Using Controlled Shunt Reactors for Voltage Stabilization on the Example of Real Electric Power System

A S Gusev[1], **A A Suvorov**[1] **and A O Sulaymanov**[1]
[1]National Research Tomsk Polytechnic University, Lenin Avenue 30, Tomsk, 634050, Russia

E-mail: lejkasvr@yandex.ru

Abstract. The article is devoted to actual task of real-time simulation controlled shunt reactors to use in the appropriate electric power system. Such development allows fully and reliably reproducing the processes running in controlled shunt reactors and electric power systems as whole. As an example of such task solution the working results of controlled shunt reactors simulation and its application for voltage stabilization are presented.

1. Introduction

One of the main operation conditions of electric power systems (EPS) is a voltage level. The values of this are connected to reactive power (RP) flow. The main voltage stabilization and generation RP devices are located on power stations, so located in electrical network devices is not provide necessary voltage level and RP regulation. For example, in Russian networks, the most widespread devices for reactive power compensation (DRPC) are providing only single-stage voltage regulation shunt reactors. An effective way of solving this problem is using Flexible Alternative Current Transmission Systems (FACTS) technologies, such as: controlled shunt reactors (CSR) [1], static reactive power compensator (SPC), static synchronous compensator (STATCOM) and others. Nowadays, the CSR is the most widespread FACTS devices, representing a device with continuously variable inductive reactance [1-3].

Design, research and exploitation of EPS, including CSR, are based on the analysis and using information about a full spectrum of various processes in CSR and EPS as a whole. The known specificity of electrical power systems is excluded the possibility of obtaining this information by full-scale test, so the main way of getting information is simulation, mostly mathematical because of the difficulty of the real EPS and impossibility of full physical simulation [4, 5]. As a result, for reliable and efficient operation of CSR as EPS part is necessary to create a mathematical model CSR, and software and hardware are adapted for using in the appropriate EPS.

2. Creating a CSR mathematical model

The describing the running processes in the CSR equations are taken into account the interaction of each phase coil with its own main magnetic flux and stray flux, so created mathematical model have to include a system of three phase three-circuit equations:

1) Equations magnetically coupled by magnetic flow phase each winding:

$$w_{PWi}\frac{d\Phi_{0i}}{dt}+L_{PWi}\frac{di_{PWi}}{dt}+r_{PWi}i_{PWi}=u_{PWi} \tag{1}$$

$$w_{CWi}\frac{d\Phi_{0i}}{dt}+L_{CWi}\frac{di_{CWi}}{dt}+r_{CWi}i_{CWi}=u_{CWi} \quad (2)$$

$$w_{CONWi}\frac{d\Phi_{CONWi}}{dt}+L_{CONWi}\frac{di_{CONWi}}{dt}+r_{CONWi}i_{CONWi}=u_{CONWi} \quad (3)$$

where: j – power, control and compensation winding; w_{ji} – number of turns; i – A, B, C; Φ_0 – main magnetic flux i; Φ_{YO} – control winding magnetic flux i; L_{ji} – winding-leakage inductance i; i_{ji} – current in winding; r_{ji} – active resistance; u_{ji} – line voltage.

2) Equations magneto-motive forces for each phase:

$$w_{PWi}\cdot i_{PWi}+w_{CWi}\cdot i_{CWi}+w_{CONWi}\cdot i_{CONWi}=F_{MMFi} \quad (4)$$

where F_{MMFi} – magneto-motive force for phase i, MMF is determined by taking into account the possible saturation of steel:

$$F_{MMFi}=K_{\mu}\Phi_{0i}^{p}. \quad (5)$$

The resulting system of equations allows synthesizing CSR mathematical model reproducing running processes in the windings, with the non-linearity of magnetic circuit, and hardware and software of models implementation. It allows solving the nonlinear system of differential equations without any decomposition and limitation on their duration in real time with guaranteed accuracy [6, 7]. Structural diagram of the specialized reactor processor (SRP) implements CSR mathematical model, see Figure 1.

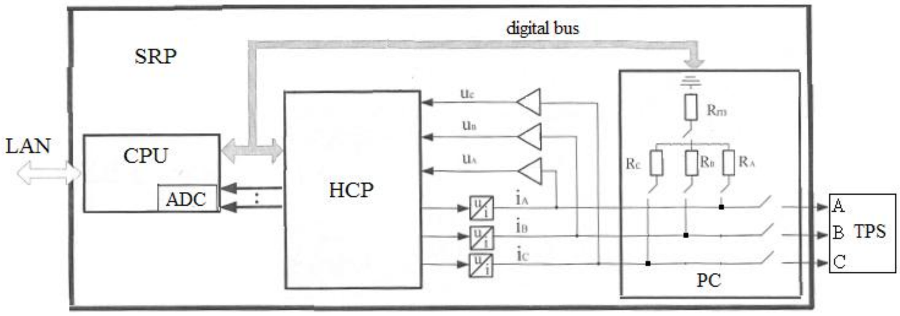

Figure 1. The structural diagram of the hybrid software and hardware simulation of CSR.

where: SRP - specialized reactor processors, LAN – local area network, TPS – three-phase switch, CPU - central processing unit, ADC –analog-to-digital converter; HCP – hybrid coprocessor; PC - switching processor; u/i - voltage-current converter.

This SRP realized in the Hybrid Real Time Power System Simulator (HRTSim), which is developed in Institute of Power Engineering of Tomsk Polytechnic University [8]. It represents multiprocessor software and hardware system that provide the real time continuous implicit integration of differential equations system describing processes in three phase power system. HRTSim allows avoiding decomposition of power system processes and simplification of power equipment models independently on the size of modeled EPS. Besides, the capability to provide any longitudinal and transversal commutations this system allows simulating any abnormal regime of power system [9, 10].

3. Research the CSR effectiveness in real EPS

A current pilot project on creation of system with FACTS devices for 'Elgaugol' energy cluster which is a part East Power System is being implemented in Russia. A scheme of simulated East Power System including Elgaugol energy cluster and adjacent network is given in Figure 2 [11].

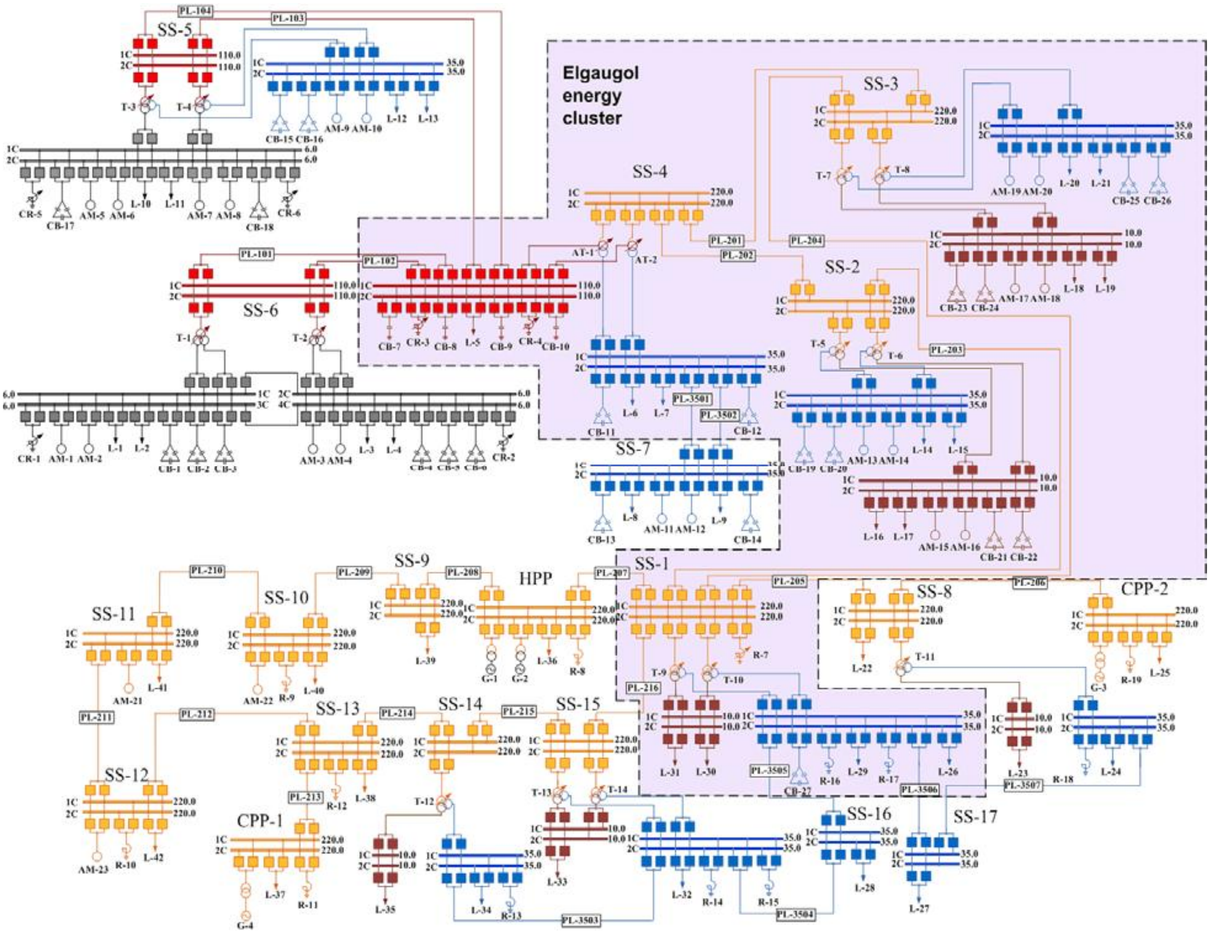

Figure 2. Simulated power system: SS – substation, CPP – co-generation power plant, HPP – hydro power plant, PL – power line, CB – capacitors bank, CR – controlled shunt reactor, R – switched reactor, L – load, AM – asynchronous motor, G – generator, (A)T – (auto) transformer.

The major components of energy cluster power equipment controlled shunt reactor (CSR): 100 Mvar reactor is expected to be installed at Prizeyskaya substation that powers energy cluster and two 25 Mvar reactors are planned to be installed at Elgaugol substation. Automatic control system (ACS) of CSR contains hysteresis regulator which switches-on/off one or several banks of capacitors (BC) in case CSR experiences maximum/minimum reactive power load level and this level is being hold for certain period of time. The purpose of researching is check CSR effectiveness for voltage and RP regulation, it allows: to support acceptable voltage level in EPS; to reduce electricity losses during transportation and distribution; to provide positive effect on operational conditions of energy cluster and EPS as whole.

The purpose of the first experiment was to investigate the CSR application for stabilization voltage level in load node when operating electrical equipment for real the daily schedule of active and reactive loads mining enterprise in three-shift work in winter. The example of real time simulation results of self-starting process of energy cluster consumer's asynchronous motors and CSR actions in the case of voltage dip occurring when total loads are increasing according to the daily schedule is performed in Figure 3 and Figure 4.

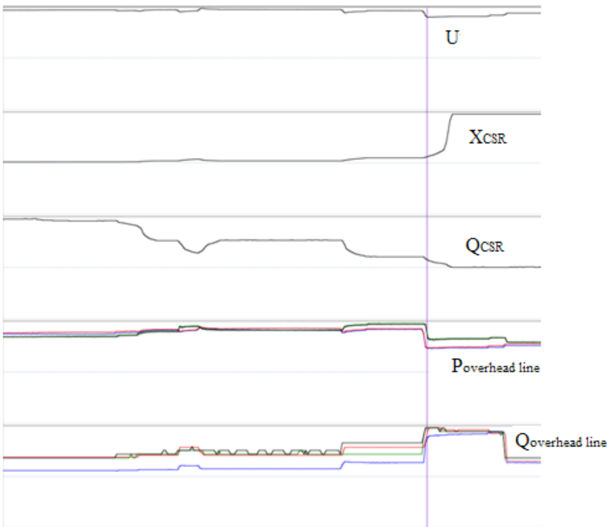

Figure 3. Real time data oscillogram of changing loads, CSR and banks of capacitors switching-on.

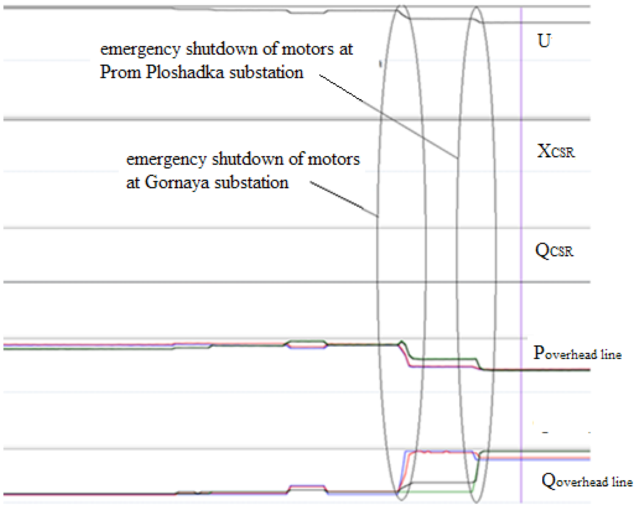

Figure 4. Real time data oscillogram of changing loads, CSR and banks of capacitors switching-off.

ACS CSR runs with increasing load and unloads the reactor power, because of this bus bar voltage level does not leave the permissible 5 percent level from the set point, and a power failure consumer does not occur, see Figure 3. On the next diagram Figure 4, a significant voltage dip occurred during increasing the load, it led to stop the located on the SS Prom Ploshadka and SS Gornaya motors are powered by bur buses 110 kV Elgaugol with installed DRPC. As a result, active power connected SS Elgaugal and motor consumers overhead lines sharply decreased and reactive power increased. Obtained diagrams shows that continuity of power supply main customers Elgaugol energy cluster depends on the functioning CSR.

The following are the results of experiments demonstrating the CSR influence on the operation stability consumer when one of the energy cluster supplying power overhead line is suffered a short circuit is performed in Figure 5, 6. At some moment of time a short-sscircuit is simulated on the supplying power overhead line, it is followed to activate of relay protection (RP) and the successful automatic reclosing. Thus, the load stability is preserved, see Figure 5. Figure 6 shows the results of a similar experiment when CSR and banks of capacitors are disabled. Obviously, motors of Elgaugol energy cluster have stopped after a short circuit in the EPS.

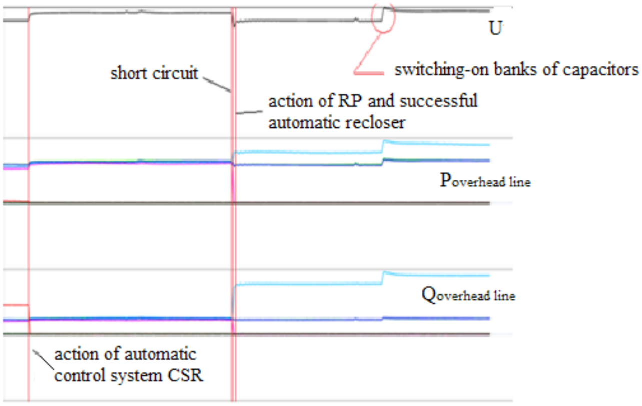

Figure 5. Real time data oscillogram of changing loads on time feeder short-circuit, CSR and banks of capacitors switching-on.

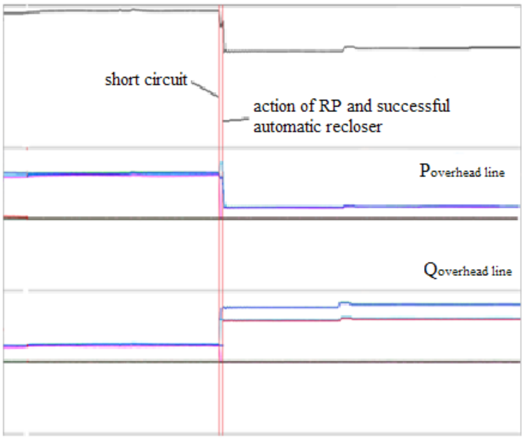

Figure 6. Real time data oscillogram of changing loads on time feeder short-circuit, CSR and banks of capacitors switching-off.

Losses of active and reactive power overhead lines and transformers of Elgaugol energy cluster are taken readings for researching the power losses, see Figure 7. Presented results show that the active and reactive losses are higher when CSR and banks of capacitors are disabled than with their using.

a b

Figure 7. Real time data oscillogram of total power losses in Elgaugol a - CSR and banks of capacitors switching-on, b - CSR and banks of capacitors switching-off.

4. Conclusion

Currently, the voltage stabilization and RP generation in EPS are carried out by means of shunt reactors, capacitor banks, transformer and autotransformer ratio are can only be provided step regulation and such regulation is proved to be insufficient to maintain the voltage level within permissible limits. In this regard, approach is to use DRPC becomes justified and useful. It allows carrying out the automatic continuous voltage stabilization and RP generation. The finished research shows that the combined using of CSR and banks of capacitors allow solving the tasks formulated by above. However, CSR is not always able to provide the stability of consumers in emergency conditions because of its response time, it was established. It depends on many factors, such as the fault location, the running time of relay protection, the duration automatic recloser et al, so in some cases, to use a high-speed device is more profitable, such as for example a static synchronous compensator (STATCOM).

Acknowledgment
This work was supported by mega-grant "Hybrid simulation and control of smart grids".

5. References

[1] Canizares C A 1999 Modeling and Implementation of TCR and VSI Based FACTS Controllers *ENEL Int. report* (Milan: Polytechnics di Milano) p 43
[2] Borovikov Yu S, Gusev A S, Sulaymanov A O and Ufa R A 2014 Hybrid real-time simulator of power system for advanced simulation of the FACTS and HVDC system based on Voltage Source Converter *Proc. Int. Conf. Systems and Informatics (ICSAI 2014) (Shanghai)* (Beijing: IEEE) pp 148–52
[3] Borovikov Yu S, Gusev A S, Sulaymanov A O and Ufa R A 2014 Synthesis of a hybrid model of the VSC FACTS devices and HVDC technologies *Proc. Int. Conf. Modern Techniques and Technologies (MTT 2014) (Tomsk)* (London: Institute of Physics Publishing) pp 1–6
[4] Mahseredjian J, Dinavahi V and Martinez J 2009 Simulation tools for electromagnetic transients in power systems: overview and challenges *IEEE Transactions on Power Delivery* **24(3)** 1657-68
[5] Woodruff S Complexity in power systems and consequences for real-time computing 2004 *IEEE PES Proc. of the Power Systems Conf. and Exposition* (Atlanta: IEEE) pp 1770-75
[6] Gusev A S, Gurin S V, Svetchkaryov S V and Plodisty I L 2004 Hybrid methods as a way out of electric power system modeling problem *Proc. Int. Symp. KORUS 2004 (Tomsk)* vol 1 (Tomsk: Tomsk Polytechnic University) pp 215–19
[7] Gusev A S, Svechkarev S V and Plodisty I L 2005 Basic aspects of modeling problem for electrical power systems, perspectives and methods of their solution *Proc. Int. Symp. KORUS 2005 (Novosibirsk)* (Novosibirsk: Novosibirsk State Technical University) pp 322–26
[8] Borovikov Yu and Sulaymanov A 2013 Information and control system for use in the real time multiprocessor simulation of power equipment *Russian Electrical Engineering* **84** 290–95
[9] Borovikov Yu S, Sulaymanov A O, Gusev A S and Andreev M V 2014 Simulation of automatic exciting regulators of synchronous generators in hybrid real-time power system simulator *Proc. Int. Conf. Systems and Informatics (ICSAI 2014) (Shanghai)* (Beijing: IEEE) pp 153–58
[10] Ruban N Yu, Borovikov Yu S and Sulaymanov A O 2014 Simulation of transmission lines phase-comparison protection for optimization its settings *Proc. Int. Conf. IFOST 2014 (Cox's Bazar)* (Bangalore: IEEE) pp 264–67
[11] Borovikov Yu S, Prokhorov A V and Andreev M V 2012 Application of hybrid real time simulator for solution of smart grid tasks on the example of Elgaugol energy cluster pilot project *Proc. Int. Conf. IFOST 2012 (Tomsk)* vol 2 (Tomsk: Tomsk Polytechnic University) pp 604–08