8)$$

Where,
F = Change in frequency.
Ptie = Change in tie line power.

Using ISE technique, optimum proportional-integral controller gains are found to be Kp = 0.3 and KI = 0.12. By adopting the above PI gain, the two area thermal system is simulated with 1% step load disturbance in either area. The dynamic parameters such as frequency deviation in area 1, area 2 and tie line power deviation are not properly settling down with the consideration of PI controller. From the simulation results, it is found that the tie-line power deviation has high frequency oscillation around the set point. So, it is necessary to develop an alternate controller, which is capable of handling area frequency deviation and tie-line power deviation. Fig 2, 3 & 4 shows the simulation results for conventional PI controller.

IV. SMES UNIT

Superconducting Magnetic Energy Storage (SMES) unit with a self-commutated converter is capable of controlling both the active and reactive power simultaneously and quickly, increasing attention has been focused recently on power system stabilization by SMES control. The operation of smes units, which is charging, discharging, the steady state mode and the power modulation during dynamic oscillatory period are controlled by the proper positive or negative voltage to inductor [11]. The super conducting coil can be charged to a set value from the utility grid. The dc magnetic coil is connected to the ac grid through a power conversion system (PCS) which includes inverter / rectifier. When there is sudden rise in the demand of load, the stored energy is almost immediately released through the PCS to the grid as the line quality AC. Fig.5, 6 & 7 shows the simulation result for smes unit. Result shows that smes unit yields good settling time

Fig. 2 change in frequency in area 1 with conventional PI

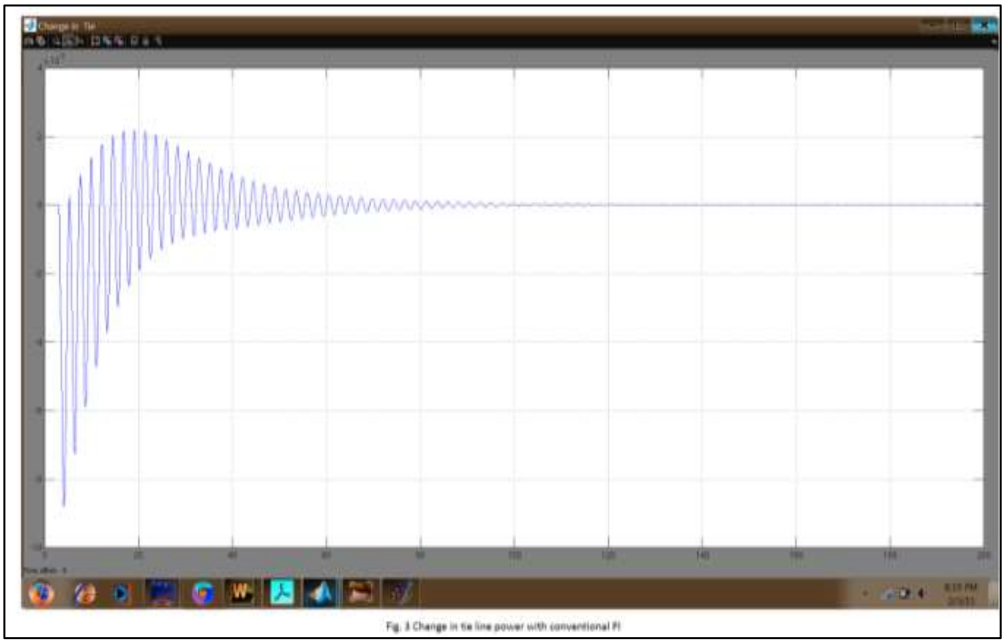

Fig. 3 Change in tie line power with conventional PI

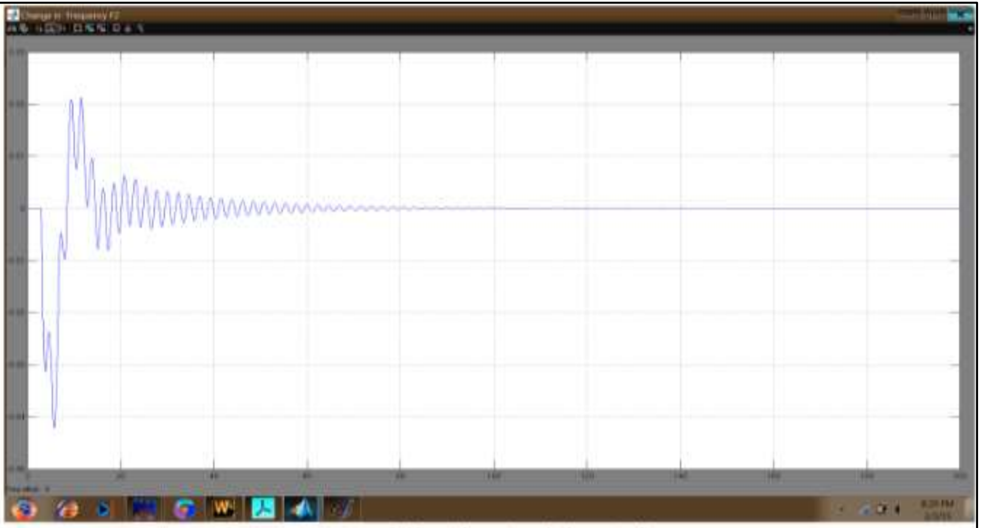

Fig. 4 Change in frequency in area 2 with conventional PI

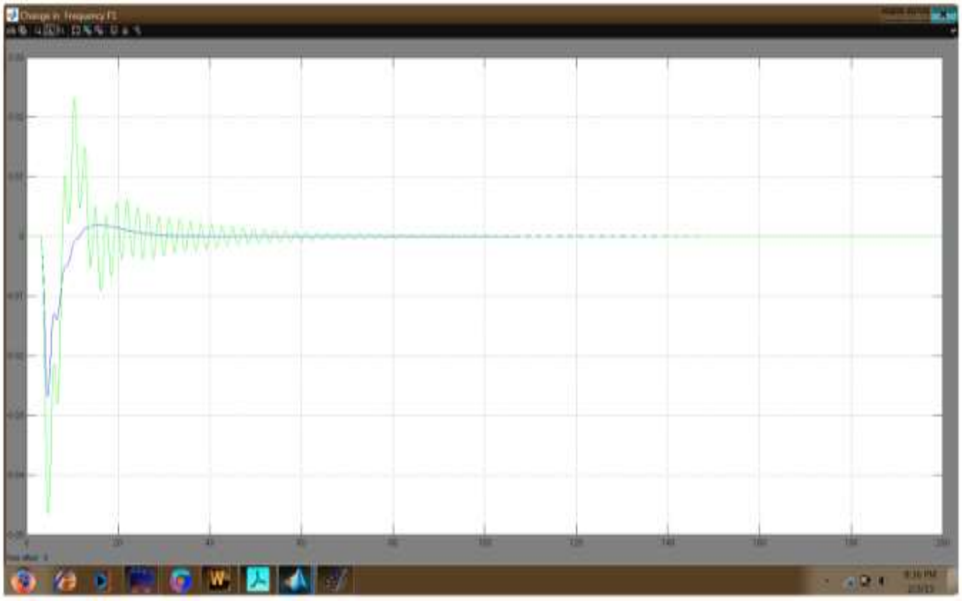

Fig.5 Change in frequency in area 1 with smes and conventional PI

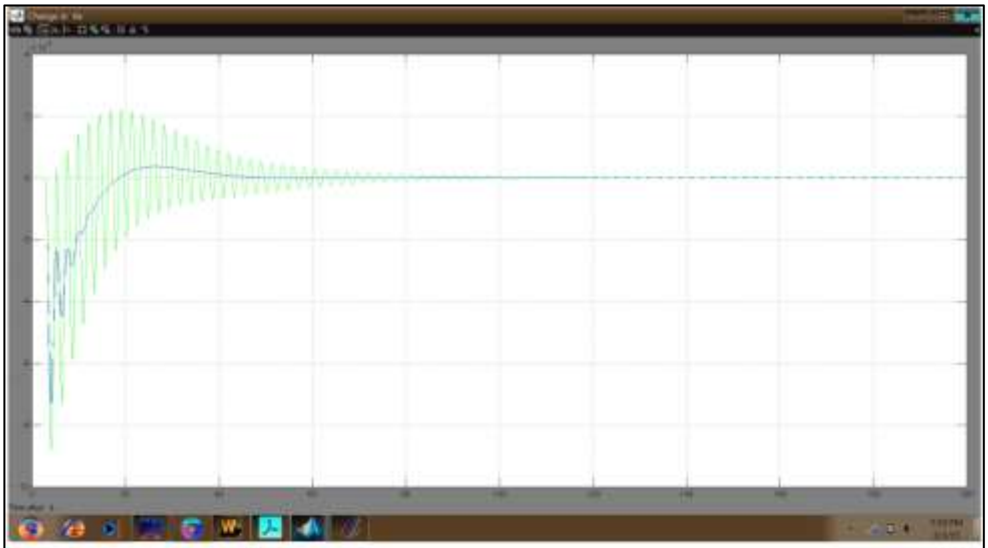

Fig.6 Change in tie line power with smes and conventional PI

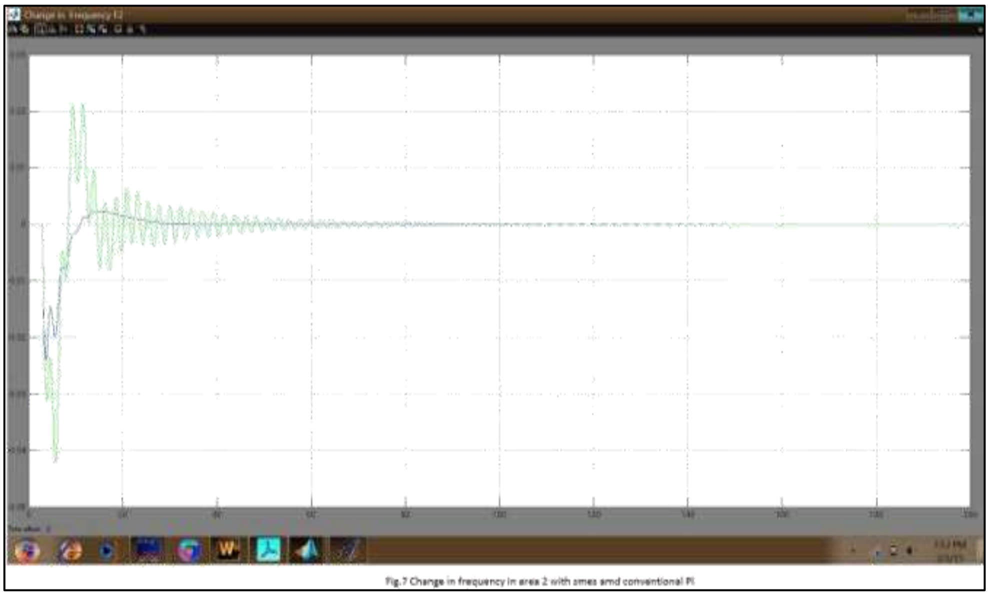

Fig.7 Change in frequency in area 2 with smes amd conventional PI

V. CONCLUSION

In this paper, two area thermal power system with generation rate constraint and governor dead band is considered for simulation purpose. The system performance is observed on the basis of dynamic parameter (i.e.) settling time. The comparison of the dynamic responses of proposed controllers is shown in table 1. The simulation result shows that the LFC yields much improved control performance with the consideration of smes when compared to conventional PI controller.

Controllers	ΔF_1	ΔF_2	ΔPtie
Conventional PI without smes	150	150	200
Conventional PI with smes	44	44	68

Table 1: Comparison Study of Settling Time

VI. APPENDIX

P_{ri} =2000 MW
T_{ti} =0.3s
T_{gi}=0.08s
K_{ri}=0.5s
T_{ri}=10s
K_{pi}=120 Hz/pu MW
T_{pi}=20 s
T_{12}=0.086
R_i =2.4 Hz/ pu MW
B_i =0.425 pu MW/Hz

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