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Unified Control of APF and SMES Based on Fuzzy Logic Control

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Abstract—**This paper proposes two single closed-loop control methods to achieve unified control of active power filter (APF) and superconducting magnetic energy storage (SMES). For the DC-DC chopper circuit, this paper proposes a fuzzy logic control (FLC) method to achieve the stabilization of the DC link voltage and the charge and discharge control of the SMES coil. For the back-stage DC-AC converter circuit, hysteresis current method realizes tracking control of reference current. The control method enables the SMES device to not only implement active filtering but also to suppress the active power oscillation of the system caused by sudden load changes. The simulation model of the whole system was built by Matlab/Simulink for verification analysis.**

Keywords-active power filter (APF); superconducting magnetic energy storage (SMES); fuzzy logic control (FLC)

I. INTRODUCTION

Since more and more power electronic devices are widely used in power systems, the problems of harmonic pollution and reactive power consumption caused by them have become increasingly serious while greatly improving the working efficiency [1]. And with the development of high temperature superconducting technology, SMES plays an important role in improving power safety and power quality [2-4].

This paper proposes two single closed-loop controllers instead of dual loop control. For the DC-DC front-stage chopper circuit, this paper proposes a fuzzy logic control method to achieve voltage stabilization on the DC link and charge and discharge control of the SMES coil current. For the post-stage DC-AC converter circuit, the hysteresis current control method is adopted to realize the tracking control of the reference current. It can be known from the simulation results that the above control methods can achieve unified control of APF and SMES, and has a better control effect.

II. UNIFIED CONTROL SYSTEM OF SMES AND APF

A. Main Circuit Structure of Unified Control System

The main circuit of the SMES device with APF function is composed of a converter, a chopper circuit, a nonlinear load, the control circuit, and a SMES coil [3]. The schematic diagram is shown in Fig. 1. The three-phase grid voltage are u_{sa} , u_{sb} , u_{sc} ; three-phase grid current are i_a , i_b , i_c ; the nonlinear load current are i_{La} , i_{Lb} , i_{Lc} ; SMES coil output current are i_{ca} , i_{cb} , i_{cc} ; DC link capacitor voltage is U_{dc} ; SMES coil current is I_{sc} .

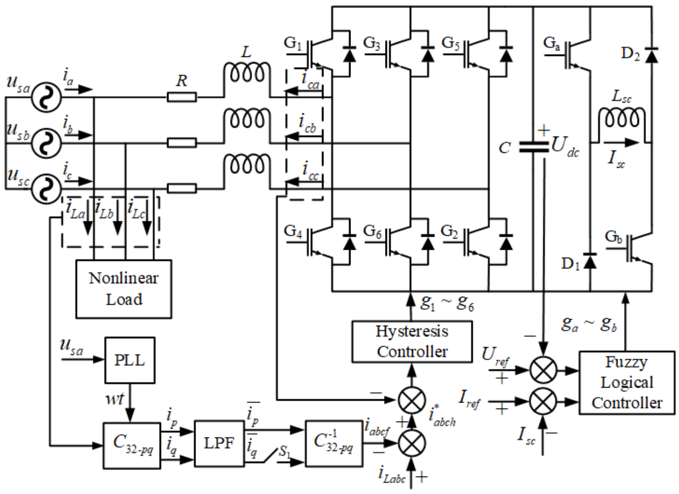

Figure 1. Schematic diagram of the unified control system.

B. Design of Fuzzy Logic Controller

Because the voltage stabilization on the DC link is a necessary condition for stable energy exchange between the DC link and the AC link, and the performance of the conventional PI controller depends on the selection of parameters, while the fuzzy logic controller has better robustness Therefore, this paper proposes fuzzy logic control method to achieve voltage stabilization on the DC link and charge and discharge control of the SMES coil [5].

i) Fuzzy input and output variables. This paper adopts a dual input single output fuzzy logic controller. The two inputs are the DC link capacitor voltage deviation ΔU_{dc} and the SMES coil current deviation ΔI_{sc} . The output is the duty ratio *D* of the IGBT in the chopper circuit. By adopting control rules to change the duty ratio *D*, the stability of the DC link voltage, and the charge and discharge control of the SMES coil is achieved. The input and output variables are defined as three fuzzy subsets respectively. The fuzzy subset selection in this paper selects the triangle membership function with good performance and easy calculation.

$$\Delta U_{dc} = \{NB \quad NS \quad Z \quad PS \quad PB\} \tag{1}$$

$$\Delta I_{sc} = \{N \quad Z \quad P\} \tag{2}$$

$$D = \{N \quad Z \quad P\} \tag{3}$$

ii) Fuzzy control rule. To achieve the voltage stabilization on the DC link and the charge and discharge control of the SMES coil, the control rules of the fuzzy logic controller are: when the voltage deviation modulus value is greater than the set value, the duty ratio *D* changes with the change of the voltage polarity; When the voltage deviation modulus value is smaller than the set value, the duty ratio *D* changes with the change of the current deviation polarity.

III. Simulation Results

In this paper, a simulation model of SMES device with APF function is established in Matlab/Simulink, and the simulation results are verified and analyzed.

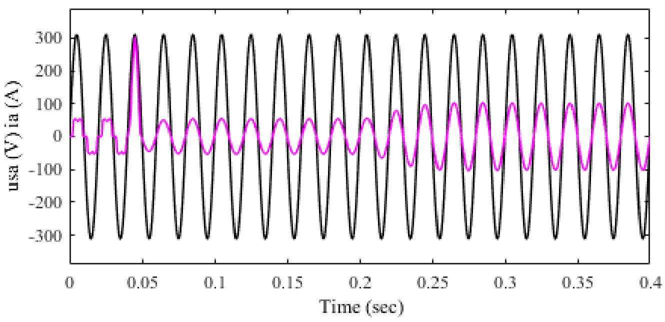

Figure 2. Profiles of phase-A grid voltage and current.

As shown in Fig. 2, it can be observed that the SMES device was not connected to the system before 0.04s, and the grid current was distorted under the effect of nonlinear load. After 0.04s, the SMES device was connected to the system. After brief dynamic changes, the grid current becomes a sine wave with the same phase of the grid voltage. Available from FFT analysis results, the total harmonic distortion (THD) of the grid current has been reduced from 24.72% to 1.91%.

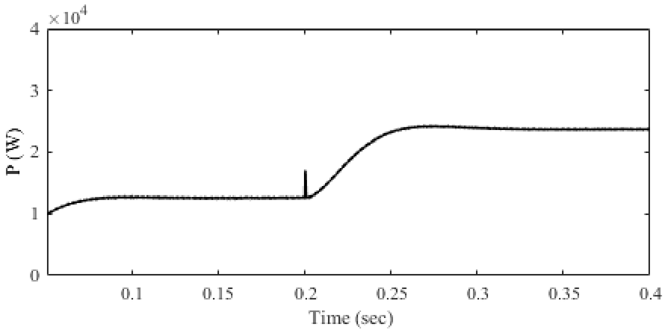

Figure 3. Performance of the grid output active power.

As shown in Fig. 3, the load suddenly changes at 0.2s. It can be observed that the SMES device suppresses the sudden change of the active power output of the grid within 10us by outputting the energy stored in the SMES coil, which makes the power output of the grid more stable. And the active power of the grid also keeps rising steadily and smoothly.

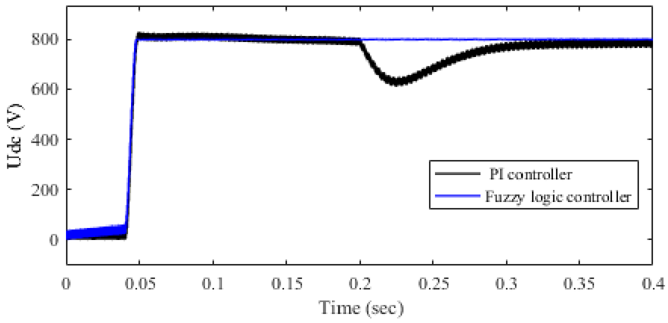

Figure 4. Comparisons between PI controller and fuzzy logic controller for DC link voltage.

Fig. 4 reveals the comparison results of the DC link voltage after the load of suddenly changes with PI, and Fuzzy logic controllers, respectively. At 0.2s, when the load suddenly changes, it can be observed that with the use of the conventional PI controller, the DC link voltage appears to decline first, then rise, and finally stabilize at 800V. However, with the use of the fuzzy logic controller, the DC link voltage is still stable at the set value of 800V. Obviously, the fuzzy logic controller has more superior robustness and stability than the PI controller.

IV. Conclusions

From the simulation results, it can be known that the control strategy proposed can better achieve unified control of active filtering and active power oscillation suppression. By comparing the simulation results of voltage control on the DC link with conventional PI controller and fuzzy logic controller, the fuzzy logic control method proposed improves the robustness of the whole system and has superior steady state performance.

References

[1] W. U. K. Tareen and S. Mekhielf, "Three-Phase Transformerless Shunt Active Power Filter With Reduced Switch Count for Harmonic Compensation in Grid-Connected Applications," IEEE Transactions on Power Electronics, vol. 33, no. 6, pp. 4868-4881, June 2018.

[2] A. Abu-Siada and S. Islam, "Application of SMES Unit in Improving the Performance of an AC/DC Power System," IEEE Transactions on Sustainable Energy, vol. 2, no. 2, pp. 109-121, April 2011.

[3] J. Y. Zhang et al., "Electric Energy Exchange and Applications of Superconducting Magnet in an SMES Device," IEEE Transactions on Applied Superconductivity, vol. 24, no. 3, pp. 1-4, June 2014.

[4] Z. Zheng, X. Chen, X. Xiao and C. Huang, "Design and Evaluation of a Mini-Size SMES Magnet for Hybrid Energy Storage Application in a kW-Class Dynamic Voltage Restorer," IEEE Transactions on Applied Superconductivity, vol. 27, no. 7, pp. 1-11, Oct. 2017.

[5] K. Gong, J. Shi, Y. Liu, Z. Wang, L. Ren and Y. Zhang, "Application of SMES in the Microgrid Based on Fuzzy Control," IEEE Transactions on Applied Superconductivity, vol. 26, no. 3, pp. 1-5, April 2016.