EXPERIMENTAL STUDY OF DYNAMIC BEHAVIOR OF DIFFERENT FLEXIBLE SYSTEMS FOR REACTIVE POWER COMPENSATION

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Abstract. The paper presents the results obtained from a study of flexible reactive power compensation systems. The aim is to evaluate the application of flexible reactive power compensation systems for industrial consumers and to develop stability and quality comparison for two fundamentally different high speed reactive power compensation systems. The first of them is system with constant volume of compensation capacitors and in parallel to them regulated by thyristors reactors; the second one is so named STATCOM system with modulated by transistors parameters of reactors-capacitor circuits. Both investigated systems can react very fast to changes of power relations in compensated load circuits, i.e. they are a flexible compensation systems. Comparison of the both systems is reduced to investigation of their response time to load power component deviations.

Keywords: capacitor, reactor, power, compensation, thyristor, transistor, balance.

Introduction

The answer to the question about power quality is not fully accepted, but surely the response involves waveforms of current and voltage in an ac system, the presence of harmonic signals in bus voltage and load current, the presence on spikes and momentary low voltages, and other issues of distortion. Perhaps the best definition of power quality is the provision of voltages and system design so that the users of electric power can utilize electric energy from the distribution system successfully, without interference or interruption. A broad definition of power quality borders on system reliability, dielectric selection on equipment and conductors, long-term outages, voltage unbalance in three-phase systems, power electronics and their interface with the electric power supply, and many other areas. A narrower definition focuses on issues of waveform distortion [1; 2].

In this paper power quality will be examined by means of flexible reactive power compensation in objects where it is required. But as it is well known the compensation systems that regulate the balance of reactive power consists not only on reactive elements but also on semiconductor converters that create distortions in network current.

The following popular versions with static elements were selected to provide flexible compensation [3-5]:

1. A thyristorized compensation system: capacity of capacitor banks is constant, but the balance of reactive power is changed with flexible regulation of reactor inductivity.
2. A transistorized compensation system: fast operating semiconductor modulator, which can smoothly change the reactor current, using a capacitor as a dc source.

To reach the goal set, several tasks were performed:

1. Thyristorized flexible capacitor-reactor system was studied by regulating reactor inductivity with thyristors.
2. Modulated transistorized capacitor-reactor system was made by using a modulator as an active rectifier with diode-transistor elements.
3. The compensator impact on network was evaluated.
4. The stability of both systems was verified.

Description of the investigated compensation systems

1. Thyristorized compensation system

The flexible reactive power compensation system with thyristor regulated reactors and capacitors with constant capacity is shown in Fig. 1 [4; 6].

In systems with the line voltage U_n=380 V, the capacity of capacitors is constant but the reactor current (I_L) and the power (Q_L) is regulated with thyristors [4; 6]. It is assumed that the reactive power of the capacitor Q_C is equal to the maximal load reactive power $Q_{load\ \max}$. If $Q_{load}<Q_{load\ max}$, reactive power of reactors Q_L>0. If the load operates in absolutely active regime then $Q_{Lmax}=Q_C$. If the load cannot be absolutely active and the reactive power of the load is minimal ($Q_{load\ min}$), then Q_{Lmax} can be smaller than Q_C, i.e.,

$$Q_{L\max} = Q_C - Q_{load\ \min} = Q_C(1-k)\,, \tag{1}$$

where k – the ratio between the minimal and maximal load reactive power.

The regulation system (Fig. 1b) includes the reactive power sensor (*SQ*) that actually can inform about reactive power in the previous half-cycle, consequently with delay till half period starting from changes of load reactive power. The reactive power sensor can be replaced with delay angle φ_t of network current.

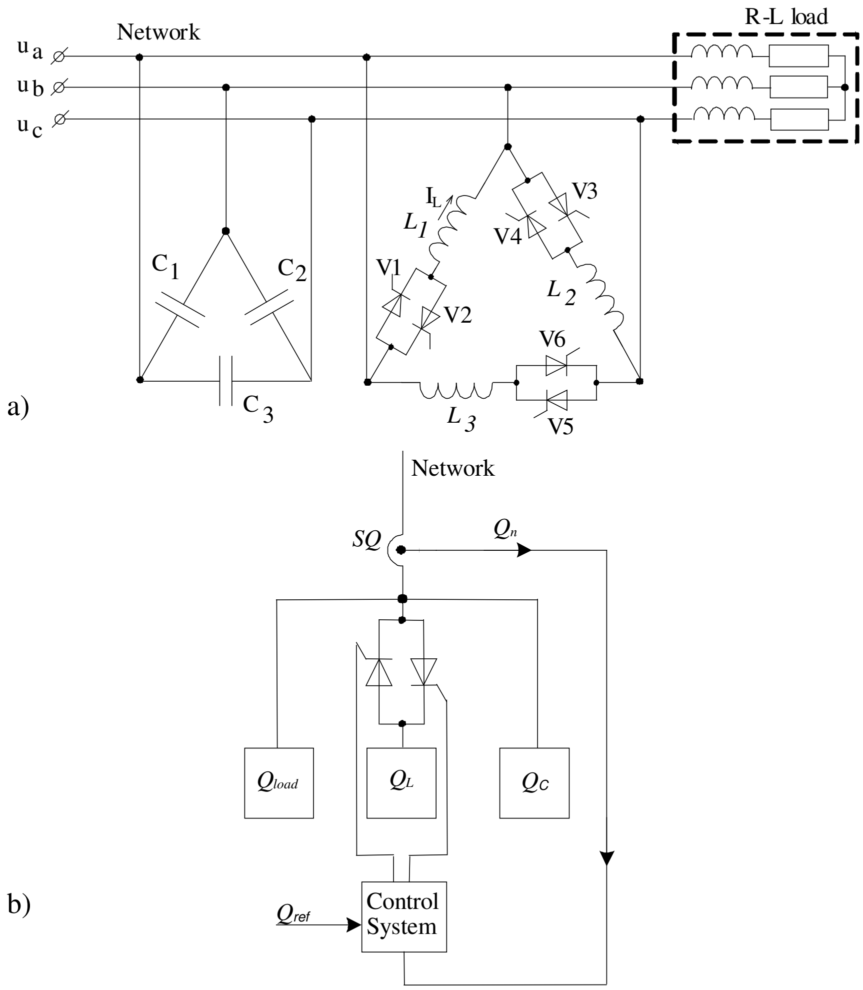

Fig. 1. **Generalized flexible reactive power compensation system with thyristor regulated reactors:** a – scheme; b – simplified control system

Thyristors are used as regulation elements in the reactor circuit. However the thyristor operation regime can be changed only in the next half-cycle after *SQ* reaction that makes time delay in the system.

2. Transistorized compensation system

A transistorized compensation system consists of the three-phase voltage source converter (*VSC*), which works as a reactive power compensation system (Fig. 2) [3-6].

In this system according to the network reactive power Q_n control system is changing modulation intervals in order to increase or decrease the amplitude of the leading reactor current (I_{Lm}) which actually defines reactive power of the compensator:

$$Q_k = \sqrt{3} U_n \frac{I_{Lm}}{\sqrt{2}} = Q_t \,. \tag{2}$$

If the network reactive power Q_n=0 then the maximal reactor current I_{Lm}=0. The bigger is Q_n – the bigger is I_{Lm}.

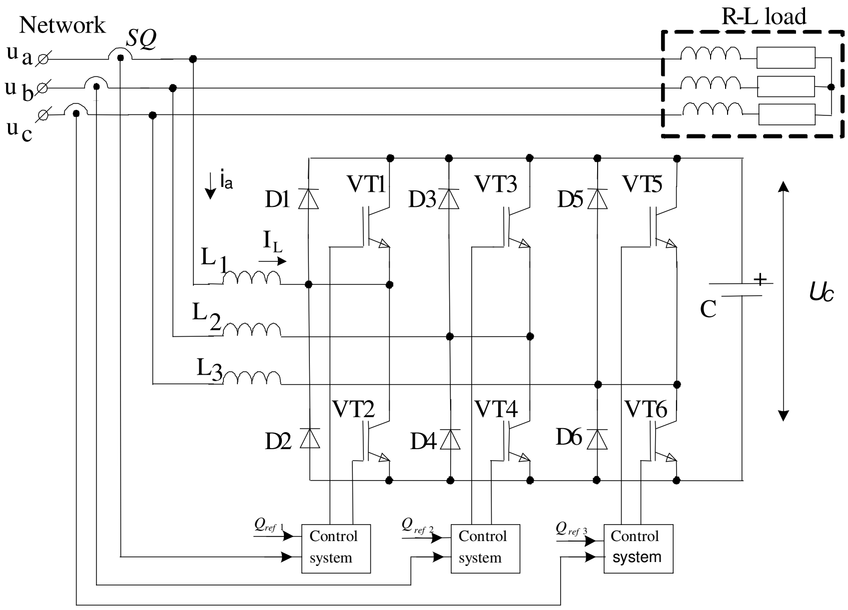

Fig. 2. **Generalized power and control circuit of transistorized compensator**

In this system the predictable sin curve amplitude of the reactor current can be changed almost momentary after reaction of the *SQ*. Consequently, in such system predictable high-speed operation is bigger.

Reaction time of the discussed systems

1. Thyristorized compensation system

To evaluate the reaction time of the thyristorized reactive power compensation system elements there was a closed-loop PSIM model developed where the reactive power of capacitors and reactors is 24 kVAr. For this case the compensation system was examined without load. In order to change the compensator reactive power we should change the thyristor regulation angle α. The regulation angle was changed with a jump from α=92º (Q_L=23 kVAr) to α=143º (Q_L=2.6 kVAr).

As we can see (Fig. 3), in the thyristorized compensation system time delay of the changes of reactor current (I_L) and network current (I_n) in the aspect of all three phases is about 10-15 ms. Generally, with the implemented time delay of the reactive power sensor, the system delay at frequency f=50 Hz is about 20-25 ms.

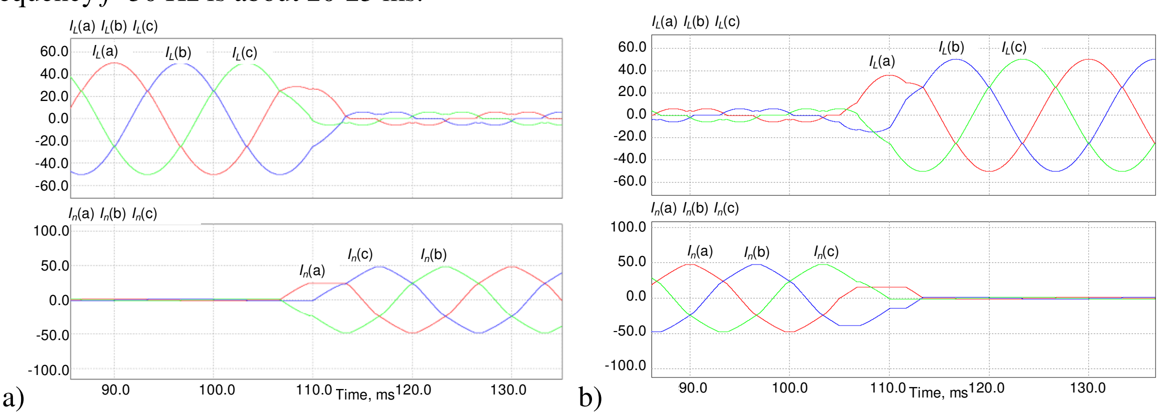

Fig. 3. **Reactor current and network current at different reactive powers of reactors during switching at 105 ms:** a – from Q_L=23 kVAr to Q_L=2.6 kVAr; b – from Q_L=2.6 kVAr to Q_L=23 kVAr

2. Transistorized compensation system

To evaluate dynamics and stability of the transistorized reactive compensation system there was a closed-loop PSIM model developed. Also in this case the first task was to evaluate the reaction time of the modulated diode-transistor bridge. For that experiment the system was considered without load. The reaction of the system was evaluated by the changing reference signal of the transistor control system. There was specific time set when the control system switches the transistors from one condition to another.

Fig. 4 shows network voltage (U_n) and network current (I_n) waveforms in all phases before and after changes of the control system reference reactive power Q_{ref}.

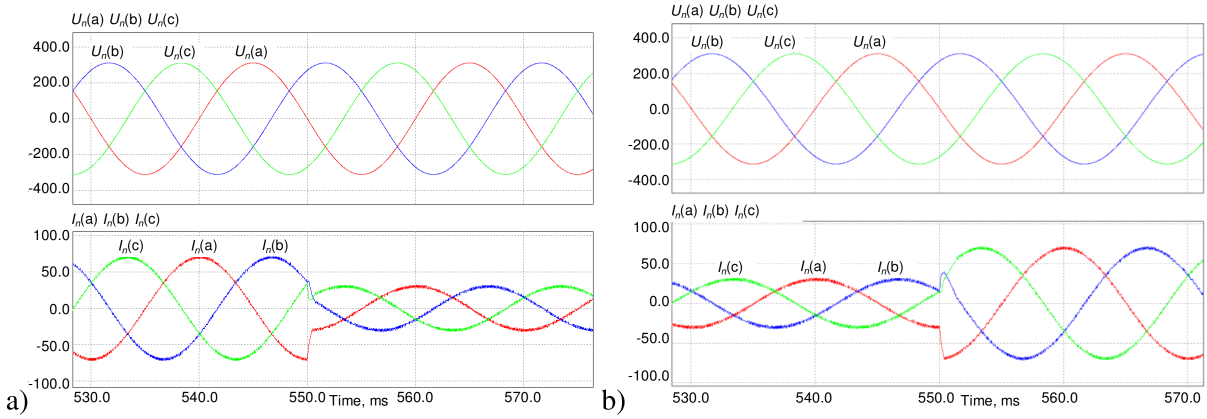

Fig. 4. **Reaction of network voltage and network current before and after changes of the control system reference value:** a – from Q_{ref}=32.5 kVAr to Q_{ref}=12 kVAr; b – from Q_{ref}=12 kVAr to Q_{ref}=32.5 kVAr

As we can see in Fig. 5, the reaction time of the system is relatively short (some μs).

Dynamics and stability of the compensation system

1. Thyristorized compensation system

For testing the compensation system at real conditions there was system evaluation with *R-L* load made as it is shown in Fig. 1 (a). To examine the operation of the three-phase thyristor regulated system the evaluation at momentary changes of *SQ* signal was made. The load reactive power changed with a jump from Q_{load}=8.63 kVAr to Q_{load}=22.35 kVAr and opposite. Consequently, also the thyristor regulation angle α is changing to reach the system compensation. The changes of network voltage (U_n), network current (I_n), reactor current (I_L) and load current (I_{load}) are shown in Fig. 5.

As we can see in Fig. 5, the system reacts on changes of the load reactive power within 10-15 ms.

2. Transistorized compensation system

Also this system was tested and evaluated with *R-L* load like the thyristorized compensation system as it is in Fig. 2.

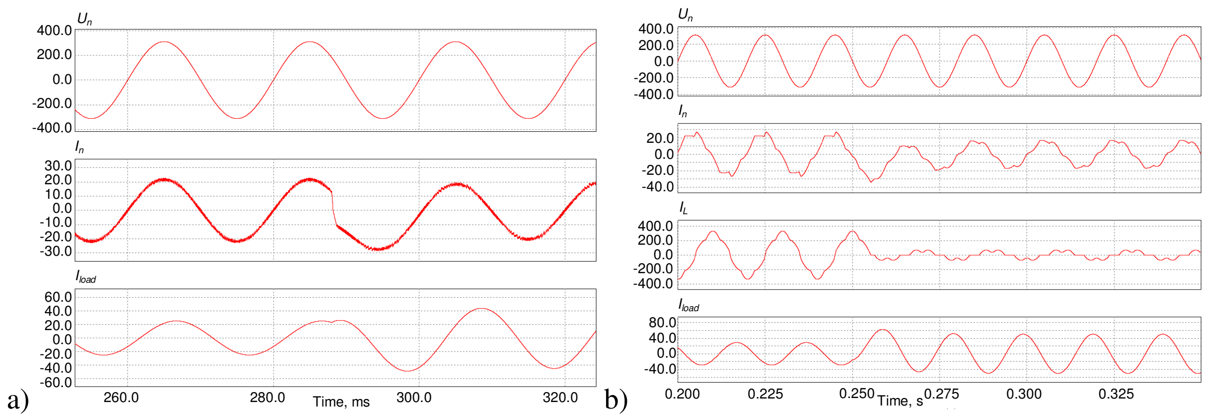

Fig. 5. **Changes of compensation system parameters at different Q_{load}**
a – from Q_{load}=8.63 kVAr to Q_{load}=22.35 kVAr; b – from Q_{load}=22.35 kVAr to Q_{load}=8.63 kVAr

To check the system performance the reactive power of load was switched from one condition to another (from Q_{load}=5.86 kVAr to Q_{load}=18.61 kVAr and opposite).

The changes of network voltage (U_n), network current (I_n) and load current (I_{load}) are shown in Fig. 6. As we can see the system response on the changes of the load reactive power (Q_{load}) is also relatively fast (some μs) and without heavy transients.

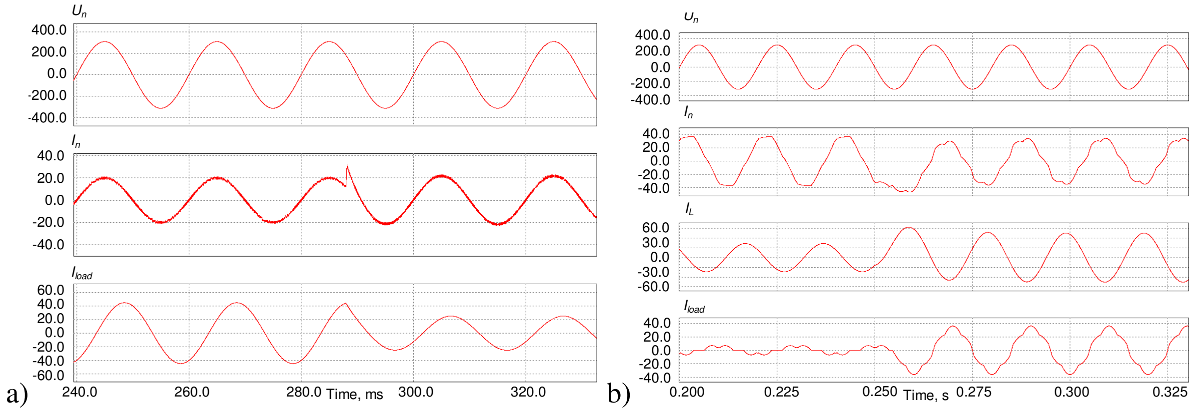

Fig. 6. **Changes of compensation system parameters at different Q_{load}:**
a – from Q_{load}=5.86 kVAr to Q_{load}=18.61 kVAr; b – from Q_{load}=18.61 kVAr to Q_{load}=5.86 kVAr

Conclusions

In the paper two principally different flexible reactive power compensation systems – thyristorized and transistorized – were evaluated.

During momentary changes of the load reactive power the transistorized compensation system can react faster than the thyristorized compensation system. The thyristorized compensation system can respond on changes of the load reactive power only in the next half-cycle because of the thyristor properties.

As it was shown, voltage and current waveforms of both systems have good stability after momentary changes of the load reactive power. All the transients end in time of one half cycles after changes.

The waveforms of the network current in both systems are not much distorted, but as it is visible, at different load reactive powers the transistorized compensation system network current is closer to the sin wave than the network current of the thyristorized system.

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