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Powery System Stabilization by Superconducting Magnet Energy Storage (SMES) Controlled by 6 Pulse Converter

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1. Introduction

Superconducting Magnetic Energy Storage System(SMES) is an effective measure as an energy storage system.

In order to increase the stability and to suppress the voltage fluctuation of power system by SMES, the real power (P) and the reactive power (Q) must be supplied simultaneously from SMES to the power system. For simultaneous control of P and Q, symmetrically controlled 12 pulse converter has been used conventionally. But asymmetrically controlled 6 pulse converter can be applied to the simultaneous control of P and Q.

Asymmetrical control is known to have shortcomings such as third harmonic output ripple, second harmonic line current distortion and danger of commutation failure.

In this paper, asymmetrical control theory is expanded to control P and Q simultaneously. Stable control region where commutation failure does not occur is found, so that danger of commutation failure which is the most undesirable feature at asymmetrical control and reduction of operational reliability due to the commutation failure are overcomed. Computer simulation of model power system is done in order to show the effectiveness of the proposed method.

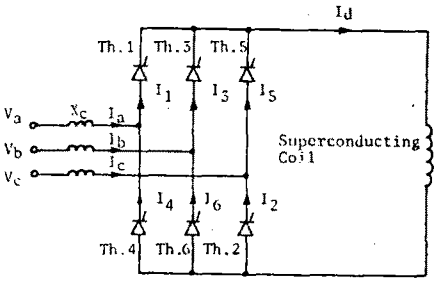

Fig. 1 6 pulse converter and superconducting coil connected to the power system

2. Commutation phenomena and maximum control angle

In Fig. 1, energy stored in superconducting coil is controlled by 6 pulse converter. Assume Th.3 or Th.4 begins to conduct while Th.1 and Th.2 are conducting.

2.1 Commutation without commutation interference

When upper or lower thyristor begins to commutate while Th.1 and Th.2 are conducting, time interval where commutation interference between upper and lower thyristors does not take place is

$$\alpha_1 + u_1 + \omega t_{off} > \alpha_2 + \frac{\pi}{3} \quad \cdots\cdots 1)$$

$$\alpha_2 + u_2 + \frac{\pi}{3} + \omega t_{off} > \alpha_1 \quad \cdots\cdots 2)$$

2.2 Commutation with commutation interference

Time interval where commutation interference takes place can be expressed as

$$\alpha_1 + u_1 + \omega t_{off} < \alpha_2 + \frac{\pi}{3} \quad \cdots\cdots 3)$$

$$\alpha_2 + u_2 + \frac{\pi}{3} + \omega t_{off} < \alpha_1 \quad \cdots\cdots 4)$$

Duration of each thyristor group's commutation may increase or decrease by the commutation interference. And if $\alpha_1 + u_1 < 5\pi/6$, re-triggering of commutated upper thyristor does not occur though lower thyristor begin to commutate within the lapse of turn-off time because negative forward blocking voltage is applied to the just commutated thyristor. Re-triggering of commutated lower thyristor does not occur because of the same reason as above if $\alpha_2 + u_2 < \pi/6$

At asymmetrical control, thyristor fired may not start to conduct. When Th.4 is fired within $\alpha_2 < \pi/6$ while upper thyristors are commutation, Th.4 cannot commence to commutate because i_4 becomes negative. Th.4 can start to conduct at $\omega t = \frac{\pi}{6}$ or after the completion of upper thyristor group's commutation. If Th.3 is fired first at $\alpha_1 > 5\pi/6$ while lower thyristors are commutating, conduction of Th.3 is delayed as the same reason above.

Simultaneous commencement of upper and lower thyristor group's commutation is represented in Fig. 2.

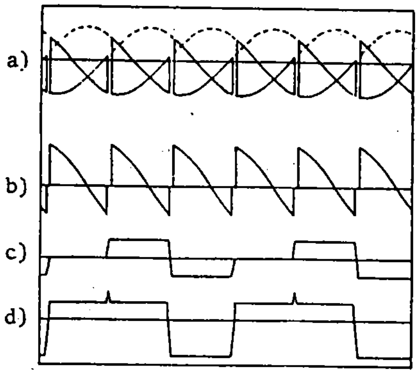

Fig. 2 Commutation phenomena at simultaneous commencement of upper and lower thyristors, $\alpha_1 = 100°$, $\alpha_2 = 40°$ and $X_c = 0.15$ pu

a) phase voltage
b) load voltage
c) secondary current of transformer
d) primary current of transformer

2.3 Maximum control angle

Simultaneous commutation of upper and lower thyristor group can take place in asymmetrically controlled converter. At this case, maximum control angle α_{max} is different from that of symmetrically controlled converter because both groups are influenced by each other.

If there is no commutation interference, α_{max} is the same as that of symmetrical control.

In case of commutation interference, commutation critical points which distingishing stable control region from unstable control region can be classified into five cases as in Fig. 3.

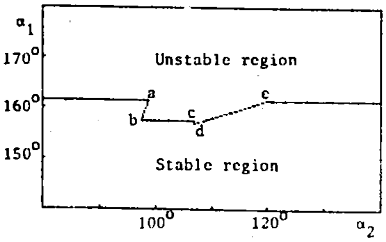

Fig. 3 Stable control region

$X_c = 0.05$ pu, $I_d = 200$ A, V = 100 V
and $t_{off} = 100$ μs

3. Simultaneous control of real power (P) and reactive Power (Q)

In symmetrical control, P depends on Q and vice versa. Dashed area A in Fig. 4 represents the control region at symmetrical control. Solid arc B and C are an example of asymmetrical control where one thyristor group is fully advanced (arc B) or fully retarded (arc C) and the other thyristor group is phase controlled in other to give the desired output voltage. Futhermore, if upper and lower thyristor group are controlled without any constraints, control region can be expanded to the dashed area in Fig. 4. This means simultaneous control of P and Q can be realized with 6 pulse converter.

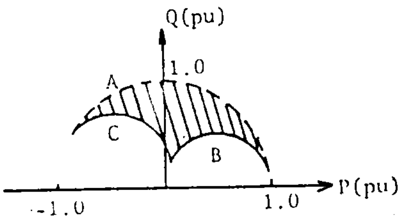

Fig. 4 Control region

A : symmetrical control
B,C : minimum reactive power control
/// : asymmetrical control

Neglecting the effect of commutation interference first, relation between P, Q and the control angle α_1, α_2 is given as follows.

$$P = \frac{1}{2} E_{do} I_d (\cos\theta_1 + \cos\theta_2) \quad \cdots\cdots 5)$$

$$Q = \frac{1}{2} E_{do} I_d (\sin\theta_1 + \sin\theta_2) \quad \cdots\cdots 6)$$

$$\cos\theta_i = \cos\alpha_i - \frac{3X_c I_d}{\pi \cdot E_{do}}$$

where X_c : commutation reactance
E_{do} : converter maximum output voltage at no load

4. Harmonic components

When a 6 pulse converter is asymmetrically controlled in order to minimize the reactive power, even harmonics in line current and third multiple of harmonics in load voltage are generated. The same asymmetrical control is adopted to control P and Q simultaneously.

SMES generates only lagging reactive power under the condition of natural commutation, therefore, capacitor for power factor correction must be used in order to generate leading reactive power. The rating of the capacitor is assumed to 0.7 pu. Fig. 5 shows the harmonic component of transformer primary current, while $\sqrt{P^2+Q^2}$ varies from 0.5 pu to 1 pu.

5. Power system stabilization by SMES

Two stabilizing effects of the SMES are examined by computer simulation of the model power system. One is the suppression of the power system oscillation that arises when one circuit of a double cir-

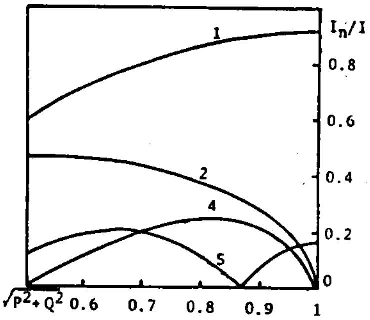

Fig. 5 Harmonic components of transformer primary current, while $\sqrt{P^2+Q^2}$ varies from 0.5 pu to 1 pu

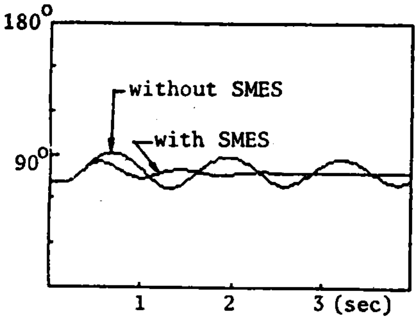

Fig. 7 Example of damping improvement by SMES controlled by the proposed 6 pulse converter, angular shaft angle displacement

cuit transmission line is opened. The other is the transient stabilizing effect when a three phase ground fault arises in a transmission line.

Fig. 6 shows the configuration of the model power system. Fig. 7 shows generator shaft angular displacement δ during the ocillation which aries by opening one transmission line.

6. Conclusion

This paper has shown that the real and reactive can be controlled simultaneously with 6 pulse converter by asymmetrical gating. Commutation phenomena during the asymmetrical gating has been analyzed and stable control region at this case has been shown. Thus, danger of commutation failure can be avoided.

According to the results, the maximum gating angle of asymmetrically controlled converter decreased slightly compared to that of symmerically controlled converter. The proposed 6 pulse converter turned out to be as effective as 12 pulse converter in reducing the power system transient instability. Power system ocillation was vanished within two seconds and step out of synchronous generator was prvented.

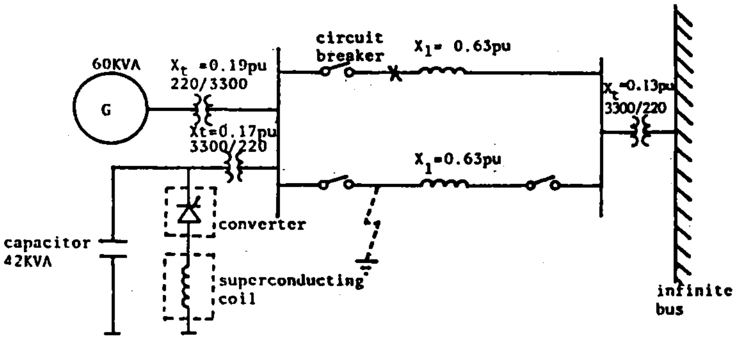

Fig. 6 Model power system

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