Individual parameters of dark and light radiators powered by complex waveform current

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Abstract. The power factor is an important indicator of the installations efficiency with light and dark infrared radiators, their individual characteristics. The efficiency of installations depends on used electrical mode. In this paper, the object and subject of research are infrared ceramic lamps for heating, flexible heating tapes for electric heating systems, light infrared radiators and their operation modes powered by complex waveform current. The purpose of the research is the individual parameters of infrared radiators when the amplitude and frequency of the supply voltage are changing and develop recommendations on the choice of effective modes. The authors have solved the following tasks: to develop a method to research the physical models of installations with infrared radiators and to develop recommendations to choose the effective load operating modes based on the results of energy parameters measurements. The authors have obtained the following values of the power factor in the normal and new modes: the ceramic lamp and light radiator – 0.97, the flexible heating tape - 0.83. In addition, the authors have proved that the harmonic composition of supply voltage did not deteriorate in the new mode.

1. Introduction.

Work [1] proved that low-frequency electromagnetic waves (helicons and Alfven waves) could propagate in metal. Langmuir oscillations with a frequency from 16 to 2000Hz can be excited in a gas-discharge plasma [2]. There are different ways to change energy efficiency. According to work [3], we can use a magneto hydrodynamic (MHD) mixing. It allows reducing the melting time from 1151 seconds for natural convection of the melt to 400 seconds for forced convection and improving the electric power efficiency. Power supplying MHD machines with non-sinusoidal current controlling the current form provides a shock effect on the melt. This reduces the melting time and eliminates the micro-uniformity of the melt [3]. Modeling methods for installations using ultra-high frequencies (microwave) are developed taking into account the dynamics of changes in the properties of dielectrics and the relationship of physical processes when harmonic microwave electromagnetic oscillations affect them. Yu. S. Arkhangelsky developed a mathematical model for microwave installations for processing porous dielectrics in a three-dimensional setting. In subsequent works, he developed mathematical models for microwave ray-type installations, etc. [4, 5]. Heating of dielectrics in high-frequency fields provides high heating speed, environmental friendliness and ease of temperature control [6, 7]. However, there is a problem of uneven temperature field, reduced product quality and equipment complexity.
Work [8] proved that low-frequency external influences affect the energy parameters of radiators: in low-pressure fluorescent lamps, the value of the anode-cathode potential drop and the anode-cathode power loss decreases and the light output of column increases at a frequency of 200-400Hz. Such changing the light output of the discharge column occurs due to a broadening of the radial distribution of excited mercury atoms at $^6P$ levels, which facilitates the output of resonant radiation. The thermal movement of radiating (absorbing) atoms causes an additional broadening of the energy levels and corresponding spectral lines in the linear spectra of the gas discharge. In the works of G. Mecker and V. Filkenburg, the influence of current frequency on gas discharge radiation is established [9].

The works of O. A. Popov and S. A. Svitnev [10] established improving the efficiency of ultraviolet radiation sources. Tubular ferrite-free induction UV lamps filled with a mixture of argon and mercury are used for water and air disinfection. Work [11] proved that effective frequencies for infrared radiators are frequencies in the range of $10^2$-$10^3$ Hz. For example, the electromagnetic component in installations with light radiators can affect the radiation process. Ohmic heating occurs in the radiator when the current flows. Energy is transferred to electrons that are in thermal motion. The electrons move under the action of the field at an average drift speed. Thermal excitation of atoms occurs in inelastic collisions, which pass into a state with lower energy and emit photons. In this case, the emission process of electromagnetic waves occur. When heat is transferred by radiation, part of the heat energy on the surface of the radiator is converted into the energy of electromagnetic vibrations (visible rays). Therefore, the external driving force (electromagnetic component), along with the temperature component, under conditions of resonant frequency coincidence, causes a change in its photometric and radiometric, colorimetric parameters. Work [12, 13] proved using of infrared heating for improving the quality of welded joints.

In Work [14], the authors used plates with dyes in the area of the weld. The plates convert the absorbed light into heat and the quality of the weld is improved.

Heating systems are used for agriculture. Various enterprises, such as oil refineries, use electric heating systems: submersible heaters, flanged submersible heaters, flow-through electric heaters, duct air heaters. The power of such heaters can be more than 5 MW, and the heating temperature is up to 800°C. Modern heating systems can use a resistive cable, skin effect system, or self-regulating cable with various insulations: InWarm Wool, InWarm Flex. Thus, using of skin effect systems - rod inductors and inductor-resistive heating systems required the development of a method for calculating the power loss for hysteresis [15].

Another way improving the efficiency of infrared radiators is using complex waveform current (CWC). For example, the scheme of bridge inverter to the resonant transformer of semiconductor complex [16] and concentrating systems with parabolic and mirror reflectors to produce powerful radiation fluxes [17]. However, the literature does not reflect the influence of CWC on the efficiency of devices with dark and light radiators, heating and electric heating systems.

The issues of effective operation of the technological load in the modes with CWC supply are not also reflected in the literature.

The research was made using the methods of theoretical foundations of electrical engineering, the theory of vibrations and the theory of electrical machines.

The purpose of the paper is research the modes of dark infrared heating elements, flexible heating tape, ceramic lamp heating when the parameters of electric modes change (amplitude and frequency supply voltage (DC)) and develop recommendations for selecting effective operation modes.

The authors have solved the following tasks:
- to develop a method for researching the physical models of installations with infrared radiators;
- to develop recommendations for choosing effective load operating modes based on the results of energy parameters measurements.

2. Methods and Instruments
The authors have used the following instruments for research:
- analyzer of electric energy quality - ANALYST 2060 for measurement electrical parameters;
- thermocouple integrated into the dark radiator for measurement of the temperature of the radiation surface;
- Testo 885-2 thermal imager for measurement of the temperature fields of the infrared radiator.

Based on the research results, we obtained files of radiometric thermograms processed using the software of the testo 885-2 portable thermal imager. The thermal imager visualized the IR radiation (radiation power) from each point of the IR radiator and non-contact measured the surface temperature of its surface.

The experiments have been done using the physical models of the installations with dark and light radiators in two electrical modes: a normal mode with the current frequency of 50 Hz and a new mode with complex waveform current without a constant component.

In the normal mode, the physical model of installation consisted of a single-phase transformer 220/110V with NLTC and a load. In the new mode - the single-phase transformer, a saturation choke and the load.

As a load, the authors have used the following devices: a flexible heater tape (FHT), a ceramic lamp 150W and an incandescent lamp 100W. They have been individually connected to the load node. FHT are used for frost protection, heating and compensation of heat loss various technological equipment: pipelines, heat exchangers, tanks, etc.

The main parameters of the FHT: voltage – 220V, power – 0.05kW, heater length – 2.6 m, width – 23 mm, thickness – 3.3 mm, maximum surface temperature – 60 °C, heat dissipation – 40 W/m.

Saturation choke is used to regulate of the supply voltage (current) shape.

### 3. Results and Discussion

Tables 1-6 show the operation parameters of the installations and the individual parameters of the load in two different modes. In works [11, 15], we have proved positive physical and technological effects for installations with dark and light radiators powered by CWC. For example, the output of photons from the surface of the diffuser increased at the same value of color temperature, the illumination and light flux increased for light radiators [11]; the speed of surface temperature rise increased for different types of dark radiators [15]. However, individual parameters of dark and light radiators were not considered.

The analysis of the results show us that the operation parameters of the installations get better in the new mode powered by CWC: power factor of the installation with the light radiator improved from 0.405 to 0.880, with the infrared ceramic lamp from 0.45 to 0.90 and with the flexible heating tape from 0.260 to 0.708.

The individual parameters (power factor) of the researched radiators do not get worse in the new mode and have high values as in the normal mode: light radiator – 0.97; infrared ceramic lamp – 0.97; flexible heating tape – 0.83. These results allows us to draw conclusions about the feasibility of using the new mode powered by CWC for improving the efficiency of installations.

Figures 1 and 2 show waveform and harmonics spectrum of the supply voltage for the installation with ceramic lamp. They have been obtained from the side of the transformer's primary winding in the new mode. It has been proved, the harmonic composition of the voltage in the supply network does not deteriorate.

### Table 1. Parameters of the installation with the light infrared radiator (incandescent lamp 100W).

| Electrical modes | Network power | Power factor | Voltage in the load node, V |
|------------------|---------------|--------------|-----------------------------|
|                  | Active, kW    | Reactive, kvar | Complex, kVA |                      |
| Normal mode: alternating current, 50 Hz | 0.047 | 0.106 | 0.116 | 0.405 | 115.0 |
| New mode: CWC without constant component. | 0.037 | 0.0198 | 0.042 | 0.880 | 115.0 |
### Table 2. Individual parameters of the load with the light infrared radiator (incandescent lamp 100W).

| Electrical modes                      | Load power | Power factor | Voltage in the load node, V |
|---------------------------------------|------------|--------------|-----------------------------|
| Normal mode: alternating current, 50 Hz | 0.031      | 0.0078       | 0.032                       | 0.97            | 115.0           |
| New mode: CWC without constant component | 0.031      | 0.0078       | 0.032                       | 0.97            | 115.0           |

### Table 3. Parameters of the installation with infrared ceramic lamp, 150W

| Electrical modes                      | Network power | Power factor | Voltage in the load node, V |
|---------------------------------------|---------------|--------------|-----------------------------|
| Normal mode: alternating current, 50 Hz | 0.053        | 0.105        | 0.118                       | 0.45            | 115.0           |
| New mode: CWC without constant component | 0.044        | 0.021        | 0.049                       | 0.90            | 115.0           |

### Table 4. Individual parameters of the load with infrared ceramic lamp 150W

| Electrical modes                      | Load power | Power factor | Voltage in the load node, V |
|---------------------------------------|------------|--------------|-----------------------------|
| Normal mode: alternating current, 50 Hz | 0.0378     | 0.00964      | 0.039                       | 0.97            | 115.0           |
| New mode: CWC without constant component | 0.0378     | 0.00964      | 0.039                       | 0.97            | 115.0           |

### Table 5. Parameters of the installation with flexible heating tape 50W

| Electrical modes                      | Network power | Power factor | Voltage in the load node, V |
|---------------------------------------|---------------|--------------|-----------------------------|
| Normal mode: alternating current, 50 Hz | 0.027        | 0.099        | 0.103                       | 0.26            | 115.0           |
| New mode: CWC without constant component | 0.017        | 0.0169       | 0.024                       | 0.708           | 115.0           |

### Table 6. Individual parameters of the load with flexible heating tape 50W

| Electrical modes                      | Load power | Power factor | Voltage in the load node, V |
|---------------------------------------|------------|--------------|-----------------------------|
| Normal mode: alternating current, 50 Hz | 0.011      | 0.0072       | 0.0132                      | 0.83            | 115.0           |
| New mode: CWC without constant component | 0.011      | 0.0072       | 0.0132                      | 0.83            | 115.0           |
4. Conclusions
The authors have experimentally confirmed that using CWC allows getting the following positive effects:
- installations with light and dark radiators, installations with the electrical heating system and installations with heating systems can operate at a lower level NLTC (OLTC) of the transformer and high power factor (by reducing the inductance of transformer windings);
- changing the radiation spectrum of light radiators,
- regulating the speed of temperature rise of dark radiators [11, 15].

The individual parameters of installations with dark and light radiators do not deteriorate when powered by CWC.

Research of operating modes of installations with dark and light infrared radiators of different types has proved the feasibility of using an additional frequency control channel (frequency spectrum) in automatic control systems of installations.

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