Dispatch's decision-making support during operational voltage control in control stations

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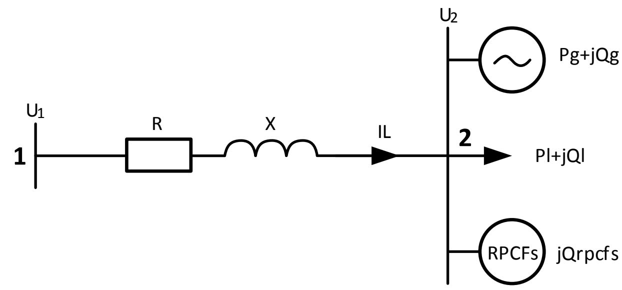
Abstract. Voltage and reactive power mode control is performed by dispatcher for the purpose of ensuring required reserves on steady state stability and load stability as well as permissible voltage operating conditions of electric grid equipment. The decision made by dispatcher engaged in controlling reactive power and voltage modes is founded on instructional materials developed in advance for each voltage control station (CS) with focus on data about typical modes of power system or energy area operation. The actual efficiency of reactive power compensation facilities depends on many factors (the composition and operation of grid elements, the composition and operation of generating equipment, etc.). To make final and balanced decision, in some cases, it is necessary to perform some estimation calculations, which take more time for decision making. To minimize and reduce the time required by dispatcher for their decision making and improve its accuracy when involved in voltage and reactive power mode control, it is reasonable to develop software able to determine the efficiency of reactive power compensation facilities in real time.

Voltage and reactive power mode control is one of the critical goals and responsibilities of dispatch control in accordance with [1] and [2]. Voltage and reactive power mode control performed by the dispatch control is aimed at ensuring required reserves of steady state stability and load stability as well as permissible voltage modes of electric grid equipment operation.

Dispatcher involved in voltage and reactive power mode control takes decisions on the need to change operating conditions and modes of reactive power compensation facilities (RPCFs) and generating equipment. The decision made by the dispatcher is based on instructional materials developed in advance for each voltage control station (CS). When developing guidance materials, the estimation of the RPCF and generating equipment efficiency intended for voltage regulation of each CS is determined under typical modes of power system and energy area operation. The actual RPCF and generating equipment efficiency, in most cases, will differ from that specified in recommended guidance materials. These differences can be explained, first of all, by inconstancy of factors that determine the voltage at initial and final stages of power transmission.

Let us consider the relation of voltages without taking into account its shunt admittance and external connections features (see Fig. 1). To cope with the specified task, a transmission line is used as a simplified example.



U_1 – voltage at the beginning of the transmission line (node 1);

U_2 – voltage at the end of the transmission line (Node 2);

R , X – active resistance and inductance of the transmission line;

I_L – current flowing through the transmission line;

P_l , Q_l – active and reactive load power in node 2;

P_g , Q_g – active and reactive power of a generator in node 2;

Q_{rpcfs} – reactive power produced by RPCFs.

Fig. 1. Equivalent circuit of the transmission line without shunt admittance adjacent to the power system node.

According to [3], the voltage at the beginning of the U1 branch depends on the voltage at the U2 end and transmission line parameters. This relation can be described by the following expression:

$$U_1 = \sqrt{U_2^2 - \left[\sqrt{3}\left(I_L^{'}X - I_L^{''}R\right)\right]^2} - \sqrt{3}\left(I_L^{'}R + I_L^{''}X\right) \quad (1)$$

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Real and imaginary parts of the overhead line current I can be found from the following expression:

$$I_L = I_L^{'} - jI_L^{''} = \frac{P_l - P_g}{\sqrt{3}U_2} - j\frac{Q_l - Q_g - Q_{rpcfs}}{\sqrt{3}U_2} \qquad (2)$$

From expressions (1) and (2) the following conclusion can be drawn: voltage in CS depends on the composition and operating modes of its network elements, the composition and operating modes of generating equipment, RPCFs and the power of consumers. In the case when the specified transmission line functions as a part of a complex power system, the relation of the above mentioned elements becomes much more complicated.

When controlling the electrical mode, the dispatcher do not have up-to-date information on the RPCF and generating equipment performance efficiency, which can lead to unfounded decisions. In some cases, to make a balanced decision on the feasibility to use the appropriate RPCFs or generating equipment for voltage regulation, the dispatcher need to perform some operational calculations for steady-state modes using software systems. This can take more time for decision-making.

As an example, let us consider the efficiency of the operating mode impact of some RPCFs and generating equipment on the voltage in the CS of busbar of 500 kV Barabinskaya substation. The following factors may have a significant impact on the utilization efficiency of PECFs and generating equipment involved in voltage regulation in the considered CS depending on the current circuit conditions:

1. Reactive load capacity of the controlled RPCFs in operation:
   1.1. Controlled shunt reactor R-532 at 500 kV Barabinskaya substation;
   1.2. Controlled shunt reactor UShR-1-500 at 500 kV Voskhod substation;
   1.3. Controlled shunt reactor 2R-500 at 500 kV Tavricheskaya substation;
   1.4. Static thyristor compensator STK-1 at 500 kV Zarya substation.
2. The state of the 500 kV Barabinskaya - Voskhod and 500 kV Zarya - Barabinskaya transmission lines, as well as the active-power flow according to the data of the 500 kV power transmission line data;
3. The state of 1AT 500/220 kV 500 kV CS Barabinskaya and AT-1 500/220 kV 500 kV Voskhod substations;
4. Availability of reactive power reserves at power plant generators of the power system in Novosibirsk and Omsk regions.

Table 1 shows a list of actions with RPCFs and generating equipment which use is the most effective for voltage regulation in the considered CS indicating their maximum and minimum efficiency performance determined for the operating modes in July and December 2019.

Table 1. Efficiency performance of RPCFs for voltage regulation in the CS of busbar 500 kV Barabinskaya substation

№	Actions with RPCFs for voltage regulation in the CS of busbar 500 kV Barabinskaya substation"	Efficiency of RFCF performance	
		Minimum	Maximum
1.	Changes in reactive power consumption by a controlled shunt reactor		
1.1.	R-532 at the 500 kV Barabinskaya substation	14 MVAr/kV	10 MVAr/kV
1.2.	Controlled Shunt Reactor (CSR) -1-500 at the 500 kV Voskhod Substation	–[1]	35 MVAr/kV
1.3.	2R-500 at the 500 kV Tavricheskaya substation	–[1]	55 MVAr/kV
2.	Consumption and reactive power output variations by a static thyristor compensator STK-1 at 500 kV Zarya substation	–[1]	75 MVAr/kV
3.	Change of the shunt reactor state		
3.1.	R-534 at the 500 kV Barabinskaya substation	10 kV	20 kV
3.2.	R-2-500 or R-3-500 at the 500 kV Voskhod Substation	1 kV	5 kV
3.3.	1R-500 at the 500 kV Tavricheskaya substation	–[1]	3 kV
3.4.	R-532 at the 500 kV Zarya substation	–[1]	4 kV
4.	Total reactive power load variation of power plant generators		
4.1.	Power system of Novosibirsk oblast	500 MVAr/kV	20 MVAr/kV
4.2.	Power system of Omsk oblast	–[1]	185 MVAr/kV

[1] – the sign «–» means that for a given RPCF, the efficiency characteristic of the impact of its reactive power load variation on the voltage in the considered CS is in the ineffective regulation zone.

The utilization efficiency of the RPCF used for voltage regulation is a complex parameter expressed as the dependence of the voltage in the CS on the consumption / reactive power output of a step-controlled or continuously variable RPCF. The efficiency characteristic of the impact of the continuously adjustable RPCFs in the general case consists of a section, where the variation in the output / consumed reactive power of RPCFs does not cause significant voltage regulation in the CS (hereinafter referred to as the ineffective regulation zone) and a section where the change in the output / consumed reactive power leads to significant voltage regulation in the CS (hereinafter referred to as the effective regulation zone).

In the effective regulation zone, the dependence of the voltage on the RPCF reactive power is close to linear; accordingly, it can be represented by a constant efficiency value. Figure 2 shows an example of a generalized efficiency characteristic of the controlled shunt reactor impact on the voltage in the CS.

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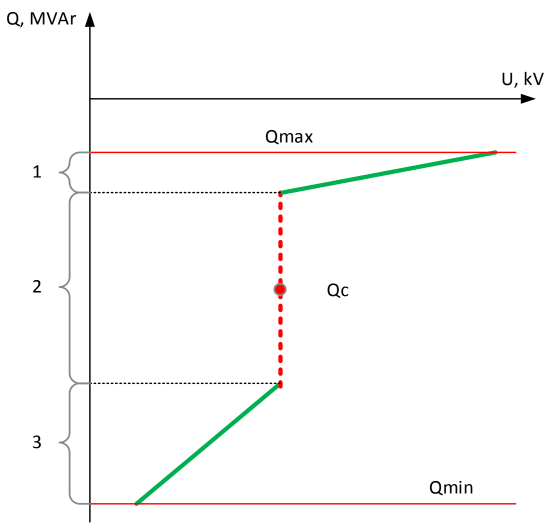

1 – effective regulation zone by the decrease of the CSR reactive power consumption;
2 – ineffective regulation zone;
3 – effective regulation zone by the increase of the CSR reactive power consumption;
Qc – CSR reactive power consumption in current operation state.

Fig. 2. Efficiency characteristic of a controlled shunt reactor impact on voltage in CS

The availability of an ineffective regulation zone is due to the presence of a reserve of reactive power for loading or unloading of continuously adjustable RPCFs, which ensure the voltage maintenance directly in the CS. For different RPCFs, the width of the ineffective regulation zone and the characteristic slope in the effective regulation area are in the general case different. These parameters are also not constant for the same RPCFs operating in various circuit-mode situations. The lack of information about the availability of an ineffective regulation zone can also significantly complicate the dispatcher decision-making.

The development of automation technology intended for dispatching control makes it possible to increase the relevance and reliability of information provided to the dispatcher, reduce the decision making time required by this personnel for controlling the power system voltage performance and minimize unreasonable decisions making. Software is being developed in the Siberian department of «SO UPS», JSC in cooperation with Tomsk Polytechnic University. The developed software allows determining in real time the efficiency of the RFCF performance for voltage regulation in the CS using information on the current circuit-mode situation in the power system.

For the software being developed, the initial data are:

1. File with information about the current balanced steady-state electrical mode (hereinafter referred to as the File);
2. List of CS;
3. List of the RPCFs and generating equipment used for voltage regulation in each CS;
4. Information concerning connection of CS, RPCFs and generating equipment to the computational power system model.

The information on the current steady-state electrical mode is formed by an algorithm state estimation in accordance with [4] and [5], whose input receives information from the operational information complex of a dispatch center about the current electrical mode in the form of telemetering signals. This information is generated in the form of a file as a software format for calculating steady-state electrical modes, which is fed to the input of the algorithm for determining the RPCF efficiency for voltage regulation in the CS. An enlarged algorithm for determining the RPCF efficiency for voltage regulation in the CS is shown in Figure 3.

After completing the calculation cycle, the information on relevant efficiency of all RPCFs intended for voltage regulation in CS is displayed in special output forms for each control station. In these forms for each CS, all RPCFs and generating equipment are ranked according to the degree of their application efficiency for voltage regulation. After that, the information is transmitted to the operational information complex for its analysis by the dispatcher during the actual control of the electric power voltage mode.

Table 2. Actual efficiency of actions with RPCFs for voltage regulation in the CS

№	**Actions with RPCFs for voltage regulation in the CS of busbar of the 500 kV Barabinskaya substation**	**Efficiency of RPCF utilization for loading/unloading**
1.	Variations in reactive power consumption by a controlled shunt reactor	
1.1.	R-532 at the 500 kV Barabinskaya substation	13,7/13,8 MVAr/kV
1.2.	CSR -1-500 at the 500 kV Voskhod Substation	38,2/–[1] MVAr/kV
1.3.	2R-500 at the 500 kV Tavricheskaya substation	–/–[1]
2.	Variation in consumption and reactive power output by a static thyristor compensator STK-1 at 500 kV Zarya substation	–/–[1]
3.	Changes in the shunt reactor state	
3.1.	R-534 at the 500 kV Barabinskaya substation	11,4 kV
3.2.	R-2-500 or R-3-500 at the 500 kV Voskhod Substation	1,5 kV
3.3.	1R-500 at the 500 kV Tavricheskaya substation	–
3.4.	R-532 at the 500 kV Zarya substation	0,6 kV
4.	Total reactive power load variation of power plant generators	
4.1.	Power system of Novosibirsk oblast	24,1/53,3 MVAr/kV
4.2.	Power system of Omsk oblast	–[1]

[1] – the sign «–» means that for a given RPCF, the efficiency characteristic of the impact of its reactive power load variation on the voltage in the considered CS is in the ineffective regulation zone.

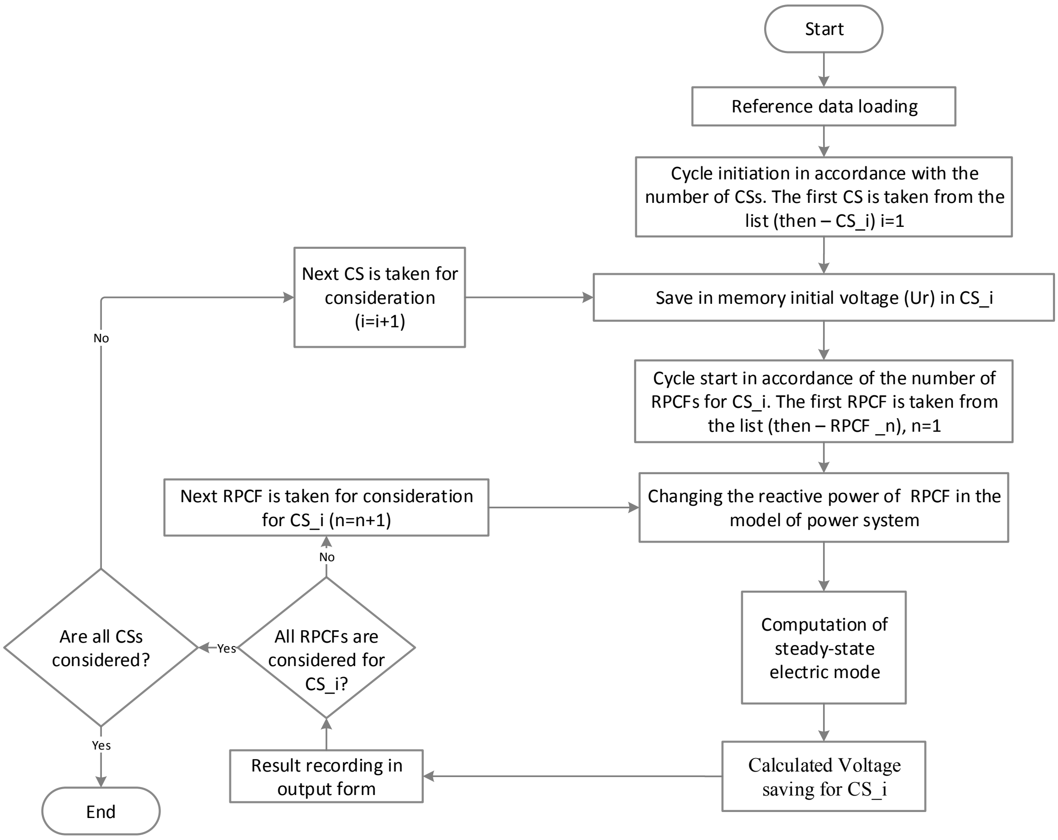

Fig. 3. Block-diagram of an enlarged algorithm for evaluating the RPCF efficiency for voltage regulation in the CS

For the above-mentioned CS of busbars of the 500 kV Barabinskaya substation, Table 2 shows the actual efficiency of actions with RPCFs for voltage regulation in the CS, as well as the information about ineffective voltage regulation zones in the CS in the mode on 28.12.2019.

For the mode under consideration as can be seen in Table 2, measures 1.1 and 3.1 have the highest efficiency for voltage regulation in the CS of busbars 500 kV Barabinskaya substation. These measures are associated with the shift in the reactive power balance directly in the CS, while the application of measures 1.3., 2, 3.3. and 4.2 is unreasonable.

In the course of practical calculations employing the developed software for real modes, the following issues were resolved:

1. Means with the highest efficiency intended for voltage regulation in the CS have been determined;
2. Ineffective means for voltage regulation in the CS have been identified;
3. Fast response and high speed of balanced decision made by the dispatcher when dealing with voltage regulation in the CS have been ensured.

In this paper, an efficient algorithm is developed and analyzed. The developed algorithm ensures an efficient performance assessment of facilities used for voltage regulation in control stations in the real-time mode utilizing information on real circuit conditions and power system operating parameters. Moreover, the proposed algorithm offers the best compromise to dispatcher in terms of accuracy and optimal decision-making time when using control means for voltage regulation in control stations.

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