Prospects for Further Improvement of Filter-Compensating Devices for Agro-Industrial Complex Consumers

A A Shunina¹, G V Masyutina², A T Rostova², G Y Kolesnikov² and E V Lubentsova³

¹Stavropol State Agrarian University, per. Zootechnicheskiy, 12 Stavropol, Russian Federation
²North-Caucasus Federal University, pr. 40 let Oktyabrya, 56, Pyatigorsk, Russian Federation
³Kuban State Technological University, ul. Moskovskaya, 2, Krasnodar, Russian Federation

E-mail: Aa_shu@mail.ru

Abstract. Energy saving in technological processes of agro-industrial complex is an integral part of the development of a market economy, since nowadays there is a total interest of suppliers and consumers in economical energy supply. At present, the concept of electromagnetic compatibility in matters of power quality assurance covers almost any type of interaction between various devices and systems using electromagnetic phenomena, as well as the interaction of these systems with living organisms. There is an increasing need to analyze the impact of energy losses on energy efficiency in general and the need to analyze additionally arising losses caused by a sharp deterioration in the power quality readings. At present stage, more accurate information is required about the state of the electrical networks modes to determine the level of losses and reduce the commercial component of losses. In this situation, power systems require more accurate forecasts of the load of distribution networks in order to achieve excellence in operation, planning the development of networks and optimization of energy resources management, but the process of high-quality compensation remains rather complicated due to the growth of distortions in low-voltage distribution networks. In contrast to the existing solutions, the authors of the article offer to introduce into the method (algorithm) for controlling a compensation device the operation of forecasting the value of active power of non-stationary non-linear load on the forthcoming period of the supply mains voltage according to the results of monitoring the change in the active power of the load during the previous periods and statistical processing of the data obtained.

1. Introduction

The present-day analysis of energy systems shows that the existing methods of obtaining information on energy resources optimization of agro-industrial complex consumers are not enough; more accurate information is required about the state of the electric network modes to determine the level of losses and reduce the commercial component of losses.

In this situation, power systems require more accurate forecasts of network load distribution in order to achieve operational excellence, planning of network development and optimization of energy resource management; however, the process of high-quality compensation remains quite complicated due to the growth of distortions in low-voltage distribution networks.
In contrast to the existing solutions, the main task of the authors is to introduce into the method (algorithm) of controlling the reactive power compensation device the operation of predicting the value of the active power of the non-stationary nonlinear load in the upcoming period of the supply mains voltage based on the results of monitoring the change in the active power of the load during the previous periods and the statistical processing of the data received.

The main technical result is an increase in the efficiency and electromagnetic compatibility of the electrical energy conversion when the waveform of the mains current coincides with the voltage form in case of non-stationary nonlinear loads, provided that the voltage is sinusoidal.

2. Research objects and methods

The above-mentioned result is achieved when using a method for controlling a reactive power compensation device in real time for cases of non-stationary non-linear loads; according to this method, during a given number of supply voltage periods without gaps between intervals, instantaneous values of voltage and load current of the mains are measured; in regards to them, for each observation period (observation interval), the active power is determined and this information is stored; after that, the forecast value of the active power for the forthcoming period (control interval) of the supply network voltage is calculated from the obtained measurement results.

The forecast value of the active power is used to determine the required instantaneous current generated into the network by the compensator (in order to eliminate the distortion of the network current waveform), connected in parallel to the load, as the difference between the instantaneous load current and the product of the instantaneous mains voltage multiplied by the quotient of division the previously forecast active power of the consumer per square of the effective value of the supply voltage [1].

To determine the output current of the reactive power compensation device, provided it is connected in parallel to the load, a well-known expression is used to determine the inactive (passive) component of the consumer current [2]:

\[ I_p(t) = i_n(t) - \frac{P}{U^2} u_m(t), \]

(1)

with \( i_n(t) \) – instantaneous values of the nonlinear load vector consumed from the mains;
\( u_m(t) \)– instantaneous values of the mains voltage vector;
\( P \) – active load power;
\( U \) – effective mains voltage,

The active power of the load is determined by the results of measurements of the instantaneous values of the mains voltage and the load current:

\[ P = \frac{1}{T} \int_0^T u_m(t) i_n(t) dt, \]

(2)

The effective mains voltage is determined from the results of measurements of the instantaneous mains voltage:

\[ U = \sqrt{\frac{1}{T} \int_0^T (u_m(t))^2 dt}. \]

(3)

The effective mains voltage will be considered unchanged.

Relation (3) has a significant limitation associated with the mandatory requirement of constant active power in the averaging interval (period of the mains voltage). However, for non-stationary loads, this requirement is not feasible [3].

In order to eliminate the existing contradiction, it is proposed to use the forecast value of the active power of the consumer for the upcoming period based on the results of monitoring the change in active power in previous periods (background) and statistical processing of the initial data, namely:

\[ i_p(t) = i_n(t) - \frac{P_{\text{forecast}}}{U^2} u_m(t). \]

(4)
Determination of the predicted value can be performed using well-known extrapolation methods: splines, wavelets, autocorrelation functions, and others [4].

As an example, a relationship is given for forecasting the values of a time series based on correlation analysis. In foreign literature, this relationship is known as the recursive Burg’s algorithm [5]:

\[ A_{k+1} = A_k + \mu V_k. \]  

with \( A_k \) – initial time series;  
\( \mu \) – calculated factor;  
\( V_k \) – a copy of the initial time series with the reverse order of the elements;  
\( A_{k+1} \) – the initial time series, but with an additional element containing the value of the extrapolation coefficient for the \( k \)-th step of the recursion procedure [6].

The \( \mu \) factor [7] is calculated using autocorrelation functions under the condition of minimizing the sum of the squares of the extrapolation error. The recurrent formula is:

\[ \mu = \frac{-2 \sum_{n=0}^{N-k-1} f_k(n+k+1)b_k(n)}{\sum_{n=k+1}^{N} f_k(n)^2 + \sum_{n=0}^{N-k-1} b_k(n)^2}, \]  

with \( N \) – number of elements in the initial time series;  
\( k \) – number of extrapolating elements;  
\( f_k \) – sequence of elements of the original series for the \( k \)-th extrapolating element;  
\( b_k \) – sequence of elements of the initial series, but with the reverse order of elements for the \( k \)-th extrapolating element.

The forecast value is determined by the expression [8]:

\[ P_{\text{forecast}} = \sum_{i=0}^{m} a_i P_{N-i} \]  

with \( P_{\text{forecast}} \) – the forecast value;  
\( m \) – the number of the last elements of the initial \( P_N \) time series, according to which the forecast is built;  
\( a_i \) – extrapolation factors;  
\( P_N \) – initial time series containing \( N \) elements.

The results of mathematical modeling of the forecasting algorithm in the VisualStudio environment using the algorithmic programming language C++ are shown in figure 1.

As an example, Figure 1 shows a comparison of the values of the initial series obtained in the study of currents and voltages at the input-distribution device of the greenhouse complex of StSAU during the operation of the irradiator in the mode of supplementary illumination of the seedlings of cucumbers and tomatoes described in [9], and the forecast time series.

The original series is represented by one of the possible implementations of the function \( y(x) = \exp(-x/100) \cdot \sin(x/10) + 0.5(rnd(1) - 0.5) \) with a noise in the form of a uniformly distributed random variable in range from 0 to 1, generated by the random number generator caused by the \( rnd(x) \) function.

The forecast values are calculated by the last thirty values of the elements of the initial time series [10].
3. Results
Analysis of the results obtained shows that the maximum forecast error for the first three forecast periods does not exceed 3%.

The speed of modern tracking digital control systems is quite enough to have a forecast value of the active load power in the first forthcoming period of the mains voltage.

4. Conclusion
The proposed method for controlling a reactive power compensation device using a forecasting algorithm can be used to create digital control systems for compensating installations tracking their operation in real time and at the pace of ongoing electromagnetic processes when compensating for reactive power and correcting the forms of mains voltages and currents of non-stationary non-linear loads.

The proposed method for controlling a reactive power compensation device using a forecasting algorithm is valid for a wide range of technological processes in the agro-industrial complex having non-stationary power consumption modes.

References
[1] Demirchyan K S 1984 Reactive or exchange power Energy and Transport 2 66–72
[2] Savina N V 2010 System Analysis of Electricity Losses in Distribution Electric Networks Under Conditions of Uncertainty Abstract of the thesis for the degree of Doctor of Technical Sciences (Institute of Energy Systems named after L A Melentiev, Siberian Branch of the Russian Academy of Sciences)
[3] Savina N V and Tsys D A 2017 Statistical Analysis of Reactive Energy Losses in Electrical Distribution 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 nonlinear loads in steady mode Engineering for Rural Development 515–520
[5] Rapoport M B 1993 Computer Science in Field Geophysics 350 p
[6] Vorotnikov I, Mastepanenko M, Gabrielyan Sh Zh and Shunina A A 2019 Modified control algorithm for reactive power compensator for non-stationary loads Electrical Engineering Russia 3 11–14
[7] 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-Conference on Industrial Engineering and Modern Technologies, Far East Con

[8] 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 review Przeglad Elektrotechniczny 4 162–165

[9] Vorotnikov I, Shunina A, Permyakov A, Danchenko I and Masyutina G 2020 Improvement of energy-saving technologies in units of irradiation and lighting of plants in greenhouse complexes IOP Conference Series: Earth and Environmental Science. Ser. “International Scientific and Practical Conference Biotechnology in the Agro-Industrial Complex and Sustainable Environmental Management” 12–16

[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 Conference 2 1017–1021