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FEATURES OF OPERATING MODES OF SYNCHRONOUS AND STATIC COMPENSATORS

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Abstract. *The article presents the features of the operating modes of synchronous and static compensators. The purpose of the article is to provide students, undergraduates and graduate students with new material on new domestic microprocessor-based integrated automatic devices and systems, to promote advanced training of personnel at power plants and electric power systems and to introduce into operation microprocessor-based automation equipment and relay protection of electric power systems in the process of its modern updating.*

Keywords: *microprocessor-based integrated automatic devices, power plants, electric power systems, microprocessor technologies, automation equipment.*

ОСОБЕННОСТИ РЕЖИМОВ РАБОТЫ СИНХРОННЫХ И СТАТИЧЕСКИХ КОМПЕНСАТОРОВ

Аннотация. *В статье представлены особенности режимов работы синхронных и статических компенсаторов. Цель статьи — обеспечить студентов, магистрантов и аспирантов новым материалом по новым отечественным микропроцессорным комплексным автоматическим устройствам и системам, способствовать повышению квалификации кадров на электростанциях и в электроэнергетических системах и внедрению в эксплуатацию микропроцессорных средств автоматизации и релейной защиты электроэнергетических систем в процессе их современного обновления.*

Ключевые слова: *микропроцессорные комплексные автоматические устройства, электростанции, электроэнергетические системы, микропроцессорные технологии, средства автоматизации.*

INTRODUCTION.

Modern high-and ultra-high-voltage power transmission lines are powerful uncontrolled generators of reactive power when the transmitted active power P_l is less than natural P_{nat}, or consumers - when $P_l>P_{nat}$. Therefore, traditional modern reactive power generators - synchronous compensators function as controlled reversible sources, i.e. and as its consumers.

New reactor (consuming) and reactor-capacitor (reversing) static reactive power compensators, designed for connection to the buses of power stations and intermediate node substations of main power transmission lines, have been created and continue to be developed.

Results and Discussion. A synchronous compensator is used in modern EPS not only as a generator of reactive power, but also as its controlled consumer. The generation (output) or consumption mode is determined by the excitation of the synchronous compensator.

In accordance with its U-shaped characteristic (Fig. 1, a) at the rated excitation current $I_{ex.nom}$, the synchronous compensator produces reactive power

$$Q_{SK.nom} = U_B\left(E_{q.nom} - U_B\right)/\, x_d \quad (1)$$

and in the absence of excitation (I_{ex}=0) - consumes reactive power

$$\left|-Q_{SK0}\right| = \frac{U_B^2}{x_d} \approx 0{,}5Q_{SK.nom} \quad (2)$$

The highest possible load of the synchronous compensator with consumed reactive power is achieved either with a marginal negative excitation current, or in the absence of excitation Iв=0 and the internal angle of the compensator δ=π/2 (Fig. 1, c), i.e. when the rotor is located along the transverse axis. Wherein

$$\left|-Q_{SK.br}\right| = \frac{U_B^2}{x_d} \approx 0{,}75Q_{SK,nom} \quad (3)$$

The boundary mode of reactive power consumption is determined by the condition for the stability of the synchronous compensator - maintaining synchronism. The synchronizing torque is generated by a synchronous electromagnetic M_S and reactive (due to salient polarity) M_R moments

$$\left.\begin{aligned} M_S &= \frac{E_q U_B}{x_d}\cdot \sin\delta; \\ M_R &= \frac{U_B^2}{2}\cdot\frac{x_d - x_q}{x_d x_q}\cdot \sin 2\delta. \end{aligned}\right\} \quad (4)$$

In particular, in the absence of excitation, the synchronous compensator is kept in synchronism only due to the reactive torque. With negative excitation, the synchronous torque counteracts the reactive torque and impairs the stability of the synchronous compensator.

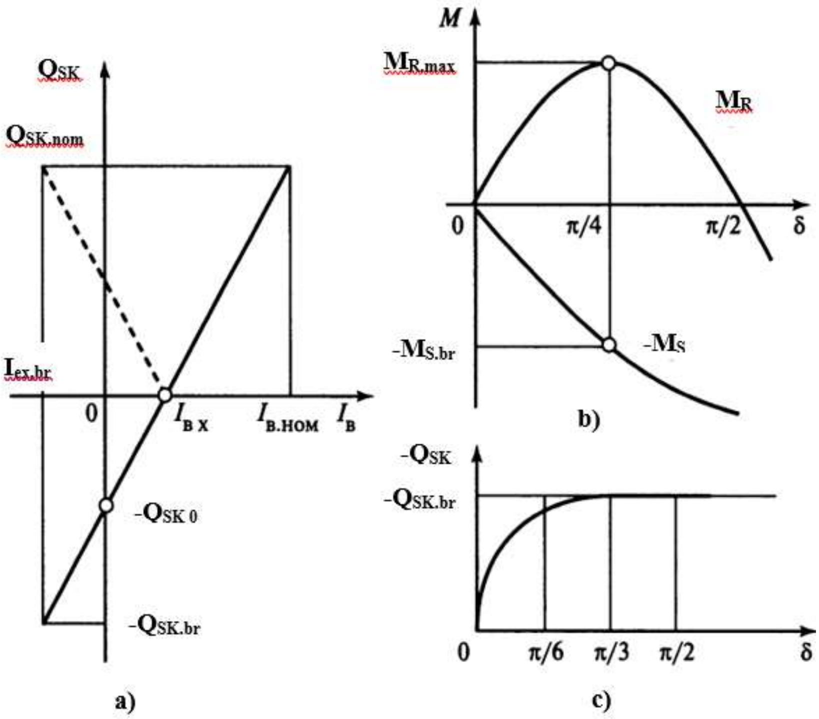

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Fig. 1. Graphs of the dependences of reactive power on the excitation current (a) torque (b) and consumed reactive power (c) on the internal angle of the synchronous compensator

Limit value of negative EMF $E_{q.br}$ is determined by setting the derivative of the synchronizing torque with respect to the angle δ to zero. Taking into account (4)

$$\frac{d}{d\delta}\left(M_S + M_R\right) = \frac{E_{q.br} U_B}{x_d} \cdot \cos\delta + U_B^2 \frac{x_d - x_q}{x_d x_q} \cdot \cos 2\delta = 0, \quad (5)$$

at δ=0

$$-E_{q.br} = U_B \frac{x_d - x_q}{x_q} = U_B \frac{\Delta x}{x_q} \cdot (6)$$

With negative excitation, the highest reactive power consumption is $-Q_{SK.br}$ theoretically achieved in the boundary mode at δ=0. In practice, due to the presence of active power losses (for ventilation, friction), the power $-Q_{SK.br}$ is achieved at angle δ≈π/10.

In boundary mode, the synchronous compensator falls out of synchronism. According to (4) and Fig. (1, b) at δ=π/4

$$\left|-M_{S.br}\right| = M_{R\max}, (7)$$

and at δ>π/4 the synchronizing torque is negative. Even in the absence of negative excitation, the angle δ>π/4 increases as the reactive torque decreases. At δ=π/2, i.e. when the rotor is positioned along the transverse axis, the stator resistance is equal to x_q and the power consumption reaches close to the highest value (3) in the absence of excitation (I_{ex}=0). But such a mode is possible only under conditions of artificial stability of the synchronous compensator.

The possibility of continuous control of the power of reactors and discrete changes in the power of capacitor units by powerful thyristor controlled devices and thyristor switches, respectively, led to the development of reversible controlled static compensators (STC), more reliable, fast-acting and less expensive than rotating synchronous compensators. In connection with the revealed features of switching sectionalized capacitor units, it turned out to be advisable to carry out STC consisting of a continuously controlled reactor part and a permanently switched on or only switched on and off capacitor unit as a whole. Since continuously controlled reactor STCs generate harmonic components of voltage and current in modes of low load of consumed reactive power (at large switching angles of thyristors π/2<α<2π/3), it was necessary to section them and carry out discrete-continuous control of their power, i.e. . switch on and off individual reactors with continuously varying power of each of them using thyristor converters operating with small thyristor switching angles (π/6<α<π/2). Therefore, two types of STC were defined: both consist of separate sections (modules), but one with a permanently connected capacitor unit, and the second with a periodically switched one.

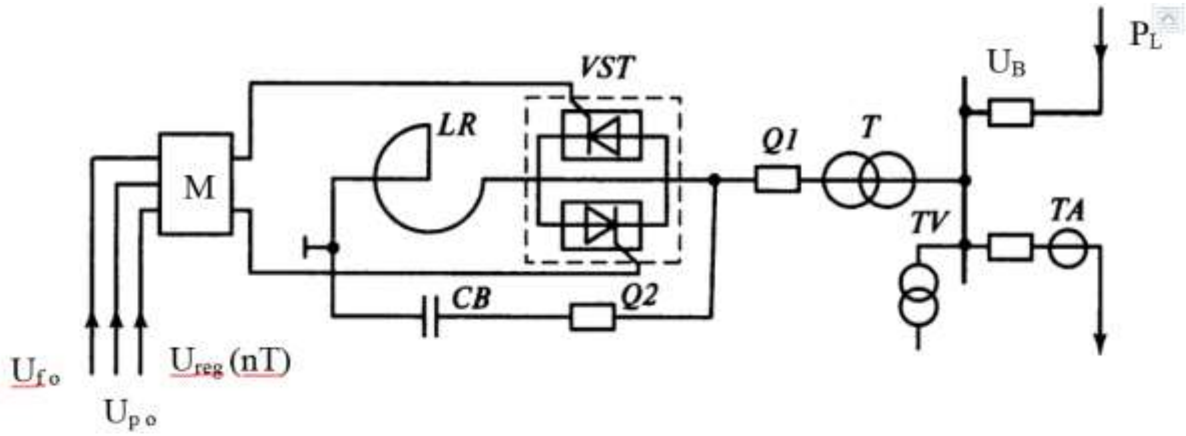

Fig. 2. Scheme of STC reactive power microprocessor system for integrated control and protection of STC

The first type of STC is partially, and the second is completely reversible. For example, the control system of one of the substations with a voltage of 1150 kV consists of 14 reactor continuously controlled modules consuming reactive power up to -1100 Mvar, and a capacitor unit with a capacity of +300 Mvar. The reversible STC with a power of +55 Mvar contains a continuously controlled thyristor converter VST (see Fig. 2, a) reactor part LR and a discretely controlled non-sectional one, i.e. switched on or off, capacitor unit - CB battery with voltage of 10 or 20 kV [3].

Synchronous electric motors also serve as compensators for consumed reactive power (its generators). However, they practically cannot work in the reactive power consumption mode.

CONCLUSION

1. The highest possible load of the synchronous compensator with consumed reactive power is achieved either with a marginal negative excitation current, or in the absence of excitation I_{ex}=0 and the internal angle of the compensator $\delta=\pi/2$, that is when the rotor is located along the transverse axis.
2. Since continuously controlled reactor STCs in low load modes of consumed reactive power (at large switching angles of thyristors $\pi/2 < \alpha < 2\pi/3$) generate harmonic components of voltage and current, this increases losses in electrical networks.

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