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IMPLEMENTATION OF FUZZY LOGIC CONTROLLERS AND SMES UNITS IN THE AUTOMATIC GENERATION CONTROL OF THREE-AREA INTERCONNECTED POWER SYSTEM

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Abstract:

This paper provides an efficient method based on the fuzzy PID control scheme for the automatic generation control (AGC) of a three-area system. The model of hydel-thermal power system is established with the equations of dynamic behavior of the system. Control scheme is developed in Matlab-Simulink. Latest technology of super conducting magnetic energy storage (SMES) devices has also been studied as a supplementary energy source for the system. FLC theory together with the use of SMES units is the focus of our study for improved system dynamic response. Typical frequency and active power responses have been illustrated using the simulation techniques of the Simulink program. Results of FLC including SMES have been compared with the conventional PID controllers and it is proved that the system performance improves significantly.

1. Introduction:

The concept of power production in bulk has given importance to Automatic generation control (AGC) strategies for electrical utilities as well as IPPs because of increasing frequency oscillation and system stability problems. It helps not only in the control of power system but the reliability also improves with the use of modernized programs for feedback control of the system. During load perturbations, the control response should be such that the frequency deviations do not go past the critical limits of frequency change.

Generation in a large interconnected power system is usually the combination of hydro, nuclear, thermal and gas generation units running in parallel. Nuclear units, owing to their high efficiency, work as base load plant and gas units are usually a small percentage of power system. So the choice for AGC is either hydel and thermal units or a system containing both. In this study we have implemented the AGC scheme on a three area power system containing one hydel and two thermal power stations.

The objective of AGC is to keep the system stable by i) Regulating the system frequency and ii) Establishing the scheduled tie-line flows between the generating units. The AGC based on the Fuzzy PI type controllers has been proposed in this paper. Fuzzy logic controller which is a non-linear type model-free controller is a better choice in situations where the system has non-linearities and changing operating point. Fuzzy logic controllers are knowledge based (KB) controllers which are derived from system knowledge acquisition techniques. In this way the FLC can be viewed as a non-linear control surface which is based

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on a system operators' previous knowledge. Moreover in AGC, the problem of instantaneous mismatch of demand and supply of real power is compensated with the use of SMES devices which store energy when the system is in equilibrium and then supply the stored energy during load perturbations.

2. Literature review:

The AGC problem is being dealt for almost four decades. Major work has been performed by introducing the linear models of single and multi-area power networks [1-4].Also the effect of GRC in the commercial utilization of AGC was also introduced and in these studies both continuous and discrete models of the system were used [5]. Moreover the system models were not necessarily linear so considerable attention was given for considering the linarites in the AGC studies because without considering the linarites the stability of the system cannot be ensured [6]. In earlier days the AGC problems were considered using a central control strategy for the entire network. Some authors in [7] proposed a proportional controller. The main limitation of this strategy was that information was hard to exchange over widely spread complex network. The decentralized control philosophy appeared to deal with this problem and much work was done both with the use of continuous as well as discrete system model. Extended research work has been done for AGC schemes of interconnected networks [8].

Later in AGC methodology, the use of digital networks increased because of their accuracy, reliability and flexibility. The researchers focussed on producing more digital schemes and this field evolved. Ross [9] first developed digital AGC regulator which was first detailed direct regulator. ACE in digital networks can be calculated by sampling the frequency error signal and also the tie-line signals. The effect of sampling was investigated by Bohn and Miniesy [10]. New ACE is deduced in discrete model of a reheat thermal system based on frequency and tie-line control and also including time error and other changes. This stability margin was used in the development of PI controllers and then the performance was compared with step loads with both conventional and new Area control error [11]. Adaptive and self-tuning techniques of Artificial intelligence have been helpful in AGC of systems with non-linarites. Fuzzy logic theory diverts from the conventional theory based on the mathematical models. Controller is not designed quantitatively but instead this technology adopts the control methodology of system operators and experts. Studies which are based on this fuzzy philosophy in the AGC of electrical power have appeared in the literature [12]. Considerable work is also done in the AGC of interconnection of AC and DC transmission systems [13]. In these studies some work has been dedicated for the regulator design of parallel AC &DC. The use of fast acting BES (battery energy storage) for AGC regulations has been studied to dampen out oscillations due to sudden system changes [14]. The use of SMES in the LFC has been introduced in [15] including the system dynamics and use of ACE as control signal. Static var compensators (VAR) have also been studied to be helpful in damping the electro-mechanical load stresses during AGC control [16].

3. Conventional PI Controller:

Conventional controllers are the mathematical models deduced with the formulation of proportional and integral functions to bring the error signal to zero. The formulation with the K_p, the proportional multiplier and K_i, the integral multiplier, is given below:

$$U = K_p e + K_i \int e dt \tag{1}$$

The value of K_p and K_i are calculated for the optimized system performance based the system parameters. The proportional term when multiplied with the error gives the system response direction based on the error function. The second term is the integral term and its value makes sure that the steady state error is always zero. These controllers have good performance which has enabled them to be used in AGC schemes over many years. But with the advent of expert systems and use of sophisticated control systems, the performance has been improved with these modernized controllers.

4. Fuzzy Logic Controller:

In this paper the proposed solution strategy to the AGC problem is the use of FLC with SMES. Parameter estimation for a non-linear system is not required in FLC because it is a model free approach. The PID Controller is modified with a two input fuzzy PID controller. In the design of fuzzy logic controller, work is done in three steps namely: defining the areas of inputs in fuzzy environment, defining the rules for the fuzzy universe based on system control history and then the output is defuzzified to real form and fed as feedback signal to the system. The input to the FLC is ACE which is calculated by the rate of frequency change and the rate of tie-line power deviations and then their effect is combined in a single term.

$$\text{ACE} = \text{Tie-line power error} + \beta * \text{frequency change error} \quad (2)$$

Here β is frequency bias. ACE represents the mismatch of generation and required system demand.

(A) Allocation of Area of Inputs

ACE is the main input to the FLC and it is the main component for the AGC strategy. The ACE and dACE are the factors which determine the amount of control action. They are defined into a seven membership functions of control areas based on the magnitude and their signs. They are namely: NB, NM, NS, Z, PS, PM, PB.

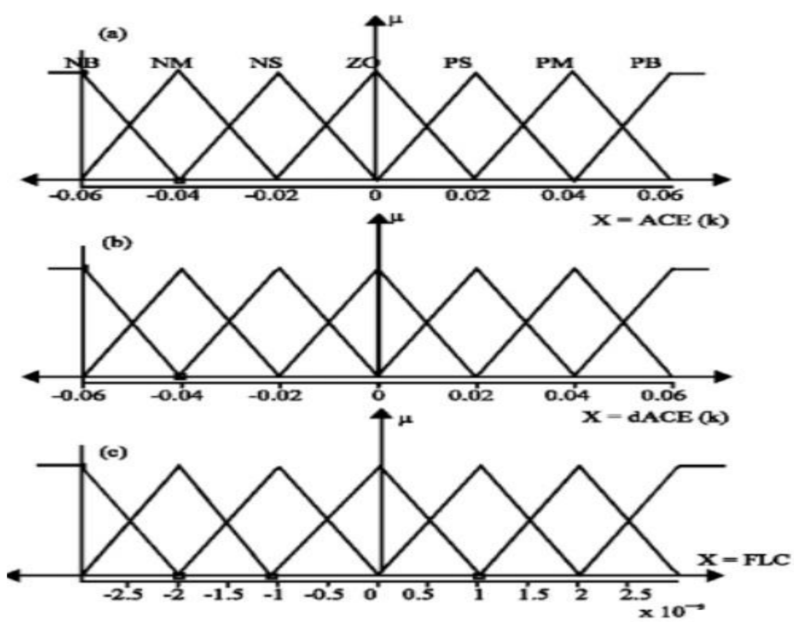

Figure 1: Fuzzy Membership Functions for inputs ACE, ΔACE and Output X

(B) Fuzzy Rules

Fuzzy rules are defined as statements which give a conditional result representing the relationship of the defined fuzzy sets. They are based on the control history of the respective system under analysis. They are described as if-then rules. The output response is continuously monitored and then the control action is maintained in quantitative constraints based on these rules. The rules are interpreted in the following pattern:

"If ACE is NB and dACE is NS then output is taken as PM" or "If ACE is PS and dACE is PM then output is taken as NM".

ACE

ΔACE	**NB**	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	PB	PB	PB	PB	PM	PM	PS
NM	PB	PM	PM	PM	PS	PS	PS
NS	PM	PM	PS	PS	PS	PS	ZO
ZO	NS	NS	NS	ZO	PS	PS	PS
PS	ZO	NS	NS	NS	NS	NM	NM
PM	NS	NS	NM	NM	NM	NB	NB
PB	NS	NM	NB	NB	NB	NB	NB

Table 1: Fuzzy Logic Rules for the Fuzzy Output

The output of the fuzzy inference process is then defuzzified. "Mamdani" method is employed in Simulink which calculates the aggregated value of the output functions and then "centroid" method gives us a single value which represents a new operating point of the power system.

5. Super Conductor Magnetic Energy Storage Devices

SMES devices help in controlling the fluctuations of electrical frequency by supplying active energy when load demand suddenly increases. In this way they act as supplementary source of energy and improve stability marging.

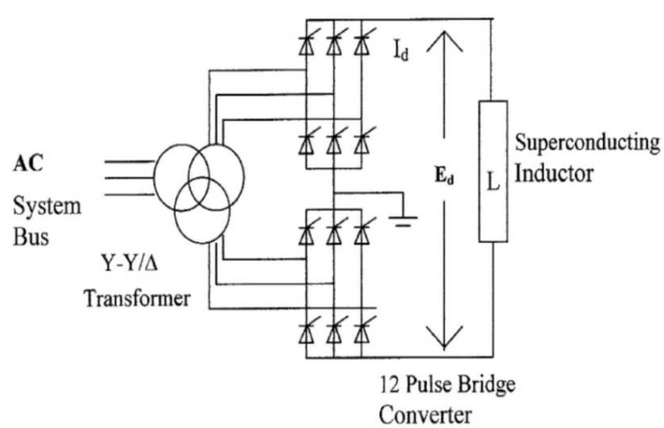

Figure 2: SMES Schematic Representation

We have used SMES devices as supplementary source of energy because they help in stabilizing the system in load perturbations. They act as energy sink when the system frequency rises. They consume a very low power for their operation. Real power change as result of the change in the inductor current and inductor voltage of the SMES unit is given in the relationship below:

$$\Delta P_{smi}(t) = \Delta E_{di} I_{di} + \Delta E_i I_{di}$$
(3)

The ΔP value remains positive when power is interchanged form system to the DC coil of SMES and it is negative when the process is reversed.

6. System Investigated

Power system is a large interconnected network of different generating units having individual control areas and thus they have complicated non linear models for each unit. In power system under observation, we have two thermal reheat power turbines and one hydel generating unit having individual loads and inter-connected by tie-lines.

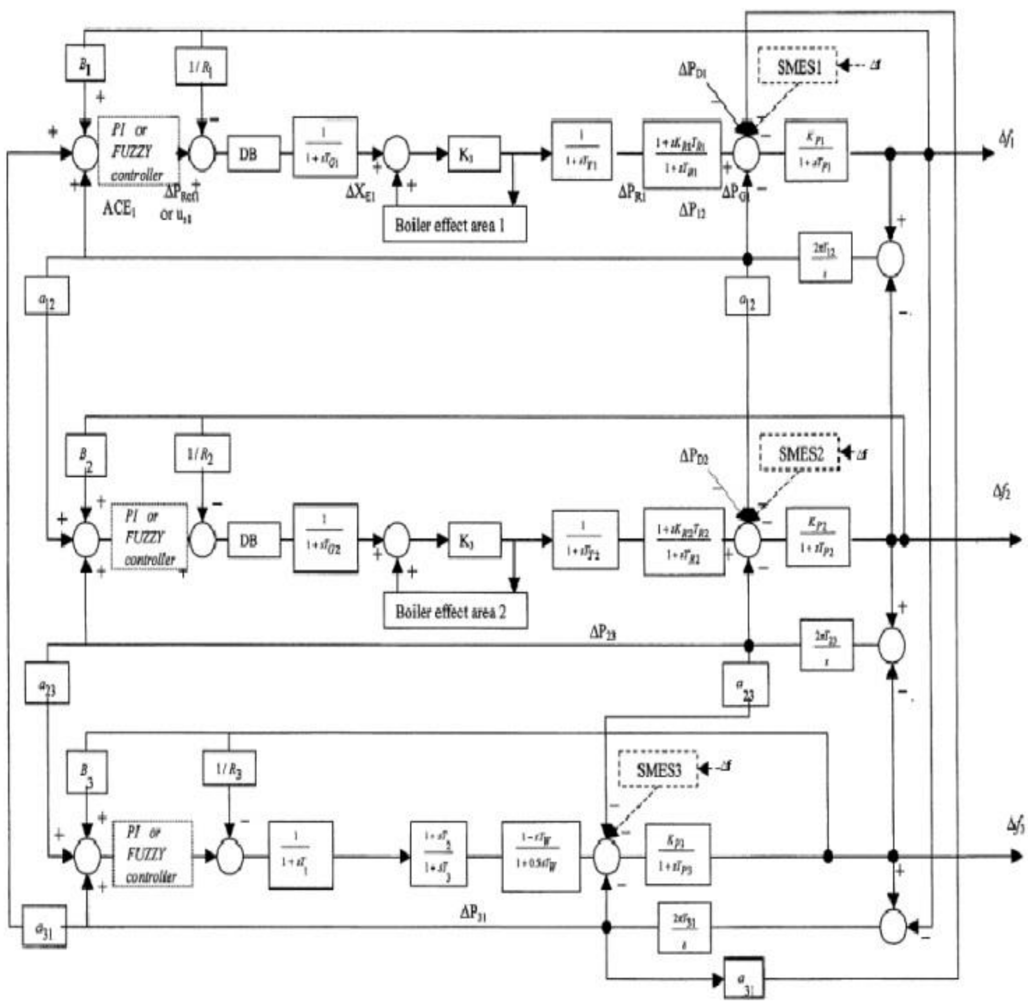

Figure 3: Three-Area Power System Investigated with both PI and FLC including SMES

Effects of generation rate constraints and SMES units are investigated. Generation rate constraint is the design limitation for maximum rate of generation for AGC purpose. GRC and SMES units are included in the control area of each generating unit. ACE and dACE are given as input to the Fuzzy PID controller. Steam and hydro turbine response, governor and boiler effect are included for each of hydel and thermal units. The system parameters are given in detail in Appendix. They are derived for a system of Area1=Area2=2000MW and Area3=1500MW.

7. Simulation Results

Case 1:

Load demand of step change is applied across the Area 1 of both PID controlled system and FLC controlled systems with SMES. Two separate simulation results show the comparison of PID with fuzzy and PID with Fuzzy SMES. In fig.5 the tie line interchange power flow ΔP_{23} and ΔP_{31} is shown and in fig.4 the frequency deviations Δf_1, Δf_2 and Δf_3 of all three areas as a result of load step change are shown.

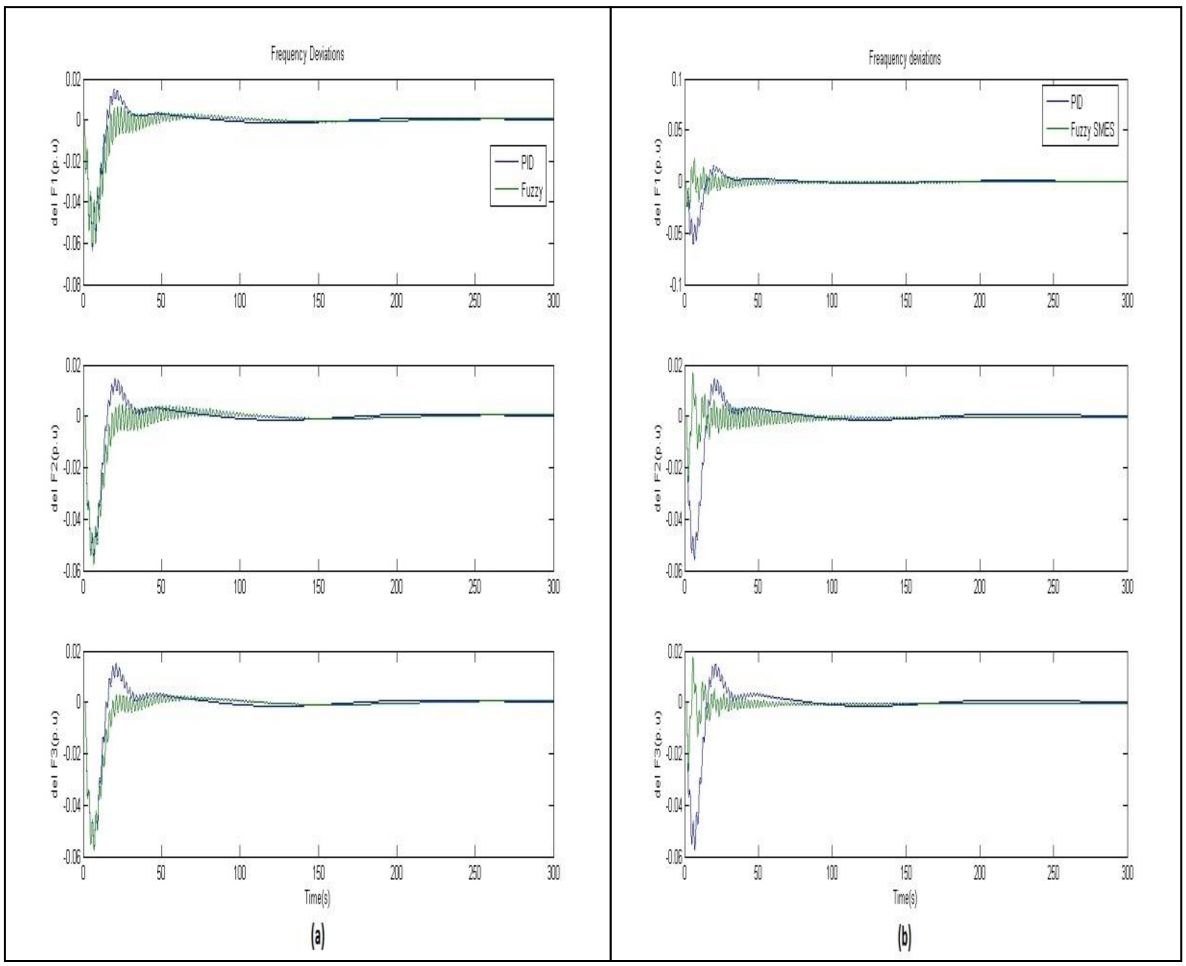

Figure 4: Frequency Change after step load disturbance in first area Δf_1, Δf_2 and Δf_3 Comparison of (a) PID and FLC (b) PID and FLC with SMES

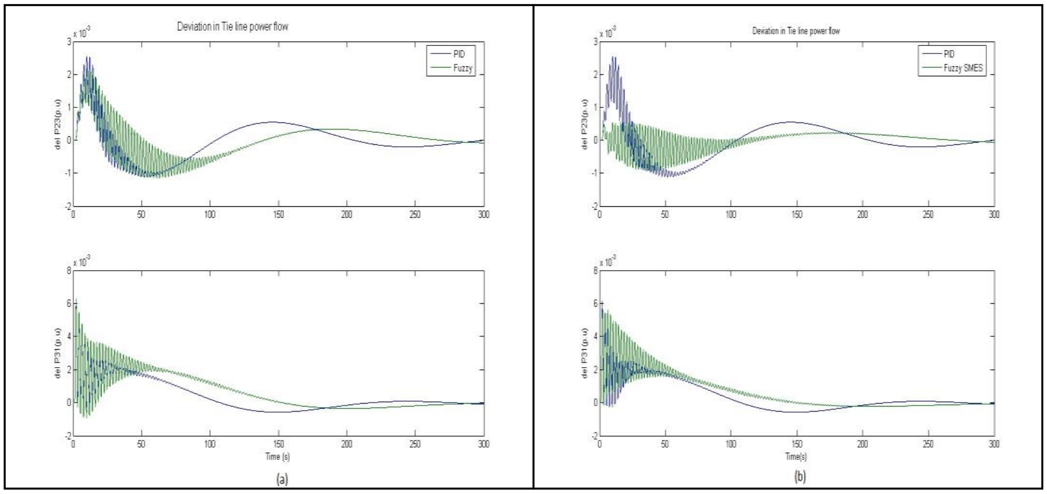

Figure 5: Tie line Interchange ΔP_{23} and ΔP_{31} (a) PID and FLC (b) PID and FLC with SMES

Case 2:

Load demand of step change is applied across the Area 3 of both PID controlled system and FLC controlled systems with SMES. Two separate simulation results show the comparison of PID with fuzzy and PID with Fuzzy SMES. In fig.7 the tie line interchange power flow ΔP_{23} and ΔP_{31} is shown and in fig.6 the frequency deviations Δf_1, Δf_2 and Δf_3 of all three areas as a result of load step change are shown.

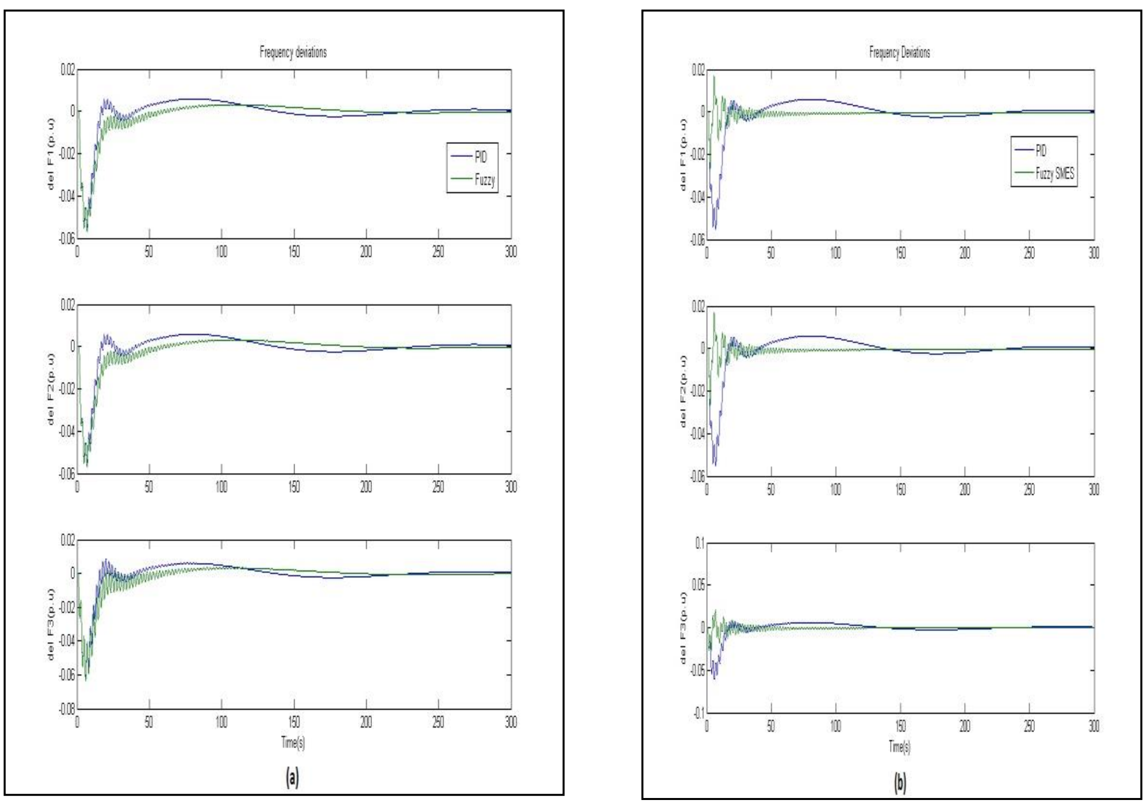

Figure 6: Frequency Change after step load disturbance in third area Δf_1, Δf_2 and Δf_3Comparison of (a) PID and FLC (b) PID and FLC with SMES

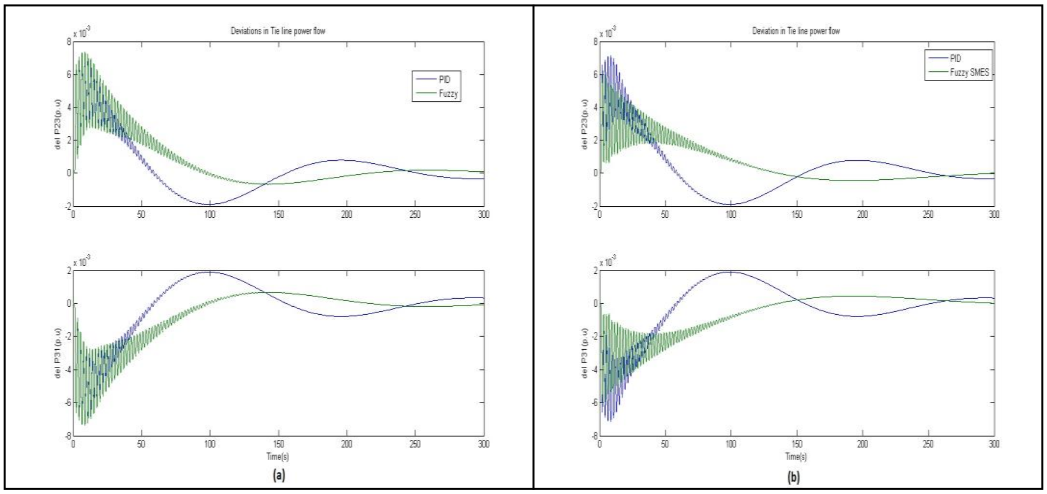

Figure 7: Tie line Interchange ΔP_{23} and ΔP_{31} (a) PID and FLC (b) PID and FLC with SMES

Case 3:

Load demand of step change is applied across the Area 1&2 of both PID controlled system and FLC controlled systems with SMES. Two separate simulation results show the comparison of PID with fuzzy and PID with Fuzzy SMES. In fig.9 the tie line interchange power flow ΔP_{23} and ΔP_{31} is shown and in fig.8 the frequency deviations Δf_1, Δf_2 and Δf_3 of all three areas as a result of load step change are shown.

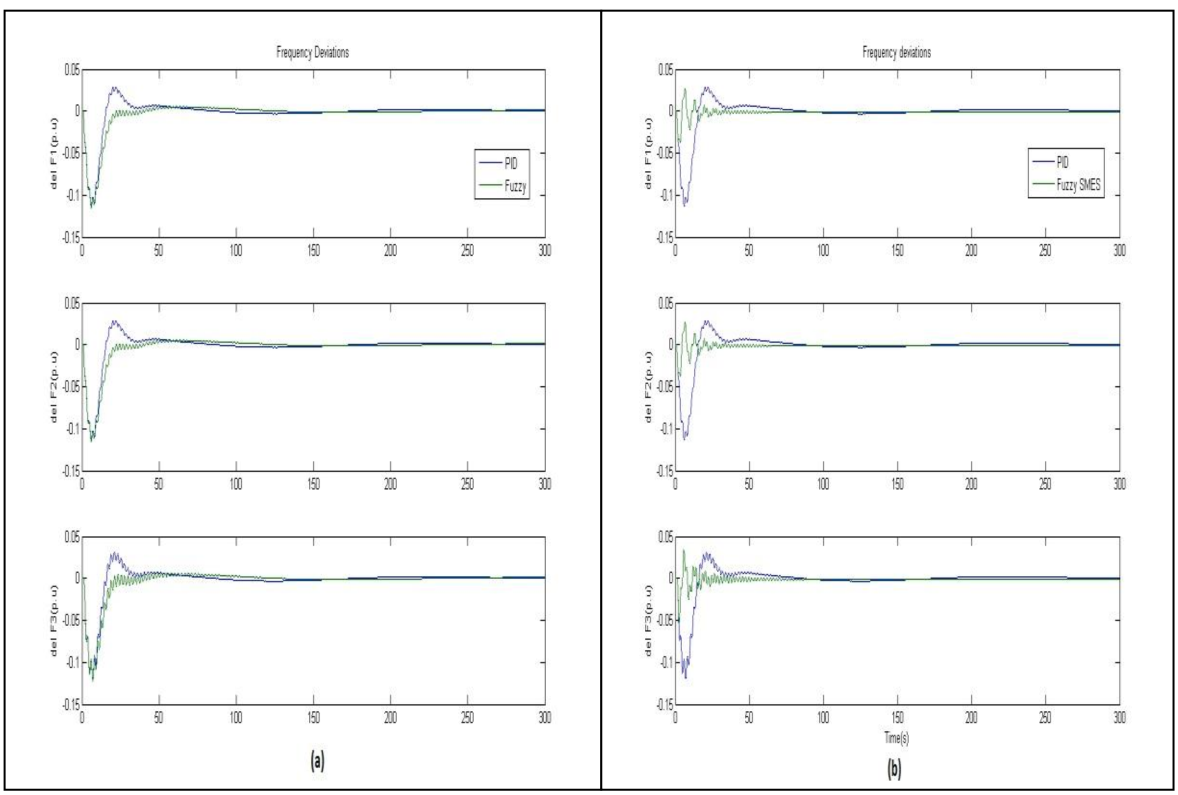

Figure 8: Frequency Change after step load disturbance in Area1&2 Δf_1, Δf_2 and Δf_3 Comparison of (a) PID and FLC (b) PID and FLC with SMES

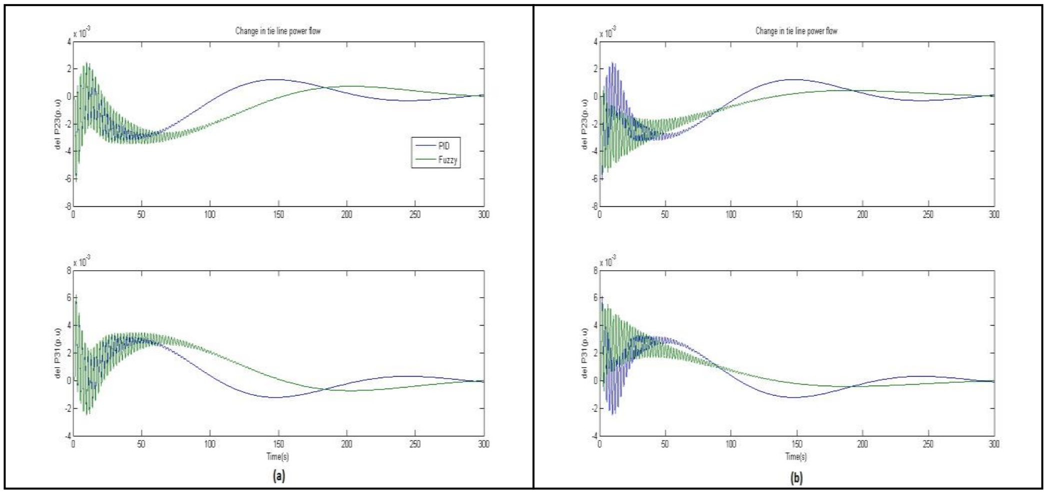

Figure 9: Tie line Interchange ΔP_{23} and ΔP_{31} (a)PID and FLC (b) PID and FLC with SMES

8. Conclusion and Future Scope

Significant element of this study is that we have been able to apply Fuzzy control theory in combination of modern day SMES technology applications. System has been designed taking into account all the important dynamics. Generation rate constraints, turbine reheat, boiler effect and governor response have also been taken into account. Frequency deviations and the settling time are the indicators of the performance of the controller keeping the tie-lines within their scheduled values. Step load perturbation is applied for system investigations. PID controllers, due to the fixed gain values, lag behind in their performance as shown by the frequency deviation graphs.FLC is robust in its performance and the results show that the settling time of frequency deviation is less compared to the PID controllers. Also the initial maximum overshoot from the zero is also less for FLC.

In all three cases above, the simulation results are carried out considering the impact of SMES together with the FLC. Results show that the system response improves significantly to damp out the frequency oscillations in all three cases. Tie-line interchanges also improve. System is in stability in lesser time compared to the system with only PID and fuzzy controller under varying operating conditions. SMES is the online storage strategy which augments the performance of intelligent controllers. The graphical results show the optimal output it gives when system is under huge load stresses. System constraints like GRC affect the controller performance but then SMES helps to reduce the effect of these constraints. Number of membership functions affects the system performance. Seven membership functions used in FLC give best performance with lesser calculations.

In future, work needs to be done to bring down the critical temperature values of superconducting materials with the advent of new conducting alloys. This will help in the development of SMES which will be more feasible economically and technically. Also more work needs to be done for the development of expert systems like neural networks together with supplementary storage devices in addressing the AGC problem.

9. Appendix

Nominal Frequency (f)=50Hz, P_{r1} & P_{r2}=2000MW, P_{r3}=1500MW, Reheat time constant (T_r)=10sec, Inertia constant (H1=H2)=5sec, Reheat constant(K_r)=0.5, Governor speed regulation parameter (R_1, R_2)= 2.4 Hz/unit MW, Steam governor time constant (T_g)=0.08sec, Steam turbine time constant (T_t)= 0.3 sec, Water starting time (T_w)= 1.0

sec, Proportional Gain (K_p)=1, Derivative Gain (K_d)=4, Integral Gain (K_i)=5, Load Frequency Coefficient ($\Delta P_d/\Delta f_i$)= D_1=D_2=0.0083 MW/Hz, $2H_i/f^*D_i$ (K_{pi})=20 sec, $1/D_i$ (T_{pi})= 120 Hz/p.u MW, Tie line Power ($P_{tie\ Max}$)=200 MW.

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