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Application of FACTS Devices in Power Supply Systems of Coal Mines

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Abstract. In this article, the authors discuss the use of FACTS devices in coal mine power systems. The problems of reactive power compensation and the disadvantages of regulatory and technical documentation regarding the use of modern reactive power compensation devices are considered. The main types of FACTS devices that can be used in coal mines are identified. The scientific publications in the field of application of FACTS devices in power supply systems of industrial enterprises are analyzed. The cost indicators of FACTS devices are considered and conclusions are drawn on the theoretical technical and economic efficiency of using FACTS devices in mine conditions.

1 Introduction

Since the beginning of the XXI century, there has been a transition to technological structures “longwall face - mine” with an increase in power supply and the level of voltage of electrical equipment in coal mine extraction areas. Despite the increase in power supply, the design of power supply systems for coal mine extraction areas is still carried out following the outdated "Instructions for the design of electrical installations of coal mines, open pits, concentration, and briquette factories" (1993) (hereinafter - the Instruction). This Instruction was developed in the 60-80s of the XX century and therefore does not take into account the features of the electrical complex of extraction areas of modern coal mines.

Among the features of power supply systems in coal mine extraction areas, it is worth noting the lack of reactive power compensators (RPC) in the underground part of the power supply system [1], which was previously associated with the absence of explosion-proof RPC. However, currently on the market of compensating devices, there are explosion-proof RPC - UKRV. Besides, in the explosion-proof version, static var compensator (SVC), dynamic voltage restorer (DVR), static synchronous compensator (STATCOM) can be made. The above devices have a high speed compared to UKRV, which is especially important for coal mine extraction areas which are characterized by a sharply variable nature of the electrical load.

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Section 6 of the Instruction contains recommendations on the use of RPC devices with automatic regulation and on their placement at each stage of the distribution network, including the underground one. At the same time, an indication was given that the design of RPC should be carried out following RTM36.18.32.6-92 “Instructions for the design of reactive power compensation units in general-purpose electrical networks of industrial enterprises”. This document is outdated and does not take into account the availability of modern intelligent flow control devices for active and reactive power. It also does not provide an answer to the question of how to approach the task of optimizing the placement of RPCs of different types and operation speed.

Note that in [2], to ensure the sustainable development of the coal industry of the Russian Federation, the requirements to reduce the cost of coal by 2035 to the level of 68% relative to 2016 are defined. In this regard, it becomes relevant to assess the feasibility of placing FACTS devices in the underground part of the coal mine, which will realize the potential of energy conservation and reduce the share of energy costs in the cost of coal mining.

This article has the following structure. The second section describes the types of FACTS devices that can be used in coal mines and their possible locations the coal mine power supply system. The third section discusses the cost performance of modern FACTS devices. Finally, the fourth section contains a conclusion on this article.

2 Types of FACTS devices and possible locations in the coal mine power supply system

FACTS devices are widely used in system-forming electric networks of 110-750 kV to maintain the specified voltage levels at the control points of the network, increase the transmission capacity of power lines, control power flows, and also to increase static and dynamic stability [3, 4]. Given the reduction in the cost of power electronics, the use of FACTS devices is also possible in networks of a lower voltage class, including networks of industrial enterprises. Two generations of FACTS devices are distinguished:

1. First-generation FACTS devices providing scalar voltage (reactive power) control.
2. Second generation FACTS devices that provide vector control of operating parameters and are built based on fully controllable power electronics devices (IGBT transistors, IGCT thyristors, etc.).

The classification of FACTS devices is presented in Figure 1.

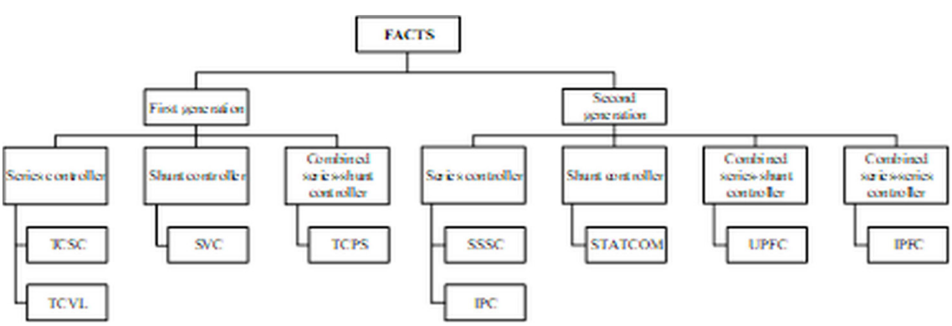

Fig. 1. The classification of FACTS devices.

Among the above devices, power supply systems of large industrial enterprises can find applications of the shunt switching device - SVC and STATCOM. FACTS series switching devices (for example, SSSC) have the main task in controlling power flows [3], which is not required for the power supply system (PSS) of industrial enterprises.

In accordance with the algorithm for selecting FACTS devices developed by M. Balobanov [5], it is advisable to use devices like APF (active power filter), PF (power filter), SVC (static var compensator) in coal mines PSS. The reason for this solution is that in coal-mine power supply systems, it is possible to observe strong fluctuations in reactive power, harmonic distortion, and flicker. In [6], it is also noted that the most suitable FACTS devices for power supply systems of the mine are shunt switching devices - SVC and STATCOM.

The widespread use of variable frequency drives, as well as load sensitive to the power quality, necessitated the management of the power quality in the power supply systems of consumers of electric energy. Passive devices for limiting electromagnetic interference have many disadvantages, for example, stepwise regulation, the difficulty of choosing parameters in a changing network configuration, the risk of resonance phenomena, large dimensions, etc. This has led to the need for active power quality management devices based on FACTS. Such devices are called Distributed-FACTS (D-FACTS) and Custom Power Devices (CPD) [7-9]. These devices are in many ways similar to FACTS devices and have a common technical base with them, but differ in their smaller size, power, and price, which allows them to be used in power supply systems of consumers.

The classification of CPD devices is presented in Figure 2.

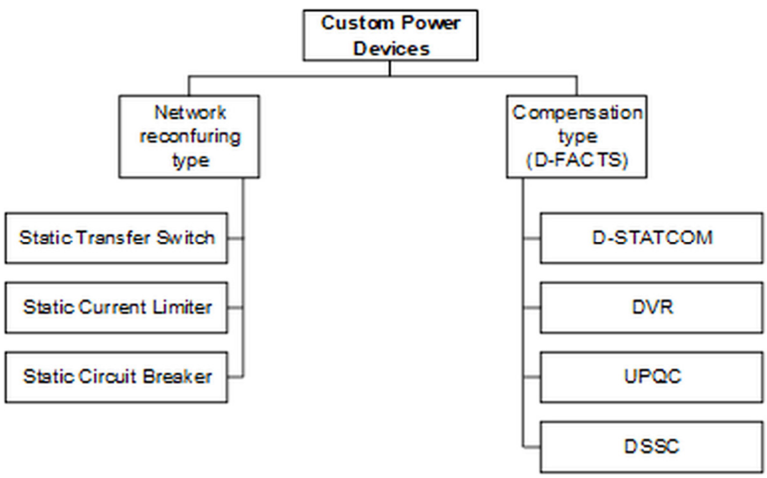

Fig. 2. The classification of CPD devices.

D-STATCOM, as well as STATCOM, is designed for dynamic compensation of reactive power and voltage regulation. However, D-STATCOM can also perform the functions of an active filter, eliminating higher harmonics and current unbalance [10].

DVRs are connected to the network in series and are used to compensate for voltage dips and interruptions on the supply lines with a sensitive load. In [11], the feasibility of using these devices for electric drilling rigs is noted.

The D-SSSC device is described in [12]. It is a combination of low-power modules, consisting of a single-phase inverter and a transformer, mounted directly on the wires of the power lines. D-SSSC allows you to adjust the impedance of power lines, increasing its capacity. The design of D-SSSC presented in [12] is intended for overhead power lines; therefore, for the application of these devices in power supply systems of coal mines, their substantial processing will be required.

UPQC is the most sophisticated CPD device and is a combination of D-FACTS and DVR [10], combining their functions.

When placing FACTS and CPD devices in coal mine power supply systems at underground distribution points in cramped conditions, these devices are required to be compact and explosion-proof.

In China, research is actively being conducted on the development of explosion-proof FACTS devices, in particularly, it is necessary to note the patent for the construction of explosion-proof STATCOM [13], which can be placed in the underground part of a coal mine.

Having analyzed the product line of FGI Science and technology Co. dependences of the rated power of the manufactured STATCOM on the dimensions of the devices in cubic meters were compiled (Figure 3).

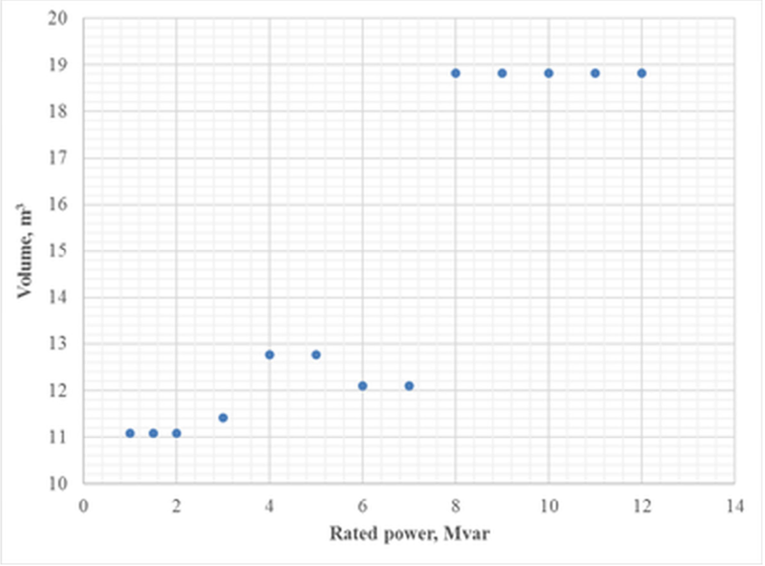

Fig. 3. The dependence of the rated power of STATCOM 6 kV on the dimensions of the device.

In [9], the possible connection points of D-STATCOM devices are considered. It is noted that centralized compensation from the side of the lower voltage of the transformer when using D-STATCOM is very costly and limits the power of the device to several thousand var, with centralized compensation from the side of the higher voltage of the transformer it is possible to increase power D-STATCOM up to several MVAr, however, in this case, the use of a communication transformer is required, which increases the dimensions of the device.

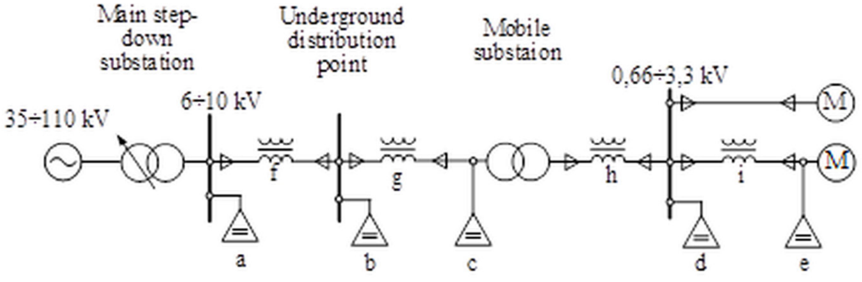

Fig. 4. Possible locations for reactive power compensators.

Various optimization methods are used to select connection points for D-STATCOM devices. The main criteria, as noted in [8], are: reduction of power losses; reduction of voltage fluctuations; increased reliability; cost reduction; high harmonics limitation; reactive power compensation. For this, the voltage sensitivity index and the power loss index are used.

The power range of D-STATCOM is from several kVAr to several MVAr, which allows them to be used for both group and centralized compensation. Thus, the choice of connection points for these devices is limited only by dimensions, the ability to perform in explosion-proof performance and cost indicators.

Comparative characteristics of these devices are presented in Table 1.

Table 1. Comparative characteristics of the use of FACTS devices in coal mines.

FACTS device	Functions	Advantages when used in a coal mine	Disadvantages when used in a coal mine	Possible placement points (fig. 4)
Static var compensator (SVC)	Regulation of voltage (reactive power); increase of stability and limits of transmitted power on power lines	fast response (<20 ms) [6]	- large size	a
Static synchronous compensator (STATCOM)	Dynamic voltage stabilization, increase in transmission line capacity, decrease in voltage fluctuations, increase in stability	fast response (< 1 ms) [6]	- large size	a
Distribution Static synchronous compensator (D-STATCOM)	Dynamic voltage stabilization, voltage regulation, reactive power compensation, harmonic limitation	- compact size - fast response - harmonic filtering - load balancing		b-e
Dynamic voltage restorer (DVR)	Dynamic compensation of voltage dips in power lines, elimination of asymmetry and unsinusoidality of voltages	- compact size - fast response - harmonic filtering - load balancing		f-i
Unified Power Quality Conditioner (UPQC)	Limitation of electromagnetic interference of voltage and current, reactive power compensation	- compact size - fast responce - harmonic filtering - load balancing	- high cost	b-i

The following comparative characteristic of CPD devices (Figure 5) is presented in [18]. For each comparison criterion, CPD devices are assigned a conditional value from 1 to 4. The higher the value, the better this property is expressed.

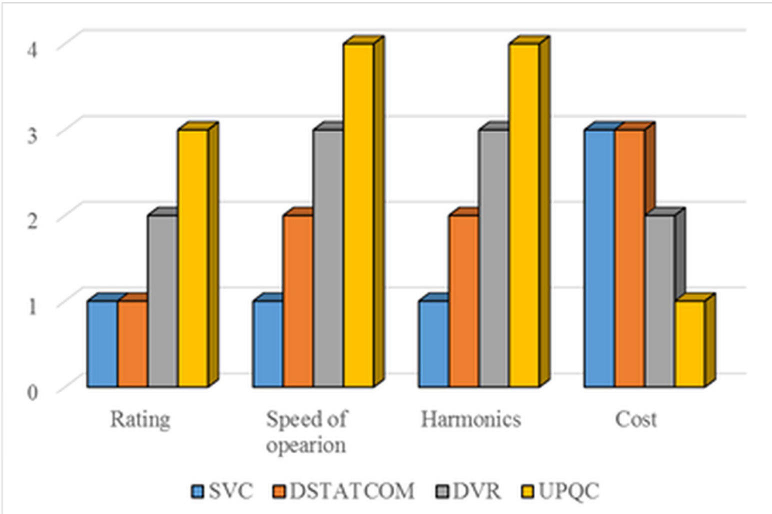

Fig. 5. Comparative characteristic of CPD devices [18].

It has been shown that a DVR is superior to SVC and DSTATCOM. However, if there is no cost consideration, then UPQC is the better choice for improvement of power quality.

3 Cost indicators FACTS devices

According to [14], the costs of FACTS devices can be divided into two categories: cost of equipment; the cost of the necessary infrastructure. The cost of equipment is determined not only by the rated power of the entire device but also depends on the required level of reliability, seismic protection, environmental conditions, including the need to use explosion protection. The second category of costs is determined by the need to install new switching and protective equipment for connecting the device, building premises to accommodate indoor equipment, allocating additional land, etc.

For FACTS devices, the following specific cost indicators are distinguished (Figure 6):

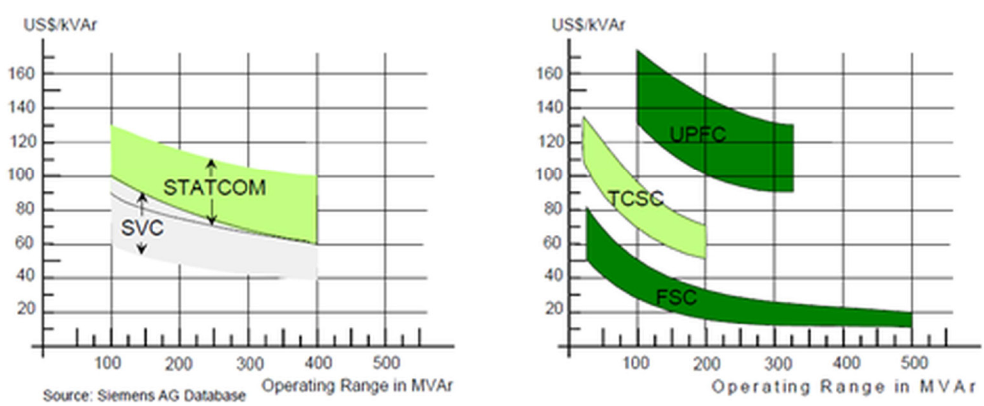

Fig. 6. Unit cost indicators of the STATCOM, SVC, UPFC, TCSC, FSC installation [14].

In [15], unit cost curves are used to estimate the capital costs of STATCOM, DVC, and SVC:

$$C_{STAT} = 553\left(-0,0008 \cdot Q_{STAT}^2 + 0,155 \cdot Q_{STAT} + 120\right),$$
$$C_{DVR} = 553\left(-0,0008 \cdot Q_{DVR}^2 + 0,155 \cdot Q_{DVR} + 120\right),$$
$$C_{SVC} = 553\left(0,0003 \cdot Q_{SVC}^2 - 0,3051 \cdot Q_{SVC} + 127,38\right),$$

where Q_{STAT}, Q_{DVR}, Q_{SVC} – rated power of STATCOM, DVR, SVC, respectively, MVAr; C_{STAT}, C_{DVR}, C_{SVC} – capital costs for STATCOM, DVR, SVC, respectively, £/MVAr. Operating costs are accepted at a rate of 5% for SVC and 10% for STATCOM and DVR of their capital costs.

4 Conclusion

1. It was established that FACTS devices are necessary in the underground part of the coal mine power supply system for the reactive power compensation consumed by mining equipment.
2. Two generations of FACTS devices are considered, as a result, it was found that in coal mines it is advisable to use FACTS devices of the APF, PF, SVC and STATCOM types. FACTS devices of the D-FACTS and CPD types are very promising for use in coal mine conditions.
3. The product line of the company FGI Science and technology Co. (China) was analyzed. It was established that the volume of space occupied by STATCOM is in the range from 10 to 20 m^3 with rated unit power of 1 to 12 MVAr.
4. In conclusion, the results of a qualitative comparison of various FACTS devices for use in coal mine PSS are presented.

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