Automatic Generation Control with Z-N Tuned PID Controller in the Two Area Power System with Energy Storage Unit

Pratap Chandra Pradhan[1], Nibedita Satapathy[2], Prasanta Kumar Pany[3], Jayakrushna Moharana[4]

Associate Professor, Dept. of EE, DRIEMS, Cuttack, Odisha, India[1]

Assistant Professor, Dept. of EE, DRIEMS, Cuttack, Odisha, India[2]

Professor, Dept. of EE, ABIT, Cuttack, Odisha, India [3]

Professor, Dept. of EE, HIT, BBSR, Odisha, India[4]

ABSTRACT: The Automatic Generation Control is the main control in power system to match the generation with demand. Power system size and the type of load, makes the AGC more important. In this work Hydro plants and thermal plants are taken into consideration. Two models are developed using MATLAB/SIMULINK. Single area thermal power system is one. Similarly, thermal plant and hydro plant are considered as separate areas and they are connected with tie-line to form two area hydro thermal system. When the systems are subjected to load change of 1%, there is variation in frequency and tie-line power which can be reduced by using secondary controller. PID controller is used in this paper as secondary controller. The different controller parameters for single area and two area power system are tuned by Z–N method. The concept of SMES unit applied to AGC has also been made. Apart from the secondary controller, Superconducting Magnetic Energy Storage device is used for frequency control in two area power system. The results are compared to determine the performance of the system with SMES and different controllers using SIMULINK.

KEYWORDS: AGC, PID, SMES, ACE, Ziegler-Nichols (Z–N).

I. INTRODUCTION

The main aim of power system utility is to sustain uninterrupted supply of electrical power with an acceptable quality, to the consumers in the system. The power system will be in equilibrium, when there is a balance between demand and generation. There are two fundamental control mechanisms used to attain reactive power balance and real power balance. The former is called Automatic Voltage Regulator and latter is called Automatic Generation Control (AGC) [1]. The purpose of AGC in an interconnected system is to reduce the variation in frequency, tie-line power exchange and their steady state errors to be zeros [2]. It is not possible to retain the balances between generation and demand without control. Therefore, a control system is necessary to cease the effects of the random load changes and to keep the frequency at the normal value. The AGC loop always regulates the real power output of the generator to match with the varying load [3]. Cohn [4] discussed the significance of tie line power and frequency and tie line bias control for interconnected power system. The innovative idea of optimal control for LFC of multi area power system was discussed by O.I.Elgerd [5]. R. K. Green [7] suggested a new formulation of LFC principles. He also discussed about transformed LFC, which is having the ability to remove the requirement of bias setting by controlling directly the set point frequency of each unit. Mohd. Hassan et. al. [8] reviewed the total overview and potential use of SMES in power systems. Praghnesh Bhatt et. al. [9] presented the comparative discussion on the combination of TCPS-SMES, SMES-SMES and SSSC-SMES on a two area hydro-hydro power system. R.K. Sahu et. al. [11] explained a new hybrid Differential Evolution and Pattern Search optimized fuzzy PI/PID controller for Load Frequency Control of multi-area power system. When the speed governing system is unable to absorb the frequency variation due to its slow response,

active power source with fast response such as SMES is very effective in enhancing the expected performance of the system [12,13].

Literature survey shows that, the performance of the power system depends on the controller structure and the methods used to optimize the parameters of controller and also the use of SMES has been found outrightly.

So, this paper highlights the analysis of Single area thermal power system and AGC of a two-area hydrothermal power system considering storage unit like SMES in area-1. Area 1 consists of a nonreheat turbine and area 2 consists of a hydro unit.

In simulation, a step load variation of 1% of the nominal loading is considered in Single area as well as two area power system. For comparison, the following power systems are considered:

a) Single area Thermal power system

     i. Conventional integral controller

     ii.ZN-P, ZN-PI and ZN–PID controller.

From the result it observed that ZN –PID controller is superior than conventional controller, as the objective of this paper.

b) Two area hydro thermal power system

     i. ZN –PID controller without SMES,

     ii. ZN –PID controller with SMES in area-1.

From the result it observed that the performance of ZN –PID controller with SMES in area-1 is better than without SMES, as the other main objective of this paper.

The system parameters are given in the Appendix. Model of single area power system (thermal) is shown in figure 1. Two-area AGC system block diagram with SMES in area-1 is shown in figure 2.

II. MATERIAL AND METHOD

A. Power system model

Single area thermal system

In a single area system, the role of the AGC is only to bring the frequency to the nominal value. This will be achieved using the secondary loop. Secondary loop uses the controller to change the reference power setting so as to change the speed set point. The controller gain needs to be tuned for better response of the system. In this paper Single area Thermal power system is considered. The model is developed using SIMULINK [15] which is shown in figure 1. The different types of controllers like Integral, P, PI, and PID are used in single area power system. The parameter values of P, PI, PID controllers for the power system are tuned by ZN method.

Two area hydro thermal system

An interconnected power system can be divided into number of control areas connected by tie-lines. In each control area, all generators are tightly coupled together to form a coherent group. Some of the areas in the power system are experimented having load disturbances of same magnitudes. Each control area should strive to deliver its own load and tie-lines permit electric power to flow between areas. Hence, a load disturbance in one of the areas influences the output frequencies of other areas and power flows on tie-lines. Due to the above the control system of the areas wants information about all areas to bring the frequency to its nominal value.

In present work, two area hydro-thermal model has been considered for AGC studies which is shown in figure 2. The model is developed using SIMULINK [1-2, 15].

B. Modeling of SMES in AGC

The SMES circuit diagram is shown in figure 3. In the SMES, a dc magnetic coil is connected to the ac grid through a Power Conversion System which consists of an inverter/ rectifier. The superconducting coil can be charged from the grid during normal operation of the power system. After the superconducting coil gets fully charged, it conducts current with no losses [8, 12–13] because the coil is maintained at low temperatures. When there is a sudden increase in the load demand, the stored energy is supplied through the PCS to the power system as alternating current. Since the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the coil current changes back to its initial value. Similarly during release of loads the coil immediately gets charged towards its full value. So it absorbs some amount of the excess energy in the system and when the system returns to its steady state, the excess energy absorbed is released and the coil current attain to its usual value.

The control of the converter firing angle α provides the dc voltage appearing across the inductor to be continuously varying within a certain range of positive and negative values. Initially the inductor is charged to its rated current I_{d0} by applying a small positive voltage. When the current meets its rated value, it is maintained to be constant by decreasing the voltage across the inductor to zero because the coil is superconducting.

By neglecting the converter and the transformer losses. The dc voltage is given below

$$E_d = 2V_{d0} \cos\alpha - 2I_d R_C \qquad (1)$$

where E_d is the dc voltage applied to the inductor in kV, α is the firing angle in degrees, I_d is the current flowing through the inductor in kA, R_C is the equivalent commutating resistance in kΩ and V_{d0} is the maximum circuit bridge voltage in kV. Charging and discharging of the SMES unit is controlled through the change of commutation angle α. If α is less than 90^0, converter acts in the converter mode (charging mode) and if α is greater than 90^0, the converter acts in the inverter mode (discharging mode).

SMES control strategy

When power is to be pumped back into the grid in the case of a decrease in frequency, the control voltage E_d is to be negative because the current through the inductor and the thyristors cannot change its direction. The incremental change in the voltage applied to the inductor is expressed as

$$\Delta E_d = \left[\frac{K_{SMES}}{1+S\,T_{DC}} \right] ACE_1 \qquad (2)$$

where, ΔE_d is the incremental change in converter voltage; T_{DC} is the converter time delay ; K_{SMES} is the gain of the control loop and ACE_1 is the input signal to the SMES control logic.
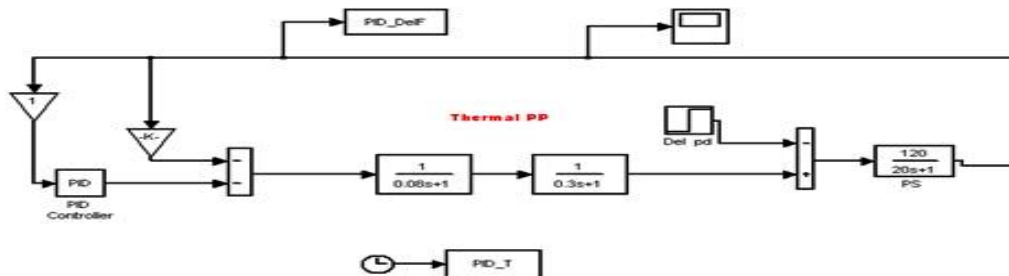

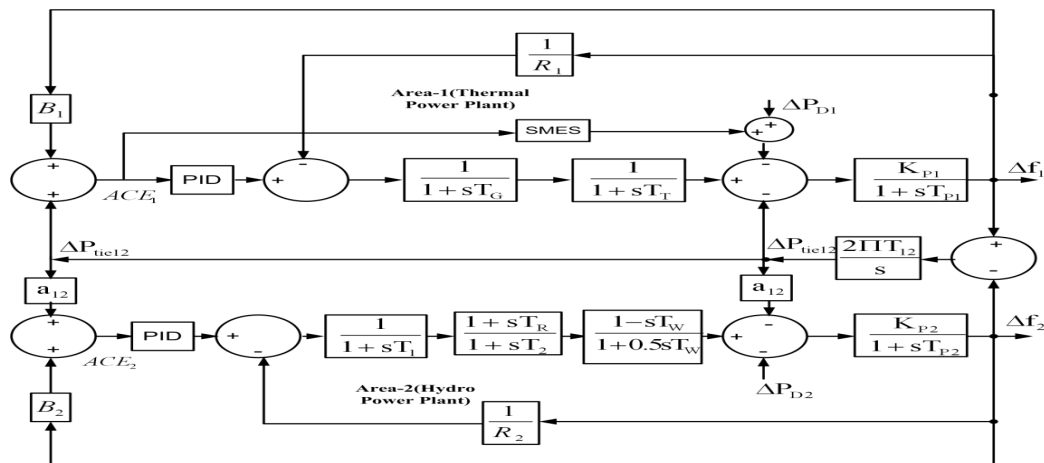Figure1. SIMULINK model of single area power system(thermal)

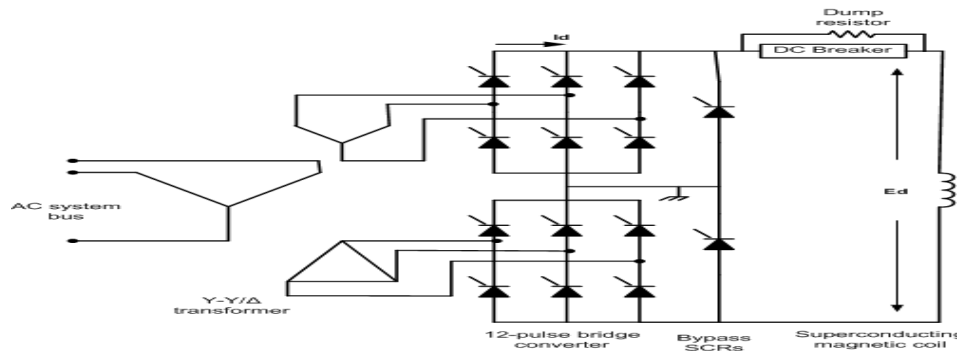Figure 2. Two-area AGC system block diagram with SMES in area-1

Figure 3. SMES circuit diagram.

The inductor current deviation is given in Eq. (3)

$$\Delta I_d = \frac{\Delta E_d}{sL} \qquad (3)$$

In the present work, area control error (ACE) of area 1 is considered as the input signal to the SMES control logic (i.e., ACE_1). The area control error of the two areas are expressed as

$$ACE_i = B_i \, \Delta f_i + \Delta P_{tie \, ij}, \quad i, j = 1,2 \qquad (4)$$

Where Δf_i is the change in frequency of area i and ΔP_{tieij} is the change in tie-line power flow out of area i – j. So, from Eqs. (2) and (4),

$$\Delta E_d = \left[\frac{K_{SMES}}{1 + S \, T_{DC}} \right] (B_1 \, \Delta f_1 + \Delta P_{tie \, 12}) \qquad (5)$$

Note that $ACE_1 = (B1 \, \Delta f_1 + \Delta P_{tie12})$. However, it is presented in [12-13] that, the inductor current in the SMES unit will return to its nominal value very slowly only by use of Eq. (5). But, the inductor current must be restored to its nominal value very fast after a system disturbance so that it can respond to the next load disturbance instantly. Therefore, the inductor current deviation can be sensed and used as a negative feedback signal in the SMES control loop for current restoration to its nominal value for improvement. SIMULINK model of SMES unit with the negative inductor current deviation feedback is shown in figure 4. Therefore, the dynamic equations for the inductor voltage deviation and current deviation of the SMES unit is given below

$$\Delta E_d = \frac{1}{1 + S \, T_{DC}} [K_{SMES}(B_1 \, \Delta f_1 + \Delta P_{tie \, 12}) - K_{id} \, \Delta I_d] \qquad (6)$$

C. Controller structure

PID controllers are useful and most accepted controllers in industrial applications due to their robustness and easy to design and make economic. PID controllers provided in each area to control the frequency which is shown in figure 5.

III. TUNING OF PID CONTROLLER BY ZIEGLER -NICHOLS (Z-N) METHOD

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. It was developed in 1942 by John G. Ziegler and Nathaniel B. Nichols.

A. Ziegler - Nichols closed - loop   tuning method

The Ziegler-Nichols closed-loop tuning method use the ultimate gain value K and the ultimate period of oscillation T, to calculate K_p, K_i and K_d. It is a easy method of tuning PID controllers and can be refined to give better approximations of the controller.
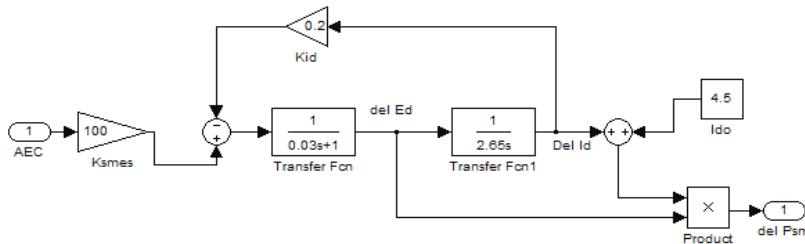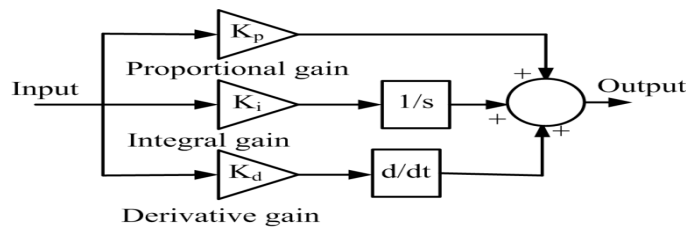
Figure 4. SIMULINK model of SMES unit

Figure 5 Structure of PID controller.

The K_p, K_i and K_d can be obtained for a system with feedback. The Ziegler-Nichols closed-loop tuning method is restricted to tuning processes that cannot run in an open-loop environment [10, 14].

Determining the final gain value K is accomplished by finding the value of the proportional gain that causes the control loop to oscillate indefinitely at steady state. This means that the gains of the integral and derivative controller are set to zero. It tests the robustness of the K_p value so that it is optimized for the controller. One more important value associated with this proportional control tuning method is the ultimate period (T). The ultimate period is the time required to complete one full oscillation when the system is at steady state. These two parameters, K and T, are used to determine the loop-tuning constants of the controllers (P, PI, or PID). Put these values into the Ziegler-Nichols closed loop equations shown in table 1 and find out the necessary settings for the controller.

Table 1. Controller parameters using Ziegler–Nichols Method

Control type	K_p	K_i	K_d
P	0.5 K	-	-
PI	0.45 K	$1.2K_p/T$	-
PID	0.60 K	$2K_p/T$	$K_p T /8$

With the above method, the parameter values of K and T are obtained as 2.2735 and 0.9583 respectively for single area thermal system. These two parameters, K and T, are used to determine the loop-tuning constants of the controller (P, PI, or PID) which is given in the table 2.

Table 2. Controller parameters for single area thermal system using Z-N method.

Control type	K_p	K_i	K_d
P	1.1367	0	0
PI	1.023	1.2811	0
PID	1.3641	2.8469	0.1634

Similarly for two area hydro-thermal system with and without SMES the value of K and T parameters are obtained as -1.4888 and 3.8 respectively. These two parameters, K and T, are used to determine the loop-tuning constants of the PID controller, which is given in the table 3.

Table 3. PID controller parameters using Z-N method.

Control type	K_p	K_i	K_d
PID	-0.8933	-0.4701	-0.4243

IV. RESULTS AND DISCUSSIONS

A. Comparison response of single area thermal system with conventional controller and ZN Tuned Controllers:

Figure 6 gives the simulated responses for the single area thermal system with conventional controller and ZN tuned controllers with 1% load disturbance. The conventional integral controller is tuned by trial and error method and its parameter value is taken as $K_i = 0.79$.

From the comparison response shown in Figure 6, it's clear that minimum peak value and minimum settling time are achieved by ZN-PID controller than conventional controller or ZN-P or ZN-PI controller.
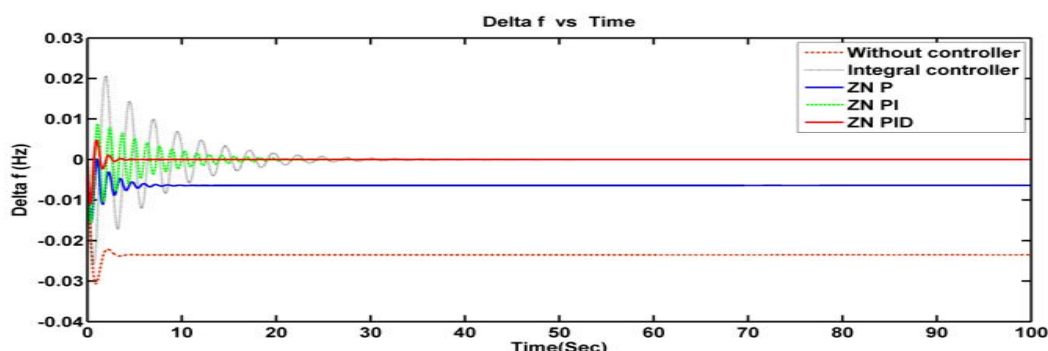

Figure 6. Comparison response of single area thermal system with conventional controller and ZN tuned controllers.

B. Response of two area hydro-thermal system with and without SMES

   Without SMES
The system is subjected to load disturbance of 1% in area-1(Thermal power plant) and area-2 (Hydro power plant). Its simulated response of frequency deviation and tie- line power deviation are shown in figure 7.

   With SMES
The system is subjected to load disturbance of 1% in area-1(Thermal power plant) and area-2 (Hydro power plant) and SMES is connected in area-1 alone. Its simulated response of frequency deviation and tie- line power deviation is shown in figure 8.
       From the responses shown in figure 7 and 8, it can be observed that, the behavior of area frequencies and tie-line power have enhanced significantly in terms of deviation and settling time in the presence of SMES.

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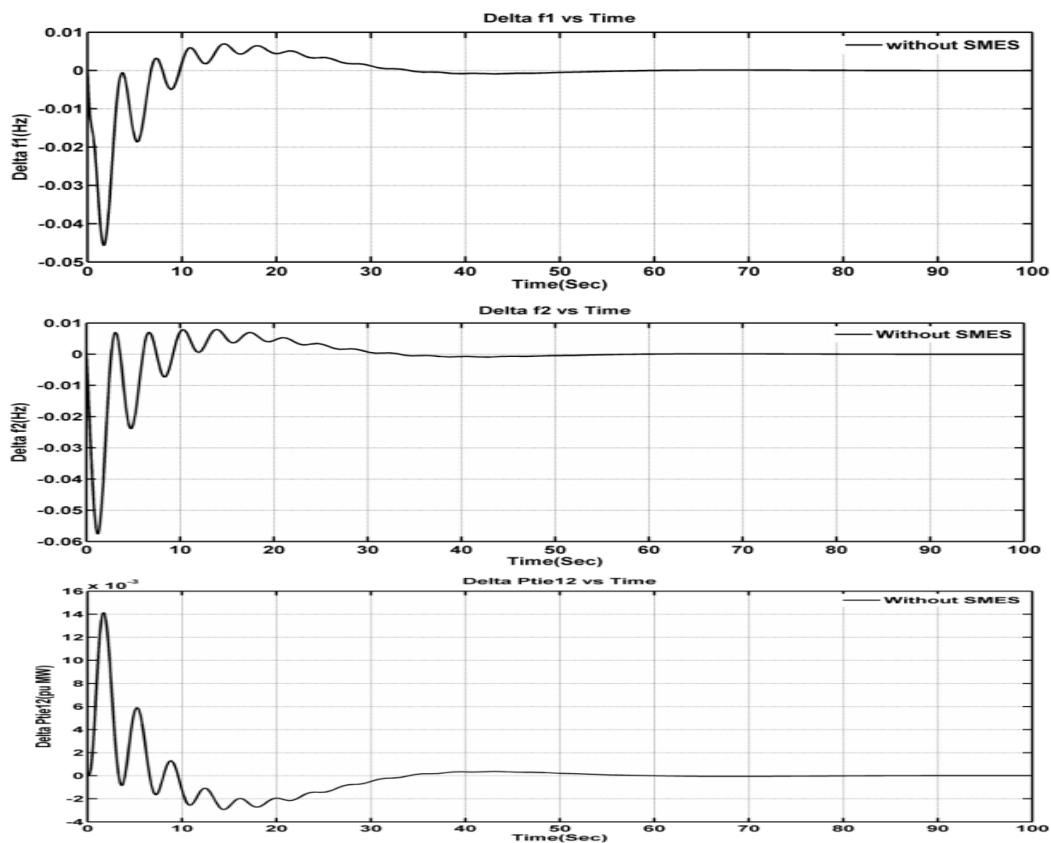
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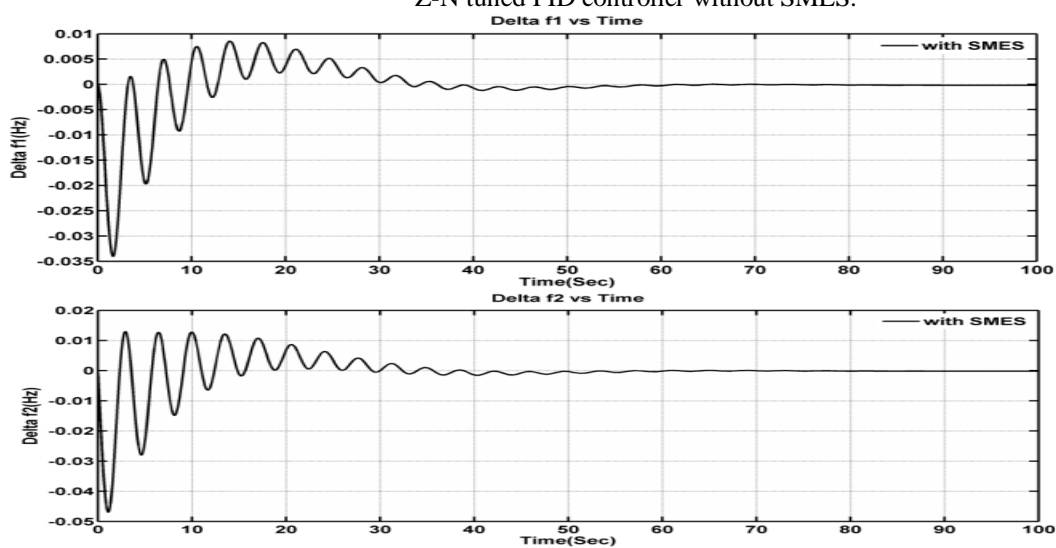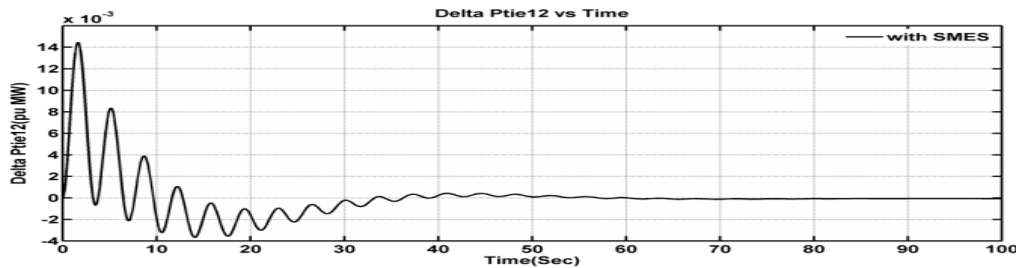
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Figure 7. Dynamic responses for Δf_1, Δf_2 and ΔP_{tie12} with 1% step load disturbance in thermal area and hydro area with Z-N tuned PID controller without SMES.

Figure 8. Dynamic responses for Δf_1, Δf_2 and ΔP_{tie12} with 1% step load disturbance in the thermal area and hydro area with Z-N tuned PID controller and SMES in thermal area.

V. CONCLUSION

The single area power system and two area power system were developed using SIMULINK. In single area power system, the comparison result shows that minimum peak value and minimum settling time are achieved by ZN-PID controller than conventional controller or ZN-P or ZN-PI controller. The PID secondary controllers for two area hydro-thermal system have been tuned using ZN method. It is evident that, the AGC performance of two area power system with SMES unit in the area-1 is improved. It is observed that, energy storage device like SMES, is able of taking up the momentary oscillations in the area frequencies and the tie-line powers following a load disturbance. It is further observed that ZN tuned PID controller with SMES provides better response in terms of less peak and less settling time.

APPENDIX

A. System data

$K_{p1}=K_{p2}$= 120 HZ/MW, $R_1=R_2$= 2.4 HZ/P.U.MW, $T_{p1}=T_{p2}$ = 20s, T_T= 0.3 s, T_1= 41.6 s, T_2= 0.513 s, T_{12}= 0.0866, T_R= 5 s, T_W= 1 S, T_G= 0.08 s, $B_1=B_2$= 0.4249, $P_{R1}=P_{R2}$=1200 MW, $D_1=D_2$= $8.333*10^{-3}$ p.u.MW/HZ.

B. SMES data

L = 2.65 H, K_{id}= 0.2 KV/KA, T_{DC}= 0.03 s, K_{SMES} = 100 kV/unit MW, I_{d0}= 4.5 K..

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