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.

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Keywords
Proportional Integral (PI) controller, Fuzzy PI controller (FPIC), Automatic Generation Control, Area Control Error (ACE), Load frequency control and multi area power system.
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.

\[
\text{ISE} = \int (\Delta P_{tie} + \Delta f + \Delta f^2) \, dt
\]

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](image1)

**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/Δ-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 \( E_d \) 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 \( E = 2 V c \). Where \( E_d \) is DC voltage applied to the inductor (kV), \( \alpha \) is firing angle (°), \( I_d \) is current flowing through the inductor (kA). \( R_c \) is equivalent commutating resistance (Ω) and \( V_{d0} \) is maximum circuit bridge voltage (kV). Charge and discharge of SMES unit are controlled through change of commutation angle \( \alpha \), less than 90°, converter acts in converter mode and if \( \alpha \) is greater than 90°, the converter acts in inverter mode (discharging mode).

![Fig.2: The schematic diagram of SMES Unit](image2)

**Control of SMES unit**

In LFC operation, the dc voltage \( E_d \) 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 feedback](image3)
SMES unit of area \( i (i=1,2,...,N) \) in Laplace domain are as follow.

\[
\Delta E (s) = K_i [B \Delta f (s) + \Delta P (s)] - K_i \Delta I (s)
\]

\[
1 + sT_i 1 + sT_i
\]

\[
\Delta I (s) = 1 \Delta E (s) sL_i \quad (5)
\]

where \( \Delta E_i \) is the incremental change in converter voltage (kV), \( \Delta I_i \) is the incremental change in SMES current (kA), \( K_i \Delta E_i \) is the gain for feedback \( \Delta E_i \) (kV/kA), \( T_{di} \) is converter time delay(s), \( k_i \) is gain constant (kV/unitACE) and \( L_i \) is inductance of the coil (H). The deviation in the inductor real power of SMES unit is expressed in time domain as

\[
\text{as follows: } 2 \text{ di } \text{ di smi }
\]

\[
W (t) = L I
\]

\[
2 (MJ) = 1, ... , 3 \quad (7)
\]

**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 the 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 characterizes 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**

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 \( U = K_p + K_i \) According to the conventional automatic control theory, the performance of the PI controller is determined by its proportional parameter \( K_p \) and integral parameter \( K_i [13] \). 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 steady state 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 steady state 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 successfully. 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 \( \dot{e} \). 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 \( A_i \) and ACE is \( B_i \) THEN \( u = C_i \) \( i = 1,2,...,n \) Fig.5.Membership function for the fuzzy variable Here \( A_i, B_i, C_i \) 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>
<thead>
<tr>
<th>ΔACE / ACE</th>
<th>NB</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>PS</td>
<td>NB</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<td>NS</td>
<td>NS</td>
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<td>NB</td>
<td>NS</td>
<td>NS</td>
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<tr>
<td>Z</td>
<td>NB</td>
<td>NS</td>
<td>Z</td>
<td>NS</td>
<td>PB</td>
</tr>
<tr>
<td>PS</td>
<td>NB</td>
<td>Z</td>
<td>NS</td>
<td>PB</td>
<td>PB</td>
</tr>
<tr>
<td>PB</td>
<td>Z</td>
<td>NS</td>
<td>NS</td>
<td>NB</td>
<td>PB</td>
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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 \( p_{L1} = 0.1 \) p.u. MW is applied in area 1 only.

Case-2: same step load increase \( p_{L1} = p_{L2} = 0.1 \) p.u, in both areas.

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 cannot 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 Fig 10.

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

<table>
<thead>
<tr>
<th>Case</th>
<th>PI</th>
<th>FPIC + SMES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 ($\Delta$Pref) 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.

References