Research of energy characteristics of frequency-regulated electric drive

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Abstract. The paper considers the urgency of the research problems of the inverter as a part of the frequency converter. Experimental studies on the influence of the nature of the load on the structure of the distribution of power consumption are used. The authors described virtual models, allowing for analysis of changes in the cardinality of the inverter-factor when using it on an active-inductive load. According to the results, there are research conclusions to determine the relationship between the current form in the DC-link constant voltage and the mode of operation of the induction motor.

1. Introduction

The process of inverting direct current (DC) consists in the use of semiconductor switches connecting the load resistor to the DC power source that provides the current reversal in the load. This creates the possibility for power receivers of the alternating current, fed from the primary electrical energy source of DC.

A standalone inverter is a converter in single-phase or multiphase alternating current (AC), whose frequency is determined by the control system, the magnitude and the form of output voltage depend on the nature and parameters of the load. Unlike the dependent of an inverter, the frequency of which is determined mains frequency, the output of the autonomous inverter receives alternating current of any frequency, and voltage continuously varies from zero to maximum allowable values [1].

The autonomous voltage inverter (AVI) finds wide application in transducer technology; it is also called the universal module of electric energy conversion. Regulators of alternating voltage, direct frequency converters, active filters, voltage and current compensators of reactive power are made on its basis [2]. Figure 1 shows a simplified diagram of the three-phase bridge AIN with the use of IGBT-transistors.
Depending on the application, the AVI discusses various ways of obtaining output values of sinusoidal current and (or) voltage. Let us consider the inverter of the variable active-inductive load, in particular an asynchronous motor (AM). In this case, the AVI can be considered as a sinusoidal current source as its size and shape determine the characteristics of the rotating magnetic field, fundamentals of multiphase electromechanical transducers. Under the observance of basic terms of creation of the work field, AM practically does not differ by the description from the engine plugged in the three-phase network of power supply with standard parameters. To perform these functions, the power supply of the inverter is possible:

- from the independent source of constant voltage (DC voltage network, generator, battery);
- from the AC mains through the rectifier unit, which is part of the frequency converter (FC).

The method of supply from the AC mains has been widely applied, that is, the work of the inverter, in the frequency converter, providing regulation of voltage and frequency at the output of the AVI, depends on the set control law. In industry the drive system FC-AM is widely used, which have a good combination of starting and adjustment properties with the possibility of automation in the production process.

Producers of converters, in particular FC, are interested in providing certain technical and economic advantages that increase the attractiveness of the introduction of these products into production. One such indicator is the power factor of the FC, the value of which most manufacturers indicate as very high: 0.96...0.98. This implies that the active-inductive load, in particular an asynchronous motor with a squirrel cage rotor, practically does not use reactive power from the external electrical network. It can be assumed that the drive with the AVI somehow generates reactive power independently of the external network; then, there is a power supply fed to the inverter to be considered according to the first variant from an independent source of constant voltage. Only this can explain such high rates of power factor when working on the active-inductive load.

However, it is well-known that the work of the inverter has a significant negative impact on the quality of electricity in the network, from which it receives electricity. At the same time, manufacturers recommend the use of different types of filter elements (built in the FC and additional units) to reduce the influence of higher harmonics, arising when the inverter is operating, the input voltage is sinusoidal [3]. The task of reducing harmonic distortion is especially important in prospective power supply systems with distributed generation facilities [4...7].

Such dual approach to the problem of power consumption structure is primarily due to commercial considerations, and this raises doubts about the validity of such characteristics. First of all, there is no method of determining the inverter power factor declared by the manufacturer, as well as in any circuit solutions parameters, which hardware is necessary to carry out these measurements. It is possible to establish conditions under which the rated power factor value will be somehow confirmed. Moreover, individual consumers of drive systems FC-AM note a very high cosine value close to 1. However, the facts that the measurements were conducted under any circumstances, how these results have come are not additionally reported [8...10].
To determine the effect of the nature of the load on the work AVI, it is necessary to conduct experimental and modelling studies of the system FC-AM. This will provide independent reliable enough results to conduct an objective analysis of the operation modes of the system. The experiment was carried out on laboratory installation, which allows investigating the operating conditions of FC-AM. As a virtual simulation system, the MatLab system is widely used.

2. Experimental study of the system FC-AM.
Figure 2 shows the results of the experiments corresponding to the change in the AM load during operation directly from the mains (Fig.2A), and FC (Fig.2B).

The value of power factor \( \cos \varphi \) varies within reasonable limits (0.35…0.53) for low power machines (up to 1kW). The resulting dependences of the power factor on the load are typical, and therefore, regardless of the mode of supply, active-reactive power has been consumed from the network.

Figure 3 shows the results of studying the structure of the power consumption when the frequency is changed and load moment is the same.

Analysis of the obtained characteristics shows that the frequency change does not greatly affect the power factor, and hence the system of the FC-AM always consumes reactive power from the external power supply network. Modeling of the system was carried out to determine the operating conditions of the DC component of the frequency converter. Figure 4 shows the structure of the virtual model.

Model studies were carried out for different modes of the operation system of FC-AM. Asynchronous motors with the squirrel-cage rotor have nominal parameters: 90 kW, 380 V, 1500 rpm. The main direction of the research is obtaining information about the operation of the DC link.
Figures 5, 6 show the characteristics of the AD and the FC when operating in the nominal mode.

**Figure 5.** Engine performance when powered from the FC (f=50 Hz).

**Figure 6.** Characteristics of the DC link FC (f=50 Hz).

The received characteristics of the AM when powered from the drive correspond to the task and completely reflect the operation process at a frequency of 50 Hz.

The view of current dependency suggests that if there is significant inductance in the load, there is the delay of the current pulses and they overlap each other. When this measure influence the nature of the load on the job link and DC reactive component power consumption, it is proposed to hold the largest pulse current rise (βi).
Figure 7. The characteristics of the DC link FC (f=35 Hz).

In the example in figure 7, there are the characteristics of the DC link when the AM is at a frequency of 35 Hz and under rated load. Obviously, the external current pulsations remain the same (about 50 A), changing only the period of oscillation and, hence, value $\beta_i$. The simulation results at different frequencies are presented in table 1.

| Frequencies, Hz | 50  | 35  | 15  |
|----------------|-----|-----|-----|
| $\beta_i$, c   | 0.005 | 0.007 | 0.021 |

To determine the effect of the nature of the load, the ratio of active and reactive power of the system, experiments were performed, simulating different modes of FC.

Figures 8, 9 show the simulation results with different ratios of the active-inductive load. The results showed that the edge of current pulse is very late due to the nature of the load, the ratio between active and reactive components of the load. Analysis of the characteristics has determined the existence of a relationship between the power factor and the characteristics of the DC link.

Figure 8. The characteristics of the DC link FC (P=38 kW, Q=55 kVAR).
It is obvious that the change of the ratio between active and reactive power, the characteristics of the DC link are modified greatly. If the reactive power is much greater than the active, in the schedule of distribution there is a negative component of the current flowing in the DC link (figure 8), which compensates for the excess reactive power. When the capacity balance (figure 9) negative current component is negligible, its presence may be explained by the inertia of the system. The complete absence of the negative component currents in DC voltage levels (figures 6, 7) may occur when observed with significant predominance of active power. The results of the study are shown in table 2.

| cos $\varphi$ | 0.566 | 0.716 | 0.768 | 0.792 | 0.813 |
|--------------|-------|-------|-------|-------|-------|
| $\beta_i, c$ | 0.004 | 0.0037 | 0.0035 | 0.0034 | 0.003 |

With the increase of the power factor of the steepness, the rise front of the current also increases. The limiting case corresponds only to the resistive load included in AVI (figure 10).

In this characteristic, there is no element of growth ($\beta_i=0$); the current pulses have a rectangular shape, which corresponds to pulse width modulator AVI.

3. Conclusion.
Experimental and modeling studies have shown that in all operating modes, the FC-FM consumes active and reactive power. The steepness of the rise front of the current determines the amount of reactive power that is consumed from the external network AVI when working on active-inductive load.
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