Static synchronous compensators based on magnetically controlled shunt reactors and capacitor banks in 110 – 500 kV grids

ABSTRACT

Magnetically controlled shunt reactors are pivotal in regulating reactive power in high-voltage grids. As the grid evolves, these reactors ensure optimized power transmission and reliability. The latest generation of these reactors offers enhanced designs, aligning with IEC standards and providing efficient power regulation. Their application can notably improve voltage quality in networks with nonlinear asymmetrical loads.

KEYWORDS:

magnetically controlled shunt reactor, reactive power, static synchronous compensators, voltage stability, IEC standards, asymmetrical load

A magnetically controlled shunt reactor is designed to regulate reactive power in high-voltage grids, supporting both automatic and manual control modes

Introduction

A magnetically controlled shunt reactor is a transformer-type electromagnetic machine designed to regulate reactive power in high-voltage grids in either automatic or manual control modes.

Today, the grid is moving towards the optimization and increase of transmitted power while preserving reliability. Maintaining the optimal level of reactive power in the network plays a key role in this process. For decades, this task has been solved using non-controllable reactors, thyristor-based static compensators and synchronous rotary machines.

Static synchronous compensators were developed at the same time, based on magnetically controlled shunt reactors and capacitor banks. They are similar in characteristics to static compensators based on thyristors or rotary machines. However, they still have a number of operational advantages. Compared to these two devices with the same functionality, they are more reliable and cheaper.

General

During the transmission of electrical energy, reactive power flows through the line, which yields an increase in losses. Therefore, the correct compensation of electrical networks not only increases the transmission capacity of the network, but also reduces losses through the energy transmission.

Insufficient compensation of reactive power means a higher amount of reactive power, which causes a reduction in voltage and transmission power. This phenomenon also negatively affects reliability.

Insufficient compensation of reactive power may lead to grid instability or serious failures [1], [4]. Optimizing the compensation of reactive power in electrical networks has become one of the basic elements of ensuring optimal grid operation and reliability.

Recently, the most common method has been the use of step-switchable shunt reactors and capacitor batteries. While this solution has relatively low acquisition costs and is easy to maintain, it also has operational shortcomings. Typically, a reactor with taps cannot ideally compensate for the reactive power in order to ensure maximum transmission power and minimize electrical losses. In addition, in lines 110 kV and above, reactive power must be compensated in both inductive and capacitive compounds. This function is performed by static thyristor compensators or rotary synchronous compensators. Their drawback is applicability in grids up to 35kV only. For their implementation in higher voltage grids, a step-up transformer must be added with a matching voltage ratio and capacity [1].

On the other hand, static synchronous compensators based on magnetically controlled shunt reactors can be directly connected to grids ranging from 110-500 kV and work in both capacitive and inductive modes. They have some further advantages, such as maintaining grid reliability. These devices consist of sequentially connected static capacitor banks and a controllable reactor in a parallel connection with the bank.

Correct compensation of electrical networks enhances the transmission capacity and reduces energy losses, whereas insufficient compensation can lead to grid instability or serious failures

> **Static synchronous compensators based on magnetically controlled shunt reactors can be directly connected to grids from 110-500 kV, boasting several benefits like improved grid reliability**

A static compensator based on a capacitor battery and a controllable shunt reactor

The advantages of a static VAR compensator are:

- increase in grid transmission capacity,
- higher voltage stability at the appropriate grid voltage
- reduction in transmission losses
- substitution of synchronous compensators

The above-mentioned properties decrease the necessity of building new transmission lines in numerous cases [2]. This article does not aim to deeply analyze further consequences such as transient stability, power swing and harmonic distortion. Those and other effects are touched on in [2] and may be discussed in a separate article.

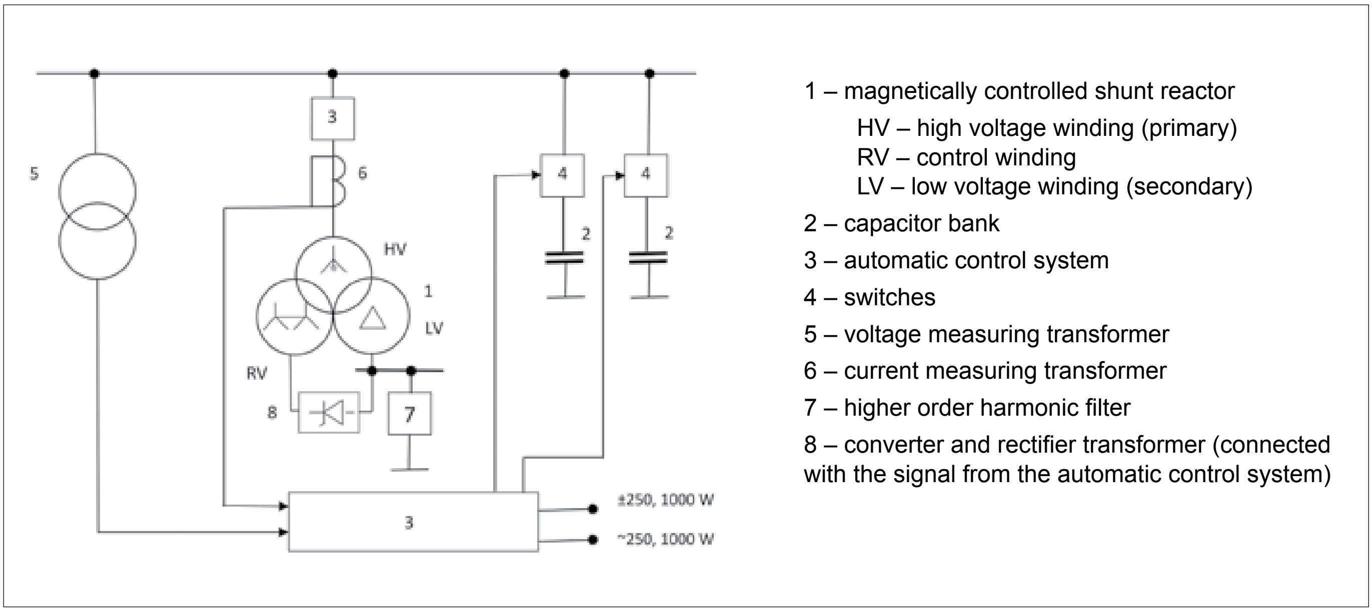
The power regulation speed of such a compensator from no-load to rated power ranges between 0.1-0.2 seconds, depending on the current state of the grid at the place of installation. The regulation speed does not affect the stability of the system as a whole. The reactor's power regulation is based on the principle of saturating its core with DC current, which changes the reluctance of the core and the reactor power. Reactive power compensators of this type, with capacities of 10, 25, 32, 63, 100 and 180 MVA, have been manufactured and can operate successfully. They are directly connected to networks with voltage levels ranging from 110 to 500 kV without the need for additional step-up transformers, which enables an increase of voltage stability on a given level [3]. Their operational experience has demonstrated high efficiency, reliability and low maintenance requirements.

Fig. 1 shows a static synchronous compensator based on magnetically controlled shunt reactors and capacitor bank.

If the grid is unloaded or lightly loaded, its capacitive behaviour prevails, leading to an increase in voltage. It is detected by voltage transformers. The control system then excites the reactor. When the magnetic circuit is magnetized by a direct current, the inductance of the reactor decreases while the inductive current drawn by the reactor from the grid increases. The whole system then works in the inductive energy consumption mode. When grid loading increases, the deficit of reactive energy arises in the grid, the power of the controllable reactor gradually decreases to zero, and a capacitor bank is switched on. The capacitor bank is connected in parallel with the shunt reactor, and the reactor now partially compensates for the capacitor bank with fixed capacity. The compensator works in capacitive energy consumption mode. When loading in the grid decreases, the network voltage increases, and it is necessary to switch back to the inductive load area. The capacitor bank is disconnected, and the compensator goes to inductive mode.

From the beginning of industrial production to the present, this compensator type has been used in Kazakhstan, Azerbaijan, Russia, Lithuania, Angola and South Africa networks. More than 100 compensator units are in operation with a power from 10 to 180 MVAr and a voltage from 10 to 500 kV.

Experience with the operation of the first generation of reactors has shown that, in some cases, the nonlinear parameters of the reactors can stabilize the voltage at the connection point and the surrounding area.



1 – magnetically controlled shunt reactor
  HV – high voltage winding (primary)
  RV – control winding
  LV – low voltage winding (secondary)
2 – capacitor bank
3 – automatic control system
4 – switches
5 – voltage measuring transformer
6 – current measuring transformer
7 – higher order harmonic filter
8 – converter and rectifier transformer (connected with the signal from the automatic control system)

Fig. 1.: Single-pole scheme of static compensator

Differences in the modified design of magnetically controlled reactors

A new generation of magnetically controlled reactors has been developed, which eliminates the shortcomings of previous generations while maintaining all basic functions.

Fig. 2 shows a single-pole diagram of a new generation static reactive power compensator based on the principle of a magnetically controlled reactor and capacitor bank.

The basic difference between the modified design and the first generation of reactors is the use of a broadband filter of higher harmonics, which improves the character of current and voltage in order to match with IEC standards.

The new generation design brings new technical solutions and optimization criteria, consisting of connecting the capacitor bank to the secondary winding of the controllable shunt reactor and optimizing the design of the controllable shunt reactor. All this makes it possible not only to preserve all functional properties of the previous generations but also to expand their functional capabilities further:

- Overloading up to 1.4 times the rated power while maintaining the sinusoidal current and secondary winding voltage throughout the power regulation range
- Continuous power regulation from nominal power in inductive mode to nominal power in capacitive mode in the case of connecting a capacitor battery to the secondary winding in 0.2-0.3 s time.
- Loading the secondary (LV) side with up to nominal power.
- Parallel connection of capacitor bank, rated up to the value of the nominal power of the controllable shunt reactor primary winding (HV).
- Taking power from the secondary winding (LV) to any network up to the power of the primary winding (HV).

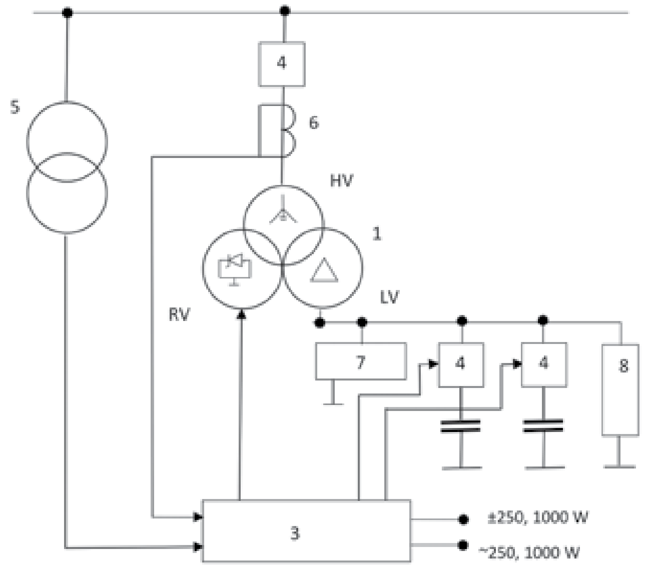
The new generation enables independent regulation of the performance of each phase in the entire regulation range. Thanks to this, it is possible to use compensators in networks with non-symmetrical nonlinear loads, e.g. for supplying railway traction. In addition, a single-winding design is also possible.

Such single-winding reactors with a voltage from 6 to 35 kV have already been manufactured and have been successfully operating for more than 10 years in the power grids of Russia and Kazakhstan, with more than 15 operational units. At the moment, it is possible to manufacture reactors of this type up to 110 kV voltage and up to and including 100 MVAr power.

In conclusion, the use of static compensators enables the generation of reactive

> **A new generation of magnetically controlled reactors has been developed, which eliminates the shortcomings of previous generations while maintaining all basic functions**

> **The use of static compensators enables the generation of reactive power differently in individual phases and thus greatly symmetrizes unbalanced loading like a nonlinear two-phase load**



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5 – voltage measuring transformer
6 – current measuring transformer
7 – higher order harmonic filter
8 – additional load, which might be connected with low-voltage winding

Fig. 2.: Single pole of a new generation of static compensator

power differently in individual phases and thus greatly symmetrizes unbalanced loading like a nonlinear two-phase load. This increases the possibility of using a direct connection of transformers to supply traction from a three-phase network.

Summary

1. Original types of magnetically controlled reactors can cause the appearance of higher harmonic voltages at the point of connection to the network, the level of which exceeds the values permitted by IEC standards.

2. Magnetically controlled reactors of the new generation expand the functional characteristics of the shunt reactors that currently work in the grid.

3. Reactive power compensators, with the regulation of each phase separately, guarantee the voltage quality required by the standard in a three-phase network loaded with a nonlinear asymmetrical load.

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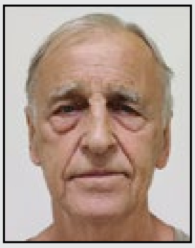
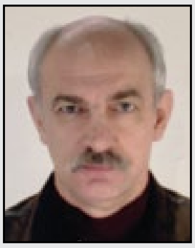


Sergey Ukolov was born on 20 April 1953 in Zaporizhzhia, Ukraine. He graduated from the Faculty of Electrical Engineering at the Technical Institute of Zaporizhzhia. He worked at VIT as a designer of reactors and special transformers from 1975 to 1991. In 1991, he started work at ZTR, where he was the head of the Department of Reactors. He remained there until 2014, moving on to the positions of head of the Department of Electrical Reactors Design, technical vice-director of electrical reactors, and technical director of electrical reactors. He was then a consultant for magnetically controllable reactors at ESK and Clever Reactor in Riga, Latvia. Since 2022, he has been employed at ETD Pilsen as a specialist for reactors.



Igors Gruseckis was born on 27 March 1957 in Riga, Latvia. He graduated from the Faculty of Physics and Mathematics at the University of Latvia. He obtained his PhD in 1993. From 1992 to 2012, he was a vice director at Petrobalt SIA, and since 2012, he has been a board member of Clever Reactor.

Milan Valečka was born on 12 July 1970. He graduated from the Faculty of Electrical Engineering, College of Mechanical and Electrical Engineering in Pilsen, with a specialization in electrical machines. He obtained his PhD at the University of West Bohemia, specializing in the cooling of power transformers. From 1993 to 1996, he worked at Škoda as a designer of power transformers. From 1996 to 2004, he was employed at Škoda Energo in Pilsen as an electromagnetic designer of power transformers, moving on to the position of head of electromagnetic design of power transformers, where he stayed until 2016. Since 2016, he has been the technical director at ETD Transformátory, Pilsen. Of note, from 2004 to 2006, he was engaged in activities at the University of West Bohemia in Pilsen, working on the analysis of transformer operation.