The Implementation of Energy-Saving Technologies for Reactive Power Compensation in Grids of All Voltage Levels Based on Static Converters

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ABSTRACT

In this paper, the technology of increasing the level of energy-saving due to the effective compensation of reactive power (RP) is considered in electric power grids of high and ultra-high voltage. For these grids, two variants of hardware implementation of static compensation devices of reactive power, based on capacitor batteries and power transformer equipment, have been developed. The conclusions are made about economic feasibility of the application of the developed devices in modern electric power systems (EPS) on the basis of the analysis of the obtained technical and economic characteristics of these devices.

INTRODUCTION

Modern EPS are a complex multi-level system that performs the functions of generation, transportation and distribution of electric energy. Its efficiency and reliability is largely determined by the degree of controllability including the one at the hardware level. In this context, the wide application of the principles of Smart Grids in EPS is of great importance.

The Smart Grid is a complex technology based on the use of devices in the EPS that allow to quickly change the parameters of grid in order to maintain the operating mode with maximum energy efficiency in the conditions of changing load parameters. This technology combines all elements of the EPS at the physical level and manages them.

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The relevance of implementation of modern hardware solutions for a wide class of grids (from 6 kV to the class of ultra-high voltages of 750, 1150 kV) which satisfy all technological requirements (including price—quality ratio) is determined by their ability to optimally control the modes of EPS.

These solutions completely comply with the technology of flexible alternating current transmission systems (FACTS) as one of components of the Smart Grid direction. At present, a large amount of research and development has been carried out in the field of creating devices for regulating the modes of grids of different EPS voltage classes[1-7]. The main devices used in the framework of FACTS technology in relation to reactive power (RP) compensation are:

- Controlled thyristor capacitor installations (CTCI);
- Controlled shunt reactors;
- Static reactive power compensators (SRPC).

At present, the above-mentioned devices are well developed in theoretical terms and widely used in grids of appropriate EPS voltage levels [8-10]. Nevertheless, there is an urgent need to create the unified hardware and cost-effective solutions that could be applied to grids of all EPS voltage levels. The authors see the solution of these issues, among other things, in implementation of the functions of static compensators on the basis of capacitor batteries and power transformers connected in a certain way. In this connection, two variants of static devices, RP regulators, are of particular scientific-practical interest and discussed below.

**STATIC CAPACITOR COMPENSATION RP DEVICES**

The developed controlled thyristor capacitor installation (CTCI) is a capacitor battery that is connected in parallel to the grid with the help of power switching devices [11]. The analysis of various methods of switching capacitor batteries showed the economic feasibility of using power thyristors and solid-state relays as switching devices [12]. This allows to completely get rid of moving mechanical parts that increases the life of product. On the other hand, the use of semiconductor devices increases the speed of the system and service life. The controlled thyristor capacitor installation can be easily integrated into the automated process control system (APCS) of industrial enterprises with the developed microcontroller control system and corresponding software [13]. This applies to distribution grids of 0.4 -10.0 kV where the low specific cost (compared with similar devices) of the compensating RP is predicted, that is, of the order of 115 r/kVAr. Thus, the energy-saving is estimated at 2.4 million rubles per year in the RP compensation of three asynchronous pump motors of the boiler house with the help of the controlled thyristor capacitor installation. The efficiency of the developed circuit design and software solutions of the controlled
thyristor capacitor installation was experimentally confirmed for low–voltage physical models [15].

But this hardware solution is universal for grids of all voltage levels. So, the connection of controlled thyristor capacitor installations in high-voltage networks (35-330 kV) is assumed with the help of power thyristor assemblies in conjunction with high-voltage electro–gas and vacuum circuit breakers. In addition to increasing the life of switches, this method allows to achieve greater saving when switches are already installed on substations. In this case, the specific cost of RP reaches, on average, 30 r/kVAr, for compensation of 50 MVAr. The conducted research of a typical substation 110/220 kV allows us to conclude that the use of controlled thyristor capacitor installations can reduce the average value of load losses by more than twice. It corresponds to saving of 30 thousand rubles per day when the substation is loaded at 2500 MW*h/day [14].

STATIC TRANSFORMER COMPENSATION DEVICES OF RP

The loading of high–voltage transmission lines is carried out in stages during their operation in the EPS. As a rule, in the early stages, the high – voltage transmission lines are not fully loaded and, to maintain the required voltage levels, the compensation is needed for the charging power of lines. For this purpose, reactors are used. This article shows the possibility and feasibility of using power auto-transformers, i.e. booster transformers, incorporated in their neutral, as to compensate for RP [16,17].

Hardware solutions are known when the power transformers with booster transformers are used to regulate the high–voltage transmission lines (220-1150 kV). The power transformers with booster transformers usually have a device for switching the release adjustment under load. The efficiency of such devices can be increased by replacing mechanical devices with thyristor voltage regulators. According to conducted research, various circuit variations of thyristor voltage regulators for power transformers with booster transformers provide high - quality regulation on high—voltage transmission lines both at lower voltage (at first stages of line operation) and increasing voltage (at the stages of full load of transmission lines) [8]. As noted above, the compensation is required for charging power of lines and the adjustment effect from using the thyristor voltage regulators is insufficient in order to maintain the required levels of voltage. However, there is a possibility of implementing such an algorithm for operation of power (thyristor) switches of thyristor voltage regulators in which power transformers and booster transformers are transferred to an operation mode, similar to conventional controlled shunt reactors with magnetization [18, 19]. In this case, power transformers and booster transformers function as controlled shunt reactors at the required time compensating for RP (by calculations, compensation of up to 30 % of the total capacity of power transformers and
booster transformers is possible). Such a hardware solution is very effective as it allows either to completely abandon the use of controlled shunt reactor or to use reactors with much lower installed capacity. The algorithm of power switches of thyristor voltage regulators does not provide RP regulation, but the regulation of transmission lines downwards with the following voltage increase (which gives the ability to provide the required levels of voltage, minimize power losses and increase the capacity of the line) [20].

CONCLUSION

The conducted technical and economic analysis of the proposed hardware solutions shows the efficiency of the specially connected capacitor batteries, power transformers and auto-transformers use as static compensations of reactive power.

The controlled thyristor capacitor installation discussed above can be effectively applied to ultra-high, high and low voltage grids.

By using the proposed method, the control of power transformers and autotransformers allows to significantly expand their functionality for voltage and reactive power regulation in ultra–high and high voltage grids.

REFERENCES

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