To the question of effective modes mixed load with the complex waveform current supply

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Abstract. Currently, the effective technologies and modes development of electrotechnological installations is relevant. Power supply of electrotechnological and lighting load with calm character is usually realized from the busbars of a transformer. The effective operation mode of an electrotechnological and a lighting installation may be provide by the complex waveform current supply. In the article, the operation of the mixed load after switching in the network and the transient process are researched by the example of the low-voltage electrode water heater and energy-saving lamp physical models.

The purpose of the paper is study of the energy parameters and the transient process in a connection node included the electrode water heater and the energy-saving lamp with the complex waveform current supply and select the effective modes of the mixed load in the steady state after switching. It required the solution of scientific problems in the development of methods for study of mixed load with CWC in the transition from one stationary state to another, the transition process, to develop recommendations for the selection of effective modes necessary for the synthesis of the automatic control algorithm. The decision tasks have revealed that in the steady state after switching of mixed load works in the effective mode; the nature of the transition process with CWC changes.

1. Introduction

The efficiency of an electrotechnological installations (ETI) increases when use of energy-saving technologies: for example, for induction heating of light alloys, losses in multilayer windings of the inductor reduced; energy cost for precision heating of long-length blanks reduced, etc. [1, 2, 3]. In electrotechnology increase of efficiency ETI is possible at improvement of an electric mode: due to use of the low frequency current in arc steelmaking furnaces with a capacity of 100 tons (DSP), decrease resistance of a current lead, decrease consumption of reactive power and increase electric efficiency, increase power factor are noted [4]. In arc steelmaking furnaces of small capacity, in electrolysis installations (with solutions, melts of electrolytes), electric resistance furnaces (EPS) of direct and indirect heating (with dark and light infrared radiators, etc.) the use of complex waveform current (CWC) allows to obtain positive technological and energy effects. When the ETI works, changing modes or turning off the arc furnaces (for downloading slag), shunting a part of the electrolyzers to output in repair, cyclic operation of electric resistance furnaces, etc are possible.

Low-voltage electrode water heaters are a calm load. Power supply is realized from the busbars of a transformer substation together with a lighting load. Switching processes can be accompanied of dangerous overvoltages in a load node. Researches in electric power systems prove that the occurrence of low-frequency oscillations reduces the reliability of systems [5], the operation mode of the transformer neutral affects on the character of transients in network [6], in [7] the improvement of methods for calculating transients is considered, in [8] the mathematical model of the transition
process of the welding arc is researched. However, the literature does not reflect the researches results of the energy parameters of mixed load with the power supply of the CWC in the steady state after switching on the network and the characteristics of the transition process.

2. Purpose of the paper
Research of the energy parameters and the transient process in the mixed-load connection node with an electrode water heater and an energy-saving lamp with complex waveform current supply after switching to the network to select the effective modes. For achievement of the purpose, scientific problems solved: development of research method of the mixed load with CWC supply in a stationary state after switching, transition process, development of recommendations for the choice of the effective modes necessary for synthesis of functioning algorithm of automatic control system.

3. Used instruments
- Fiber optic spectrometer AvaSpec-ULS2048-USB2 with software AvaSoft-ALL.
- Analyzer of electric energy quality ANALYST 2060 was used for measurement of electrical parameters.
- Thermocouple included in the multimeter EM5512 was used to measure the temperature of water heating.
- Two-channel USB-oscilloscope in the "Recorder" mode, compatible with PC and 1:100 voltage divider was used for oscillography of the transient process.
- Thermal imager Testo 885-2 for measure the temperature. The thermal imager visualized IR radiation (radiation power) from each point and non-contact to measure the surface temperature.

4. Experimental researches
The presented results are made in comparison of two electrical modes: normal mode with a current supply of 50 Hz and new mode with complex waveform current supply without a constant component because the rectified current (its constant component) causes water electrolysis. In the normal mode the mixed-load power supply was carried out from a single-phase transformer 220/110V with switching voltage without excitation A-X1, A-X3. In the new mode a throttle was provided to regulate the form of the supply voltage (current). The physical model of the low-voltage electrode water heater is a glass vessel with an unspent water volume of 500 ml. It was fixedly set two steel plate electrode 18x90 mm2. The experiments used the same organoleptic properties of water composition: drinking water. The initial water temperature in the experiments was 24 °C. Experiment time was 5-7 minutes. The LUXRAY energy-saving lamp of 20 W was used as a light source.

5. Experimental results
The experimental results for the normal electrical mode are presented in table 1. The experiments were made in a mixed-load node with connected the energy-saving lamp and the electrode water heater.

| Electrical mode                                      | Network power              |                  |                  |
|------------------------------------------------------|----------------------------|-----------------|-----------------|
|                                                      | Active, kW                 | Reactive, kVar  | Full, kVA       |
| Normal mode: alternating current, 50 Hz              | 0.079                      | 0.096           | 0.125           | 0.632          |
| New mode: complex waveform current without direct component | 0.063                      | 0.017           | 0.065           | 0.969          |

Figures 1-4 show the windows of radiation spectra, colour diagrams, values of colour temperature, luminous flux and photon output from the diffuser surface for the energy-saving lamp with a power of
20 W under the following conditions in the load node: a) only the energy-saving lamp is turned on (figure 1-2); b) energy-saving lamp and electrode water heater are turned on (figure 3-4)

![Figure 1. The radiation spectrum window of LUXRAY energy-saving lamp of 20W for the new mode: the intensity of radiation at a wavelength of 430 nm – 33000, 550 nm – 46000, 620 nm – 47000](image1)

![Figure 2. The color chart window of LUXRAY energy saving lamp of 20 W for the new mode: the colour temperature T = 3104.2 K, the luminous flux – 4982.3 lm, the photons output from the surface of the diffuser 2.977 e-5 µMol](image2)
Figure 3. The radiation spectrum window of LUXRAY energy-saving lamp of 20W for the new mode: the intensity of radiation at a wavelength of 460 nm – 33000, 550 nm – 52000, 620 nm – 52000

Figure 4. The color chart window of LUXRAY energy saving lamp of 20 W for the new mode: the colour temperature $T = 3115.2$ K, the luminous flux $\sim 5603.3$ lm, the photons output from the surface of the diffuser $3.575 \times 10^{-5}$ $\mu$Mol

Figure 5 shows colour chart, colour temperature, luminous flux and photon output from the diffuser surface for the energy-saving lamp in the normal mode when the mixed-load (the energy-saving lamp and the water heater) are connected to the supply node.
Figure 5. The colour chart window of LUXRAY energy saving lamp of 20W for the normal: the colour temperature $T = 3115.2$ K, the luminous flux $- 5603.3$ lm, the photons output from the surface of the diffuser $3.575 \times 10^{-5}$ $\mu$Mol.

The figures 6-7 show the transient oscillograms for the mixed load when the electrode water heater is turned on or off for two modes: normal - with powered by alternating current of 50 Hz frequency and new - with the complex waveform current without a constant component. The transient oscillograms are taken in the "Recorder" oscilloscope mode.

Figure 6. The oscillogram window of transition process for the normal mode: the oscilloscope in the "Recorder" mode (the electrode water heater is turned on and off).
6. Analysis of the results

For analysis of the results in the water heaters a hypothesis was adopted that in the new electric mode when the frequency of the water molecules vibration coincides with the frequency of the external driving force, the amplitude of fluctuations and displacement increases, the mobility and kinetic energy of water molecules, the number of collisions increase which causes an increase in the rate of temperature rise (intensity of heat). In the same rate of temperature rise in the compared modes (from 24 to 350°C in 7 minutes), the transformer can operate at a lower stage in the new mode. The efficiency of the mixed load increases by reducing the consumption of reactive power. And for light sources, the possibility of improving energy performance was experimentally and theoretically proved [9-11].

According to the results of experiments for the mixed load in the new mode, the power factor increased from 0.63 to 0.97 (table 1). The intensity of the radiation lines of the energy-saving lamp when connected to the electrode water heater increased (figure 1 and figure 3), the photons output from the diffuser surface increased (figure 2 and figure 4).

Comparison of the lighting parameters in the normal and new modes showed that for the same value of the colour temperature 3116.9 K (figure 4) and 3115.2 K (figure 5) the photons output from the diffuser surface increased.

Analysis of the transient process oscillograms in the load node showed that in the normal and new modes, the nature of the transient process was different when the electrode water heater was switched on or off. In the new mode, the commutation in the mixed load node was not accompanied by overvoltage in the electrical network: slight changes in the amplitude of the voltage were noted.

7. Conclusion

It is experimentally established that in the power node with the mixed load (low-temperature electrode water heater and energy-saving lamp), the efficiency increased when the complex waveform current supply was used. In a steady-state mode, after switching in the network, the efficient mode was saved for the mixed load and for each electrical individual receiver.

For the water heater, the electromagnetic component along with the temperature affects the mobility of charged particles in the water. It increases efficiency of the heating process. The photons output from the diffuser surface indicates that the electromagnetic component in the lamp also activates the
processes along with the temperature component. For the researched mixed load, it is manifested in the increase the power factor in the power node: from 0.63 (normal mode) to 0.97 (new mode).

8. References

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