Multi-level control of high-pressure sodium lamps parameters network technology

A D Semenov 1 and A V Volkov 2,*

1 Department of Automation and Telemechanics, Penza State University, Penza, Russia
2 Department of Information Security and Service, Ogarev Mordovia State University, Saransk, Russia

* elsoldador@rambler.ru

Abstract. We created a mathematical model of a sodium high-pressure lamp. To develop the model, we used a mathematical model. An analytical method was used to describe the operation of a sodium lamp based on differential equations. We also used the singular value decomposition algorithm to find the coefficients of the ARMA model. Also, the transfer function of the ARMA model was obtained. Then we tested the models to control the quality of sodium lamps in production. The obtained results of the simulation coincide with the experimental results. Using a series of tests based on the singular value decomposition method, we confirmed the adequacy of the elaborated model by Wilcoxon criterion.

1. Introduction
Sodium high pressure lamps are widely used for outdoor and indoor lighting, including lighting plants in greenhouses. After manufacturing before shipment to the consumer, these lamps must undergo the process of bench testing and sorting. The operator tests the lamps according to the test results [1]. Until now, the operator monitored the lamp voltage, what led to errors in operation and made it difficult to analyze the reasons for the appearance of the marriage [2].

2. Formulation of the problem
Tasks were set to automate the testing of lamps and assess their suitability. The automated system should provide visualization of the test progress, be reconstructed from one type of test lamps to others, keep the test results archives, transmit data to the site master's personal computer for displaying statistical information in a graphical form. In addition, it should be possible to compare the model of an "ideal" lamp with a model based on an array of measurements. However, due to the complexity of the interrelationships between the manufacturing process regimes and their technological control, recommendations for choosing the lamp parameters are substantiated, first of all, by practical experience and experimental research results [3, 4].

Obviously, it is impossible to determine experimentally the cause of marriage at the production stage. Mathematical modeling can carry out calculation of the progress of the technological production stage:

- Firstly, is assumed hypothesis about the stationarity and ergodicity of a random process of distributing the voltage value on a lamp in a steady state.
- Secondly, is experimentally formed the choice of voltage values for various types of lamps.
- Finally, the hypothesis of statistical compliance with two time series is tested according to the non-parametric Wilcoxon test.
- If the results of the tolerance control and the Wilcoxon test are positive, one man makes a decision on the validity of the product.

The process parameters thus modeled allow the most accurate description of the process of testing sodium high-pressure lamps.

Studies conducted on mathematical models showed quite good agreement with the calculated data, and the simulation error did not exceed 10%.

3. Theory

At present, mathematical modeling is the main means of research and design of electrical equipment. It is very relevant to develop visual and easy-to-use mathematical models (ideal) of high-pressure lamps. A number of papers have proposed differential equations [5, 6], as well as their implementation in the MATLAB computing environment using the programming language and the built-in functions of this medium [7].

In [5] are formulated the requirements for the equations of the differential model of a lamp. In particular, the limitations of models based on algebraic approximation are noted. Differential mathematical models allow us to take into account the initial conditions of discharge development in the lamp, as well as the inertia of the development process of this discharge. It should also be possible to easily measure or accurately calculate the parameters that determine the behavior of the model. The determining parameters proposed for use [5] are related to the particles behavior, which are capable of storing energy in any form corresponding to electrical, magnetic and thermal processes, as well as ionization processes of atoms.

For high-pressure lamps, acceptable results are obtained by a model displayed by a system of two nonlinear differential equations of the third order:

\[
\begin{align*}
\frac{dx_1}{dt} &= \frac{1}{L} \left[ U_s - \left( \frac{1}{x_2 x_3^2} + R \right) x_1 \right]; \\
\frac{dx_2}{dt} &= A_l U_0^2 x_2 \left( \frac{x_1}{U_0 x_2 x_3^3} \right)^2 \left( \frac{1}{1 + k_1 (\frac{U_0}{x_2}) x_3^3} \right) - 1; \\
\frac{dx_3}{dt} &= \left[ k_2 + k_3 \left( \frac{|x_1|}{U_0 x_2 x_3^3} \right)^{k_4} \right] \left[ 1 + k_1 \left( \frac{|x_1|}{U_0 x_2 x_3^3} - 1 \right) - x_3 \right],
\end{align*}
\]

(1)

where \(x_1\) – is the current flowing through the lamp;
\(x_2\) – is the reduced conductivity of the tube, taking into account the average value of the electron concentration;
\(x_3\) – a dimensionless coefficient that varies with time and takes into account the average value of the electron concentration;
\(L\), \(R\) - respectively the inductance and the active resistance of the restrictor throttle;
\(U_0\) - rated voltage on the lamp; \(U_s\) - supply voltage;
\(A_l\) is the coefficient determined by the lamp design;
\(k_1\)-\(k_4\) are the electrical coefficients determined for a particular type of lamp.

As an example, let's consider a lamp DNaz-600, for which:
\(k_1 = 0.6; k_2 = 1.5104; k_3 = 3.104; k_4 = 1.5; U_0 = 135; A_l = 5.5.\)

It is these processes that have a significant effect on the main (from the point of view of the power network) lamp parameter - its equivalent electrical conductivity [8, 9].

To simulate the course of the technological process, one should use the allocation of trend and periodic components of numerical series in the framework of the singular decomposition method. The method does not provide knowledge of the parametric model of the series and allows to work with noisy time-series (measured values of the voltage drop on the lamp or the values obtained in the lamp model considered above). In particular, it makes it possible to isolate the amplitude-modulated
harmonic components, which distinguishes it from the methods constructed on the Fourier expansion [10].

In Figure 1 shows the results of the decomposition of the initial data into periodic and random components. The blue line identifies the periodic component of the voltage, and the green line – random component of the voltage.

![Figure 1. The results of the initial data decomposition](image)

The model of the random component is represented by the model of a stationary and ergodic random process obtained by the method of the forming filter. Identification of the parameters of the shaping filter was carried out using the recursive least squares (RNNC) method [11, 12].

Figure 2 shows the estimates of the ARCC model coefficients obtained as a result of identification, indicating the convergence of the estimates obtained for sodium high pressure lamps DNaZ-600.

Figure 3 shows the transient response of the random component.
Figure 2. Coefficients of ARCC-models of random voltage components on tested lamps DnaZ-600.
According to the received ARCC models, the transfer functions of the shaping filters, that reproduce the random voltage component on the tested lamps DNaZ-600, were calculated

\[ W_{od} = \frac{0.2095z^2 - 0.2201z}{z^2 - 0.77z - 0.1502} \]  

Figure 3. Transient response the random components of the voltage on the inspected lamps.

4. Experimental results
Also, the hypothesis about the normal distribution of the stress values was tested by the Wilcoxon criterion was confirmed.

In order to verify the criterion, two experimental samples of the measured voltage drops on the lamp, each with a volume of 101047 units, were formed. From the sample, two subsamples were formed, each with a volume of 15 units, which corresponds to the number of lamps installed on the test bench. The statistical hypothesis about the belonging of these subsamples to one general population according to the Wilcoxon criterion was checked. The maximum and minimum values in the subsamples were recorded simultaneously.

The results of the calculations are shown in Figures 4 (a and b).
If we accept that the tested statistical hypothesis is accepted when the criterion value is greater than 0.5, and the tolerance limits are torn $U_{\text{max}} = 130 \text{ V}$, $U_{\text{min}} = 95 \text{ V}$, then the figures show that there are cases when the tolerance control is positive, and the Wilcoxon test is negative and vice versa the tolerance control is negative, and the Wilcoxon test is positive. However, the number of such cases for the first option does not exceed several hundred, and for the second option it is 6 and they can be neglected, taking into account the total sample size exceeding 200 thousand. As expected, the Wilcoxon test is positive in all cases, since the data was generated on the same model. If we assume that the boundaries of the tolerance field are torn $U_{\text{max}} = 163 \text{ V}$, $U_{\text{min}} = 123 \text{ V}$, then it is clear that only the case when the tolerance control is negative, and the Wilcoxon test is positive, is in place. The number of such cases is 17, with a total sample size of 150.

5. Conclusions
The elaborated mathematical model of the sodium high-pressure lamp is based on relatively simple differential equations that reflect the properties of the lamp during the test. Verification of the hypothesis of the normal distribution law of the resulting resulting stress values by the Wilcoxon test was confirmed.

As a result, in order to increase the reliability of control, it is necessary to apply multidimensional multi-alternative control in two ways: the voltage drop across the lamp and the Wilcoxon test results. Control results are considered positive if the control results for each monitored parameter are positive. Also test Wilcoxon allows to judge the stability of the process. The sample for the Wilcoxon test was formed at the expense of the neural network.

The singular decomposition of the resulting profile revealed a trend component and the absence of periodic components present in the decomposition of the original unit profile.

The model parameters for a particular type of lamp can be calculated or determined experimentally. The obtained model is adequate, which is confirmed by the experimental obtained results. The model can be used for controlling the quality of produced lamps.

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