IOP Conf. Series: Materials Science and Engineering 1019 (2021) 012063 doi:10.1088/1757-899X/1019/1/012063

Analysis of the FACTS devices impact on the transmission line protection operation

N Yu Ruban, A S Gusev, Yu D Bay and I A Razzhivin
School of Energy and Power Engineering, Tomsk Polytechnic University, Tomsk Russia
E-mail: rubanny@tpu.ru

Abstract. The effect of the static synchronous compensator (STATCOM) on distance protection of a high-voltage transmission line is studied in this article. To carry out the research stated in the topic of the paper, an experimental scheme was developed, equipment was selected, the operation settings of the 3 stages of distance protection were calculated and quad characteristics were built on their basis. All listed above, as well as further experiments, were carried out by the real time digital simulator. The STATCOM model was integrated in the scheme and set next. A series of experiments was carried out: two-phase and three-phase short circuits in various nodes of the scheme with and without the compensator and in various connection nodes. After all the experiments were carried out, appropriate conclusions were made about the impact of FACTS devices on the operation of distance protection. Possible ways to solve detected problems were also proposed.

1. Introduction

Currently, flexible alternating current transmission systems (FACTS) – a set of technical and information tools for automatic control of transmission line parameters – are widely spread and developed [1]. Many problems are solved with the help of these devices: increasing the transmission capacity of power lines; ensuring the stable operation of the power system under various disturbances; improving the reliability of energy saving of consumers; reduction of losses in electrical networks. One of such devices is a static synchronous compensator (STATCOM).

As with the putting of any new element into the system, it is necessary to study the effect of STATCOM on network operation in various modes, including faults. The role of automatic devices that detect faults and disconnect equipment or inform personnel and dispatchers about the appearance of an abnormal mode, is performed by relay protection and automation. One of the most widely used basic protection of 110–220 kV lines is distance protection (DP), the principle of this one is to calculate the resistance based on measured voltages and currents. There are guidelines for calculating and configuring relay protection for various equipment and different network modes [2]. Besides each protection manufacturer provides its own recommendations for setting up its own devices. The regulatory documents used in Russia for setting up distance protection do not contain any recommendations for their operation in networks with FACTS devices [3]. Perhaps this is due to the low prevalence of FACTS in Russia, but recently such devices have been shared quite actively.

Thus, there is a question about the qualitative and quantitative influence of FACTS devices on functioning now elements, including the relay protection of transmission lines, as well as the question of taking them into account when calculating the settings and configuring the protection. In the paper a study of the effect of a second-generation FACTS device — a static synchronous compensator — on the distance protection of a 220 kV transmission line was conducted, since it has several advantages over similar compensation devices and is widely used now and also an effective device in terms of its use for maintaining voltage levels or controlling power flows [1, 4, 5]. At the same time, there is a problem of the behavior of FACTS in case of faults, particularly their influence on the operation of relay protection [6–10].

The purpose of the study is to answer the question about the necessity of taking into account the impact of a particular device on a distance protection in Russian networks. Production companies are interested in the results in terms of improving the quality and accuracy of recommendations for protection setting up.

2. Case study

To carry out the study, a circuit in which there is a 220 kV transmission line with a three-stage distance protection installed is required. According to the [2], the first stage is adjusted from the own resistance of the protected line, the second stage is adjusted from the first stage of the previous line, the third stage is adjusted to ensure reliable coverage of the previous line. It is also possible to set from the short-circuit on the low voltage side of the transformer at the end of the protected line. Due to the above, it was decided to use the experimental power grid presented in Figure 1. All the equipment shown in the diagram is made in Russia and its parameters are selected in accordance with [11].

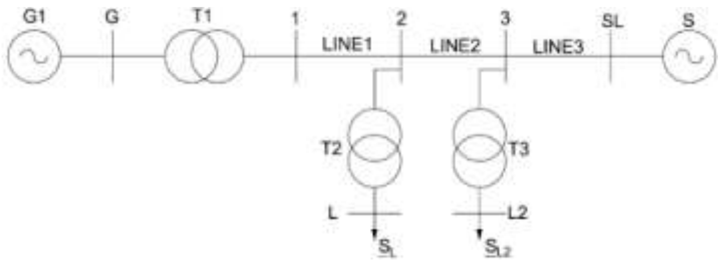


Figure 1. Experimental power grid scheme.

Generator G1 rated power is 100 MW. STATCOM rated power is 100 Mvar. Loads power (S_L) is 40+20i MVA. Lines rated voltage is 220 kV.

Calculation of distance protection parameters is carried out for a set of line 1 installed at substation 1. The model of the DP measuring body in the real-time digital simulator (RTDS) shows the primary resistance. The values of phase voltages and currents are given to the input; it is possible to monitor phase-to-ground resistances, phase-to-phase resistances, and also resistances of direct, inverse, and zero sequences at the output. In the output locuses during modeling data about line resistance are entered, as well as about calculated characteristics in primary values, using this data, the complex draws quad characteristics.

3. Quad characteristics

In general, the quad characteristic of each stage has a form shown in Figure 2.

With the help of the measuring body in the RTDS, the phase resistance is found at the specified fault (node 2), it is also own for the LINE1:

$$\underline{Z}_{LINE1} = 9.2 + j43.19 = 44.159e^{j78^\circ} \text{ Ohm}.$$

The first stage set point calculation for LINE1:

$$\underline{Z}_{set1}^{(1)} = 0.85 \cdot \underline{Z}_{LINE1} = 0.85 \cdot 44.159e^{j78^\circ} = 37.535e^{j78^\circ} \text{ Ohm}.$$

For further calculations LINE2 own resistance is needed. From similar experiment:

$$\underline{Z}_{LINE2} = 11.07 + j51.9 = 53.067e^{j78^\circ} \text{ Ohm}.$$

Matching with the previous line. The current distribution coefficient between LINE1 and LINE2 with a short-circuit at the node 2 equals one, since there are no additional sources from the beginning of the first line to the end of the second one.

The second stage set point calculation for LINE1 with matching:

$\underline{Z}_{set1}^{(2)} = 0.85 \cdot \underline{Z}_{LINE1} + \frac{0.66}{k_{cII}} \underline{Z}_{LINE2}$; $\underline{Z}_{set1}^{(2)} = 0.85 \cdot 44.159 e^{j78^\circ} + \frac{0.66}{1} 53.067 e^{j78^\circ} = 75.56 e^{j78^\circ}$ Ohm.

The third stage is calculated based on the conditions of reliable coverage of the previous line and the conditions of the required sensitivity. For this, a short-circuit is simulated at the end of the LINE2 (node 3) and the resistance of the is measured by LINE1 protection. The resulting value is:

$\underline{Z}_{LINE1}^{(3)} = 22.18 + j94.4$ Ohm.

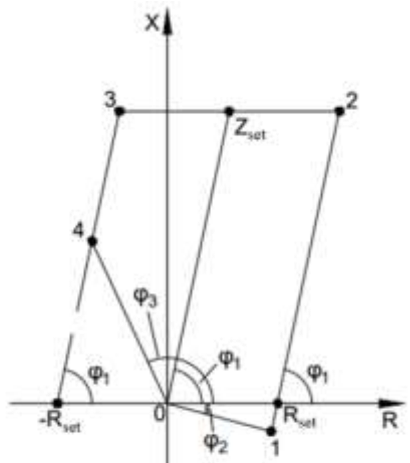


Figure 2. Quad characteristic general form, where Z_{set} – set point of the stage for which the characteristic is built; φ_1 – the angle of maximum sensitivity taken equal to the angle of the set point resistance; φ_2 – the angle of the edge 01 inclination taken to be -15° for 1 and 2 stages, for 3 stage calculated separately; φ_3 – the angle of the edge 34 inclination taken to be 115°; R_{set} – active resistance set point; edge 23 passes through the end of a straight Z_{set} and is parallel to the axis R.

Required sensitivity coefficient for the third stage is $k_s = 1.2$. The third stage set point calculation for LINE1:

$\underline{Z}_{set1}^{(3)} = k_s \cdot \underline{Z}_{LINE1}^{(3)} = 1.2 \cdot (22.18 + j94.4) = 116.365 e^{j77^\circ}$ Ohm.

The angle φ_2 is calculated next for the third stage operation characteristic:

$\cos\varphi_{\max} = \frac{\cos\varphi_{\text{nom}}}{U_{\min} I_{\text{load}\max}} = \frac{0.85}{0.9 \cdot 1} = 0.944$;

$\varphi_2 = 5 + \arccos(\cos\varphi_{\max}) = 5 + \arccos(0.944) = 24.19^\circ$,

where $\cos\varphi_{\max}$ – cosine in maximum load mode; $\cos\varphi_{\text{nom}}$ – cosine in normal load mode; $U_{\min}$ – voltage in maximum load mode, p.u.; $I_{\text{load}\max}$ – current in maximum load mode, p.u.

Active resistance set points:

$R_{set1} = 13.679$ Ohm; $R_{set2} = 19.246$ Ohm; $R_{set3} = 26.208$ Ohm

4. STATCOM model

The STATCOM model in the RTDS is represented by two blocks. Block 1 (STATCOM) is required for elements that are modeled using a small time-step in the program, while a large time-step is used for the main circuit. This block contains DC sources, rectifiers, a reactor, a filter, a special transformer model for connecting parts with different calculation steps, as well as elements generating a sawtooth signal and firing pulses based on the data received from the control system. Experimental power grid scheme with STATCOM connection is shown in Figure 3.

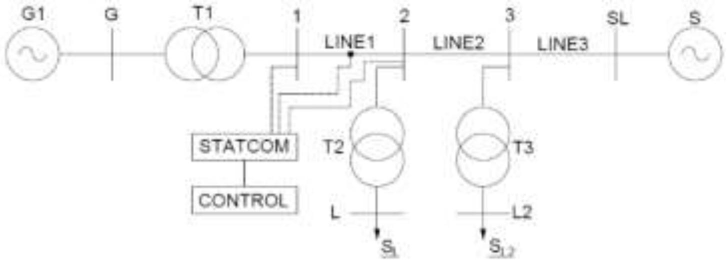


Figure 3. Experimental power grid scheme with STATCOM connection.

In block 2 (CONTROL) the control system is located. The control uses the pulse width modulation method. Based on the measured power flowing between the system and STATCOM, as well as the voltage at the common coupling point (PCC) and the set point, an angle and modulation factor are generated for the reference signal, which is compared with the carrier sawtooth signal in the firing pulse generator. The set points for voltage and active power are put in the control system (when adjusting reactive power and voltage, the set point for active power is equal to zero) in p.u. Base values are set in the measuring bodies. The installed power of STATCOM is regulated by changing the voltage of the element VDC in block 1.

5. Results

The following experiments were carried out during the studies: a two-phase short circuit between phases AB and a three-phase short circuit at the end of the protected and previous lines. Using midpoint STATCOM, additional experiments were carried out with a fault for 25% and 75% of the protected line length. The obtained polygonal operational characteristics of the starting relays of distance protection and the locuses of resistance are presented in Figures 4–10. In the Figures, the red line shows the resistance of the protected line. Blue indicates the response of the first stage, green and purple - the characteristics of the second and third stages, respectively. The graphs in Figures 4, 5 are obtained for the case of connecting STATCOM to node 1.

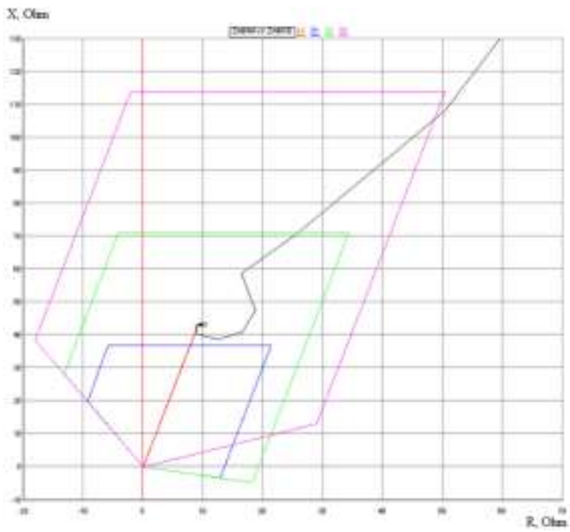


Figure. 4 Phase-to-phase fault, node 2.

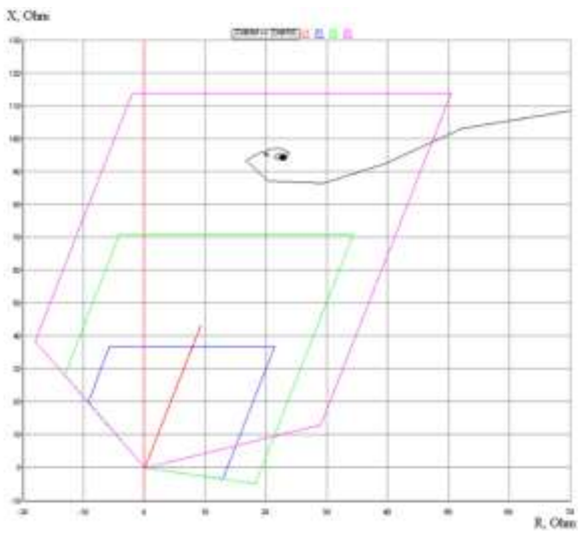
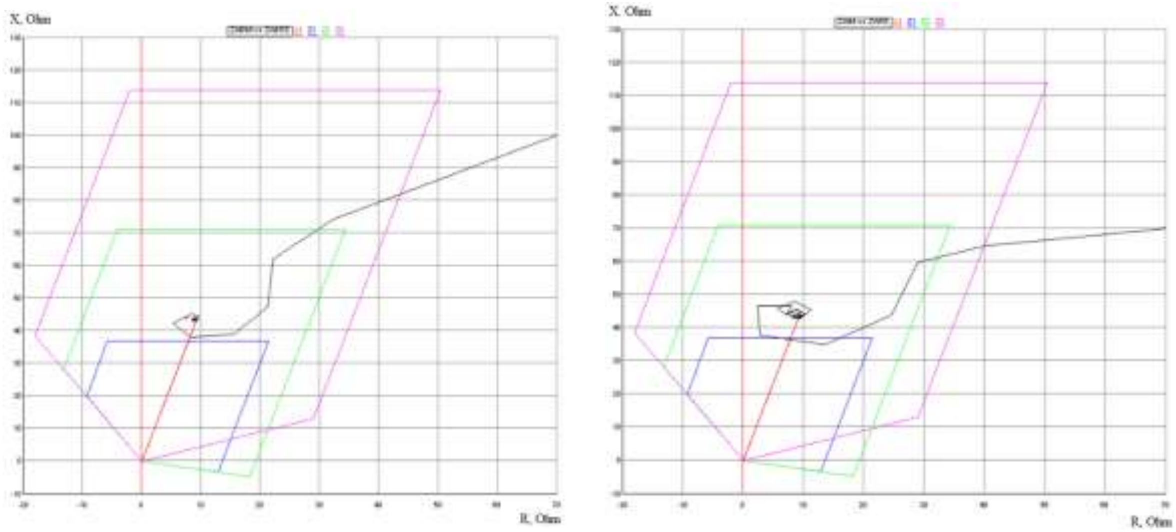


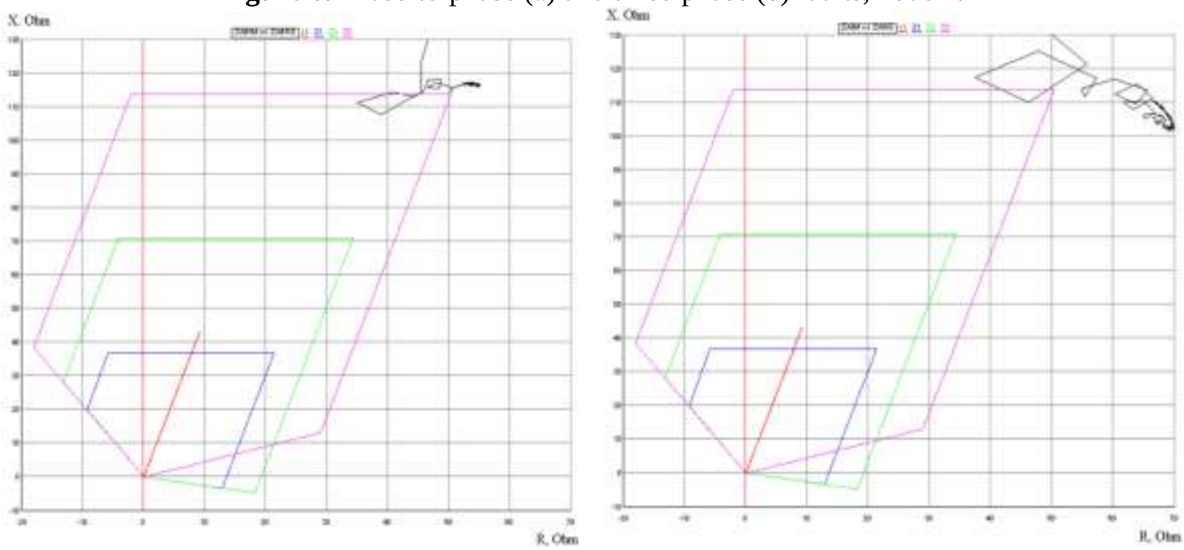
Figure. 5 Phase-to-phase fault, node 3.

The graphs in Figures 6, 7 are obtained for the case of connecting STATCOM to node 2.



a b

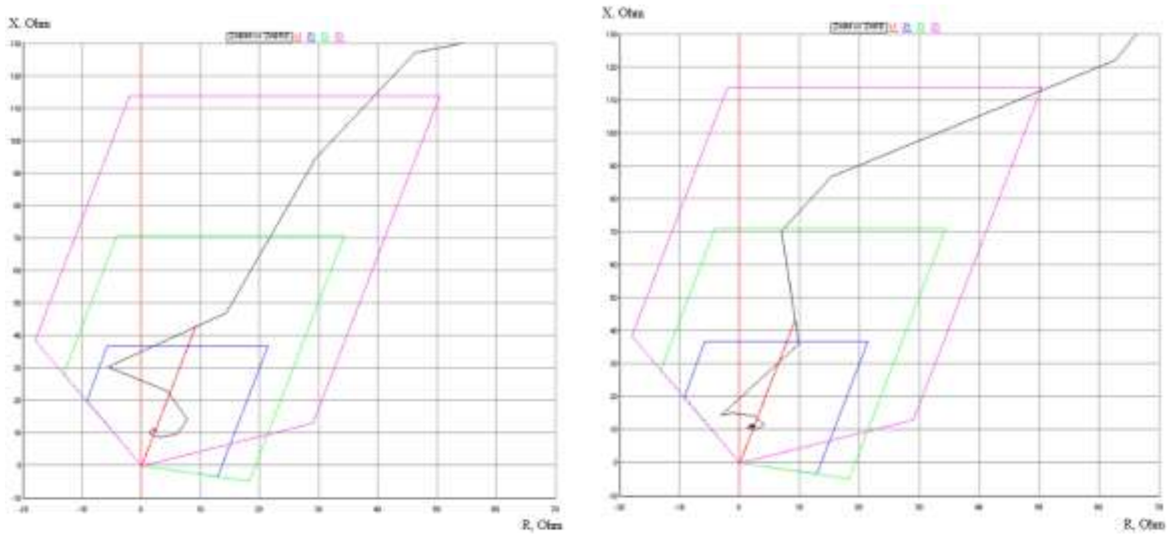
Figure 6. Phase-to-phase (a) and three-phase (b) faults, node 2.



a b

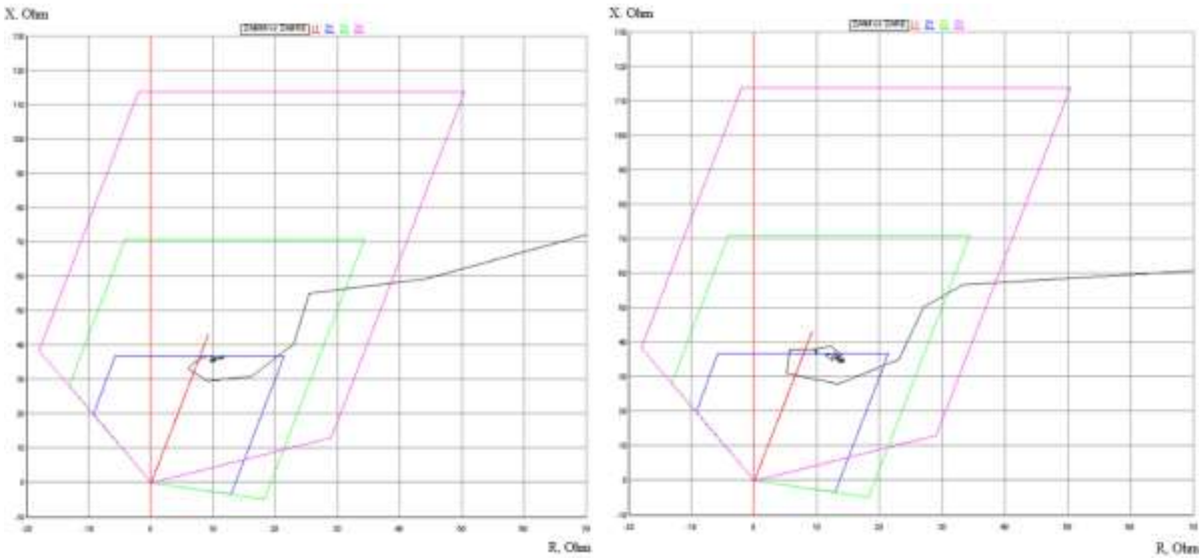
Figure 7. Phase-to-phase (a) and three-phase (b) faults, node 3.

The graphs in Figures 8–10 are obtained for the case of connecting STATCOM to the midpoint of line 1.



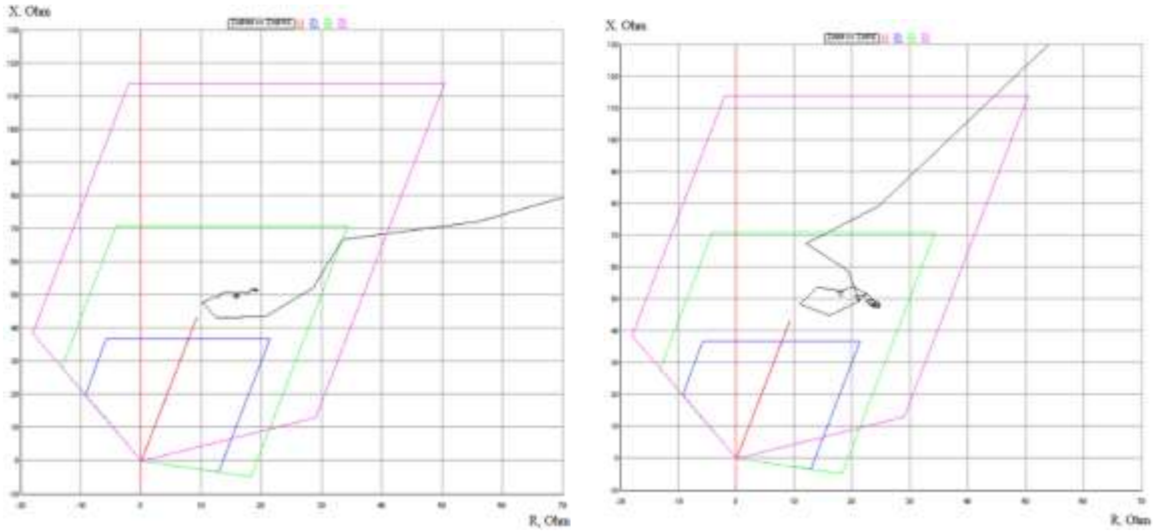
a b

Figure 8. Phase-to-phase (a) and three-phase (b) faults, 25 % length.



a b

Figure 9. Phase-to-phase (a) and three-phase (b) faults, 75 % length.



a b

Figure 10. Phase-to-phase (a) and three-phase (b) faults, 100 % length (node 2).

From the results of the performed experiments the fact of the static synchronous compensator influence on the transmission line distance protection operation was established in individual cases. STATCOM does not affect the protection operation if the fault occurs between it and the place where the distance protection is installed, as well as when the compensator is connected at the beginning of the protected line. This is due to the fact that in these cases, the measured current and voltage required to calculate the resistance either do not change or change proportionally. When the STATCOM is located between the distance equipment and the fault place, there is a noticeable influence on the behavior of the protection. For example, the third stage underreaches and does not provide long-distance backup mode with a short circuit at the end of the previous line if the compensator is installed at the end of the protected line, because the locus does not get into the third stage zone of operation. Experiments in which the STATCOM is connected at the midpoint shows that a locus shift relatively to normal operation can lead to the triggering of the second and third stages, when the first and the second ones must operate. This, in turn, leads to a delayed response and may be the result of more serious damage and emergency conditions of the power system.

6. Conclusion

According to the experiments results, it can be concluded that the compensator increases the measured reactive and active components of the resistance. This fact must be taken into account when calculating the settings for the distance protection of power lines and reflected in the relevant regulatory documents. Thus, it is possible to take this into account using the coefficient, which increases the quad characteristic edges. Another problem solution for protection manufacturers may be to develop an adaptive function. The point is to ensure the exchange of information between distance protection and STATCOM and dynamically change the operation characteristics depending on the mode of the compensator and its installed power.

Acknowledgments

The work was supported by Ministry of Science and Higher Education of Russian Federation under the governmental grant "Science" № FSWW-2020-0017.

References

[1] Tiwari R, Niazi K and Gupta V 2012 *Power Energy Soc. Gen. Meet.* 6344702

[2] Hondurov S, Ilyukhin E, Pirogov M and Soloviev A 2013 *Step distance protection of 35–220 kV transmission lines. The method of calculation* (St. Petersburg: PEIPK) p 32

[3] 2015 STO 56947007-29.120.70.200-2015 *Guidelines for the calculation and selection of settings of microprocessor-based devices for relay protection and automation* (Moscow)
[4] Lee C, Leung S and Hui S 2003 *IEEE Trans. Power Electron.* **18**(4) 1084–1092
[5] Parvathy S, Thampatty K C S and Nambiar T N P 2017 *IEEE Asia-Pacific Power Energy Eng. Conf.* 7747905
[6] Samkari H, Allehyani M and Johnson B 2015 *North American Power Symp.* 7335196
[7] Alam M, Leite H, Liang J and da Silva Carvalho A 2017 *Int. J. Electr. Power Energy Sys.* **92** 245–260
[8] Guan R, Xue Y and Zhang X 2018 *The Journal of Eng.* **15** 1038–1042
[9] Bhaskar M and Indhirani A 2014 *Nationl Conf. Emerg. Trends New Renew. Energy Sources Energy Manag. (Chennai, India)* 7088738
[10] Khederzadeh M and Ghorbani A 2014 *IEEJ Trans. Electr. Electron. Eng.* **6**(6) 525–533
[11] Neklepaev B and Kryuchkov I 2014 *Electric part of power plants and substations: Reference materials for course and degree design* (St. Petersburg: BHV-Petersburg) p 542