APPLICATION OF FUZZY CONTROLLED SMES UNIT IN AUTOMATIC GENERATION CONTROL

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ABSTARCT

At present fuzzy logic control is receiving increasing emphasis in process control applications. The paper describes the application of fuzzy logic control in an Automatic Generation Control (AGC) of an isolated power system that uses a 12-pulse bridge converter associated with Superconducting Magnetic Energy Storage Unit. A systematic approach for designing the fuzzy logic controller (FLC) is proposed in this paper. The membership functions of input-output variables are generated on-line, applicable to different of disturbances. It has been shown that the proposed mode of control greatly improves the p-f loop of the power system.

1. INTRODUCTION

The normal operation of a power system is continuously disturbed due to sudden small load perturbations [1]. The problem lies in the fact that the inertia of the rotating parts is the only energy storage capacity in a power system. Thus, when the load-end of the transmission line experiences sudden small load changes, the generators need continuous control to suppress undesirable oscillations in the system. Many kinds of stabilizers have been proposed by the researchers to improve the stability of a synchronous generator.

Superconducting magnetic energy storage units were originally proposed as energy storage units having the same purpose as pumped hydro units. Such units have recently found its application as stabilizers for power systems [2]. The superconducting magnetic energy system is designed to store electric energy in the low loss superconducting coil. Power can be absorbed or released from the coil according to the system requirement. The control is performed by changing the firing angle of the converters in the SMES unit, which rapidly moves the DC output voltage up or down in order to achieve the desired power interchange. The use of GTO converters makes it possible for the SMES unit to operate in four quadrant modes [3]. However, the effective use of SMES unit greatly depends on its control strategy. The schematic diagram of the SMES unit is shown in Fig. 1.

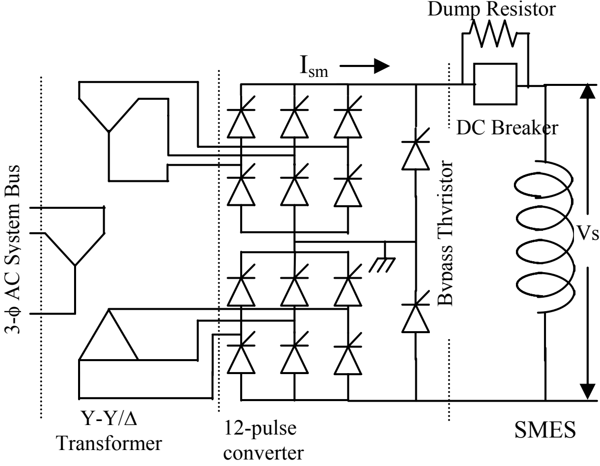

Fig. 1 Schematic diagram of the SMES unit

Different types of controllers for the SMES unit have been proposed in the literature [3-5]. In this paper, a simple fuzzy logic controller is proposed for the SMES unit. The special feature of the proposed model is the generation of membership functions at the very beginning, using sensed frequency signals and its derivative. Whatever be the grade of disturbance, the proposed fuzzy control algorithm will automatically generate the appropriate membership functions. The power compensation P_{sm} from the SMES unit is obtained directly from the FLC output, which makes it more sensitive to the system requirement. Also the gain of the control loop is changed automatically depending on the operating conditions. The proposed controller is applied to a single area power system and simulation results are presented and discussed.

2. CONFIGURATION OF THE SYSTEM

The block diagram of an isolated power system with AGC and SMES unit is shown in Figure 2. The SMES system consists of a superconducting inductor, a 12-pulse cascaded bridge type AC-DC converter and a Y-Δ/Y-Y step down transformer as shown in Figure 1. By suitable control of the firing angles (α) of the converter, the output voltage V_{sm} can be varied within a set of positive and negative values [3]. Since the output current is unidirectional, this implies that the SMES can behave as a source or sink of energy. To prevent the possibility of discontinuous condition, and to ensure the SMES energy to return to predisturbance level, limits are imposed on the value of I_{sm} [4].

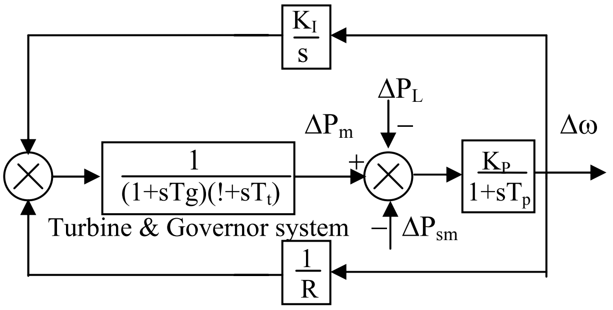

Fig. 2 AGC with SMES Unit of an isolated system

When there is a sudden disturbance in power system, the transformation of electrical energy by the SMES unit is done almost immediately depending on the system requirement. If $\alpha < 90^\circ$, the converter works as a rectifier (charging mode) and if $\alpha > 90^\circ$, the converter works as an inverter (discharging mode). Real power can be absorbed from or delivered to the power system by controlling the sequential firing angles of the thyristors [5]. In order to effectively control the power balance of the synchronous generator during dynamic period, the SMES unit is located at the load end of the transmission line [Fig. 3].

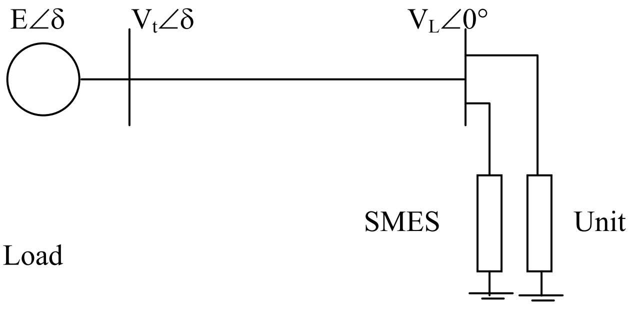

Fig. 3 Single line diagram of the test network

The current and voltage of superconducting inductor are related as

$$I_{sm} = \frac{1}{L_{sm}}\int_{t_0}^{t} V_{sm} d\tau + I_{sm0}$$

where I_{sm0} is the initial current of the inductor. The real power absorbed or delivered by the SMES unit is

$$P_{sm} = V_{sm}\, I_{sm}$$

If P_{sm} is positive, power is transferred from the power system to the SMES unit. While if the P_{sm} is negative, power is released from the SMES unit.. All the system data of generator and SMES unit are given in [3,5]. The area capacity is chosen as 2000 MW and also considered as the base value.

3. THE PROPOSED CONTROL SCHEME

3.1 Fuzzy controller

The basic structure of the proposed fuzzy logic controller is shown in Fig. 4. The development of fuzzy logic approach here is limited to the controller structure and design. More detailed discussions on fuzzy logic controllers are widely available [6].

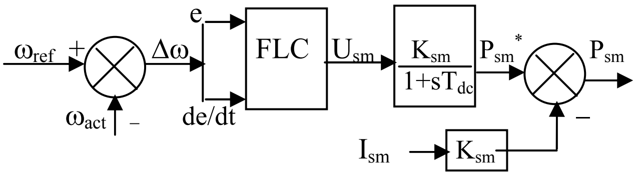

Fig. 4 Simple fuzzy logic SMES controller

Using the knowledge gained from experience, generator speed deviation (e) and acceleration ($\dot{e}$) of the synchronous generator are chosen as the input signals to the fuzzy controller. If u is defined as the control output, then each control rule R_i is of the form: **IF e is A_i and $\dot{e}$ is B_i, THEN u is C_i**
Where A_i , B_i and C_i are fuzzy sets with triangular membership functions as shown, normalized between -1 and 1, in Fig. 5. The same fuzzy sets are used for each variable of interest; only the base value is changed. These bases are W_{b1} and W_{b2} for the speed deviation and acceleration respectively. Both the input signals to FLC are normalized with respect to their base values producing a normalized control output. A specific signal may have non-zero membership in more than one set. Similarly, a specific control signal may represent the contribution of more than one rule. Rule conditions are joined by using minimum intersection operator so that the resulting membership function for a rule is: $\mu(e,\dot{e}) = \min(\mu_{Ai}(e), \mu_{Bi}(\dot{e}))$

The suggested control output from rule i is the centre of the membership function C_i. Rules are then combined using the centre-of-gravity method to determine a normalized control output U_{sm}:

$$U_{sm} = \frac{\sum_1^n \mu_{Ri}(e,\dot{e}).U_i}{\sum_1^n \mu_{Ri}(e,\dot{e})}$$

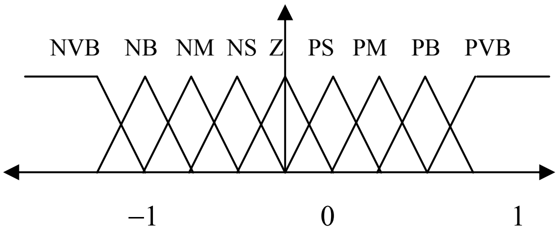

Fig. 5 Generalized fuzzy membership function

3.2 Design steps:

So far, the development of FLC is general. A particular control design requires specification of all control rules and membership functions. The control rules are designed from an understanding of the desired effect of the controller. For example consider the rule:

IF *e* is NS and $\dot{e}$ is PS, THEN *u* is Z

This rule anticipates that as the system stabilizes the SMES power is no longer needed. The complete set of control rules is shown in Table 1. The control rules are symmetric under the assumption that if necessary any asymmetry could be best handled through scaling. In addition, adjacent regions in the rule table allow only nearest neighbour changes in the control output(NB to NM, NM to NS and so on). This ensures that small changes in e and $\dot{e}$ result in small changes in u.

In the present fuzzy modeling it is assumed that the fundamental control laws change quantitatively not qualitatively with the operating conditions. In this vein, control rules and membership functions are designed once as above. To cope with various types of disturbances the base value W_{b2} for $\dot{e}$ is generated on-line when the system experiences any disturbance from its steady state operating condition. W_{b2} can be calculated using the first few samples of e. The base W_{b1} for e is then determined by using the relationship

$$W_{b1} = K_b W_{b2}$$

where K_b is a constant and can be determined once off-line by using the relationship

$$K_b = \frac{W_{b1,\max}}{W_{b2,\max}}$$

From this study K_b was determined as 0.03 in the presence of SMES unit.

Thus the membership functions of the input variables are normalized between -1 to 1 with respect to their generated bases for a particular system and operating condition. The FLC output U_{sm} is also a normalized quantity. The required SMES power P_{sm} can be determined from U_{sm} as:

$$P_{sm} = \frac{K_{sm}}{1 + sT_{dc}} U_{sm}$$

where, K_{sm} is the gain of the control loop, T_{dc} is the delay time. The SMES voltage V_{sm} is then calculated from this P_{sm} and the sensed current I_{sm}.

Once V_{sm} is determined, the corresponding firing angle can be calculated under unequal α-mode of control [5].

The FLC gain K_{sm} is determined on-line following any disturbance. If $V_{sm,max}$ and $I_{sm,max}$ are the maximum voltage and current limits for a particular SMES unit, then

$$K_{sm} = \frac{V_{sm,\max} I_{sm,\max}}{W_{b2}}$$

where, W_{b2} is the present base of $\dot{e}$. The value of K_{sm} is not fixed but is adapted depending on the operating condition and disturbance.

Table1:

↓de/dt e ⟶

	NVB	NB	NM	NS	Z	PS	PM	PB	PVB
NVB	NVB	NVB	NVB	NVB	NB	NS	Z	PS	PB
NB	NVB	NVB	NVB	NVB	NB	Z	PS	PM	PB
NM	NVB	NVB	NVB	NB	NM	PS	PM	PB	PVB
NS	NVB	NVB	NB	NM	NS	PS	PM	PB	PVB
Z	NVB	NB	NM	NS	Z	PM	PVB	PVB	PVB
PS	NB	NM	NS	PS	PM	PVB	PVB	PVB	PVB
PM	NS	PS	PM	PB	PVB	PVB	PVB	PVB	PVB
PB	Z	PM	PB	PVB	PVB	PVB	PVB	PVB	PVB
PVB	PS	PM	PVB	PVB	PVB	PVB	PVB	PVB	PVB

4. COMPUTER SIMULATION AND PERFORMANCE ANALYSIS

In order to demonstrate the beneficial damping effect of the proposed fuzzy controller, computer simulations based on system non-linear differential equations are carried out for different load change under MATLAB environment. The results of the studies are depicted in Fig. 6 and Fig.7 respectively. The performance of the proposed controller is compared with that of conventional one[4].

Figure 6 shows the system performances with and without the SMES unit following a step load change $\Delta P_L = 0.005$ p.u. (Case 1). The damping of the system frequency is not satisfactory without the SMES unit and the maximum speed deviation is 0.00125 pu. The speed deviation decreases with the addition of SMES unit. Due to efficient harnessing of the SMES power P_{sm}, a better performance is obtained when fuzzy controller is used.

For the step load change $\Delta P_L = 0.015$ p.u. (Case 2), the speed deviation increases without the SMES unit (Fig.7). Also it takes longer time to stabilize the system. When SMES unit is applied, the damping is improved significantly. It is evident that when conventional controller is used, the maximum speed deviation is 0.0335 pu., and the system oscillates for about 5 secs. Meanwhile, the fuzzy controller limits the maximum speed deviation to 0.0315 pu and no such oscillations are observed after second peak and system stabilizes within 4.5 secs. In both cases, the inductor current is returned to the predisturbance level makes the SMES unit more effective for subsequent use. A careful observation of Fig.6 and Fig. 7 show that the FLC is more sensitive to the system error and its changes, because the compensating power P_{sm} is directly obtained from these errors. Besides, for the system stabilization, the power P_{sm} is directly responsible and the voltage V_{sm} is indirectly responsible.

5. CONCLUSION

In this paper, a simple fuzzy control strategy for the SMES unit is explained. The damping of the synchronous generator is greatly improved by the SMES unit with the proposed mode of control. Speed deviation and acceleration have been used for on-line generation of fuzzy membership functions after the disturbance. Thus the control system is sensitive for different types of disturbances. The power compensation of the SMES unit is directly obtained from the fuzzy controller. The scheme proposed in the present paper makes effective use of active power modulation of the SMES unit and hence its economic advantage is expected to be stronger than that of earlier schemes. The control strategy is simple and does not require heavy computation, therefore, implementation is feasible.

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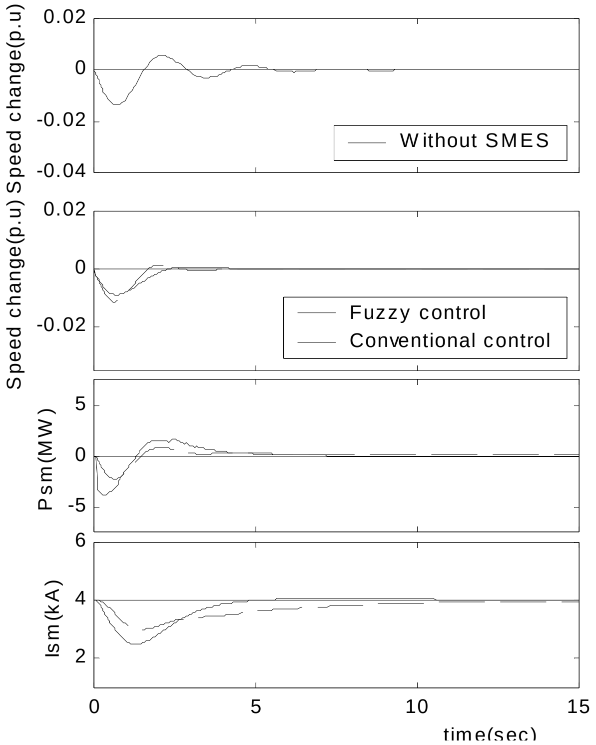

Fig. 6 System performance with ΔP_L=.005p.u(case1)

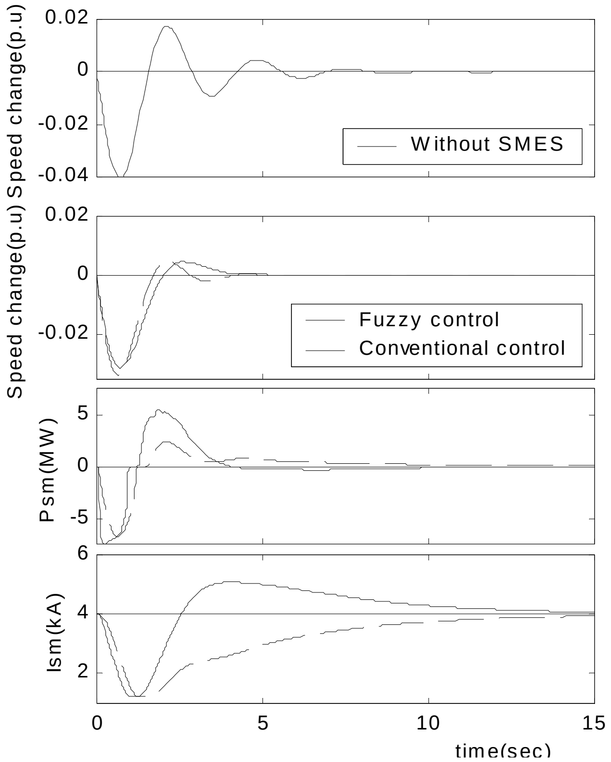

Fig.7 System performance with ΔP_L=.015 p.u (case2).