Improvement of energy-saving technologies in units of irradiation and lighting of plants in greenhouse complexes

I N Vorotnikov<sup>1</sup>, A A Shunina<sup>1</sup>, A V Permyakov<sup>2</sup>, I V Danchenko<sup>3</sup> and G V Masyutina<sup>3</sup>

<sup>1</sup>Stavropol State Agrarian University, 12 Zootechnicheskiy Ln. Stavropol, Russian Federation
<sup>2</sup>Yaroslav-the-Wise Novgorod State University, 41, ul. B. St. Petersburgskaya, Veliky Novgorod, Russian Federation
<sup>3</sup>North-Caucasus Federal University, 56 ave. 40 let Oktyabrya, Pyatigorsk, Russian Federation

E-mail: Aa_shu@mail.ru

Abstract. Today energy industry is a fundamental sector of the world economy as it is an energy component that industrialization and digitalization processes of modern society depends on. Economical activities require the following energy properties: reliability, efficiency, non-stop consumer supply. Each year, to implement these requirements becomes more difficult, since dramatic transition from the available energy supply systems to different and innovative ones is taking place in the energy supply sector. In addition, the problem of improving energy-saving technologies becomes the priority in the agro-industrial complex (APK). This article considers the issue of improving energy-saving technologies in irradiation units of greenhouse complexes due to the optimization of reactive power compensation modes using predictive algorithms for controlling devices of compensation of reactive power under non-stationary modes of non-linear loadings. A compensator control algorithm is proposed based on the correlation analysis of energy processes.

1. Introduction

Energy saving in technological processes of the agro-industrial complex is an integral part of market economy development since in modern society we observe total interest of suppliers and consumers in economical energy supply.

Today, the importance and relevance of rational energy consumption is recognized by everybody since the potential for energy conservation is high. Federal Law of 23.11.2009 N 261-FZ “On energy saving and increasing energy efficiency and on amendments to certain legislative acts of the Russian Federation” provides for many mandatory standards and procedures for all participants in the process of energy generation, distribution, and consumption. In addition, the quality of electrical power is regulated by GOST (State Standard) 32144-2013 “Electrical energy. Electromagnetic compatibility of technical equipment. Quality standards for electrical energy in general power supply systems” [1].
2. Research objects and methods

Currently, the concept of electromagnetic compatibility in matters of ensuring electrical energy quality involves practically any kind of interaction between different devices and systems which use electromagnetic phenomena as well as the interaction of these systems with living organisms [2].

The presence of higher harmonic components, non-linear, rapidly changing, and non-stationary loads in the systems of energy supply (for example, a frequency-controlled electrodrive, luminiscent lighting and irradiating equipment, pulse converters, and others) involves various kinds of electricity sources and consumers in the problem of electromagnetic compatibility [3].

So, it becomes necessary to analyze how energy losses impact on energy efficiency in general, and to assess additional losses arising because of a dramatic deterioration in energy power quality parameters. This is caused by the modern need to obtain more accurate information about the condition of electric network modes in order to determine the level of losses and decrease the commercial component of losses.

In the current situation, energetic systems require more accurate prediction of loading on distributing networks in order to achieve ideal performance, planning networks development and optimizing energetic resources control, but the process of quality compensation still remains rather difficult due to the increase in distortions in low voltage distributing networks.

Success in this field largely depends on a correct understanding and calculation of reactive power which is significantly different for cases of sinusoidal modes and non-sinusoidal modes which additionally have non-stationarity. In the case of non-stationary load the values of currents and voltages are random variables changing from one observation interval to another. The neglect of this feature leads to an increase in the additional error in evaluating the active power of the load, and, consequently, to an increase in energy losses [4, 5].

The authors propose a modified (predictive) algorithm for reactive power compensator control under non-stationary modes of non-linear loads using the example of a greenhouse complex of Stavropol GAU (State Agrarian University), which is the development of the approaches presented in [6, 7].

The essence of the proposed algorithm is the determination of the law of controlling reactive power compensator using probabilistic statistical characteristics of the load in real time on the observation interval which is commensurate with the voltage period of supplying network.

The well-known expression (1) to determine the orthogonal component of the non-linear load current (compensator current) provided that the compensator is connected to the load in parallel

\[ \vec{i}_{or} = \vec{i} - \vec{u} \frac{P}{U^2}, \]

where \( \vec{i} \) is instantaneous values of the non-linear load current vector consumed from the network; \( \vec{i}_{or} \) is instantaneous values of the orthogonal component of the non-linear load current vector; \( \vec{u} \) is instantaneous values of the voltage vector; \( P \) is a load active power; \( U \) –is a current voltage, requires stability of the load active power and a current voltage over the averaging interval (network voltage period), i.e. the stationary of the mode [8].

For the non-stationary mode a modification of the expression is proposed (1), namely: instead the value of active power of the load \( P \) on the current observation interval, introduction of the predicted value of the active power into the use on the consequent observation intervals \( P_{prediction} \):

\[ P_{prediction} = \left( M[P] \right)^2 + \sigma^2 \cdot r(\tau) \right)^{1/2}, \]

where \( M[P] \) is an expected value for a random process of active power change; \( \sigma \) is a standard deviation; \( r(\tau) \) is a normalized autocorrelation function.
The effective mains voltage $U$ in (1) is considered invariable. In other words, according to the proposed approach, the autocorrelation function of the random process of active power change on the pre-history interval is used to predict the active power on the subsequent intervals [9].

According to the recommendations of GOST (State Standard) 32144-2013 “Electrical Energy”, to calculate further it is necessary to introduce 10 observation intervals (periods) into consideration. All ten observation intervals will be considered equal to each other and equal to the supply voltage period.

The authors examined currents and voltages at the input and distribution device of the greenhouse of Stavropol State Agrarian University (StGAU) during the operation of the irradiation unit under the mode of lighting seedlings of tomatoes and cucumbers. The installed power of the equipment is 60 kW. In the unit, lamps DNAT with a power of 1 kW each are used. Measurement of oscillograms of currents and voltages was carried out using the AKIP-AKE-824 power mains quality analyzer, serial number 07040509, in the scanning mode with recording to an external memory card. Further processing of the obtained information was carried out in the MathCad environment.

Table 1 presents a fragment of the final table of the results of experimental data processing at a scale of 1:300 in relation to the initial values & random sequences of changes in active power over ten periods, expected values, standard deviation, values of autocorrelation functions of random sequences of changes in active power over ten periods with lag 0 and 1, correspondingly, the value of normalized autocorrelation function [10]. The final calculation is the predicted value of active power in the eleventh period $P_{\text{prediction}}$.

| Sample $N_e$ | P1   | P2   | m   | $P_{10}$ | $M[P]$ | $\sigma$ | R0    | R1    | r1    | $P_{\text{prediction}}$ |
|--------------|------|------|-----|----------|--------|----------|-------|-------|-------|------------------------|
| 1            | 149.6| 150.4| ... | 149.7    | 149.8  | 0.43     | 20213.2| 19975.7| 0.988 | 149.8                  |
| 2            | 151.5| 150.7| ... | 150.6    | 150.2  | 0.63     | 20300.6| 20019.8| 0.986 | 150.2                  |
| n            |      |      | ... |          |        |          |       |       |       |                        |
| 499          | 150.5| 149.1| ... | 151.8    | 149.8  | 0.93     | 20143.1| 19861.5| 0.986 | 149.8                  |
| 500          | 150.6| 148.9| ... | 150.2    | 150.0  | 1.12     | 20276.6| 19985.7| 0.985 | 150.1                  |

3. Results
By means of mathematic simulation we found that the use of the algorithm for calculation of the compensator control law proposed by the authors resulted in energy savings of up to 9% due to a decrease in losses in electro-technological units. The proposed algorithm is justified for a wide range of technological processes in the agro-industrial complex (APK) which possess the property of non-stationary modes of energy consumption.

4. Conclusion
By means of mathematic simulation we found that the use of the algorithm for calculation of the compensator control law proposed by the authors resulted in energy savings of up to 9% due to a decrease in losses in electro-technological units. The proposed algorithm is justified for a wide range of technological processes in the agro-industrial complex (APK) which possess the property of non-stationary modes of energy consumption.

References
[1] Demirchyan K S 1984 Reactive or exchange power Energy and transport 2 66–72
[2] Savina N B 2010 System analysis of electric power losses in distribution electric networks in conditions of uncertainty Abstract of dissertation for the degree of Doctor of Technical Sciences
Institute of Energy Systems named after L A Melentyev, Siberian Branch of the Russian Academy of Sciences

[3] Savina N B and Tsys D A 2017 Statistical analysis of reactive energy losses in distribution electric networks Bulletin of Irkutsk State Technical University 6 79–91

[4] Vorotnikov I, Mastepanenko M, Gabrielyan S and Shunina A 2019 Energy estimation of parameters of reactive power compensator for non linear loads in steady mode 18th International Scientific Conf. Engineering for Rural Development 22-24.05.2019 Jelgava, Latvia (Jelgava) 515–20

[5] Vorotnikov I, Mastepanenko M, Gabrielyan Sh Zh and Shunina A A2019 Modified control algorithm for reactive power compensator for non-stationary loads Electrical Engineering Russia 3 11–14

[6] Savina N V, Myasoedov Y V and Myasoedova L A 2018 Influence of quality of the electric energy on reliability of electrical supply systems International Multi-Conf. on Industrial Engineering and Modern Technologies, Far East Con 3-4 Oct. 2018

[7] Osipov D S, Lyutarevich A G, Gapirov R A, Gorunov V N and Bubenchikov A A 2016 Applications of wavelet transform for analysis of electrical transients in power systems: the reviewPrzegladElektrotechniczny 4 162–65

[8] Salmeron P, Montano J C, Vazquez J R, Prieto J and Perez A 2004 Compensation in nonsinusoidal, unbalanced three-phase four-wire systems with active power line conditioner IEEE Trans. Power Delivery 19 (4) 1968–74

[9] Litran, S P and Salmeron P 2017 Electromagnetic compatibility analysis of a control strategy for a hybrid active filter Electric Power Systems Research 144 81–88

[10] Chang G and Shee T 2002 A comparative study of active power filter reference compensation approaches Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conf. 2 1017–21