

# Principles for construction the compensators of reactive power with voltage stabilization for transformer substations

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**Abstract.** Based on the booster transformer and the transistor converter with a DC link, a system is proposed for fast and accurate unloading the electric network from reactive power with simultaneous stabilization of voltage among consumers. The system contains a discrete stage of reactive power compensation and adjustable part. The adjustable part includes series and parallel reactive power compensators. The series compensator consists of a booster transformer, a voltage inverter and is designed to be switched on to the high voltage of the transformer substations. The parallel compensator consists of a rectifier with an input choke and is connected to the low voltage of the substation. The rectifier and inverter are connected by a DC link with an LC filter. The rectifier regulates the output voltage and the phase of the sinusoidal input current. The inverter regulates the magnitude and phase of the voltage on the control winding of the booster transformer. The rectifier and inverter control systems are synchronized with the network and with pulse width modulation.

## 1. Introduction

At present, transformer substations are not equipped with power electronic devices designed to stabilize the voltage and compensate the reactive power [1, 2]. This leads to low efficiency of consumption and use of electricity in power supply systems, shortening the life of expensive equipment, and reducing the quality of products [3, 4].

In this regard, the problem of creating regulating and compensating continuous means for improving the quality of electrical energy, which have high accuracy and speed, increasing energy efficiency in consumers and in transmission and distribution systems, is very relevant [5].

The proposed technical solutions are intended for power transformers of substations with a total power up to 1000 kVA, voltage (6-10) / 0.4 kV located near the consumers and included in power supply systems of industrial enterprises, objects of agro-industrial and defense complexes, housing and communal services and Urban electrified transport.

A suitable area of application of the proposed device are transformer substations of enterprises of all industries.

## 2. Principles of construction

Based on the booster transformer (BT) and the voltage converter with a DC link on IGBT transistors, the principles of constructing devices with enhanced functionality and high speed are proposed, which can be attributed to controlled FACTS power transmissions [6, 7, 8].



The advantage of constructing AC voltage regulators based on BT is that not all of the power is regulated, but only part of it. This is the principle of separation of regulated and uncontrolled power, when only a part of the power, proportional to the range of regulation of the additional voltage, is transmitted through the BT, which allows reducing the specific weight and the installed power of the regulating device.

The arrangement of the device on the high (6-10 kV) or low (0.4 kV) side is of no small importance. Thus, the connection of a high-voltage power transformer on a high side of a transformer substation (TS) with currents is (15-25) times less than at a low one, leads to a decrease in the material consumption of connecting busbars, cables, transition tips and fasteners required for assembly work, and labor intensity of these works. It should be noted one more usefulness of including a coherent winding BT in the high-voltage circuit of the TP is the improvement of the power parameters of the power transformer of the substation proper, which is especially effective with low loads and increased network voltage. The parallel winding BT through the transistor voltage converter is connected to the secondary circuit of the same substation or other substation intended for the company's own needs. It should be noted that the best results of increasing the energy performance are achieved in all cases when the converter is connected to the substation of own needs.

The use of a voltage converter itself with a DC link creates the possibility of generating or consuming reactive power, i. e. Construction of reactive power compensators on the direct principle, in which the regulated and unregulated part of the device is 50% of the reactive power of the substation.

The converter must provide two-way energy exchange so that in the volt-up mode, the missing energy from the network goes to the load, and in the volt-down mode, the excess part of it returns freely to the network.

### 3. Structural diagram

The block diagram of the apparatus in the substation is shown in Figure 1.

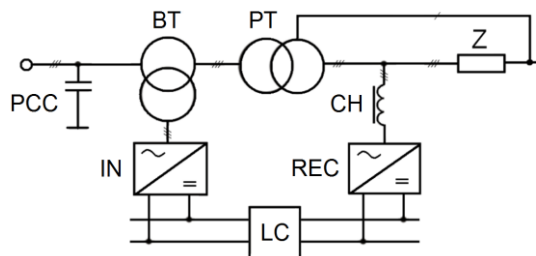


figure 1. Structural diagram of the reactive power compensator with voltage stabilization on the high side of the transformer substation

The following diagrams are introduced in the diagram (figure 1): PT - power transformer; BT - volt-auxiliary transformer; IN - voltage inverter with PWM; REC - controlled transistor rectifier with PWM; PCC - battery of power compensator capacitors; CH - input choke for a transistor rectifier; between the rectifier and the inverter, an LC filter forming a DC link

The converter with a direct current link with amplitude-pulse-phase control consists of a transistor rectifier with amplitude control and a transistor voltage inverter with an input LC filter and pulse-phase control. The rectifier and inverter are connected by a DC link, in which the voltage does not change the polarity, and the direction of energy for two-way conductivity is determined by the polarity of the current [9, 10]. This scheme is investigated in Matlab [11]. The investigations have shown that reactive power compensation is simultaneously performed by a voltage inverter and a controlled transistor rectifier. The apparatus operates as follows. A voltage and voltage phase converter, which includes an active rectifier with an input choke and a voltage inverter with an input LC filter, the semiconductor part of which is made on power intelligent modules, generates a regulated voltage from the

load voltage, which boost converter increases by  $k_{BT}$  times and is added to the mains voltage, forming the power supply voltage of the power transformer and the load voltage reduced by  $k_{PT}$  times.

The principle of voltage regulation is explained by the following formula.

$$U_{PT} = U_s + U_{BT}, \quad (1)$$

where  $U_{PT}$  is the voltage at the primary winding PT

$U_s$  - voltage of the source

$U_{BT}$  - voltage on the primary winding BT.

BT in this circuit is a scalable power adder that allows you to increase the voltage generated by the inverter and add it to the mains voltage.

When  $U_s$  and  $U_{BT}$  are in-phase, then when they are summed up, the volt-correction takes place, if they are in antiphase, then voltoff mode occurs.

The process of consumption of additional active power with a booster and vice versa, the return of active power to the DC network at volt-off mode, is explained by the following expression

$$P_{BT} = U_{BT} \cdot I_s \cdot \cos\varphi, \quad (2)$$

where  $P_{BT}$  is the power from IN through BT to PT;

$U_{BT}$  - voltage on the primary winding BT;

$I_s$  is the current in the high-voltage circuit;

$\cos\varphi$  - the cosine of the angle given when the inverter generates an additional voltage.

Since the current in the high-voltage circuit is one, then according to expression (1) we obtain:

$$P_s = P_{PT} + P_{BT}, \quad (3)$$

where  $P_s$  is the active power consumed from the source;

$P_{PT}$  - active power consumed by PT under load.

According to expressions 2 and 3, we conclude that PW will be consumed from the network with positive  $\cos\varphi$  at  $\varphi$  from -90 to 90 degrees (booster mode). At angles from 90 to 270 (the mode of volt-off) degrees  $P_{BT}$  as a surplus power will be returned to the network.

By the principle of additional adjustable power, the reactive power compensation process also takes place. This is explained by the following expression:

$$Q_s = Q_{PT} + Q_{BT} + Q_{rec} \quad (4)$$

where  $Q_s$  is the reactive power consumed from the network;

$Q_{PT}$  - reactive power consumed by PT with load;

$Q_{BT}$  - additional reactive power, coming from IN through BT to PT.

$Q_{rec}$  - the reactive power consumed by the rectifier.

In this case, by regulating the magnitude and sign of  $Q_{BT}$ , it is possible to produce both the generation of reactive power and its consumption.

$$Q_{BT} = U_{BT} \cdot I_s \cdot \sin\varphi, \quad (5)$$

$\sin\varphi$  is the sinus of the angle specified when the inverter generates an additional voltage.

According to expressions 4 and 5, we conclude that  $Q_{BT}$  will be consumed from the network with a positive  $\sin\varphi$ , with  $\varphi$  0 to 180 degrees. At corners from 180 to 360 deg, the process of  $Q_{BT}$  generation for the load will occur, thereby reducing its consumption from the network.

The regulation of the voltage phase in the direction of advance in case of undercompensation and in the direction of the lag in case of overcompensation allows, together with the battery of cosine capacitors, to provide direct full compensation of the reactive power at the input terminals of the substation.

When designing the apparatus, the following features should be considered. The intensity of the phase control of the input rectifier current is limited by the possibility of the appearance of a constant component of the current in the secondary circuit of the power transformer and the actual power of the converter. At the same time, the speed of reactive power control by means of a rectifier is comparatively higher than the voltage inverter with BT. This is due to the fact that if the permissible intensity of phase regulation of the output voltage of the inverter and the additional voltage at the input of the PT arises, one-sided magnetization of the magnetic circuit BT occurs.

#### 4. Results

Compensation for the reactive power consumed by the substation from the network is performed by three units of the device. This is an unregulated battery of cosine condensers PCC, designed to compensate for 50% of the average reactive power of the substation and two regulated units - serial and parallel, also designed to compensate for 50% of the reactive power of the substation. The serial adjustable compensator contains a voltage inverter and BT. It is included in the high-voltage circuit of the PT and compensates for voltage and reactive power deviations, regulating the additional voltage in magnitude and phase. A parallel regulated compensator is a transistor rectifier, which, together with the load, is connected to the low voltage PT target. It performs reactive power compensation by anticipating the phase of its input current. Each of these adjustable compensators can create both a capacitive and an inductive reactive component of reactive power. Both adjustable compensators, by their joint action, supplement the action of the PCC in case of lack of compensation, or neutralize its action in case of overcompensation.

As BT, a three-phase voltage transformer of suitable power can be used, intended for the sequential inclusion of the primary winding in the circuit of the primary winding of the substation PT.

As a voltage converter with a DC link, a commercially available regenerative frequency converter with a PWM voltage can be used in which the frequency control channel in the inverter is replaced by a phase-controlled PWM voltage control channel synchronized with the network.

The technical result of the solution of the task is to compensate the reactive power at the output of the substation and in the network, as well as in the stabilization of the voltage at the input of the substation and the consumers, providing the power transformer with high power and useful efficiency. In the process of reactive power compensation with simultaneous voltage stabilization, a simple PWM algorithm is used in the converter control system. The introduction of a discrete stage of compensation of reactive power in the form of a battery of cosine capacitors made it possible to realize the possibility of a booster device to supplement the action of the capacitor in case of undercompensation or to neutralize its action during overcompensation. Such a methodological approach to the implementation of research and development (R & D) creates a high level of willingness to serial production of phase converters for transformer substations with the least costs for the execution of design documentation, the preparation of production and the mastery of a new technological process. It is expedient to carry out research and development with the orientation to mass production at specialized enterprises that produce frequency converters for an asynchronous electric drive.

#### 5. Conclusion

As a result of the solution of the task, the situation changes for the substation power transformer. But, at the same time, it is useful for consumers and for electrical networks. Consumers maintain a voltage at a given level and, consequently, rational energy consumption is achieved, and in networks the amount of current consumed is reduced and, consequently, losses in the transmission of electricity are reduced. Thus, the technical result consists in a comprehensive increase in the energy efficiency of the power supply system, simplifying the device, and improving the mass-dimension coefficients.

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