Efficiency study of the reactive shunt compensation device in power lines

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Abstract. We consider the devices for reactive shunt compensation and simulated their use in a real energy facility.

1 Introduction

During out investigation we studied an increase in the PTL transmission capacity due to usage of STATCOM devices and a reduction in the cost of transporting electricity. The power system of the Vologda region is considered as an object under study and the efficiency of using the FACTS device systems in it is analyzed.

Perspective sales markets for FACTS devices are main and distribution PTL [1–8], PTL with limited capacity (Siberia UES is the European part of OES, OES of the Center is OES of North Caucasus), unstable electrical networks (OES of Siberia, and North Caucasus), suboptimally loaded parallel PTL (OES of the North-West, line of voltages of 330/220/110 kV, 500/220/110 kV, Mosenergo PJSC). Also, the market is the industry (steelmaking, arc furnaces, rapidly alternating loads).

The power system of the Arkhangelsk region has the following urgent problems:

1. The generating capacity is not enough for uninterrupted and reliable power supply of some areas;
2. Modernization of existing power network infrastructure facilities is necessary.

The power system of the Arkhangelsk region consists of two main energy centers: the Arkhangelsk center (redundant in generation) and the Kotlas center (deficient in generation). All generating facilities are located in the northern part of the region, and the most industrialized and densely populated areas, including the regional center, are located much to the south. Huge distances and very long transitions significantly reduce the quality and reliability of power supply to the region.

Connection of new energy consumers in large cities of the region (Arkhangelsk, Severodvinsk, Onega, Kotlas, and others) resulted in a situation that is close to catastrophic. The construction of residential houses and social facilities is frozen due to the lack of transformer capacity in the cities and on the way from generating facilities.

In the Arkhangelsk energy center, almost the entire generation of power system is concentrated, but due to the existing network limitations at the Vologda-Konosh and Plesetsk-Nyandam cross sections, some of the generated power is “locked”.

Besides this, the deficit Kotlas energy center meets the requirements of industrial consumers and residents of the region only with the help of power flows from other regions. The lack of electricity can be eliminated more efficiently by transit from the central regions of the Russian Federation, where the production of electricity is cheaper than in the Russian north.

Solving the problems of the Arkhangelsk power system is one of the priorities of the power industry of Russia: it is a rapidly developing industrial region, which is expected to stagnate without new capacity and improving the reliability of energy supply.

To increase the transmission capacity of the 220 kV section of the Vologodskaya-Konosha PTL, increase the stability and reliability of power supply and maintain the quality of electricity of this power unit at the substation "Konosha" the installation STATCOM is proposed.

Demonstration of ways to reduce the cost of electricity transmission is carried out using the Matlab SimPowerSystems software, in particular, by STATCOM installation at the 220 kV Vologda-Konosha PTL.

2 Materials and methods

The model of the 220 kV power system of the Vologodskaya substation – the Konosha substation is shown in Figure 1.

The three-phase voltage source in the considered section of the network is the 220 kV Vologodskaya substation. To simulate a three-phase voltage source, we use the "Three-Phase Source" block, the parameters of which are presented in Table 1.

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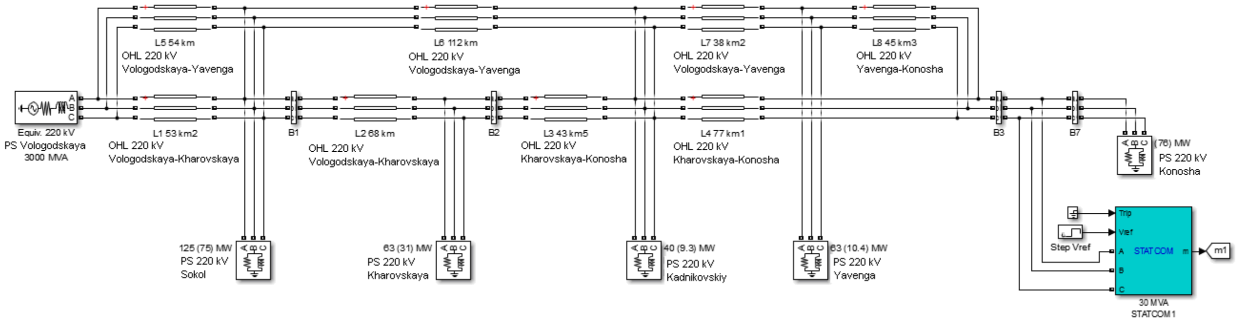

Fig. 1. The model of the 220 kV power system of the Vologodskaya substation - the Konosha substation.

Table 1. Parameters of a three-phase voltage source (220 kV Vologodskaya PS).

Characteristics	Value
Phase-to-phase rms voltage (V)	220 kV
Phase angle of phase A (deg)	0
Frequency (Hz)	50 Hz
Internal connection: (Y is for star, Yn is for star with zero wire, Yg is for star with the grounded neutral)	Yg
3-Phase short-circuit level at base voltage (VA)	6000 MVA
Base voltage (Vrms ph-ph)	220 kV
X/R ratio	8

The loads in the simulated network are PS 220 kV. PS 220 kV loads during the winter maximum are presented in Table 2.

Table 2. PS 220 kV loads during the winter maximum.

Substation	Load, P+jQ (MVA)
PS 220 kV Sokol	75 + j 12.4
PS 220 kV Kharovskaya	31 + j 1.7
PS 220 kV Kadnikovskiy	9.3 + j 5.9
PS 220 kV Yavenga	10.4 + j 2.6
PS 220 kV Konosha	76 + j 31

To simulate three-phase loads we use the block "Three-Phase Parallel RLC Load". The block parameters on the example of PS 220 kV Falcon are presented in Table 3.

Table 3. Parameters of a three-phase parallel RLC load.

Characteristics	Value
Nominal phase-phase voltage Vn (Vrms)	220 kV
Nominal frequency fn (Hz)	50 Hz
Three-Phase active power P (W)	75 MW
Three-Phase inductive reactive power QL (positive var)	12.4 Mvar
Three-Phase capacitive reactive power QC (negative var)	0

When calculating EPS modes, electrical networks are presented in the form of connected equivalent circuits of individual elements, which serve as the basis for the further formation of matrices of their generalized parameters in the mathematical model of EPS.

The equivalent circuit of a multi-wire line, shown in Figure 2, consists of distributed resistance and conductivity, which represent linear losses, and inductance and capacitance, which represent the magnetic and electrostatic characteristics of an overhead line.

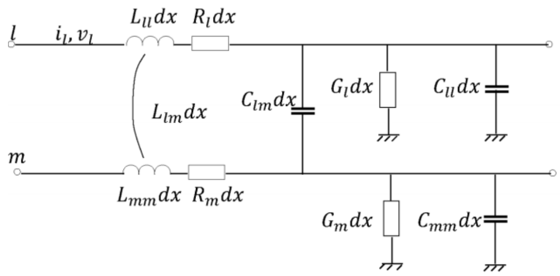

Fig. 2. An infinitely small element of two phases of a multi-wire line: R_l, L_u, C_U, G_l are resistance, inductance, capacitance and active conductivity of leakage to earth of a wire l per unit length, L_{lm}, C_{lm} are mutual inductance and capacitance between wires l and m per unit length of a line.

For wire *l*, one can write the following equations for voltage and current:

$$\begin{cases} -\dfrac{\partial u_l}{\partial x} = \sum\limits_{m=1}^{n} L_{lm} \dfrac{\partial i_m}{\partial t} + R_l \cdot i_l; \\ -\dfrac{\partial i_l}{\partial x} = \sum\limits_{m=1}^{n} C_{lm} \dfrac{\partial (u_l - u_m)}{\partial t} + C_U \dfrac{\partial u_l}{\partial t} + G_l \cdot u_l, \end{cases} \quad (1)$$

where *x* is coordinate along the line; *t* is time, s.

To determine the listed parameters of the overhead line, such as active, inductive resistance, capacitive and active conductivity, a large volume of calculations is required. The calculations become much more complicated if we take into account the crown loss and the fact that the phase conductors can be split and made of steel wires. Also, the simultaneous consideration of the influence of the earth and the crown is a complex task, which can be solved only using computers.

The Compute RLC Line Parameters tool, included in the MATLAB Powergui block, automatically determines the parameters of PTL models based on the geometric dimensions of the line and the wires characteristics. The tool window is shown in Figure 3.

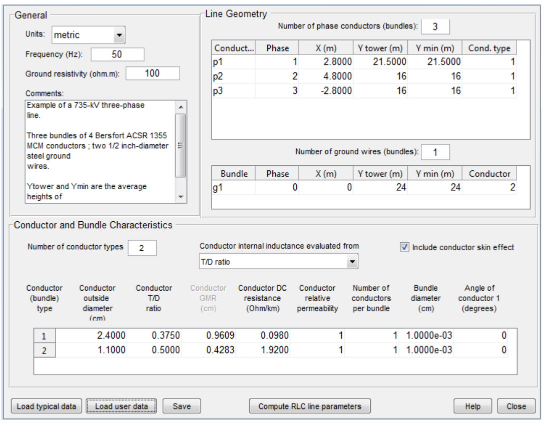

Fig. 3. Compute RLC Line Parameters tool window.

According to the results of study the installation of FACTS devices at the Vologda-Konosha 220 kV line [9–13], after installing the 30 MVA STATCOM, the increase in transmission capacity for active power was 8 MW according to calculations performed in MATLAB (see Table 4).

Table 4. Changes in U, Q and P on the B3 bus.

STATCOM operation mode	t, s	U, kV	Q, Mvar	P, MW
Turned-off	t = 0–0.2 s t = 0.6–0.8 s	222	41	77
Voltage-decrease mode	t = 0.2–0.4 s	216	60	74
Voltage-increase mode	t = 0.4–0.6 s	233	3	85

To assess the technical and economic effect of the use of flexible power transmission line (FPTL) devices in the power industry of the Russian Federation, we take into account factors related to:

1. An increase in transmission capacity of power networks of the Unified National Electric Grid;
2. An increase of static and dynamic stability of the electric power system;
3. An alternative to construction of new power network and generating facilities;
4. Redistribution of power flows in the main network, depending on demand;
5. Limitation of short circuit currents;
6. An increase of operation cost-effectiveness of power supply systems.

With a one-rate tariff of 1.21 rubles/kWh for transmission of electrical energy for high voltage consumers, the cost of transmission of 8 MW will be:

$$C = 8{,}000 \text{ kW} \cdot 1.21 \text{ (rub)/(kW} \cdot \text{h)} = 9{,}680 \text{ (rub)/h} \quad (2)$$

This characteristic per 1 month will be:

$$C_{(month)} = 9680 \text{ (rub)/h} \cdot 24 \text{ h} \cdot 30 \text{ days} =$$

$$= 6{,}969{,}600 \text{ (rub)/(month)} \quad (3)$$

For a quarter it will be:

$$C_{(quart)} = 6{,}969{,}600 \text{ (rub)/(month)} \cdot 3 \text{ months} =$$

$$=20{,}908{,}800 \text{ (rub)/(quart)} \quad (4)$$

Thus, the cost reduction for producing of 8 MW of EE will amount to 20,908,800 million rubles for a quarter.

The results of calculation of cost reduction for production of EE after installing the STATCOM device in the network are summarized in Table 5.

3 Conclusions

The savings from the installation of the STATCOM device with a capacity of 30 MVA for the second year of operation amounted to 79,559.996 rubles.

Payback of the STATKOM device will be 1 year and 2 months. Thus, the project to increase the PTL capacity at the expense of FACTS devices is appropriate.

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Table 5. Cost reduction for production of EE after installing the ORPM device into the energy network.

No.	Characteristics	2020 year (forecast)	Including			
			1 quarter	2 quarter	3 quarter	4 quarter
1.	Cost reduction for production of EE in terms of money, total (ths. rub.)	83635.2	20908.8	20908.8	20908.8	20908.8
2.	The volume of sales of goods in physical terms: Electricity, kWh	69 120	17 280	17 280	17 280	17 280
3.	One-rate tariff, rub./KWh (single (boiler) tariffs for services for transfer of EE through the networks of the Vologda region)	1.21 rub./kWh	-//-	-//-	-//-	-//-

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