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Analyzed Model of The Active Filter combined with SMES

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Abstract-- **Recently, utility network is becoming more and more complicated and huge due to IT and OA devices. In addition to, demands of power conversion devices which have non-linear switching devices are getting more and more increased. Consequently, because of the non-linear power semiconductor devices, current harmonics are unavoidable. Sometimes those current harmonics flow back to utility network and become one of the main reasons which can make the voltage distortion. Also, it makes noise and heat loss. On the other hands, voltage sag from sudden increasing loads is also one of the terrible problems inside of utility network. In order to compensate the current harmonics and voltage sag problem, AF(active filter) systems could be a good solution method. SMES is a very good promising source due to it's high response time of charge and discharge. Therefore, the combined AF and SMES system can be a wonderful device to compensate both harmonics current and voltage sag. However, SMES needs a superconducting magnetic coil. Because of using this superconducting magnetic coil, quench problem caused by unexpected reasons have always been unavoidable. Therefore, to solve out mentioned above, this paper presents a decisive method using shunt and series active filter system combined with SMES. Especially, authors analyzed the change of original energy capacity of SMES regarding to the size of resistance caused by quench of superconducting magnetic coil.**

1. INTRODUCTION

Power quality has been become a very important part of both power suppliers and consumers. From this point of the view, suppliers should supply the sinusoidal voltage source which has a constant frequency and a precisely rated voltage value, and consumers should generate the sinusoidal load current, too. However, harmonic currents are easy to be generated in electric power system by non-linear electric loads due to semiconductor switching devices. In addition to, voltage sag from sudden increasing loads has recently become a very significant problem because it makes several kinds of the malfunction operation in both loads and sources [1]. In order to compensate the harmonics current and voltage sag problem, AF(active filter) systems could be a good solution method. In case of voltage sag, it needs an energy source to overcome the energy caused by voltage sag. SMES(superconducting magnetic energy storage system) is a very good promising source due to the high response time of charge and discharge. Therefore, the combined system of AF and SMES is a wonderful device to compensate both current harmonics and voltage sag. But, SMES needs a superconducting magnetic coil. Because of the introduction of superconducting magnetic coil, quench problem caused by unexpected reasons is always existed. In case of discharge operation, quench is a significantly harmful factor as it decreases the energy capacity of SMES. [2-5]

Therefore, this paper presents a decision method of the specification of the shunt and series active filter system combined with SMES. Also, authors analyzed the change of the original energy capacity of SMES regarding to the size of resistance caused by quench of superconducting magnetic coil.

2. CONCEPTUAL DIAGRAM OF AF-SMES SYSTEM

Fig. 1 explains the schematic diagram of the AF-SMES system. Load A is the load which generates sudden voltage sag, Load B includes the non-linear power semiconductor devices which create harmonic currents, and Load C is the conventional and general resistance load. Also, SMES system is operated as the energy source of active filters.

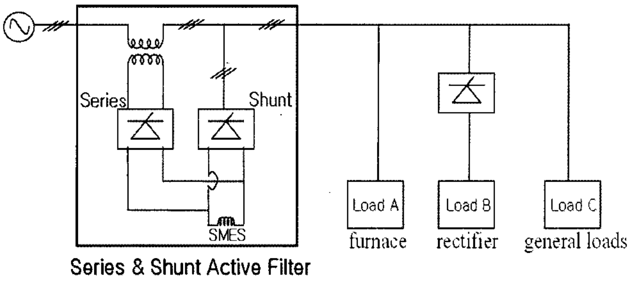


Fig. 1. Schematic diagram of the series and shunt active filters combined with SMES.

3. EMTDC MODELING OF SMES SYSTEM

Fig. 2 shows the circuit diagram of SMES which can be operated as charge and discharge modes in PSCAD/EMTDC. In this simulation circuit diagram

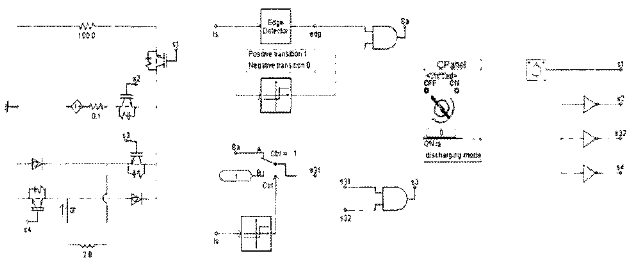


Fig. 2. Circuit diagram of SMES in PSCAD/EMTDC.

authors can easily change the time of charge and discharge and can also do the size of superconducting magnetic coil.

In this simulation analysis, authors control that the charging mode has 1.0[kA] of the upper limit and discharging mode has 0.9[kA] of the lower limit. Fig. 3 shows the current waveform of superconducting magnetic coil according to the charge and discharge operation. In order to confirm the characteristics of the superconducting magnetic coil in PSCAD/EMTDC, after operating on the charging mode until 4.7[sec], SMES system was tested as the discharging mode. After all, it is confirmed that the simulated circuit of the charging and discharging SMES system is well operated as authors expected.

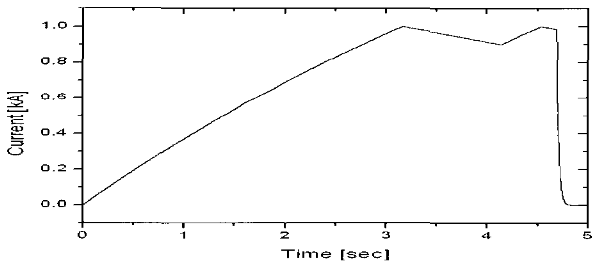


Fig. 3. Current waveform of the superconducting magnetic coil regarding to various operating mode.

4. OPERATING CHARACTERISTICS OF SERIES AND SHUNT ACTIVE FILTER

4.1. Voltage Sag Compensation by Series Active Filter System

The compensation method of series active filter is based on injecting voltage in series to the line voltage of utility. In order to confirm the performance of series active filter, a sudden change of load was assumed and compensated by series active filter energized by SMES system. Here, the size of load which increased was 16.8 [kVA] and the capacity of superconducting magnetic load was 1 [MJ].

Fig. 4 shows the voltage waveform of voltage sag for 3[sec]. As shown in Fig. 5, it was perfectly compensated. It means that the simulated circuit of series active filter energized by SMES is well designed and operated. The circuit diagram in PSCAD/EMTDC was shown in APP-Fig.1.

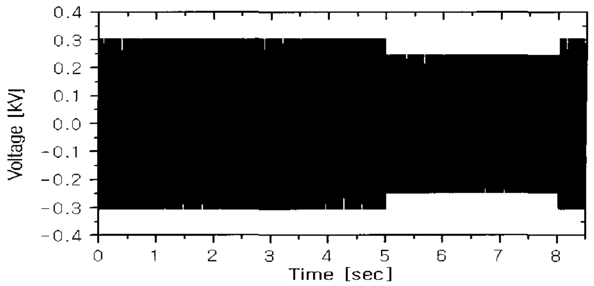


Fig. 4. Voltage waveform of voltage sag without compensation by series active filter.

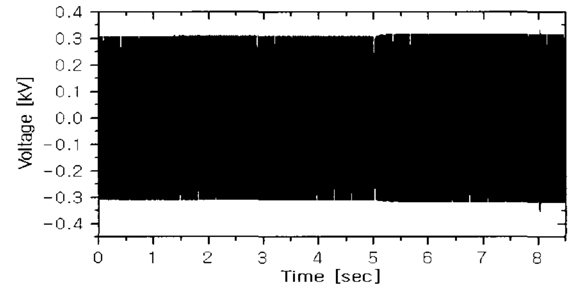


Fig. 5. Line voltage waveform of utility with compensation by series active filter.

Fig. 6 shows the current waveform of superconducting magnetic coil during simulation. The charging time is extremely fast and the charged current of SMES is discharged at the point of voltage sag. After voltage sag is cleared, it is soon converted to the charge mode.

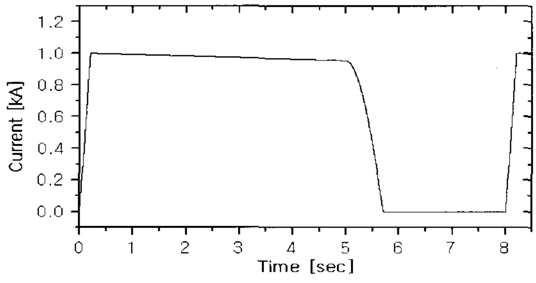


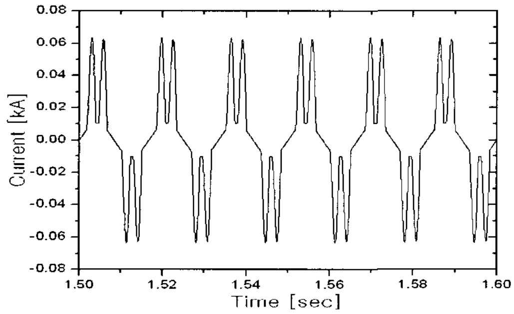
Fig. 6. Current waveform when SMES system compensation voltage sag.

4.2. Harmonics Current Compensation by Shunt Active Filter system

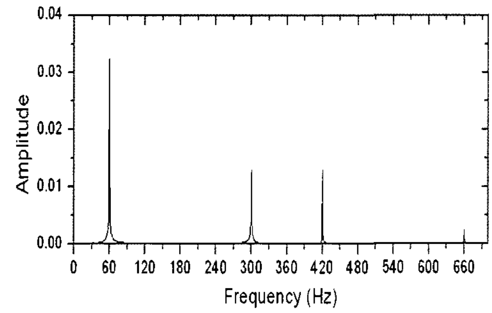
In order to confirm the performance of shunt active filter, harmonics current was intentionally generated by using a rectifier system which includes three phase full-bridge diode which is a harmonics current source, and compensated by shunt active filter. Here, the ability level of shunt active filter against the size of harmonics current is dominantly related with the capacitor bank in App-Fig.1.

Fig. 7 shows the input current of rectifier and its FFT result. According to the harmonic current as shown in Fig. 7(a), the utility line current is strongly influenced. It is well known that the harmonics current deteriorates the quality of utility. The size of harmonics current is confirmed through FFT result as depicted in Fig. 7 (b).

The input current of full-bridge diodes contains 5, 7 and 11 harmonic currents and each rate is 25%, 18% and 3%. Also, the rate of positive current is 54%. The input current generated by non-linear loads has both a positive current and harmonic currents. Therefore, in order to compensate only harmonic currents, the part of harmonic currents in Fig. 7(a) has to be only extracted. Fig. 8 shows the conceptual diagram to extract the only part of harmonics.



(a) Input current of rectifier



(b) FFT result of (a)

Fig. 7. Harmonics current waveform generated by rectifier which includes full-bridge diode.

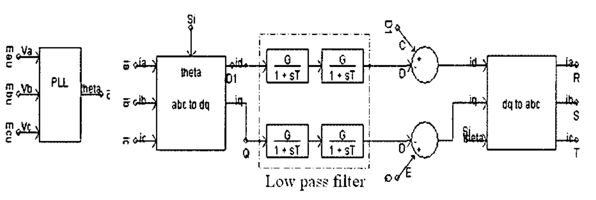


Fig. 8. Control block diagram of shunt active filter for the compensation of harmonic currents.

The waveform of Fig. 9 is used as the reference current level of the three phase DC-AC converter which is connected to utility in shunt. Fig. 10 shows the waveform of utility line current which is compensated and closed to a sinusoidal waveform. Fig. 11 is the FFT result of Fig. 10, which has no elements of harmonics, and it is confirmed that utility line current is fully compensated.

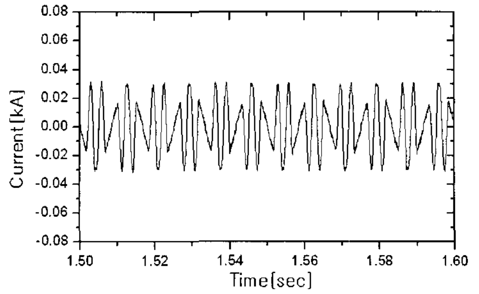


Fig. 9. Current waveform containing only harmonics obtained by Fig. 8.

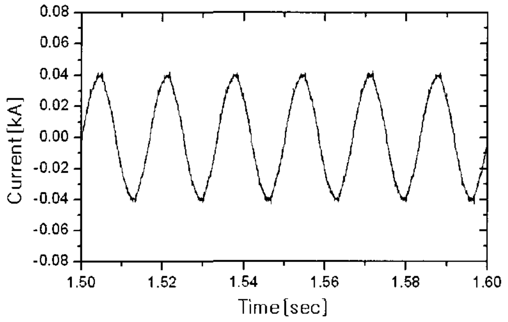


Fig. 10. Utility line current whose harmonic elements are fully compensated by shunt active filter.

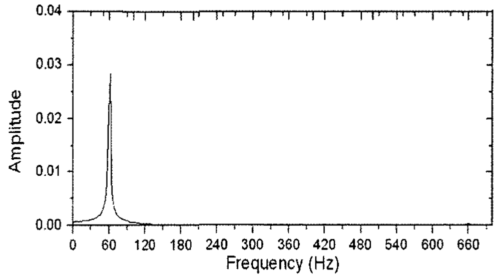
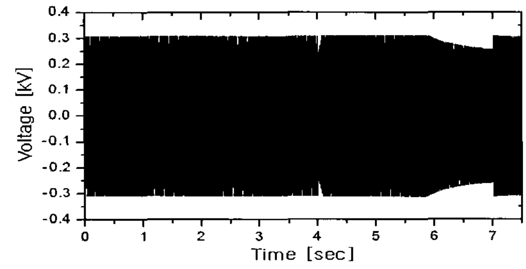


Fig. 11. FFT result of utility line current which indicates the perfectly compensated utility line current.

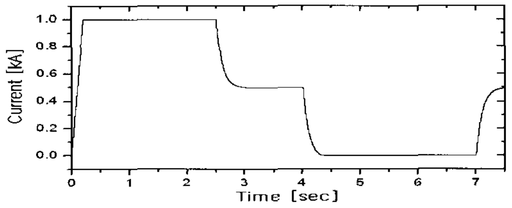
5. ANALYSIS OF THE INFLUENCES OF INTERNAL FAULT IN SMES SYSTEM

5.1. Failure of compensation by internal fault

If the superconducting magnetic coil is quenched, the total resistance level of SMES system is suddenly increased. In order to confirm the influences of internal fault in SEMS system mainly caused by quench, authors intentionally put a certain resistance value inside of superconducting magnetic coil during simulation. In case of Fig. 12, 20[Ω] of resistance is occurred inside of superconducting magnetic coil at 2.5[sec]. The current waveform of superconducting magnetic coil is shown in Fig. 12 (b), which is sharply dropped by power loss due to quench.



(a) Utility voltage waveform

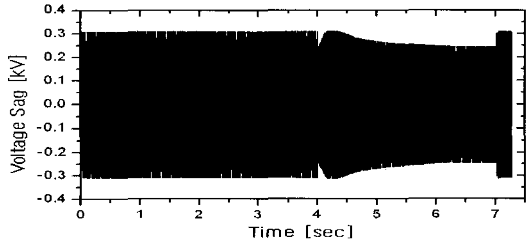


(b) Current waveform of superconducting magnetic coil

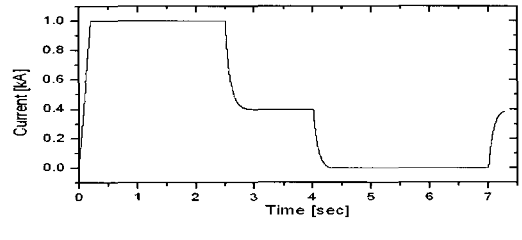
Fig. 12. In case of 20[Ω] of resistance.

SMES system may not compensate whole kinds of voltage sag. There are so many kinds of reasons which make the superconducting magnetic coil quench. However, in this paper the reasons of quench are not considered.

Fig. 13 shows the waveforms of utility voltage and the current of superconducting magnetic coil in case of 25[Ω] of resistance. Comparing with Fig. 12 and Fig. 13, the compensation time of Fig. 12 is much longer than that of Fig. 13. It means the resistance level inside of superconducting magnetic coil definitely gives effect to the compensation time against certain voltage sag.



(a) Utility voltage waveform



(b) Current waveform of superconducting magnetic coil

Fig. 13. In case of 25[Ω] of resistance.

5.2. Compensation capacity influenced by internal resistance

The size of superconducting magnetic coil is mainly related with the compensation capacity for voltage sag. However, the internal resistance occurred by quench is one of main factors which decide the ability of compensation for voltage sag, too. In order to verify how much the compensation capacity for voltage sag is influenced by the internal resistance, various conditions, which include the change of load size generating voltage sag and the change of internal resistance level caused by quench regarding to different SMES conditions, are simulated and analyzed.

Fig. 14 shows the change of compensating maximum load caused by the size of SMES influenced by resistance. As depicted in Fig. 14, the compensation capacity is dramatically dropped by internal resistance caused by quench. Not only the size of superconducting magnetic coil is very important for compensation capacity, but also the stability of superconducting magnetic coil is one of the most significant factors to improve the performance of SMES system. Even small size of resistance is occurred by quench, it is definitely harmful.

Fig. 15 shows the minimum capacity of SMES to be capable to compensating the voltage sag when the internal resistance of SMES is increased.

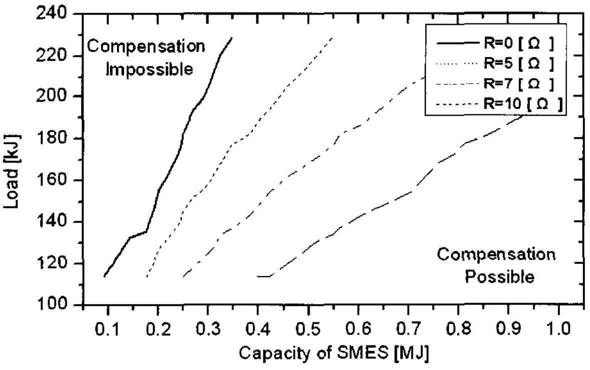


Fig. 14. Change of compensating maximum load caused by the size of SMES influenced by resistance.

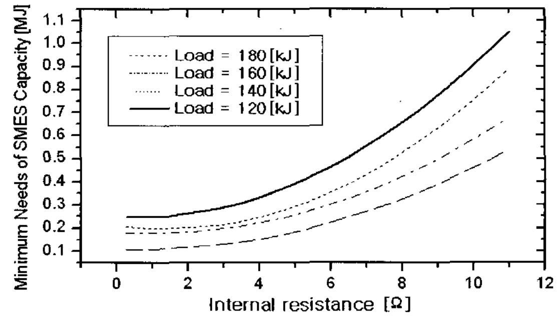


Fig. 15. Minimum capacity of SMES which can be able to compensate under the internal resistance.

6. CONCLUSION

In this paper, a PSCAD/EMTDC model for AF-SMES system was demonstrated, and described a good operation performance of both harmonic currents and voltage sag compensation. And also, in order to verify how much the compensation capacity for voltage sag is influenced by the internal resistance, various conditions, which include the change of load size generating voltage sag and the change of internal resistance level caused by quench regarding to different SMES conditions, are simulated and analyzed. Finally, not only the size of superconducting magnetic coil is very important for compensation capacity, but also the stability of superconducting magnetic coil is one of the most significant factors to improve the performance of SMES system.

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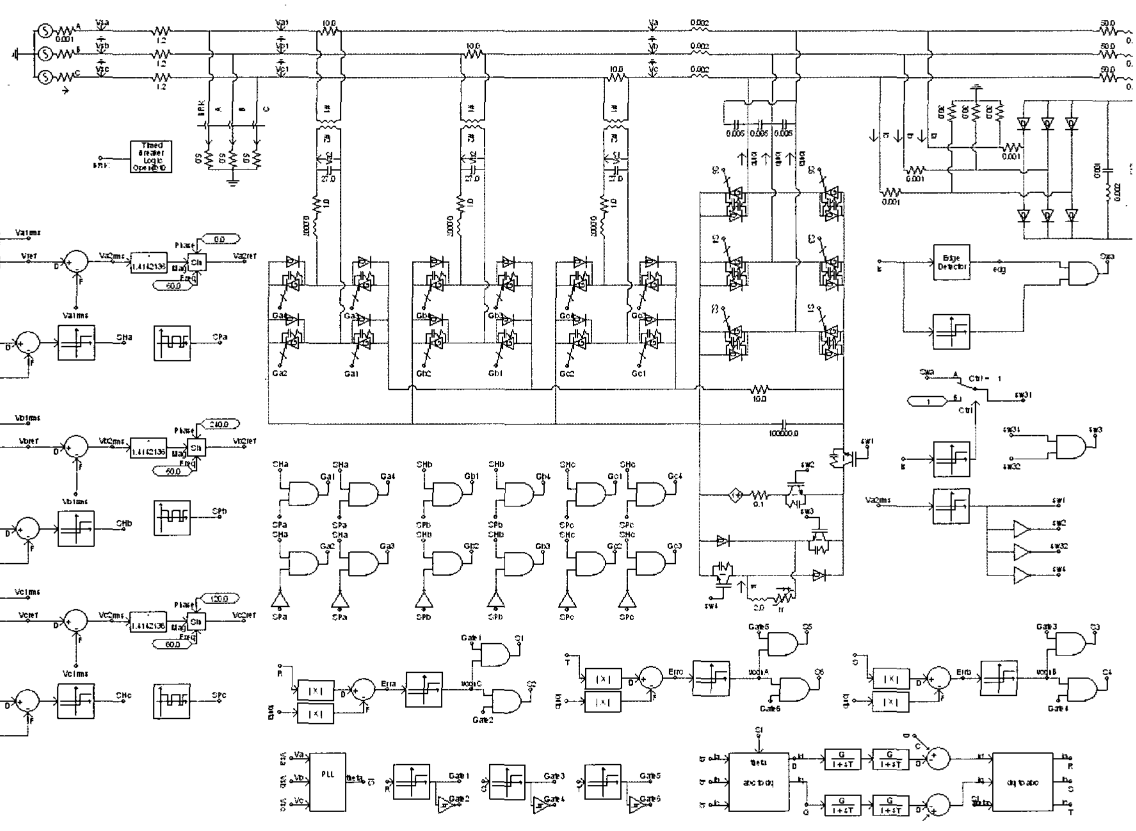
Appendix

APP-TABLE I
SPECIFICATION OF AF-SMES SYSTEM

System	Type	Filter	Devices
Shunt Active Filter	DC-AC voltage source inverter	L : 0.7[mH] C : 50[μF]	IGBT :6 EA
Series Active Filter	DC-AC voltage source inverter	L : 2[mH] C : 0.005[μF]	IGBT :12 EA
SMES	Chopper control charge and discharge	Chopper bank : 100000 [μF]	Capacity of SMES 0.1~1.0 [MJ]

Utility	Voltage Sag	Maximum load level
3Φ 380[volt]	for 3[sec]	120~180[kJ]



App-Fig. 1. Total simulation circuit in PSCAD/EMTDC.