CHAPTER 19

JOINT USE OF FILTER-COMPENSATING DEVICES AND CAPACITOR BATTERIES AND THEIR INFLUENCE ON THE QUALITY OF ELECTRIC POWER

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Abstract. The paper considers aspects of joint use of filter-compensating devices (FCD) and capacitor banks (CB). The strategies for using FCD and CB taking into account the specifics of various types of loads and network operating conditions are presented, the efficiency of such systems under the influence of network accidents, asymmetric loads and voltage fluctuations is considered. The results of modeling the use of intelligent control systems for FCD and CB on quality indicators and the amount of electrical energy losses are presented. **Keywords:** Filter-compensating devices; Capacitor banks; Power quality; Reactive power compensation; Modeling; Optimization of use strategies; Intelligent control systems.

INTRODUCTION

Modern power systems face challenges related to declining power quality, including harmonic distortions and voltage unbalance [1]. Filter-compensating devices (FCDs) and capacitor banks (CBs) are widely used to improve power supply characteristics. The combined use of these devices helps achieve a balance between reducing harmonic distortions and maintaining an optimal power factor.

FCDs can be active, passive, or hybrid. Active devices operate by injecting counter-phase harmonic currents, while passive devices use tuned LC filters. Hybrid systems combine both methods, providing more effective suppression of higher-order harmonics and improved power quality.

Capacitor banks are used for reactive power compensation and to improve the power factor, which reduces network losses and prevents penalties for a low power factor (cos**φ**) [2]. However, in the presence of higher harmonics in the network, using CBs without appropriate filters may lead to resonance phenomena and increased distortions. Therefore, it is recommended to use capacitors in conjunction with anti-resonance reactors, forming filters tuned to specific harmonics.

COMBINED APPLICATION OF FILTER-COMPENSATING DEVICES AND CAPACITOR BANKS FOR POWER QUALITY IMPROVEMENT

The combined use of FCDs and CBs allows for a synergistic effect: FCDs effectively suppress higher harmonics, while CBs compensate for reactive power, thereby collectively improving power quality. However, when designing such systems, potential resonance phenomena must be considered, and the device parameters must be correctly configured to ensure stable and efficient operation, taking into account the specifics of the electrical network and the nature of the loads.

Before designing the system, a detailed analysis of the network parameters is required, including voltage levels, the harmonic frequency spectrum, and the nature of the loads. Using software tools to simulate the behavior of FCDs and CBs in a specific network allows for the prediction of possible resonance phenomena and the adjustment of system parameters.

A phased introduction of compensating devices with constant monitoring of network parameters is recommended to promptly identify and eliminate possible problems [3]. Careful design and configuration of parallel FCD and CB systems, considering calculated parameters and the specific features of a particular electrical network, ensure effective reactive power compensation and harmonic distortion filtering, thereby enhancing power quality and equipment reliability.

There are several control methods for such systems, each with its own characteristics and areas of application.

In systems with variable reactive power consumption, automatic power factor correction is widely used [4]. This method relies on controllers that measure the current power factor and automatically connect or disconnect the appropriate capacitor banks to maintain the desired value. These systems provide step-by-step regulation of reactive energy and supply information about network parameters and equipment status.

Thyristor-switched capacitor (TSC) systems offer fast and precise switching of capacitor banks using thyristor switches. Switching occurs at voltage equalization moments between the capacitors and the network, which minimizes transients and reduces harmonic distortions. Such installations are particularly effective in networks with dynamically changing loads.

Combined systems that integrate thyristor-controlled reactors (TCR) and thyristor-switched capacitors (TSC) allow for smooth regulation of reactive power balance without significant transients. In such systems, the TCR acts as a damper, compensating for the surplus or deficiency of reactive energy generated by the TSC. This provides high responsiveness and control accuracy, which is especially important in digital networks.

Active harmonic filters are devices that generate currents opposite in phase to unwanted harmonics present in the network. This effectively reduces harmonic distortion levels and improves power quality. Active filters can work in conjunction with CBs, providing comprehensive reactive power compensation and harmonic filtering.

Stepped regulation units consist of several sections of capacitor banks, which can be switched on or off depending on the current needs of the network. Such systems allow for discrete regulation of the level of reactive power compensation, adapting to changing load conditions. However, when using them, it is necessary to consider possible transients during switching, which may cause current and voltage surges.

The choice of a specific control method for combined FCD and CB systems depends on the specific characteristics of the power system, the nature of the load, and the required power quality.

Optimization Recommendations for FCD and CB Use in Various Scenarios

1. *Loads with constant reactive power consumption*. For systems with relatively stable reactive power demand, such as lighting or heating equipment, installing fixed CBs is an effective solution. This improves the power factor and reduces energy losses. When selecting the power and type of compensating device, the power supply scheme of the facility should be considered.
2. *Loads with variable reactive power consumption*. When reactive power consumption varies over time (e.g., asynchronous motors, welding equipment), the use of adjustable capacitor banks is recommended. These systems automatically adapt to current demands by switching the required capacitor sections, minimizing energy losses in the network.
3. *Loads generating higher harmonics*. Industrial facilities with nonlinear loads, such as frequency converters or thyristor devices, can cause voltage distortion due to higher harmonics. In such cases, the use of FCDs is advisable to normalize electromagnetic compatibility parameters and improve power quality.
4. *Networks with rapidly changing loads.* In networks with sharp load fluctuations, such as arc steel-melting furnaces, special consideration is needed when using CBs. It is recommended to introduce additional active resistors in the CB circuit to reduce current overload during voltage fluctuations.
5. *Networks with high harmonic distortion levels.* In networks prone to significant harmonic distortion, using CBs without appropriate filtering may lead to resonance. To prevent this, FCDs should be used to filter harmonics and correct the power factor.

Challenges from Network Conditions

The effectiveness of such systems is significantly affected by network disturbances, unbalanced loads, and voltage fluctuations. Network failures (e.g., short circuits or line breaks) can cause sharp changes in voltage and current, leading to overload and damage of FCDs and CBs. For example, sudden voltage spikes may lead to overvoltage on capacitors, shortening their service life and increasing failure risk.

Unbalanced loads result in uneven distribution of currents and voltages across phases, causing additional losses and overloads in the network. FCDs and CBs designed for balanced load operation may perform inefficiently under unbalanced conditions, reducing their ability to compensate reactive power and filter harmonics.

Voltage fluctuations, especially in networks with rapidly varying loads, negatively impact compensating devices. Rapid voltage changes may trigger resonance phenomena between network inductances and CB capacitances, leading to additional harmonic distortion and increased current levels.

Research Findings

Studies conducted by the authors show that the results of combined FCD and CB usage depend on the initial network parameters, load type, and characteristics of the installed devices.

FCDs effectively suppress higher harmonics, reducing Total Harmonic Distortion (THD):

- Before installation, THD in networks with nonlinear loads can reach 10–20%
- After FCD installation, THD decreases to 3–5% (depending on the active filter settings)
- With combined FCD and CB use, THD stabilizes in the range of 2–4%

Phase voltage unbalance (unbalance factor) can reach 2–5% before FCD and CB installation, especially in systems with load imbalance. Combined FCD and CB use reduces this to 0.5–1.5%, meeting the regulatory requirements (GOST 32144-2013 recommends <2%).

Before reactive power compensation, active power losses due to low cos**φ** typically reach 5–10% of consumed power. After CB installation, losses are reduced by 20–30%; After combined use of FCDs and CBs, loss reduction reaches 35–50%, since both reactive components and harmonic energy flows are eliminated.

Table. Simulation Results of Combined Use of FCDs and CBs for Power Quality Improvement.

Parameter	No Compensation	FCD Only	CB Only	Combined FCD and CB
Harmonic Distortion (THD, %)	10–25%	3–6%	8–15% (resonance possible)	1,5–3%
Voltage Unbalance Factor (%)	2–6%	0,5–1,5%	1–2%	0,2–1%
Power Factor (cos**φ**)	0,7–0,85	0,85–0,90	0,92–0,95	0,98–1,00
Voltage Swings and Fluctuations (ΔU, % of nominal)	±5–10%	±2–4%	±2–4%	±0,5–1,5%
Power Losses in the Network (%)	5–12%	Reduced by 15–30%	Reduced by20–35%	Reduced by35–55%

As can be seen from the table, the combined use of FCDs and CBs allows:

- Reduction of voltage harmonic distortion to 1.5–3%
- Decrease of voltage unbalance to 0.2–1%
- Increase of the power factor to 0.98–1.00
- Reduction of voltage fluctuations to ±0.5–1.5%

- Reduction of power losses in the network by 35–55%, which are typically caused by higher harmonics and a low power factor.

Predictive control algorithms and machine learning enable dynamic adaptation of filtering depending on network parameters, further reducing residual harmonics.

CONCLUSION

Optimal strategies for using FCDs and CBs tailored to network conditions allow:

- THD reduction by 5–10 times (to 1.5–3%)
- Voltage unbalance reduction by 3–6 times (to 0.2–0.8%)
- Increase of power factor to 0.98–1.00
- Voltage fluctuation reduction by 3–6 times (to ±0.5–1.5%)
- Power loss reduction by 35–55%

These improvements contribute significantly to enhancing power quality and system reliability.

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