OPTIMIZATION OF COEFFICIENTS SPECIFIED WITH NON-SINUSOIDAL AND NON-SYMMETRY FEEDING VOLTAGE IN ELECTRICAL SUPPLY SYSTEMS IN INDIVIDUAL RESIDENTIAL SECTOR

M A Averbukh and E V Zhilin
Department of Power Engineering and Automation, Belgorod State Technological University of V.G. Shukhov, Belgorod, 308012, RU

Abstract. In this paper, we consider coefficients that characterize nonsinusoidality and asymmetry. It is revealed that due to the presence of single-phase electric receivers with nonlinear volt-ampere characteristic in the power supply systems of Individual residential sector, their values exceed the maximum permissible values, this leads to the emergence of additional energy losses that amount to 14% of the total power consumption. Therefore, the goal of the work is to optimize the coefficients, according to the criterion of minimum energy losses with a minimum of costs for the installation of technical equipment.

The main consumers of the electricity supply system individual residential sector (IRS) are single-phase household electrical receivers. They have a nonlinear current-voltage characteristic, since they contain semiconductor elements in their structure. This leads to the appearance of higher harmonics of current and voltage in the system of electricity supply of individual residential sector S. In addition, the uneven distribution of single-phase electric receivers in a three-phase four-wire network causes the appearance of an unbalance current in the zero conductor. The presence of higher harmonics and asymmetric connection of electric receivers leads to a decrease in the quality of electricity (QE) in the electricity supply system individual residential sector [1].

To the indicators characterizing the non-sinusoidal operating mode in the systems of power supply individual residential sector you can include the total coefficient of harmonic components of voltage and current [2]:

\[ \frac{1}{100} \sum_{n=1}^{N} U_{n}^2; \]

\[ K_v = \frac{1}{100} \sum_{n=1}^{N} I_{n}^2; \]

individual residential sector Here \( n \) is the ordinal number of the harmonic component; \( U_{n} \) is the actual value of the \( n^{th} \) harmonic component.

Thus, in order to estimate the coefficients that determine the non-sinusoidality of periodic curves, it is necessary to know the spectral composition of non-sinusoidal currents and voltages.

Another characteristic of non-sinusoidality is the coefficient of the \( n^{th} \) harmonic component of voltage and current:

\[ K_{U(n)} = \frac{U_{(n)}}{U_{1}} \times 100; \]

\[ K_{I(n)} = \frac{I_{(n)}}{I_{1}} \times 100. \]

The asymmetric mode of operation characterizes the unbalance coefficient of the voltage in the reverse and zero sequence:
The values of the unbalance coefficients of the stresses in the negative sequence K2U and the unbalance of the voltages along the zero sequence K0U at the point of transmission of electrical energy averaged over a time interval of 10 minutes should not exceed 2% in the course of 95% of the time and 4% of the time interval in one week.

The high level of non-sinusoidal and non-symmetric coefficients in the power supply systems of the private housing construction leads to the appearance of additional energy losses, which can reach 14% of the total consumed electricity [3].

To reduce the coefficients, and as a result of additional losses of electricity, there are many different methods and technical devices [4]. However, this will require additional financial investments. As a result, there are two interrelated components of costs: the cost of installing technical devices to reduce the coefficients and costs from poor quality of electricity.

Applying various methods that reduce the coefficients of nonsense and non-symmetry in the electricity system of IRS is very difficult, and sometimes impossible, and the use of various technical devices does not always pay off even for the entire period of operation.

Therefore, the main purpose of optimizing the coefficients characterizing the non-sinusoidality and asymmetry is the choice of technical means to compensate for excess reactive power, distortion current, and unbalance current from an asymmetric load. The optimization problem is solved by minimizing the energy losses caused by the presence of higher harmonics and unbalanced currents.

Setting optimization task is to determine the object, parameters and optimization criteria, as well as restrictions for the objective function.

The choice of the optimal type, capacity and location of technical means to reduce power losses in the system of power supply individual residential sector is performed taking into account two criteria: a minimum of the resulted costs and a minimum of losses of active capacity. The objective function for the first criterion Z(Ε) contains two terms: the cost of electricity losses in the electricity supply system of the housing construction company, the cost of installing technical equipment.

\[
Z(ΔΕ) = c_1 \cdot ΔΕ + K_{m} \cdot K(Ε) \rightarrow \min,
\]

where, \( c_1 \) - cost of losses of 1 kW • h of electricity; \( ΔΕ \) - electric power losses for a specified period; \( K \) - normative factor of recoupment of investments; \( Z(Ε) \) - capital costs for the installation of technical equipment.

The target function is subject to the restriction area, which is conditioned by the technical requirements for the individual residential sector power supply system.

\[
\left[ \begin{array}{l}
U_i(Y_{pu}) \leq U_{(1)EX} ; \\
K_1(Y_{pu}) \leq K_{1EX} ; \\
K_2(Y_{pu}) \leq K_{2EX} ; \\
K_{w1}(Y_{pu}) \leq K_{w1EX} ; \\
K_{w2}(Y_{pu}) \leq K_{w2EX} ; \\
\cos \phi_{a,b,c}(Y_{pu}) \leq \cos \phi_{a,b,c,nor},
\end{array} \right.
\]

Where \( Y_{pu} \) is the vector of the conductive column of the PU, Sm; \( U_{(1)EX} \) - current (allowable) direct sequence voltage in the network node, V; \( \cos \phi_{a,b,c,nor} \) - current (normative) value of the power factor; \( K_{z2} \) - current (permissible) value of the voltage unbalance factor in the reverse order,%; \( K_{z1} \) - current (permissible) zero-sequence voltage unbalance coefficient,%; \( K_{w1} \) - current (permissible) value of the total coefficient of harmonic components by voltage,%; \( K_{w2} \) - current (permissible) value of the total coefficient of harmonic current components,%;

The system of power supply IRS is described by the method of nodal potentials. The initial data are technical and economic indicators, as well as the cost of electricity, unit costs per unit of technical means, network parameters, load range[5].

\[
\dot{I} = \sum_{i=1}^{n} \left( S^i ((S^i)^{-1}) \cdot S(J - \sum E) + \dot{E} \right) - \dot{J}.
\]
where $E$ is the column vector of complex branch electromotive force (non-zero values for the branches of the transformer), $B$; $J$ is a column-vector of complex node currents (non-zero), $A$; $Y$ is the diagonal matrix of complex conductivities of branches, $C_m$; $I$ is the column vector of complex branch currents, $A$; $S$ is the coupling matrix.

The result of the calculations is the optimal vector of imaginary components of the conductance of branches with a minimum level of higher harmonics and asymmetry, on the basis of which the numbers of branches containing technical devices for compensation of nonlinearity and asymmetry are determined. Terms of realizability of technical means are determined by the accuracy of compensation, speed, operational reliability, unit costs for installation and operation. Therefore, it is necessary to analyze all methods of compensation for higher harmonics and asymmetrical currents in the system of electricity supply of IRS, taking into account its features.

For example, consider a fragment of the power supply system IRS, shown in Fig. 1. For the nodes of the power supply system, it is required to determine the value of the third harmonic compensation current, based on the condition of minimum total costs for installing these devices and covering the losses of active power.

The initial data is the mains voltage ($U_{nom}=0.4$ kV), the resistance of the line ($R_1=0.4$, $R_2=0.5$), the third harmonic current at the nodes ($I_{h_1}=3.12$, $I_{h_2}=3.62$ ), unit costs for the installation of technical devices ($Z=0.5$ y.e./A), unit costs for covering the losses of active power ($C_p=10$ y.e. /kW).

![Figure 1. Fragment of the electricity supply system IRS](image)

The objective function is the total cost of installing technical devices and covering the losses of active power in the power supply system IRS:

$$Z = Z_0 - (I_{1} + I_{2})^2 + a_1 \cdot (I_{h_1} + I_{h_2}) - I_{e_1} - I_{e_2})^2 + a_2 \cdot (I_{h_2} - I_{e_2})^2 \to \min ,$$

where $a_1 = R_1 \cdot C_p \cdot 10^{-5}$; $a_2 = R_2 \cdot C_p \cdot 10^{-5}$, $I_{e_1} \cdot I_{e_2}$ – compensation current.

Introduction of a numerical coefficient $10^{-5}$ It is necessary to reduce all components of the objective function to one dimension (standard units).

To solve the problem, we choose the coordinate-wise "descent" method. For this, it is necessary to determine the partial derivatives of the objective function with respect to the variables $I_{e_1}$ and $I_{e_2}$.

$$\frac{\partial Z}{\partial I_{e_1}} = Z_0 - 2 \cdot a_1 \cdot (I_{h_1} + I_{h_2} - I_{e_1} - I_{e_2});$$

$$\frac{\partial Z}{\partial I_{e_2}} = Z_0 - 2 \cdot a_2 \cdot (I_{h_1} + I_{h_2} - I_{e_2}) - 2a_2 \cdot (I_{h_2} - I_{e_2}).$$

We take the initial approximation $I_{e_1} = 0$, $I_{e_2} = 0$. For these values, we calculate the values of the objective function and its partial derivatives: $Z_0 = 22,8$ standart units, $\frac{\partial Z}{\partial I_{e_1}} = 0.45$, $\frac{\partial Z}{\partial I_{e_2}} = 0.41$.

Obviously, in the direction of the variable $I_{e_1}$ the target function $Z$ is stronger than in the direction $I_{e_2}$, since the derivative $\left| \frac{\partial Z}{\partial I_{e_1}} \right| > \left| \frac{\partial Z}{\partial I_{e_2}} \right|$.

Therefore, in the direction $I_{e_1}$ we begin the "descent". We take the step size $\lambda = 4$ A, then the first approximation will be $I_{e_1} = 0$, $I_{e_2} = 4$, and the value of the objective function will be $Z' = 22,725$ cu. The second step is $I_{e_1} = 0$, $I_{e_2} = 8$, the value of the objective function $Z'' = 22.81$ standart units.

From the results of the calculations of the objective function, it is clear that the "descent" along the coordinate $I_{e_1}$ is worthwhile to cease, because $Z'' > Z'$, and return to the values of the variables obtained in the first step. Performing a new second step in the direction of the first variable $I_{e_1} = 4$, $I_{e_2} = 4$, the value of the objective function $Z_3 = 22.79$ cu. Movement in the direction of the first variable is inadvisable because $Z'' > Z_3$.

The point with the coordinates $I_{e_1} = 0$, $I_{e_2} = 4$ is in the vicinity of the minimum of the objective function $Z$, with the adopted step length $\lambda = 4$ A, a more accurate solution can not be obtained without the use of computational programs. Thus, for the most effective reduction of the coefficients, it is necessary to in-
stall a filter compensating device in the second node with a compensation current of the third harmonic of 4 A.

In conclusion it should be said that the analysis of the power supply system IRS showed the presence of higher harmonics and currents of asymmetry, which lead to additional losses and an increase in the coefficients characterizing non-sinusoidality and asymmetry.

The choice of technical devices to reduce the coefficients characterizing non-sinusoidality and asymmetry must be performed simultaneously by several parameters, by solving a nonlinear optimization problem.

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