Improvement of Transient Stability using Fuzzy Logic Controlled SMES in Matlab

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ABSTRACT:
In this paper, the transient stability of an electric power system is improved by fuzzy logic controlled superconducting magnetic energy storage (SMES). The effectiveness of the proposed fuzzy controlled SMES is compared with a conventional proportional integral (PI) controlled SMES. In addition to it a comparison between the fuzzy controlled SMES and fuzzy controlled braking resistor (BR) is also carried out. The simulation results show that under 3 phase fault, the fuzzy controlled SMES performance is better than PI controlled SMES. Furthermore, the performance of SMES is better than that of BR. The proposed method provides a very simple and effective means of improvement of transient stability.

KEYWORDS: Braking resistor (BR), Fuzzy logic-controller (FLC), MATLAB – Simulink, Proportional-integral (PI) controller, Superconducting magnetic energy storage (SMES), Transient stability improvement.

1. INTRODUCTION

Transient stability is mainly concerned with the immediate consequences of a transmission line disturbance on generator synchronism. Rigorous development in power electronics and superconductivity has provided power transmission and distribution industry with superconductive magnetic energy storage (SMES) units. The SMES systems have received much attention in power system applications after the successful commissioning test of the BPA 30–MJ [1]. Based on the power system requirements the real power can be absorbed or released from the low loss superconducting magnetic coil. The firing angle of the converters of the SMES unit controls the amount of energy to be supplied or received by the SMES unit. The technology offers various chances for the transient stability improvement of power systems by the usage of reliable, high speed electronic switches; one among them is thyristor controlled SMES unit. Many articles are reported [2]-[6] demonstrating the use of SMES unit for the improvement of transient stability. SMES is controlled through conventional controllers in most of these works. The power system stability is mainly dependent on the appropriate control strategy of SMES. Though many SMES control strategies [2]-[6] are proposed in the literature, the real problem is the determination of the best or optimal switching strategies. Hence, continuous attempts to explore novel and effective control options are in progress.

Fuzzy logic is based on natural language and is conceptually easy to understand. Fuzzy logic is a powerful tool with a numerous application in embedded control and information processing. Fuzzy logic is tolerant of imprecise data and can handle uncertainty. The effectiveness of SMES for transient stability enhancement has been demonstrated for a balanced fault in the power system [2]-[6]. In order to carry out a detail study; the effectiveness of the proposed fuzzy controlled SMES is compared over conventional proportional integral (PI) controlled SMES in improving the transient stability under balanced 3 phase fault in the power system. The braking resistor (BR) is known to be a very effective device for transient stability control [7]. It can be viewed as a fast load injection to absorb excess transient energy from an area that arises due to severe system disturbances. In some articles [7], [8] the effectiveness of fuzzy logic controlled BR in improving the transient stability of electric power systems has been verified. Although transient stability control is achieved by both SMES and BR [9], this paper presents a comparative study between fuzzy logic-controlled SMES and fuzzy logic-controlled BR in MATLAB Simulink environment.

This paper is organized as follows: power system model in MATLAB Simulink environment, modeling of SMES unit, design of fuzzy logic and PI controllers, simulation results and conclusions of proposed control strategy in transient stability improvement.

2. POWER SYSTEM MODEL

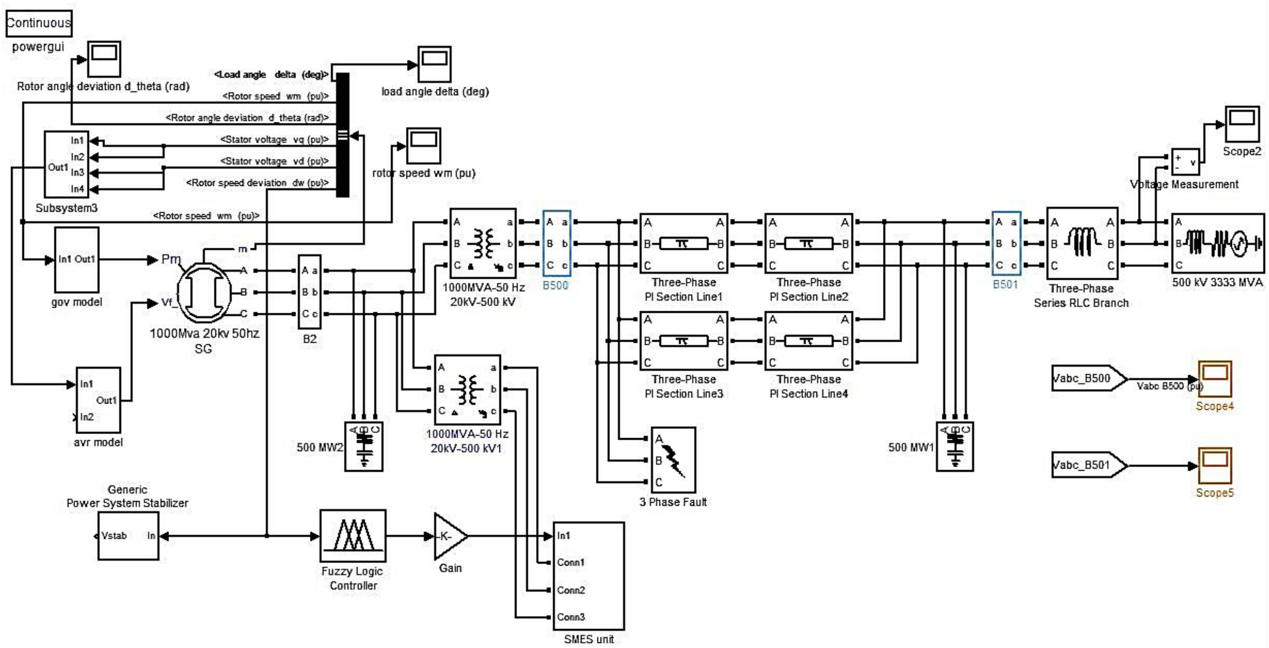

Fig. 1. Power System Model with Fuzzy SMES

In this paper for the analysis of transient stability, the power system model [8] connected with a fuzzy controlled SMES under the three-phase fault at the generator at line 3 as shown in the power system model shown in Fig. 1 has been simulated in Matlab Simulink environment. The 3 LG fault occurs at 0.1 to 0.5 s. The model system consists of a synchronous generator (SG) feeding an infinite bus through a transformer and double circuit transmission line. To effectively control the power balance of the synchronous generator during a dynamic period, the SMES unit is placed in the generator terminal bus.

The parameters of the generator used for the simulation are given in Table I.

The automatic voltage regulator (AVR) and governor (GOV) control system models, as shown in Figs. 2(a) and 2(b) respectively, has been included in this paper.

Table 1. Generator Parameters

MVA	1000	X'_d [pu]	0.169	T'_{do} [sec]	4.3
R_a [pu]	0.003	X'_q [pu]	0.228	T'_{qo} [sec]	0.85
X_a [pu]	0.13	X''_d [pu]	0.135	T''_{do} [sec]	0.032
X_d [pu]	1.79	X''_q [pu]	0.20	T''_{qo}[sec]	0.05
X_q [pu]	1.71	X_0 [pu]	0.13	H [sec]	2.894

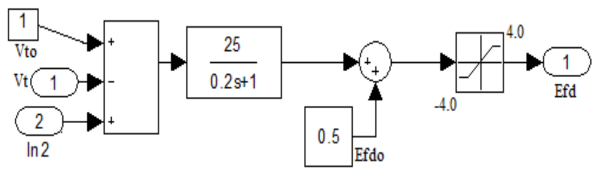

Fig. 2(a). AVR model

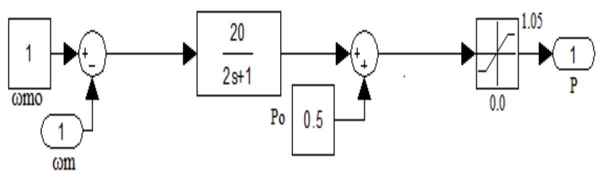

Fig. 2(b). GOV model

3. MODELING OF SMES

The SMES unit which consists of a Wye-Delta 500 KV/5 KV transformer, an ac/dc thyristor controlled bridge converter, and a superconducting coil of 0.5 H as shown in Fig. 3 is proposed. The positive or negative voltage is impressed on superconducting coil by the converter. Charge and discharge are easily controlled by simply varying the delay angle α that controls the sequential firing of the thyristors. When α is less than 90°, the converter operates in the rectifier mode (charging) and when α is greater than 90°, the converter operates in the inverter mode (discharging). As a result, power can be absorbed from or released to the power system according to the requirement. During steady state, SMES should not consume any real power.

The bridge voltage V_{sm} is held constant at a suitable positive value to initial charge the SMES unit. The inductor current I_{sm} rises exponentially and magnetic energy W_{sm} is stored in the inductor. When the inductor current reaches its rated value I_{sm0} it is maintained constant by lowering the voltage across the inductor to zero. The SMES unit is then ready to be coupled to the power system for stabilization. It is desirable to set the rated inductor current I_{sm0} such that the maximum allowable energy absorption equals the maximum allowable energy discharged.

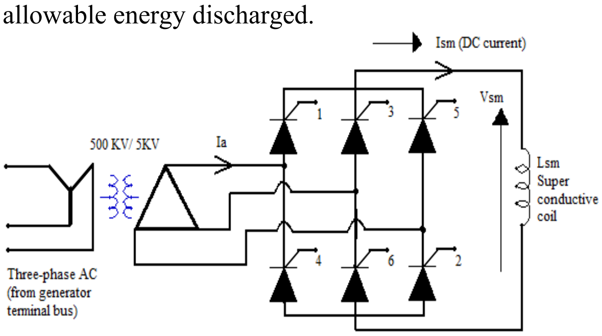

Fig. 3. SMES unit with six-pulse bridge ac/dc thyristor controlled converter

The voltage V_{sm} of the dc side of the converter is expressed by

$$V_{sm} = V_{sm0} \cos\alpha \tag{1}$$

where V_{sm0} is the ideal no-load maximum dc voltage of the bridge. The current and voltage of superconducting inductor are related as

$$I_{sm} = \frac{1}{L_{sm}} \int_{t_0}^{t} V_{sm} d\tau + I_{sm0} \tag{2}$$

where I_{sm0} is the initial current of the inductor. The real power P_{sm} absorbed or delivered by the SMES can be given by

$$P_{sm} = V_{sm} I_{sm} \tag{3}$$

since the bridge current I_{sm} is not reversible, the bridge output power P_{sm} is uniquely a function of α, which can be positive or negative depending on V_{sm}. When V_{sm} is positive, power is transferred from the power system to the SMES unit and when V_{sm} is negative, power is released from the SMES unit. The energy stored in the superconducting inductor is

$$W_{sm} = W_{sm0} + \int_{t_0}^{t} P_{sm} d\tau \tag{4}$$

where $W_{sm0} = \frac{1}{2} L_{sm} I_{sm0}^2$ is the initial energy in the inductor.

The assumptions considered in modeling of present SMES unit are as follows:

1- The effect of the ripple of the DC is ignored as the superconducting coil has a large inductance.
2- The superconducting coil resistance is zero.
3- The converter thyristor voltage drop is ignored.
4- Harmonic power generated by the converter is neglected.

A comparison is also carried out by placing a braking resistor in place of SMES unit of the power system model shown in Fig. 1.

4. DESIGN OF FUZZY LOGIC AND PI CONTROLLERS

Fuzzy logic controller is one of the most practically successful approaches to design a controller for utilizing the qualitative knowledge of a system and to solve a problem with vagueness or uncertainties. The fuzzy logic controller is realised through three sections: fuzzification, rule base and defuzzification.

4.1. Fuzzification

For the design of the proposed FLC for SMES, the deviation of speed of the synchronous generator, Δω, and firing angle of thyristor, alpha (α), are selected as input and output variables respectively. Fig. 4 shows the membership functions for input variable Δω and output variable alpha (α) for SMES. The linguistic variables for Δω are n, z and p represents negative, zero, and positive respectively. The linguistic variables for alpha (α) are sm, me and bg stand for Small, Medium and Big.

For the design of the fuzzy logic controller for BR, deviation of speed of the synchronous generator Δω and firing angle alpha (α) are selected as the input and output variables, respectively. Fig. 5 shows the membership function for input variable Δω and output variable alpha (α). The linguistic variables for Δω are n, z and p stand for negative, zero and positive. The linguistic variables for alpha (α) are s and b stand for Small and Big. The membership functions are decided by the trial and error approach in order to obtain the best system performance.

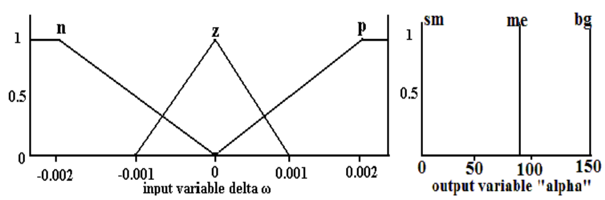

Fig. 4. Membership functions of input variable Δω(pu) and output variable alpha for SMES

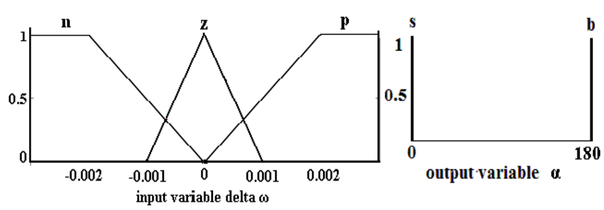

Fig. 5. Membership functions of input variable Δω(pu) and output variable alpha for Braking Resistors.

For the design of the fuzzy logic controller for BR, deviation of speed of the synchronous generator Δω and firing angle alpha (α) are selected as the input and output variables, respectively. Fig.5 shows the membership function for input variable Δω and output variable alpha (α).

The linguistic variables for Δω are n, z and p stand for negative, zero and positive. The linguistic variables for alpha (α) are s and b stand for Small and Big. The membership functions are decided by the trial and error approach in order to obtain the best system performance.

4.2. Fuzzy Rule Base and Inference engine

The proposed control strategy is very simple having single-input single-output (SISO) variable makes the fuzzy controller very straightforward [7]-[9]. The control rules of the proposed controller are determined from the viewpoint of practical system operation and by trial and error.

The basic operation of the inference engine is it deduces a logical conclusion. Actually, the inference engine is a program which uses the rule base and the input data to the controller to draw the conclusion. The conclusion of the inference engine is the fuzzy output of the controller, which subsequently becomes the input to the defuzzification interface. For the inference mechanism of the proposed FLC, Mamdani's method [10] has been utilized.

The control rules for proposed SMES are, if Δω is negative then α is big, if Δω is zero then α is medium and if Δω is positive then α is small. The control rules for braking resistor are, if Δω is negative or zero then α is big and when Δω is positive then α is small.

4.3. Defuzzification

In this last operation, the fuzzy conclusion of the inference engine is defuzzified, i.e.; it it is converted into a crisp signal. This last signal is the final product of the FLC which is, of course, the crisp control signal to the process. The center-of-area method is the most well-known and rather simple defuzzification method [11], which is implemented to determine the output crispy value.

4.4. PI Controller

The fuzzy controlled SMES in the power system model shown in Fig. 1 is replaced by the PI SMES shown in Fig. 6 and the effectiveness of the proposed fuzzy controlled SMES unit in enhancing the transient stability is compared to that of a conventional PI controlled SMES under the same three phase faulted condition. The PI controller parameters $K_p = 180$ and $T_i = 0.2s$ are determined by trial and error in order to attain better system performance.

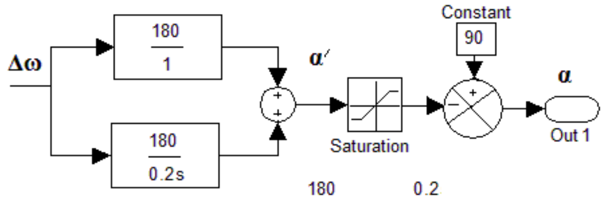

Fig. 6. Block diagram of PI controller

5. SIMULATION RESULTS

Simulations are performed under balanced 3 LG fault at the generator at line 3 as shown in the system model. The 3 LG fault occurs at 0.1 to 0.5 s. The time step and simulation time are 0.00005 and 5.0 s respectively. These simulations are carried out in Matlab Simulink environment for different cases. Fig. 7, 8, 9, 10 and 11 shows load angle responses under 3 LG fault without pss, with pss, with PI controlled SMES, with fuzzy controlled BR and with fuzzy controlled SMES respectively.

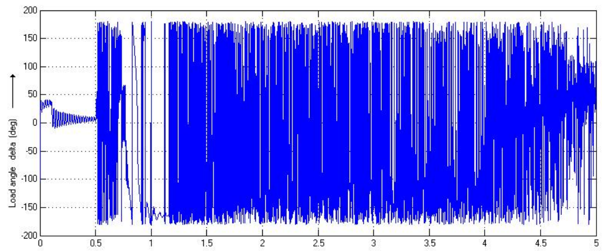

Fig. 7. Load angle response without power system stabilizer under 3LG fault

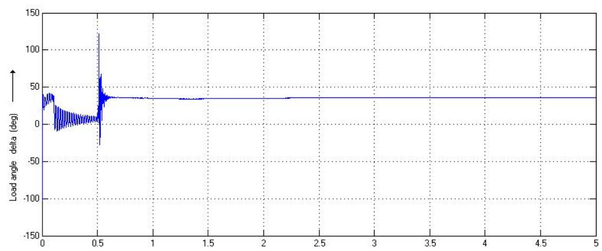

Fig. 8. Load angle response with power system stabilizer under 3LG fault

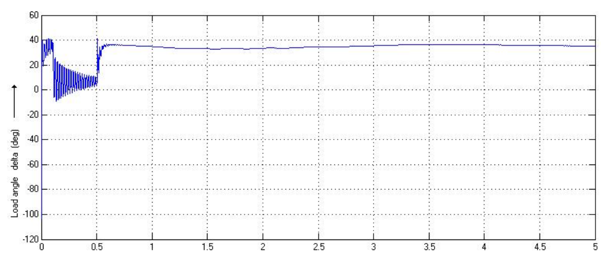

Fig. 9. Load angle response with PI controlled SMES under 3LG fault

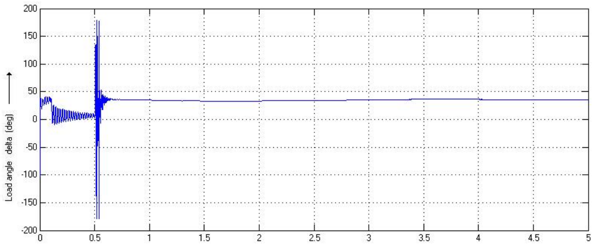

Fig. 10. Load angle response with fuzzy controlled Braking Resistor under 3LG fault

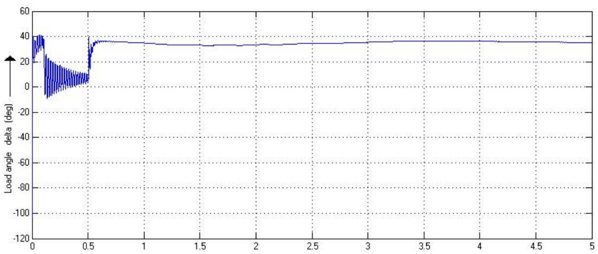

Fig. 11. Load angle response with fuzzy controlled SMES under 3LG fault

6. CONCLUSIONS

In this paper, a fuzzy logic controlled SMES with thyristor switching is proposed to improve the transient stability. Simulation results of balanced 3LG fault clearly shows the validity and effectiveness of the proposed method in enhancing the transient stability. Furthermore, the performance of fuzzy controlled SMES is found to be better than that of PI controlled SMES. The load angle responses indicate that the performance of fuzzy controlled SMES is better than that of fuzzy controlled BR from the view point of faster operation. However, in reducing the first transient swing, BR is more effective than SMES. The main reason of the better performance of SMES is its ability to control both acceleration and deceleration of the generator by consuming and supplying real power. So, it can be concluded that the proposed fuzzy logic-controlled SMES strategy is superior to the fuzzy logic-controlled BR strategy, and provides a very simple and effective means of improving power system transient stability.

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