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Research Article

Technology For Improving Power Quality and Reducing Its Losses in Existing 0.38 кV Electric Networks

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Abstract

Low-voltage electrical networks operate under conditions of significant currents and voltages unbalanced which leads to a significant distortion of the electrical energy quality standards, as well as to an increase in its additional losses. The distorted power quality is accompanied by a violation of the technical means electromagnetic compatibility, which are both electrical receivers in this network and controlling means its operation modes. An increase in power and electrical energy additional losses is accompanied not only by its overspending and a corresponding increase in the cost of power transmission, but also by significant thermal overload, which leads to fire-hazardous situations accompanied by loss of life and significant material damage. The most effective technical means minimizing these consequences is the use of a special shunt-balancing device (BD), the action of which in automatic mode significantly improves the power quality and reduces additional losses due to unbalanced power consumption. The article presents an analysis of the current 0.38 kV electrical network operating mode and shows the effect of the balancing device use on the power quality and its losses.

Keywords: Currents And Voltages Unbalance; Additional Power Losses; Power Quality Indicators; Balancing Device

Introduction

The basis for the electric receivers normal functioning in any industrial area of human economic activity, as well as in everyday life, is the conditions of these technical means electromagnetic compatibility in a single electromagnetic in the electrical network that feeds these means. The criteria for assessing electromagnetic compatibility are power quality indicators established by state Standards [1-3]. In 0.38 kV (50 Hz) electrical networks (in the United States, these are 0.48 kV – 60 Hz networks), the most frequently the power quality violated indicators are indicators characterizing the three-phase power supply voltage system unbalance. These include the negative and zero sequences voltages unbalanced coefficients, as well as the voltage deviation steady state. All these indicators are due to the current load changes in the phases of the three-phase system, creating a voltages imbalance. In accordance with [1], these indicators are determined by the following expressions:

$$K_{2u} = \frac{U_2}{U_1} \cdot 100\%; \quad K_{0u} = \frac{U_0}{U_1} \cdot 100\%; \tag{1}$$

$$\delta U_{(-)} = \left[\frac{(U_н - U_{m(-)})}{U_0}\right] \cdot 100; \quad \delta U_{(+)} = \left[\frac{(U_{m(+)} - U_н)}{U_н}\right] \cdot 100. \tag{2}$$

In addition, the zero sequence is clearly manifested in a change in the indicator characterizing the non-sinusoidality of the three-phase system. Such a coefficient is the coefficient of harmonic components that are multiples of three. The third harmonic voltage coefficient has strongest effect:

$$K_{(U3)} = \frac{U_{(3)}}{U_{(1)}} \cdot 100\%. \tag{3}$$

Since the current load imbalance creates, in addition to the positive, additional components of the negative and zero sequences currents, accordingly, additional power and electrical energy losses increase, which can be most correctly estimated using the loss increase coefficient [4]:

$$\boldsymbol{K_P} = 1 + K_{2i}^2 + K_{0i}^2 \cdot K_R. \tag{4}$$

The loss coefficient characterizes the excess of power losses in the unbalanced mode over the corresponding losses caused by currents of only a positive sequence (conditionally symmetric mode).

The ***purpose*** of the article is to study the using possibility a special balancing device (BD) that reduces the specified indicators (1) – (4) in the real electrical network when a BD is switched on. To achieve this goal, several ***tasks*** have been set: to carry out measurements in the real 0.38 kV electrical network; to determine the studied indicators; to calculate the BD parameters; to calculate the indicators taking into account the BD influence and to prove its effectiveness.

Methods, Software, and technical means of influence

It should also be noted that operation unbalancing modes lead not only to a significant deterioration in the power quality, but also, due to the neutral conductor overheating, create a risk of fires. According to the design conditions, the choice of the conductor section is carried out according to the operating current and is checked by calculations on the heating so that this current does not exceed the long-permissible value for this section. That is, the cross section is chosen with the assumption that the coefficient $Kp = 1$. At the same time, when choosing a cross-section, zero-sequence flows flowing through a zero conductor in a 0.38 kV network are never taken into account. Thus, firstly, the cross-section of the selected conductor is artificially underestimated, and, secondly, the circuit breaker nominal parameters protecting this line will also be selected incorrectly, since its selection is made according to the operating current. In addition, utility consumers connected to 0.38 kV networks (especially old buildings) that create these flows have internal wiring in which a zero-conductor cross section is often smaller than the phase conductors' cross section. As a result, in an objectively unbalancing mode, three zero-sequence currents flowing through a zero-conductor lead to its overheating and a corresponding violation of insulation. The latter leads to single-phase short circuits. And if the circuit breaker is not adequately selected in the head section, then when a short circuit occurs in a remote part of the network, the protection device often does not work. As a result, fires occur both in rural settlements, cottage buildings, horticultural farms, urban apartments, and in individual agricultural and industrial production premises. The literature analysis on the fire's occurrence in residential and agricultural premises has shown that the main causes of their occurrence are overloads and short circuits [5-6]. At the same time, none of the sources consider the zero-conductor overload due to the phase current unbalance as the cause of these modes. In addition, it should be noted that the measures being developed, methods and technical devices for reducing the currents and voltages unbalance have never been considered as a means of preventing fires. Therefore, proposing to use symmetrical devices not only as a means of improving the quality and reducing electricity losses, but also as a way to stabilize fire-hazardous conditions.

In expressions (1) – (4): K_{2u} and K_{0u} are the negative and zero sequence voltages unbalance coefficients. Their values are set in accordance with [1] within the following limits: 2% - for 95% of the measurement time interval and 4% - for the remaining 5% of this time interval. U_1, U_2 and U_0 are symmetrical voltage components of the positive, negative and zero sequences, respectively, which, in a balancing device absence, are determined by the readings of the measuring device; 〚 and - positive and negative deviation of the power supply voltage set by the Standards at the point of electrical energy transmission to the consumer no more than ± 10%, and in the point of consumer connection to the electrical network - no more than ± 5%; , - the values of the power supply voltage, smaller and larger , respectively, averaged over a time interval of 10 min. in accordance with the requirements of [1]; is a voltage equal to the standard rated voltage or the matched voltage $U_{(1)}$, $U_{(3)}$ – components, respectively, of the first (fundamental frequency – 50 Hz) and third voltages harmonics (150 Hz). These values are also determined by the readings of the device.

$K_{2i} = \frac{I_2}{I_1}$ and $K_{0i} = \frac{I_0}{I_1}$ – the negative and zero sequences currents unbalance coefficients; I_2 and I_0 – the negative and zero sequences symmetrical components of the currents, determined by the readings of the device. K_P – the power loss coefficient, which is the ratio of power losses in an unbalancing mode to the corresponding losses due to the flow of positive sequence currents only (conditionally symmetric mode); $K_R = r_0/r_1$ – the active resistance coefficient of the transmission line; $r_1 = r_{PH}$ – the active resistance of the positive sequence equal to the phase resistance of the power line; $r_0 = r_{PH.}+3r_N$ – the active resistance of the power lines zero sequence; r_N – the active resistance of the neutral conductor. With the same cross sections of the phase and zero conductors, their active resistances will be equal. Accordingly, the coefficient K_R in this case will be equal to 4.

As a means of symmetry, it is proposed to use a device with a minimum zero-sequence resistance, shown in Figure 1. The BD operation principle is based on the electromagnetic induction principle, when, with an increasing current unbalance level and a significant zero-sequence current appearance in the neutral wire, the movable armature (upper magnetic core) is retracted.

This increases the BD power. Due to the changing level of zero sequence flows, BD inductance self-regulation automatically occurs, thereby changing the parameters of the device, which are determined by the following expressions:

$$\boldsymbol{Y_{BD1}} = \boldsymbol{Y_{BD2}} = \frac{1}{\left(2*\frac{U_1}{I_1}\right)*7.0714}; \ \boldsymbol{Y_{BD0}} = 2*\left(\frac{3*I_0}{U_0}\right). \tag{6}$$

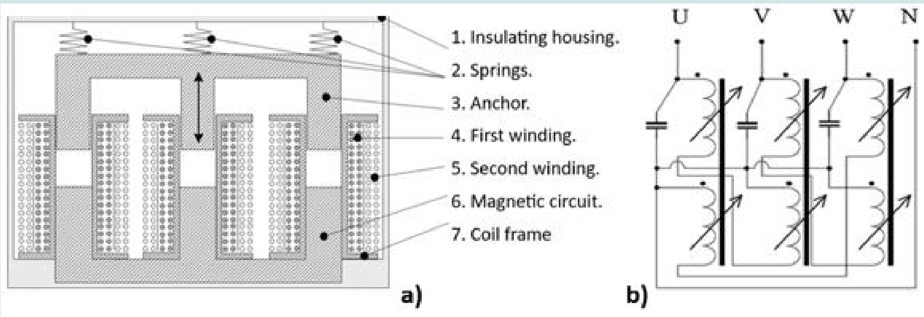

Figure 1: Electromagnetic balancing device: a) – design, b) – electrical circuit

where: , – the complex conductivities of the BD positive (negative) and zero sequence. The principle of BD operation is described in more detail in [7-9].

The studied indicators (1)–(4) when BD is switching in the electrical network are determined by the expressions [7]:

$$K_{2UX(BD)} = \frac{U_{2x}}{U_{1x}} = \frac{Y_K^2 \cdot Y_{31} \cdot Y_{x1} \cdot Y_T}{Y_{x2} \cdot Y_R^4}$$

$$K_{0UX(BD)} = \frac{U_{0x}}{U_{1x}} = \frac{Y_L^2 \cdot Y_{31} \cdot Y_{x1} \cdot Y_U}{Y_{x0} \cdot Y_R^4}$$

$$K_{2i\pi(BD)} = \frac{I_{\pi 2}}{I_{\pi 1}} = \frac{Y_K^2 \cdot Y_{31} \cdot Y_2}{Y_Q^4}$$

$$K_{0i\pi(BD)} = \frac{I_{\pi 0}}{I_{\pi 1}} = \frac{Y_L^2 \cdot Y_{31} \cdot Y_0}{Y_Q^4}$$

$$\delta U_{BD} = \delta U \cdot K_{UNB.}; \quad K_{UNB.} = K_{0UX(BD)}/K_{0UX}; \; K_{(U3)(BD)} = K_{(U3)} \cdot K_{UNB.}; \quad K_{P(BD)} =$$

$$1 + K_{2i\pi(BD)}^2 + K_{0i\pi(BD)}^2 \cdot K_R \cdot$$

In expressions (7), the index “x” means the distance at which the point of the electrical network is located, in which a balancing device can be installed, and the corresponding studied indicators are determined.

This, it is possible to install the BD in the electrical network at any distance from the power source 0.4 kV busbars. Numerous studies have established that the most appropriate place to install the BD in an electrical network with an unbalancing load distributed along the power line is the power take-off node closest to the power supply buses [9-13]. The tool for calculating asymmetric modes are software complexes developed by Prof. Naumov I.V. and presented in the [14-16].

Research Results

The practical implementation of the provisions discussed above was carried out on the studies basis carried out in the existing 0.38 kV electrical networks. Measurements of electrical energy parameters were carried out in rural areas on an outgoing power transmission line with a 0.38 kV voltage. The 420 m long line departs from the 0.4 kV tires of 10/0.4 kV power transformer with a 250 kVA capacity. The electric energy consumers connected to this line are rural single-and two-family houses. Research dates: from 2022, 11 to June 19[1]. The Resource-UF2M instrument[2] certified was used as a measuring instrument. The studies duration was 713 ten-minute intervals, in each of which the device averaged the value of the studied parameter. The entire period of continuous measurements was 7120 min.

Figure 2 show time diagrams of phase current and voltage in the studied electrical network for the measurement period. As can be seen from the figure, the current and voltage unbalance level is quite pronounced. The most loaded is “C” phase (24.06 A)[3]. The current value in the remaining phases is less: in phase “A” by 16.2%, in phase “B” - by 12%. In phase “C”, the average voltage value is 237.07 V. The voltages percentage difference in other phases are in phase “B” - by 6.2%, in phase “A” - by 2.8% less than in phase “C. Such the currents and voltages imbalance level leads to a significant change in the studied indicators (1) – (4). Figures 3-5 show changes time diagrams in the studied indicators. At the same time, each diagram shows the change in the indicator when the BD absence in the electrical network and with its possible connection at the point corresponding to the load node closest to the power supply buses. In practice, this corresponds to the input and distribution device of the first residential building located at a 48 m distance from the 0.4 kV busbars of the power transformer.

1. Protocol No. 28 at June 22, 2022
2. The Resource UF2M device, factory number 3180. Certificate of verification No. 20-0506. Date of the next verification: August 31, 2022.
3. Here and further, the average indicators values for the measurement period in 713 ten-minute intervals are taken.

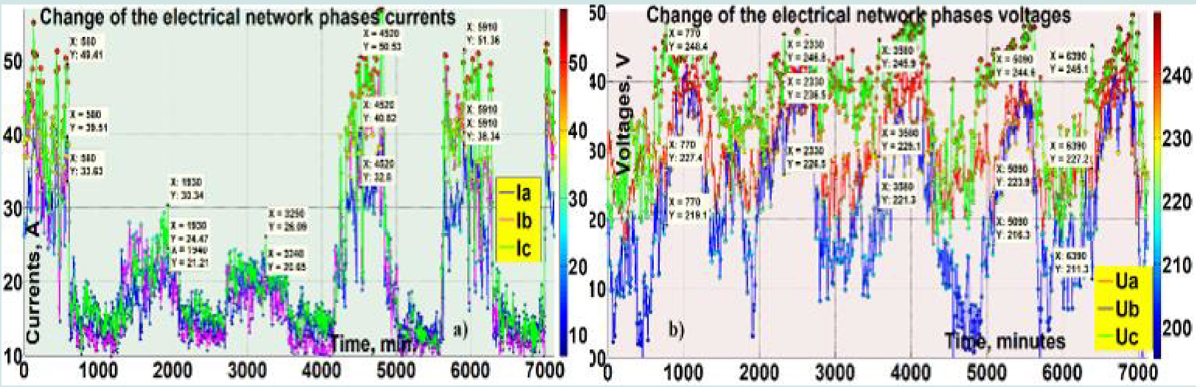

Figure 2: Change time diagrams of the electrical network currents and voltages.

Figure 3 shows graphs of changes in the zero-sequence voltage unbalance coefficient and the voltage deviation. The presented diagrams analysis in Fig. 3 shows that the average indicators value for the measurement period was: for the ***K0u*** coefficient – 2.81%, for *δU* – 4.53%. At the same time, as can be seen from the diagrams, ***K0u*** significantly exceeds the value set by the Standard (no more than 2% in 95% of the measurement interval time). The BD inclusion leads to a significant decrease in both indicators: for ***K0u*** – by 88%, for *δU* – by 86%. A similar situation develops with the *Kp* coefficients and $K_{(U3)}$ (Figure 4). When the BD absence, their average values are, respectively: 1.51 and 1.68%. And if the third voltage harmonic coefficient is within the limits established by the Standard, then the loss coefficient value indicates that, on average, additional power losses and electricity are 51% higher than losses caused only by positive sequence currents.

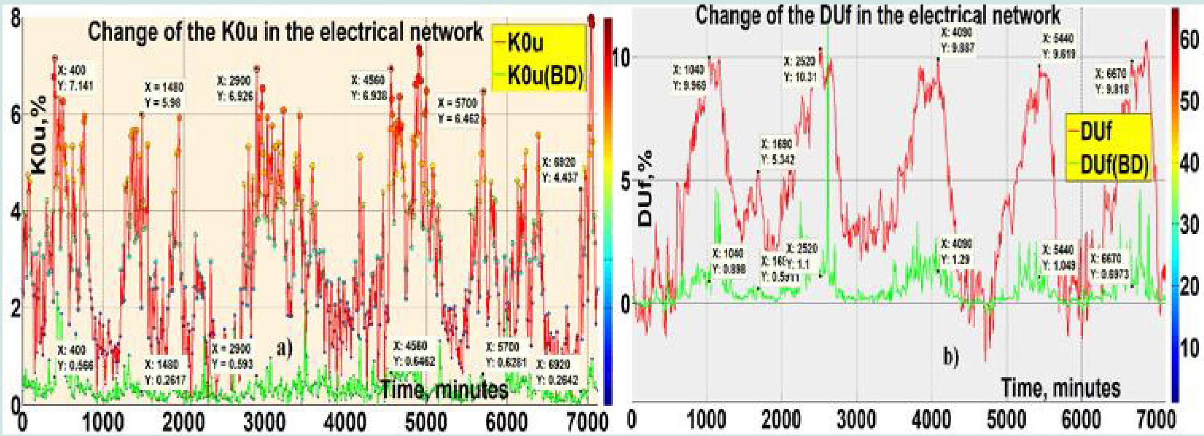

Figure 3: Change time diagrams in the electrical network: a) K0u; b) δU.

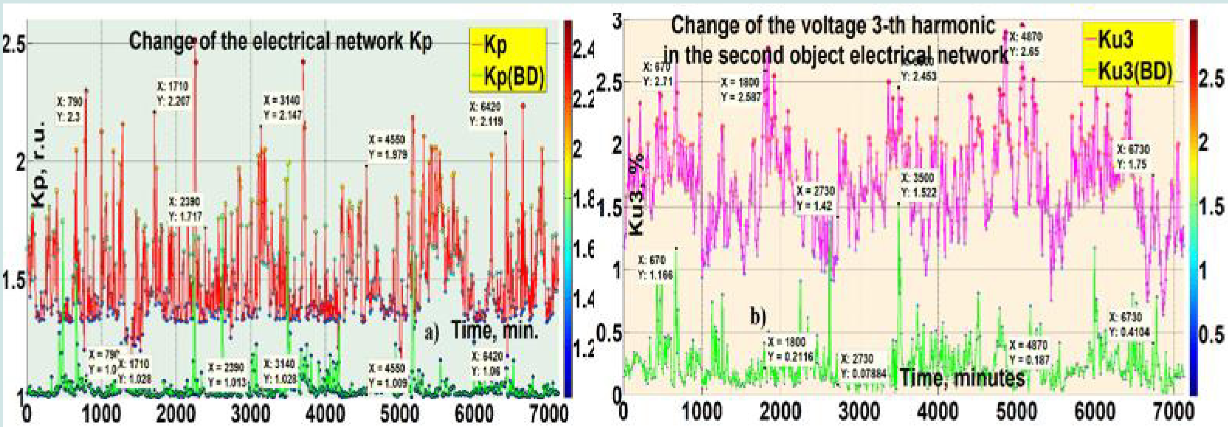

Figure 4: Change time diagrams in the electrical network coefficients: a) – Kp; b) – K(U3).

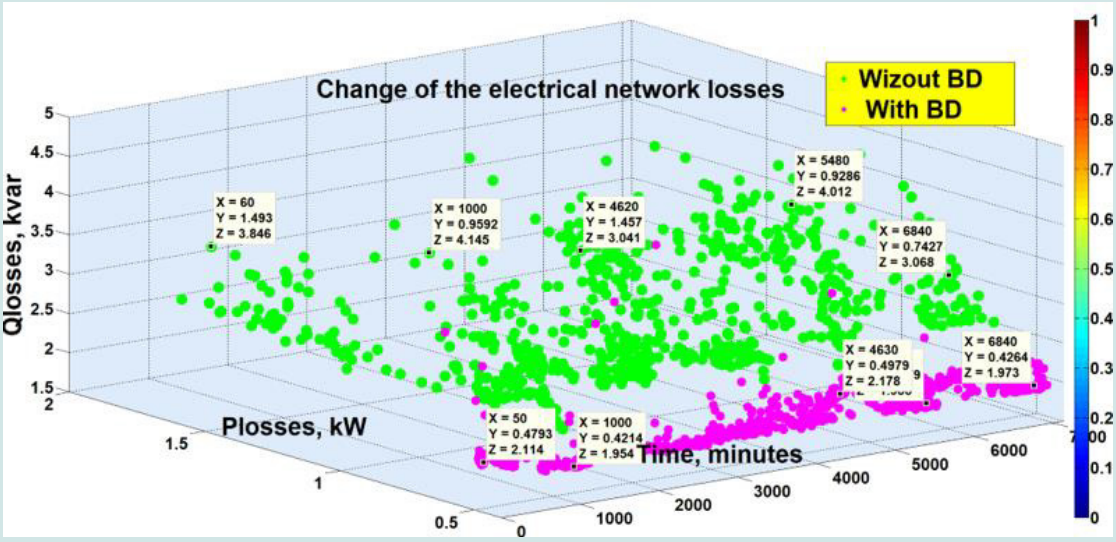

Figure 5: Change time diagrams in the total active and reactive capacities in the studied electrical network.

When BD switching in the electrical network, these coefficients reduction was for ***Kp*** – 31.2%, for $K_{(U3)}$ – 86.3%.

Let us see how BD switch on affected on the electrical energy actual loss in the studied electrical network. Figure 5 show time diagrams of changes in the total active and reactive powers (in a power transformer and power transmission line).

The Figure 5 diagrams analysis showed that when the BD was switched on, the total losses changed as follows: active power – from 0.9 kW to 0.46 kW (49% decrease), reactive power – from 3.04 kvar to 2.08 kvar (31.6% decrease). The reduction in full power total losses is 33% (from 3.17 kVA to 2.13 kVA). It should be borne in mind that, as mentioned above, these values represent the indicator average value for the entire measurement period, averaged over a ten-minute period. Thus, it can be seen that the real electrical energy losses caused by unbalanced power consumption are quite large and the balancing device inclusion allows them to be reduced very effectively.

Conclusion

Based on the studies carried out, the following conclusions can be drawn:

a) The currents and voltages unbalance in low-voltage electrical networks is an objective factor, as a result of which, to a large extent, there is a deterioration in power quality and an increase its additional losses. The most effective means of minimizing the unbalanced modes consequences is the use of special balancing devices with minimal zero-sequence currents resistance.

b) The article proposes a new shunt-symmetrical device with self-regulating inductance, the parameters of which automatically adjust to the current unbalance changing level.

c) Switch on BD in the studied operated electrical network makes it possible to reduce the voltage zero sequence unbalance coefficient by 88%, the voltage deviation steady–state and the third voltage harmonic coefficient by 86%. At the same time, the total reduction of additional power losses for this electric network can be up to 30%.

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