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A self tuning approach for AGC in two area thermal power systems with super conducting magnetic energy storage device

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ABSTRACT

Since 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. In this paper investigates the self tuning control scheme for SMES is proposed and applied to Automatic Generation Control (AGC) in power system. The system is assumed to be consisting of two areas. The proposed self-tuning control scheme is used to implement the automatic generation control for load frequency control application adding to conventional control configuration. The effects of the self tuning configuration with Fuzzy Proportional Integral Controller (FPIC) in AGC on SMES control for the improvement of Load Frequency Control (LFC) is compared with that of PI controlled AGC. The effectiveness of the SMES control technique is investigated when Area Control Error (ACE) is used as the control input to SMES. The computer simulation of the two-area interconnected power system shows that the self tuning FPIC control scheme of AGC is very effective in damping out of the oscillations caused by load disturbances in one or both of the areas and it is also seen that the FPIC controlled SMES performs primary frequency control more effectively compared to PI controlled SMES in AGC control

Introduction

Automatic Generation Control is a very important subject in power system operation for supplying sufficient and reliable electric power. This is achieved by AGC. In an interconnected power system, as the load demand varies randomly, the area frequency and tie-line power interchange also vary. The load frequency control by only a governor control imposes a limit on the degree to which the deviations in frequency and tie-line power exchange can be decreased. However, as the LFC is fundamentally for the problem of an instantaneous mismatch between the generation and demand of active power, the incorporation of a fast acting energy storage device in the power system can improve the performance under such conditions. To achieve a better performance, many control strategies are proposed in literature [1-3]. Because of non-linear nature of power system, the controller designed for operation around a point based on a linear model obtained by linearization is insufficient. The operation point of a power system may change because of changing loads during the day period. In this situation, a fixed gain controller that is optimal at an operation point may not be suitable in another operating point [3]. Therefore, variable structure controller [4–5] has been proposed for AGC. For designing these control techniques, the perfect model is required which can track the state variables and satisfy system constraints. Therefore, it is difficult to apply these adaptive control techniques to AGC in practical implementations.

When a small load disturbance in any area of the interconnected system occurs, tie-line power deviations and power system frequency oscillations continue for a long duration, even in the case with optimized gain of integral controllers. To damp out the oscillations in the shortest possible time, automatic generation control including SMES unit is used. In the proposed self tuning system, the effect of FPIC in AGC on SMES control is investigated for the improvement of LFC. This is met when the control action maintains the frequency and the tie-line power interchange at the scheduled values. For this, the area control error (ACE) is used as the input to the SMES controller. The ACE is obtained from tie line power flow deviation and the frequency deviation weighted by a bias factor as shown in

$ACEi = \Delta Ptie,i\ j + Bi * \Delta f$ (1)

where the suffix i refer to the control area and j refer to the number of generator. As the dynamic performance of the AGC system would obviously depends on the value of frequency bias factors, ,and integral controller gain value, KI, the optimal values of the integral gain of the integral controllers are obtained using Integral Squared Error (ISE) technique as shown in (2), where the detail of the performance index is explained in [6]. A characteristic of the ISE criterion is that it weights large errors heavily and small errors lightly. The quadratic performance index is minimized for 1% step load disturbance in either of the areas for obtaining the optimum values of integral gain settings. In this study, it is seen from Fig. 1 that, in the absence of dead-band and generation rate constraints, the value of integral controller gain, KI = 0.34, and frequency bias factors, =0.4, occurs at ISE = 0.0009888. The Optimal Integral Controller Gain, KI and Frequency Bias Factor, B without DB and GRC For PI controller, the integrator gain (KIi) of the supplementary controller is chosen as the fixed optimized value. And in FPIC technique the supplementary controller output (ΔPref) is scheduled to optimized value with fuzzy logic controller according to load disturbance. So it compromise between fast transient recovery and low overshoot in dynamic response of the

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system. It is seen that SMES with FPIC performs primary frequency control more effectively in AGC compared to that with fixed gain PI controller for load frequency control of multi-area power system.

$$\text{ISE} = \int_0^T (\Delta Ptie + \Delta f1 + \Delta f2$$

The model system configuration

The model of a two-area power system suitable for a digital simulation of AGC is developed for the analysis as shown in Fig. 2. Two areas are connected by a weak tie-line. When there is sudden rise in power demand in one area, the stored energy is almost immediately released by the SMES through its power conversion system. As the governor control mechanism starts working to set the power system to the new equilibrium condition, the SMES coil stores energy back to its nominal level. Similar is the action when there is a sudden decrease in load demand. Basically, Fig. 2. Typical Simulation Model of Two-Area System the operation speed of governor-turbine system is slow compared with that of the excitation system. As a result, fluctuations in terminal voltage can be corrected by the excitation system very quickly, but fluctuations in generated power or frequency are corrected slowly Since load frequency control is primarily concerned with the real power/frequency behavior, the excitation system model will not be required in the analysis [7]. This important simplification paves the way for the required digital simulation model of the example system of Fig. 4. The modeling and control design aspects of SMES are separately described in detail. The presence of zero-hold (ZOH) device in Fig.2 implies the discrete mode control characteristic of SMES. All parameters are same as those used in [6].

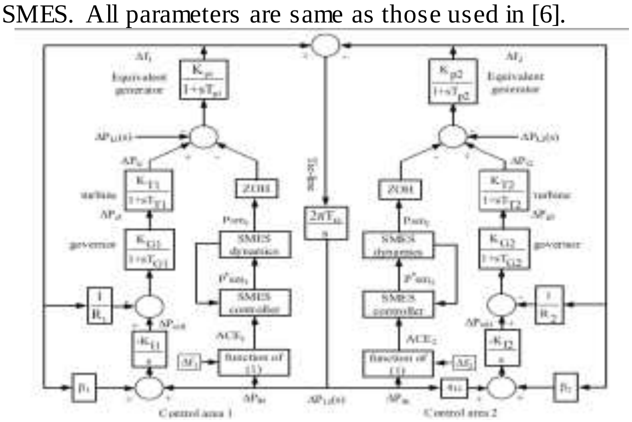

Fig.1: Typical simulation model of Two area thermal system

SMES System

The schematic diagram in Fig.3 shows the configuration of a thyristor controlled SMES unit. The SMES unit contains a DC superconducting coil and a 12-pulse converter, which are connected by Y–Δ/Y–Y transformer. The superconducting coil is contained in a helium vessel. Heat generated is removed by means of a low-temperature refrigerator. The energy exchange between the superconducting coil and the electric power system is controlled by a line commutated converter Fig. 3 The schematic diagram of SMES unit The superconducting coil can be charged to a set value from the grid during normal operation of the power system. Once the superconducting coil gets charged, it conducts current with virtually no losses, as the coil is maintained at extremely low temperatures. When there is a sudden rise in the load demand, the stored energy is almost released through the converter to the power system as alternating current. As 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 sudden release of loads, the coil immediately gets charged towards its full value, thus absorbing some portion of the excess energy in the system and as the system returns to its steady state, the excess energy absorbed is released and the coil current attains its normal value The control of the converter firing angle provides the dc voltage Ed appearing across the inductor to be continuously varying within a certain range of value, it is maintained constant by reducing the voltage across the inductor to zero since the coil is superconducting. Neglecting the transformer and the converter losses, the DC voltage is given E =2V cαo-s2I R (3)

Where Ed is DC voltage applied to the inductor (kV), α is firing angle (°), Id is current flowing through the inductor (kA). Rc is equivalent commutating resistance (Ω) and Vd0 is maximum circuit bridge voltage (kV). Charge and discharge of SMES unit are controlled through c hange o f c ommutation a ngle α I f α i s l ess then 90°,converter acts in converter mode and if α is greater than 90°, the converter acts in an inverter mode (discharging mode).

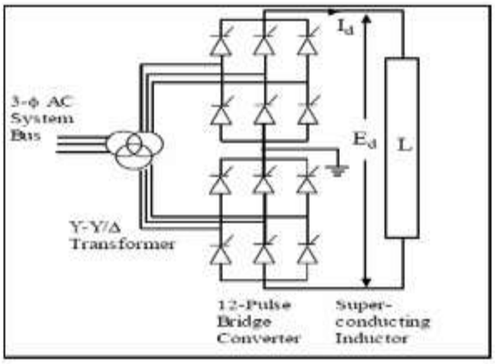

Fig.2: The schematic diagram of SMES Unit

Control of SMES unit

In LFC operation, the dc voltage Ed across the superconducting inductor is continuously controlled depending on the sensed Area Control Error (ACE) signal. In this study, inductor voltage deviation of SMES unit of each area is based on ACE of the same area in power system Moreover; the inductor current deviation is used as a negative feedback signal in the SMES control loop. So, the current variable of SMES unit is intended to be settling to its steady state value. If the load demand changes suddenly, the feedback provides the prompt restoration of current.

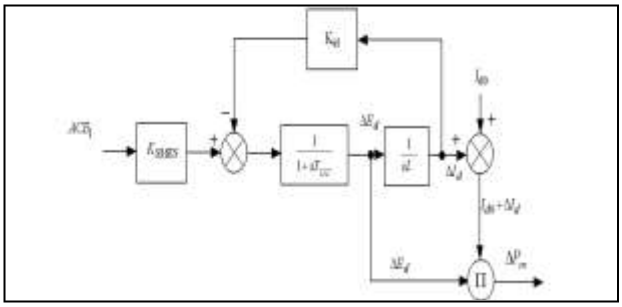

Fig.3: SMES Block diagram with inductor current deviation feed back

The inductor current must be restored to its nominal value uickly after a system disturbance, so that it can respond to the next load disturbance immediately. Fig. 4 shows the block diagram of SMES unit. Fig. 4 Block diagram of SMES unit The equations of inductor voltage deviation and current deviation of

SMES unit of area i (i=1,2,…N) in Laplace domain are as follow.
ΔE (s) = K 1 [B Δf (s) +ΔP (s)]-K 1 ΔI (s)
1+sT 1+sT
ΔI (s) = 1 ΔE (s) sL (5)
where ΔEdi is the incremental change in converter voltage (kV), ΔIdi is the incremental change in SMES current (kA), KIdi is the gain for feedback ΔId*i* (kV/kA), Tdci is converter time delay(s), K0i is gain constant (kV/unitACE) and Li is inductance of the coil (H). The deviation in the inductor real power of SMES unit is expressed in time domain assmi di di0 di di ΔP (t) = ΔE I + ΔI ΔE (6)

This value is assumed positive for transfer from ac grid to dc. The energy stored in SMES at any instant in time in is given as foll ows 2 i di smi
W (t) = L I
2 (MJ) i=1,….3 (7)

Fuzzy Logic Controller

The general practice in the design of a LFC is to utilize a PI controller. A typical conventional PI control system this gives adequate system response considering the stability requirements and the performance of its regulating units. In this case the response of the PI controller is not satisfactory enough and large oscillations may occur in the system [8-9]. For that reason, a fuzzy PI controller is designed and implemented in this study. The AGC based on FLC is proposed in this study. One of its main advantages is that controller parameters can be changed very quickly by the system dynamics because no parameter estimation is required in designing controller for nonlinear system. Therefore a FLC which represents a model-free type of nonlinear control algorithms could be a reasonable solution There are many possibilities to apply fuzzy logic to the control system. The fuzzy logic structure for the all controller design can be seen in fig 6. There are four main structures in a fuzzy system: the fuzzifier, the inference engine, the KB and defuzzifier. The first stage in the fuzzy system computations is to transform the numeric into fuzzy sets. This operation is called fuzzification.From the point of view of fuzzy set theory, the inference engine is the heard of the fuzzy system. It is the inference engine that performs all logic manipulations in a fuzzy system. A Fuzzy system KB consists of fuzzy IF-THEN rules and membership functions characteristics the fuzzy sets. The result of the inference process is an output represented by a fuzzy set, but the output of the fuzzy system should be a numeric value. The transformation of a fuzzy set into a numeric value is called defuzzification. In addition, input and output scaling factor are needed to modify the universe of discourse. Their role is tune the fuzzy controller to obtain the desired dynamic properties of the process controller loop. In this paper, the inputs of the proposed Fuzzy controllers are ACE, and change rate in ACE(as shown in fig.4,which is indeed error (e) and the derivation of the error( ) of the system, respectively).

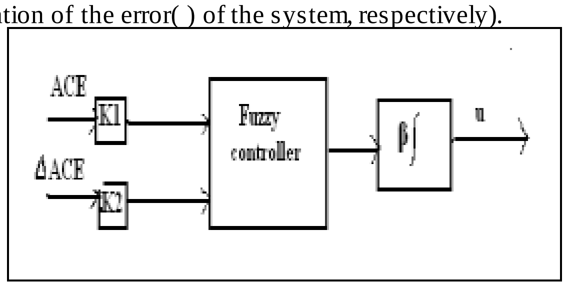

Fig.4: The PI type fuzzy controller

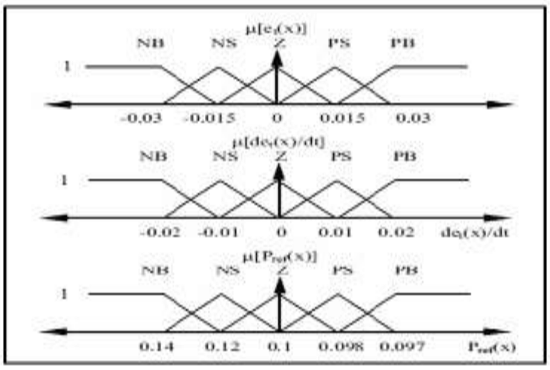

Fig.5:.Membership function for the fuzzy variable

This gives us a fairly good indicator of the general tendency of the error. Many fuzzy controller structures based on various methods have been presented. The most widely used methods in the practice is the Mamdani method proposed by Mamdani and his associates who adopted the min-max compositional rule of interference based on an interpretation a control rule as a conjuction of the antecedent and consequent. It is natural to apply the conventional theory, to solve the nonlinear problem of fuzzy controller and much work has been done in this direction. Conventional controllers are derived from control theory techniques based on mathematical models of open-loop process to be controlled. For instance, a conventional proportional-integral (PI) controller can be described by the function U= Kpe +Ki (8) According to the conventional automatic control theory, the performance of the PI controller is determined by its proportional parameter Kp and integral parameter Ki [13]. The proportional term provides control action equal to some multiple of the error, while the integral forces the steady state error to zero. Since the mathematical models of most process systems are type 0, obviously there would be steadystate error if classical PD fuzzy controller controls them Whenever the steady-state error of the control system is eliminated, it can be imagined substituting the input (of the fuzzy controller behaving like a parameter time-varying PI controller; thus the steadystate error is removed by the integration action. However, these methods will be hard to apply in practice because of the difficulty of constructing fuzzy control rules.Usually,fuzzy control rules are constructed by summarizing the manual control experiences of an operator who has been controlling the industrial process skillfully and sucessfully.The operator intuitively regulates the executer to control the process by watching the error and the change rate of the error between output of the system and the set- point value given by the technical requirement. It is no practical way for operator to observe the integration of the error of the system. Therefore it is impossible to explicitly abstract fuzzy control rules from the operator's experience. Hence, it is better to design a fuzzy controller that possesses the fine characteristics of the PI controller by using only ACE and (. 7 The control input to the plant can be approximated by u = (9) Where is the integral constant, or output scaling factor. Hence, the fuzzy controller becomes a parameter time-varying PI controller. The controller is called as PI-type fuzzy controller, and the fuzzy controller without the integrator as the PD-type fuzzy controller. The type of the FLC obtained is called Mamdani type which has fuzzy rules of the form If ACE is *Ai* and ACE is *Bi* THEN u is *Ci* = 1,2,2,…n Fig.5.Membership function for the fuzzy variable Here *Ai* , *Bi* ,*Ci* are the fuzzy sets. The triangle membership functions for each fuzzy linguistic values of the ACE and ACE are shown in Fig.8 in which

NB,NS, Z,PB,PS represent negative big, negative small, zero, positive big, positive small respectively. Also set of fuzzy rules is shown in Table I.

Table I. Rule base

ΔACE / ACE	NB	NS	Z	PS	PB
NB	PS	NB	NB	NS	NS
NS	NS	NS	NB	NS	NS
Z	NB	NS	Z	NS	PB
PS	NB	Z	NS	PB	NB
PB	Z	NS	NS	NB	PB

Simulation Results

To demonstrate the beneficial damping effect of the proposed controller, computer simulations have been carried out for different load changes using the MATLAB environment. The system performances with FPIC and PI controlled AGC with and without SMES units are shown in Fig. 9 through Fig.13 Three case studies are conducted.

Case -1: a step load increase of pL1=0.1 p.u. MW is applied in area 1 only.

Case-2: same step load increase pL1 = pL2=0.1 p.u, in both area.

For the case–I, it is seen from Fig. 9 that with SMES, the tie power deviation significantly decreases with the addition of the proposed FPIC, but when PI controller is used in AGC ,the SMES can not compensate properly.

For this tie power deviation can not be reduced to zero quickly. As the load increase in both areas is same for case-II, the tie power deviation is zero as shown in Fig10.

It is seen from Fig. 13 to Fig. 14 that when the proposed FPIC including SMES units are used, the damping of the system frequency is improved significantly and settles to the nominal value quickly.

From Figs. 13-14 it is also clear that the proposed FPIC system can reduce the real power compensation more than that in the PI control system.

Table II Shows the Comparison of Performances Between the Fuzzy-PI Controller and Conventional PI Controller with and Without SMES Unit

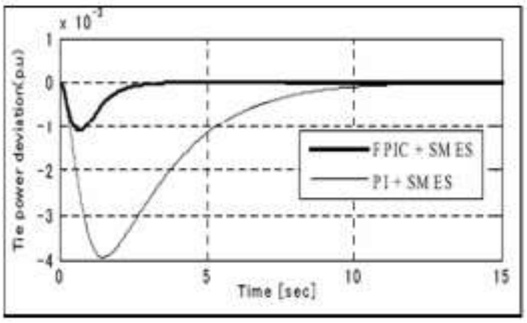

Fig.6. Performances of tie power deviation [Case-I]

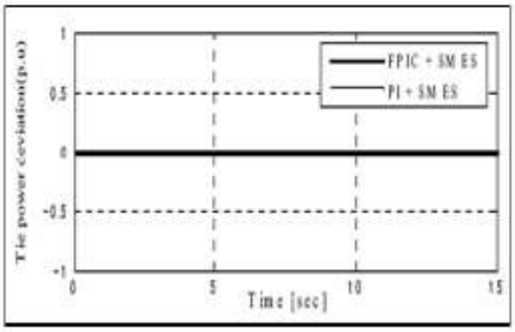

Fig.7: Performances of tie power deviation [Case-II]

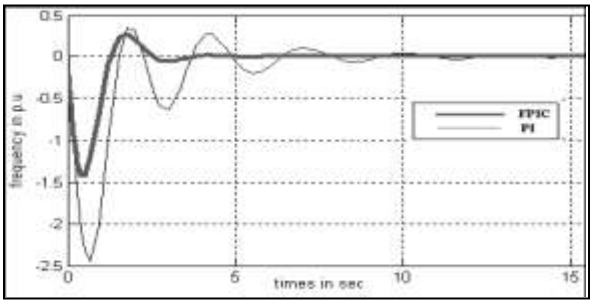

Fig.8: System performances for a step load increase ΔPL1= 0.1 p.u. in area-1 [Case-I] without SMES unit

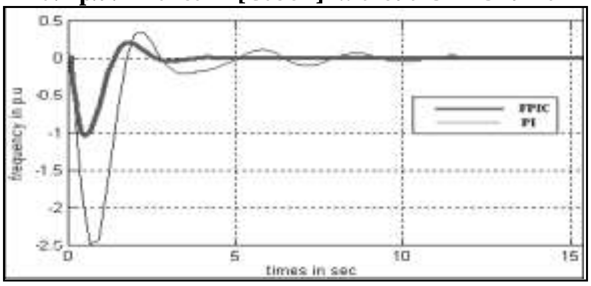

Fig.9: System performances for a step load increase ΔPL1= 0.1 p.u. in area-1 [Case-I] with SMES unit

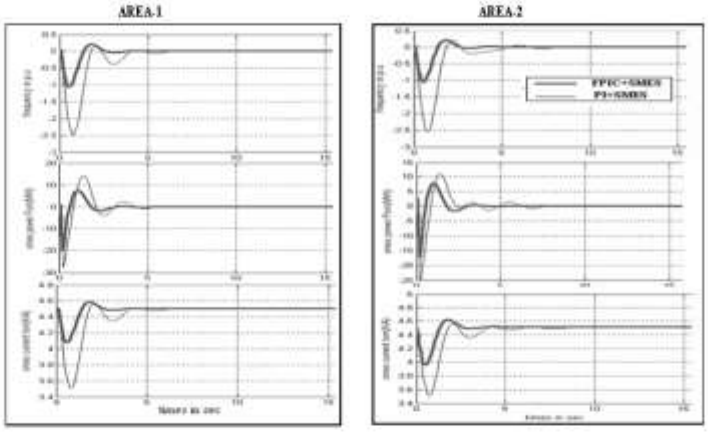

Fig.10: System performances for a step load increase ΔPL1= 0.1 p.u. in Area-1 and Area- 2 [Case-I] with SMES unit

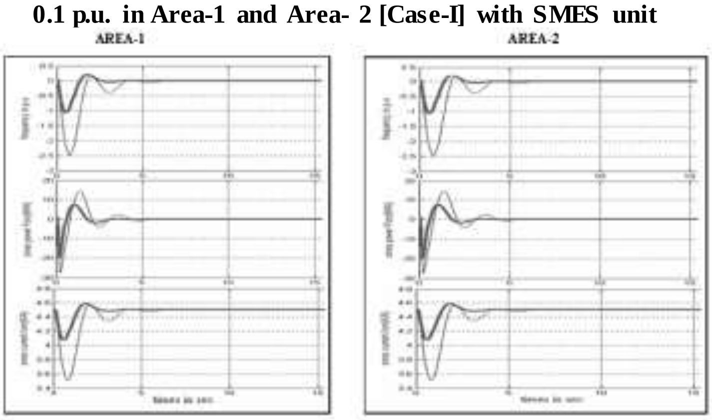

Fig.11:System performances for a step load increase ΔPL1=ΔPL2= 0.1 p.u. in Area-1 and Area-2 [CaseII] with SMES unit

Conclusion

The simulation studies have been carried out on a two-area power system to investigate the impact of the proposed intelligently controlled AGC including SMES units on the power system dynamic performance. The results show that the proposed FPIC scheme is very powerful in reducing the frequency deviations under a variety of load perturbations. Using fuzzy logic, the online adaptation of integral controller output (ΔPref) associated with SMES makes the proposed intelligent controllers more effective and are expected to perform optimally under variety of load disturbance when ACE is used as the input to SMES controller

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