Influence of Neutral Grounding Method on Voltage Unbalance in 10 kV Network With Cable Lines and Overhead Lines

Danila Kochura, Igor Tsivilyov, and Leonid Sarin

***Abstract*—The paper presents the results of experimental and computational investigations of power quality in the 10 kV network with different types of neutral grounding. It is shown that parameters of equipment, connected to the neutral point, have a significant impact on power quality in the field of voltage unbalance, up to deviation from standard values. The area of proper power quality in the field of zero sequence voltage unbalance for 10 kV network is determined. It depends on the ratio of overhead lines and cable lines capacitive current, on the type of neutral grounding. It is found out that power quality in the field of zero sequence voltage unbalance may be significantly improved by connection of additional resistance into a zero sequence circuit of the network.**

***Index Terms*—power quality, power distribution, power system analysis computing, power system measurement, electrical equipment industry.**

I. Introduction

Nowadays, the majority of distribution networks in Russia consist of both cable and overhead lines. These networks often have complex structures with long power lines. Capacitive current of such networks is significant. For its compensation, neutral grounding through a Petersen coil is usually applied.

Choice of neutral grounding method is a topical issue for distribution networks. It influence power supply reliability and safety, but often results in power quality degradation. Measures on power quality improvement based on optimization of neutral grounding method are reviewed in the paper according to the results of experimental and computational investigations.

II. Experimental Investigations in the 10 kV Network with Phase Voltages Recording

In July – October, 2013, experimental investigations were carried out with phase voltages recording in 10 kV network of 110/10 kV Mayminskaya substation. Currently, 10 kV neutral point of the network is grounded through a Petersen coil RZDPOMA-480/10 with 12.6–63 A rated current. During experiments, a power resistor RZ-1000-34-10 with 1000 Ohm rated resistance was installed to the neutral point in parallel with the Petersen Coil. Measured total capacitive current of the network is 24 A.

D. V. Kochura is with International Relations and Engineering Dept, BOLID LLC, Novosibirsk, Russia (e-mail: nio_bolid@ngs.ru).

I. Yu. Tsivilyov is with Research and Development Dept, BOLID LLC, Novosibirsk, Russia (e-mail: nio_bolid@ngs.ru).

L .I. Sarin is Director of BOLID LLC, Novosibirsk, Russia (e-mail: pnp_bolid@ngs.ru).

Oscillograms were recorded under the following conditions (see Fig. 1):

– ungrounded neutral (a);
– neutral grounding through the Petersen coil (b);
– neutral grounding through the Petersen coil and the power resistor, connected in parallel (c).

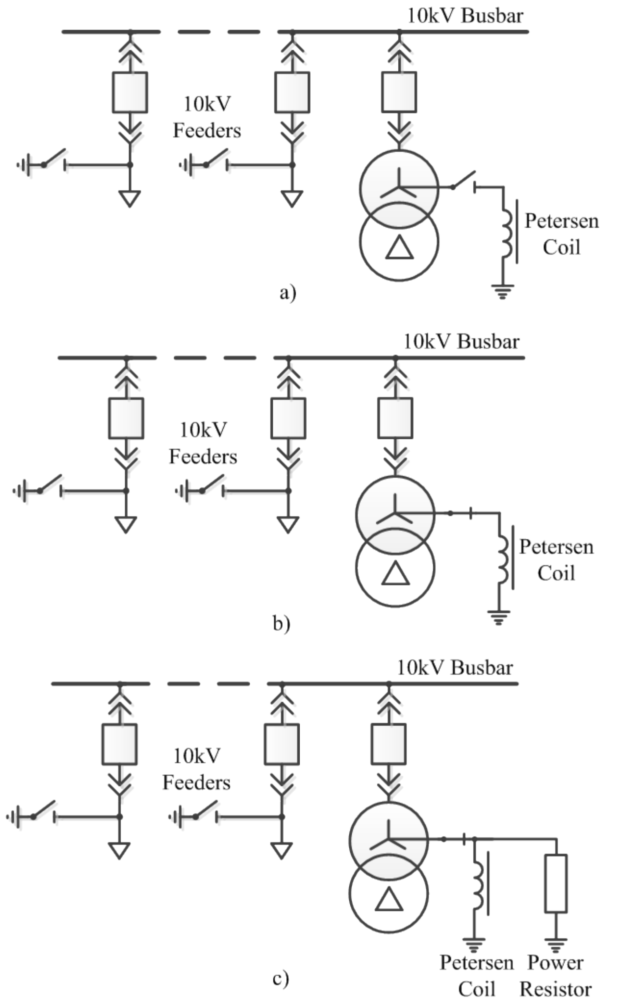

Fig. 1. Configuration of the network during experiments.

Each experiment was performed several times with different tuning of capacitive current compensation: under compensation – the Petersen coil inductance is less than the network capacitance; full compensation – the inductance equals the capacitance; over compensation – the inductance is more than the capacitance.

To define actual detuning of capacitive current compensation, additional experiments of solid single phase-to-ground

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fault were performed (as even full compensation does not mean 0% detuning). Compensation detuning ϑ was calculated in accordance with measured values of capacitive current of the network and residual current of single phase-to-ground fault:

$$\vartheta = \frac{I_{res}}{I_C} \cdot 100\% \quad (1)$$

where

I_{res} – root mean square (RMS) residual current of single phase-to-ground fault (50 Hz reactive component);

I_C – RMS capacitive current of the network (50 Hz component).

During experiments with full capacitive current compensation, actual detuning equaled 2%, with over compensation – 8%, with under compensation – 13%.

Representative oscillogram recorded during experimental investigations is shown in Fig. 2.

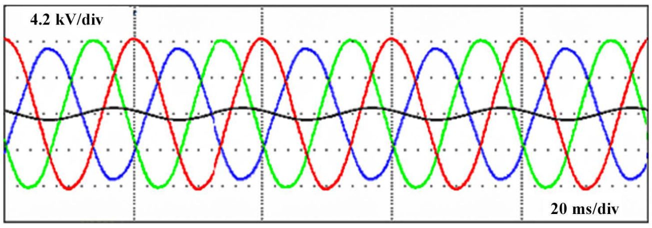

Fig. 2. Representative oscillogram recorded in the 10 kV network with neutral grounding through the Petersen coil. *Blue – phase A voltage; green – phase B voltage; red – phase C voltage; black – neutral voltage.*

During experiments, it was pointed out that significant voltage unbalance occurs in the network with neutral grounding through the Petersen coil (as shown in Fig. 2). This power quality factor is standardized by Russian National Standard GOST R 54149–2010 *Norms of Power Quality in General Purpose Power Supply Systems* (hereinafter referred to as GOST). This factor is evaluated below in accordance with GOST.

A. Evaluation of Voltage Unbalance in the Network With Different Types of Neutral Grounding

In the field of voltage unbalance GOST standardizes negative-sequence voltage unbalance ratio K_{2U} and zero-sequence voltage unbalance ratio K_{0U}. Processing of experimental oscillograms was performed based on symmetrical components method recommended by GOST. Positive- (PS), negative- (NS) and zero-sequence (ZS) voltages were obtained using Yokogawa XViewer software:

$$\underline{U}_1 = \frac{\underline{U}_A + e^{i120^\circ} \cdot \underline{U}_B + e^{-i120^\circ} \cdot \underline{U}_C}{3}, \quad (2)$$

$$\underline{U}_2 = \frac{\underline{U}_A + e^{-i120^\circ} \cdot \underline{U}_B + e^{i120^\circ} \cdot \underline{U}_C}{3}, \quad (3)$$

$$\underline{U}_0 = \frac{\underline{U}_A + \underline{U}_B + \underline{U}_C}{3} \quad (4)$$

where U_A, U_B, U_C – recorded phase voltages.

RMS positive, negative and zero sequence voltage values and ratios are presented in Table I. NS and ZS voltage unbalance ratios are calculated as follows:

$$K_{2U,\,0U} = \frac{U_{2,\,0}}{U_1} \cdot 100 \quad (5)$$

where U_1, U_2, U_0 – RMS PS, NS and ZS voltages, respectively.

According to GOST, NS and ZS voltage unbalance ratio should not exceed 2% continuously in the point of power transmission [1]. Highlighted operating conditions indicate ZS voltage unbalance ratios which exceed permissible value (see Table I). The Table shows that in the network with neutral grounding through the Petersen coil ZS voltage unbalance ratio exceeds 2% value, continuously permissible according to GOST.

High level of voltage unbalance causes additional power losses in the network [2]; decrease of transfer capacity of some power lines; reduction of lifetime of power equipment insulation. Voltage unbalance also results in increased heating of electrical machines windings. Due to that their load should be declined.

Changing the type of neutral grounding to grounding through the power resistor and the Petersen coil, connected in parallel, allows decreasing ZS voltage unbalance ratio to 1.1–1.3%. Thus, connection of additional resistance to the neutral point significantly improves power quality in the field of ZS voltage unbalance.

TABLE I. CALCULATED VOLTAGE PARAMETERS FOR EXPERIMENTAL OSCILLOGRAMS

Capacitive current compensation	Neutral point configuration	U_1 (V)	U_2 (V)	U_0 (V)	K_{2U} (%)	K_{0U} (%)
–	Ungrounded	5970	20	10	0.3	0.2
Full compensation	**Petersen coil**	**5970**	**30**	**500**	**0.5**	**8.4**
	Petersen coil and power resistor	5970	30	70	0.5	1.2
Under compensation	**Petersen coil**	**5960**	**30**	**180**	**0.5**	**3.0**
	Petersen coil and power resistor	5970	30	70	0.5	1.2
Over compensation	**Petersen coil**	**5960**	**30**	**190**	**0.5**	**3.2**
	Petersen coil and power resistor	5970	30	70	0.5	1.2

III. COMPUTATIONAL INVESTIGATIONS ON DETERMINATION OF PROPER POWER QUALITY AREA IN THE FIELD OF VOLTAGE UNBALANCE

Following the above represented experimental investigations, computations were performed to determine the area of proper power quality in the field of ZS voltage unbalance. It depends on overhead lines capacitive current and cable lines capacitive current ratio, and on type of neutral grounding.

During computational investigations, ZS voltage unbalance was considered as follows:

$$\underline{U}_0 = U_{ph} \frac{\underline{Y}_A + a^2 \underline{Y}_B + a \underline{Y}_C}{\underline{Y}_A + \underline{Y}_B + \underline{Y}_C + \underline{Y}_N} \quad (6)$$

where

U_{ph} – phase voltage;

$\underline{Y}_N = \frac{1}{R} + \left| (\vartheta - 1) \cdot \omega \cdot \sum C_{ph} \right| \frac{Q_{coil}}{1 + iQ_{coil}}$ – neutral conductivity, defined by resistance of power resistor R, compensation

detuning ϑ, Petersen coil quality factor Q_{coil}, overall capacitance of cable and overhead lines ΣC_{ph};
$\underline{Y}_{A,B,C}$ – phase conductivities.

Conductivity of each phase consists of capacitive and resistive components for cable lines (CL) and overhead lines (OL):

$$\underline{Y}_{ph} = \underline{Y}_{ROL\,ph} + \underline{Y}_{COL\,ph} + \underline{Y}_{RCL\,ph} + \underline{Y}_{CCL\,ph} \quad (7)$$

where

$\underline{Y}_{R\,ph} = \frac{\omega C_{ph}}{d}$ – resistive component defined by damping ratio d and phase capacitance C_{ph},

$\underline{Y}_{C\,ph} = i\omega C_{ph}$ – capacitive component.

Computational algorithm is implemented in MATLAB software and consists of the following steps:

1. Network parameters are assigned: rated phase voltage, power resistor resistance, Petersen coil quality factor, capacitive current compensation detuning, damping ratios for cable and overhead lines, specific phase capacitances for cable and overhead lines.
2. Initial value of cable line capacitive currents is assigned. Then, this value is varied by half-interval method with recalculation of required parameters. Value of overhead lines capacitive current is calculated iteratively to comply with ZS voltage unbalance ratio $K_{0U} = 2\%$.
3. Step 2 is repeated again to define next point. When enough points are calculated curve is drawn.

Computation results for a 10 kV network with total capacitive current value from 0 to 60 A are shown in Fig. 3. Curves are presented for different types of neutral grounding:

1 – through a 1000 Ohm power resistor and a Petersen coil with full (0% detuning) compensation (a), with 5% compensation detuning (b), with 10% compensation detuning (c);

2 – through a 500 Ohm power resistor and a Petersen coil with full (0% detuning) compensation (a), with 5% compensation detuning (b), with 10% compensation detuning (c);

3 – through a Petersen coil without power resistor with full (0% detuning) compensation (a), with 5% compensation detuning (b), with 10% compensation detuning (c).

Below each curve, ZS voltage unbalance ratio is less than 2%, above – more than 2% for respective neutral grounding type. Thus, the area below the curve is the area of proper power quality in the field of ZS voltage unbalance, the area above the curve – improper power quality area.

In accordance with the presented curves any network can be reviewed (value of cable lines and overhead lines capacitive current should be previously measured or calculated). For example, the point of Mayminskaya substation 10 kV network is shown in Fig. 3. Here, overhead lines capacitive current is 2.5 A, cable lines capacitive current is 21.5 A.

The point of Mayminskaya substation 10 kV network is located above the curves 3a, 3b, 3c (Petersen coil neutral grounding), so such type of neutral grounding causes improper power quality. The point is located below the other

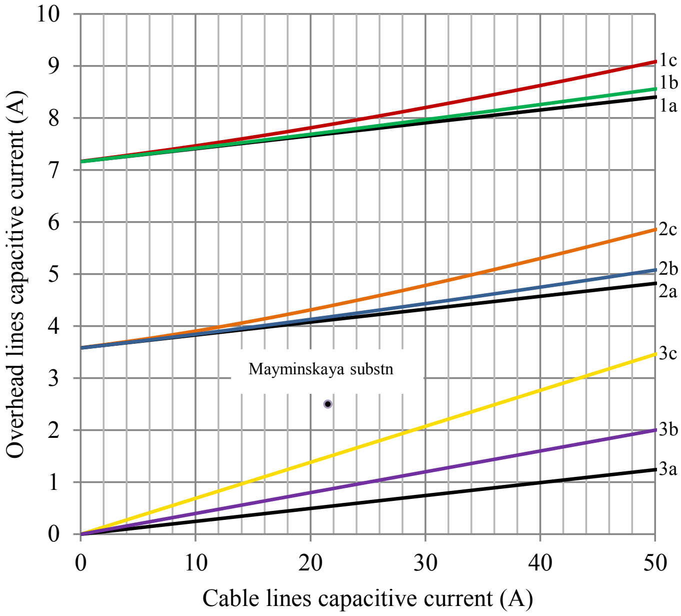

Fig. 3. Areas of proper power quality in the field of ZS voltage unbalance for 10 kV network with total capacitive current value from 0 to 60 A.

curves (neutral grounding through a power resistor and Petersen coil in parallel). It means that proper power quality in the field of ZS voltage unbalance is provided.

Computation results allow making the following general conclusions:

– Compensation detuning results in increasing of the curve inclination angle (e.g. inclination angle of the curve 2c is greater than the curve 2a), so the below-curve area increases. However, it could be noted, that compensation detuning should not be taken into consideration as a method of voltage unbalance decreasing, as operation of the network with over 5% compensation detuning is not allowed [3].
– Connection of a power resistor to the neutral point significantly moves the curve up (e.g. the curve 2a is located above the curve 3a), so the below-curve area increases. Thus, proper power quality in the field of ZS voltage unbalance will be provided for a significantly wider range of capacitive current.

IV. Conclusions

1. According to the results of experimental investigations, operation of 10 kV network with Petersen coil grounded neutral may lead to conditions occurring with impermissible power quality in the field of zero-sequence voltage unbalance according to Russian National Standard GOST.
2. During computational investigations, the areas of proper power quality in the field of zero-sequence voltage unbalance were determined. The areas are presented for 10 kV network with total capacitive current value from 0 to 60 A, and with different types of neutral grounding.
3. Experimental and computational investigations show, that connection of additional resistance into a zero sequence circuit of 10kV network allows significant improving of power quality in the field of zero-sequence voltage unbalance.

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BIOGRAPHIES

Danila Kochura was born in 1990. He received Dipl.-Ing in electrical engineering from Novosibirsk State Technical University in 2013. He is currently working as Engineer of International Relations and Engineering Dept at BOLID LLC, Novosibirsk, Russia, since 2012.

Igor Tsivilyov was born in 1986. He received M.Sc. in electrical engineering from Novosibirsk State Technical University in 2009. He is currently working as Senior Engineer of Research and Development Dept at BOLID LLC, Novosibirsk, Russia, since 2008.

Leonid Sarin was born in 1959. He received Dipl.-Ing in electrical engineering from Novosibirsk State Technical University in 1981. He is currently working as Director at BOLID LLC, Novosibirsk, Russia, since 1998.