The influence of mixed load with complex waveform current supply on the electrical energy quality

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Abstract. The joint work of heating tape and a dark infrared radiator at different electrical modes for getting positive technological and energy effects and indicators of electrical energy quality in the network have been investigated.

1. Introduction

GOST 32144-2013 “Electrical energy. Electromagnetic compatibility. Electric energy quality standards in electric power supply for common use”, enacted on the 1 of July 2014 by the order of Federal technical Regulation and Metrology Agency (Rosstandard) on the 22nd of July 2013 № 400-st, establishes the requirements for electric power quality regulation in electric power systems owned by the consumer. The consumer must provide the conditions to meet the Standard requirements on the clamps of the current-using equipment. The works [1–7] prove energy loss in power systems due to load unbalance in phases, higher harmonic component, temperature and other factors. The works [1, 2] suggest a dynamic model of the electric power system 0.4 kwh for determining the dependence of the energy losses on the level of load imbalance, as existing methods do not take into account to a full extend the factor of accidental single-phase load difference and high speed of their changes in time.

Works [3–5] prove that losses in open-wire lines depend on temperature: the temperature is a key factor determining load losses of the true power in open-wire lines.

Works [6, 7] determine that increase in power and capability in manufacturing power systems is determined by higher circuit harmonics, with the increase of the non-linear load.

In oil refineries different devices for electrical heating are used: immersion heaters, flange immersion heaters, flow-through electric heaters, pipe heaters. Modern electric heaters have capacity upto 5 MW, for the heating temperatures upto 8000 °C, the heaters operating at the pressure up to 25 MPa. Modern heating systems can use a resistive tape, surface-systems or self-regulating tape with different insulations: InWarm Wool, In Warm Foam, InWarm Flex [8]. Application of surface-systems – rod inductors and inductor-resistive heating systems (IRHS) necessiated methods for calculating loss effect for steel reversal magnetization at frequency 50 hz, that is hysteresis loss [9].

Thus, not only higher harmonics, temperature, humidity, and hysteresis losses and eddy-currents, the level of the feeding power and the current type influence the operational efficiency of the electric power systems and separate electrical devices. Real power losses at alternating current 50 hz in capacity increase in comparison with losses on the direct current due to the surface effect and proximity effect [1–10].
In electrotechnics, on the opposite, the current of the lowered or increased frequency, pulse current, complex waveform current (CWFC) with the DC component and without it (harmonic component range) are used for positive power and technological effects at high temperatures of the fused electrolytes 950 – 960 °C and for sparking discharge in melting furnaces of direct and indirect heating of a small capacity, in baking furnaces for green workpieces and gravitation [10–12]. It has been proved [10–12] that in electric resistance furnaces for direct and indirect heating efficiency upgrading is also possible due to the electrical mode enhancement: applying CWFC. Infrared ceramics heating elements (IRE) “NOMAKON” have been studied. Photon yield increase from the diffusion surface has been determined in the mode combined with CWFC for the temperature radiator by means of the electromagnetic component operating in the radiator together with the temperature component. The increase in the power factor has been denoted for the electrotechnical devices under study [10–15].

2. The purpose of the study

Studying energy parameters in the nod of the combined load to the element of flexible heating tape and infrared heater at CWFC to choose the effective modes. The following tasks have been solved: methods of studying the combined load at supplying CWFC in the determined mode in order to develop recommendations to choose effective modes, necessary for the synthesis of the functional algorithm for the system of the numerical control.

Four electric modes are compared: in a common mode with the current 50 hz, in a new mode with a dc supply (inverted current), in a new mode with CWFC supply with a constant component and without it. In a common mode the combined load supply was from a single phase transformer 220/110 W with switching voltage levels without actuation A-X1, A-X3. In the second mode – via a single phase transformer and a diode bridge. In the third and fourth modes a metering valve was used to regulate the dc supply.

An object of the research was an electrotechnical device – a heating flexible tape element HFTE-2. The main parameters and dimensions are HFTE = 2 – 0.05/220 – 2.6 (voltage is 220 W, nominal capacitance is 0.05 kW, heater’s length is 2.6 m, width is 23 mm, thickness is 3.3 mm, the extreme temperature on the surface is 60 °C, heat-liberation value 40 W/m, the protection level IP47, climatic version UHL1, food polyethilene used for the insulation). The purpose: used for freezing protection, heating and heat loss compensation in heat exchanger lines, reservoirs and other technological equipment. The heaters can be utilized in inflammable installations (outside and inside) IN-I class, IN-II, IN-III [11].

The connection to the load center of the ceramic dark infrared heating element “NOMAKON” type IRH-203-0.1/230-2 wattage 100 W with a flat emitting surface 60×60 mm with the wattage 100 W have been studied.

3. Used instruments

A fiber-optic spectrometer AvaSpec-ULS 2048-USB2, with the software AvaSoft-ALL has been used; to measure electrical parameters the quality of electrical power analizator type ANALYST 2060 has been used.

To measure temperature in electrotechnical device type EHGL-2 we used an infrared image converter type Testo 885-2, serial number № 2358782, standard lense system 30°, detector type – 3200×240 pickels, temperature sensitivity < 30 micron, wavelength range – 8–14 mkm, temperature range – –20 to +100 °C (0 to +350 °C), measuring high temperatures – from +350 to +550 °C, precision – ±2 °C (+2 %), timer, amperometer and voltmeter. In the research the thermal field of the flexible heating tape for the denoted electrical modes have been used. Based on the research findings the files of radiometric thermographs have been received. They were processed with the software included into the set of the hand-held thermal viewer Testo 885-2. Here, the infrared image converter made IR-radiation (radiation power) visible from every point of the IR-radiator and non-contactly measured its surface temperature, that is converted the radiation power into the radiator surface temperature.
4. The results of experiments

Table 1 shows the research results of the four modes with the mixed load.

| Electrical modes                                      | Network power |             | Power factor |
|-------------------------------------------------------|---------------|-------------|--------------|
| Normal mode: alternating current, 50 Hz (115 V)       | 0.050         | 0.091       | 0.104        | 0.480        |
| New mode: direct current (115 V)                      | 0.051         | 0.101       | 0.113        | 0.451        |
| New mode: Complex waveform current without constant component (115 V) | 0.043         | 0.021       | 0.048        | 0.900        |
| New mode: Complex waveform current without constant component (115 V) | 0.045         | 0.019       | 0.049        | 0.918        |

Figure 1a for a common mode shows a thermogram window at electrical power supply voltage of the load 115 V per 10 minutes of heating: flexible heating tape and a dark infrared radiator are included. Figure 1b shows a thermogram window in a new mode with the inverted (direct) current supply for a mixed load for 10 minutes of the temperature rise.

![Figure 1a](image1a.png) ![Figure 1b](image1b.png)

Figure 1. A thermogram window in a new mode with the inverted (direct) current supply for a mixed load for 10 minutes of the temperature rise: a – a normal mode at the load supply voltage 115 V; b – a new mode: direct current (115 V)

Figure 2a shows a thermogram of the temperature rise per 10 minutes of heating in a new mode at CWFC supply with a constant component for a mixed load.

Figure 2b shows a thermogram window in a new mode with the CWFC supply without a constant component correspondingly per 10 minutes of heating per mixed load.

Figures 3 and 4 show oscilogram windows for the supply voltage and corresponding harmonic spectra for a normal mode and a new electric mode with CWFC supply with the mixed load.
Figure 2. A thermogram window per 10 minutes of heating per mixed load: a – a new mode with the power supply CWFC with a normal mode; b – a new mode with the power supply CWFC with a constant mode

Figure 3. Oscilogram window for the primary voltage of the feeding transformer: a – the load in the normal mode; b – the load in a new mode with the direct current
Figure 4. Oscilogram window for the primary voltage of the feeding transformer: a – the load in the normal mode; b – the load in a new mode with the direct current; c – a new mode with the power supply CWFC

5. Conclusion
It has been determined that at equal speed of temperature rise in the compared modes the transformer operates in a new mode at a lower stage of NLTC. Due to curtailment of the volt-amperes reactive demand and line losses the installation capacity coefficient increases from 0.45 to 0.92.

The results of the research on the example of the flexible heating tape HFTE-2 and a dark radiator proved the increase in energy efficiency in the mode with CWFC supply, that becomes evident at equal speed of the temperature rise when the installation power factor increases. In the supply line the spectrum of the voltage harmonics has not changed, the total coefficient of the harmonic distortions THD was less than 3% even at the complex power supply mode.

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