Influence of an Electric Drive with Periodic Load on Voltage Quality

A. Ziuzev, A.Nakataev
Department of Electric drives
Ural Federal University
Yekaterinburg, Russia
a.m.zyuzev@urfu.ru,
aan050898@mail.ru

S. Shelyug
Department of Automated electrical systems
Ural Federal University
Yekaterinburg, Russia
s.n.shelyug@urfu.ru

V. Ippolitov
Department of Energy and transport
Russian State vocational Pedagogical University
Yekaterinburg, Russia
suchi6624@yandex.ru

2021 28th International Workshop on Electric Drives: Improving Reliability of Electric Drives (IWED) | 978-1-6654-1456-2/21/$31.00 ©2021 IEEE | DOI: 10.1109/IWED52055.2021.9376368

***Abstract*—The paper presents a computer simulation of the operation of three independent electric drives with a periodic load, connected to a common power supply network. Two cases are considered - operation of electric drives in one phase and in different phases. An analysis of their impact on the electrical supply network is carried out, the results are compared with the permissible Russian standards. An analytical optimization method based on the analysis of power graphs of electric drives with periodic load was considered. The article contains an overview of possible methods for regulating the working phase of the mechanism.**

***Keywords*— AC motors, Load modeling, Energy consumption, Energy efficiency, Fuel pumps, Variable speed drives**

I. Introduction

Currently, there are a large number of consumers whose technological process is represented by electric drives with periodic load. For example, there are water supply systems consisting of a sequence of pumping stations [1], [2]. In the oil industry, pumping stations are used to extract oil. The so-called bushes, which include several rocking units, are located in areas remote from humans. The technological process involves a rare presence of a person to check the technical condition of the equipment. In addition, such remoteness from settlements imposes restrictions on power supply issues. So, the only source of power for the bush can be a diesel generator. Pumping units are quite powerful consumers with periodic load, they can have a significant impact on the electrical network, and therefore on each other. Failure of installations and shutdown of the technological process can bring significant financial losses. This makes it important to study the influence of all installations on the quality of the electrical network of the enterprise.

II. Methods of Evaluation Drive Mode to the Electric Network

Power graphs allow evaluating the operating mode of the drive. For further data processing by means of automation, it is advisable to present the power graphs obtained during the work in an analytical form.

If it is given as an array of data, then it can be described using elementary functions.

A. Fourier series

A complex harmonic oscillation resulting from the imposition of a finite number of simple harmonics has the form (1).

$$f(t)=\frac{a_0}{2}+\sum_{k=1}^{\infty}(a_n \sin(\omega t\cdot k)+b_n \cos(\omega t\cdot k)), \quad (1)$$

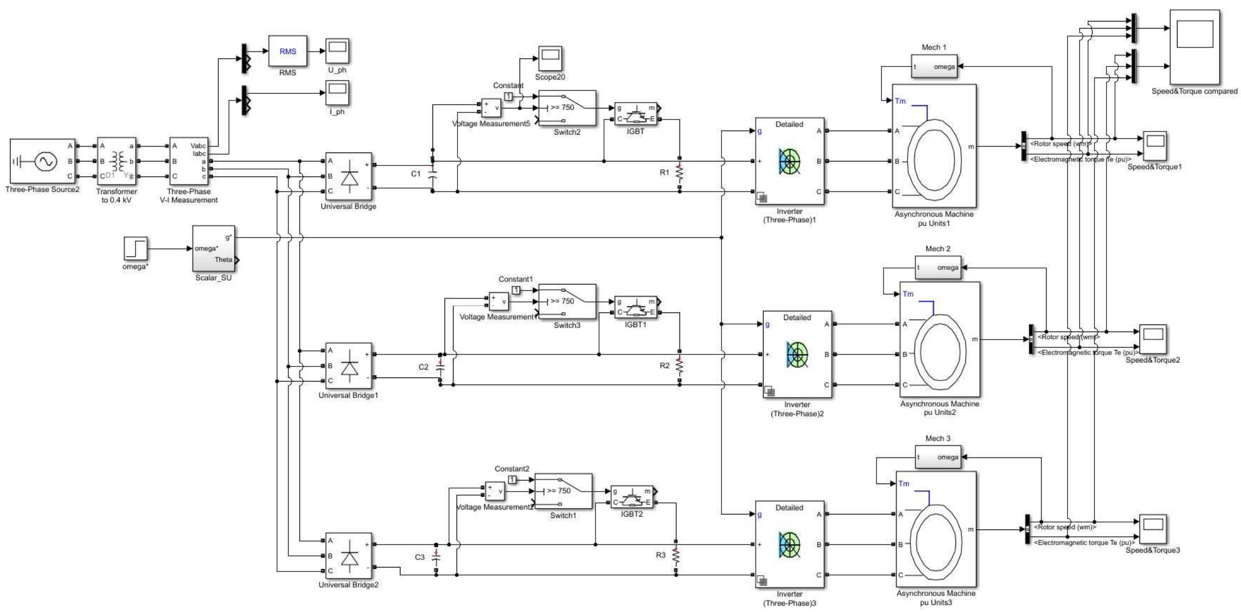

Figure 1. General view of the model

978-0-7381-4443-6/21/$31.00 ©2021 IEEE

Where a_0 - constant component, ω - angular frequency, k - harmonic number.

B. Polynomial approximation

Another way to get a function from a graph is polynomial approximation. The general view of the approximation is presented by expression (2).

$$f(t)=\sum_{n=0}^{N} a_n \cdot t^{n}, \qquad (2)$$

III. Model of Electric Network of the Plant and the Electric Drive with a Periodic Load in

Known methods for modeling mechanical loads using an asynchronous motor-generator with vector control [3]. Simulation is carried out in the Matlab / Simulink program using the SimPowerSystems library [4], [5]. As a model, a power supply scheme that is quite common for many industrial enterprises is considered. There is a limited power supply in the form of a 10 / 0.4 kV network step-down transformer. Consumers at the enterprise are connected to the secondary winding. A load consisting of three independent controlled electric drives is considered. The general view of the model is shown in Figure 1.

A. Electric drive model

An electric drive is presented in a form of an asynchronous motor, parameters of which are written in relative units.

B. Model of inverter

A motor is connected to a three-phase inverter. Its model consists of an autonomous voltage inverter, a braking resistor, a diode rectifier made according to the Larionov scheme, and a capacitor. An initial voltage of the capacitor is equal to the nominal, since processes of charging the capacitor are not considered in this work. The transistors are controlled by the control system. A scalar open loop control system is used.

C. Model of working mechanism with periodic load

The operating mechanism model represents a sine function with a period "T_sin" and an amplitude equal to 0.5. The initial phase "phi" in degree is of particular importance for this study. All three models of electric drives are completely identical, except for the initial phase value. So, for the first drive, the initial phase is set by the "phi_0" parameter (Fig. 2), for the second drive "phi_1" and for the third drive "phi_2". At the input model receives motor speed signal, the output signal has a load torque. It is important to

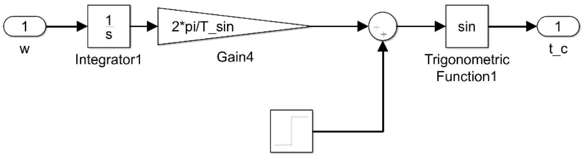

Figure 2. The structure of the model of the load mechanism for the first electric drive

note that the load is not symmetrical about zero, which is typical for most mechanisms with periodic loading.

IV. Simulation of the Operation of Electric Drives with Different Phase Values

Simulation of the operation of a group of electric drives is carried out according to the following steps - after bringing the speeds of all motors to the rated parameters, at the time t = 6 s, a load is applied.

A. Operation of electric drives in the same phases

In this case, the parameters "phi_0", "phi_1", "phi_2" are equal to zero. As you can see, all three electric drives operate in the same phase (Fig. 3). At the same time, there is a voltage drop to values of 203 V when the motors are operating in motor mode (Fig. 4). This is due to the fact that at the same times the motors increase their consumption, thereby loading the electrical network. In other cases, when there are more electric drives in one group or a lower power transformer is used, the voltage drop may exceed 10%, permissible according to Russian standards. In addition, this kind of power graph has a negative effect on the transformer, reducing its service life.

B. Operation of electric drives in different phases

In this case, "phi_0" = 0, "phi_1" = 120, "phi_2" = 240. As you can see, all three electric drives operate in different phases (Fig. 5). The voltage drop for this type of load (Fig. 6) is set at about 214 V, which is less than in the first case. An increased consumption of the motor during operation in motor mode spreads over time, the power graph is smoothed out.

C. Operation of electric drives with different load period

Value of «T_sin» was changed for every mechanism in a model. (Fig. 7 and 8). This situation can be encountered quite often. The difference in periods is due to operating conditions of each mechanism.

V. Possible Ways to Optimize the Influence of Periodic Loading on the Electrical Network

Using the analytical representation of power graphs of electric motor (1), (2), it is possible to calculate the optimal phases of operation for a variety of electric drives with different periods and phases of operation (3). It is important to note that the optimization of a drive group with periodic load with different periods is only possible using analytical evaluation methods.

$$F(P_{\mathrm{RMS}}\text{-}P_{\mathrm{AV}})\rightarrow min; \qquad (3)$$

$$P_{\mathrm{RMS}}=\sqrt{\frac{\sum_{i=1}^{n} P_i^2}{n}}; \qquad (4)$$

$$P_{AV}=\frac{\sum_{i=1}^{n} P_i}{n}, \qquad (5)$$

Where P_{RMS} – root mean squared power, P_{AV} – average power.

Minimization (3) is carried out by changing the phase of each graph. A visual representation of this minimization criterion is shown in Figure 9. Since an elementary sinusoidal function is used as the load, the criterion minimum points are the well-known values "phi_1" = 120 and "phi_2" = 240 (these parameters were used in Figure 5), at which the sum of the sine functions is equal to zero.

This can be achieved in two ways.

A. Sequential start of each mechanism with a time delay

This method can be achieved using a time relay. The method has the following advantages:

- Cheapness;
- Possibility to reduce energy consumption.

Disadvantages:

- The mechanisms are not ideal, and over time, the load curves shift in time, thereby depose the initial shift phase;
- It is required to stop the technological process;
- Before starting, an analysis of all power curves is required to select the optimal phase.

B. Adjusting of the speed reference

The known method of effective control of the sucker rod pump electric drive [7], [8] provided by smoothly adjusting of the speed reference.

Speed regulation can be carried out only in controlled electric drives. This method has the following advantages:

- Ability to maintain phase constancy (real-time monitoring of parameters);
- No need to stop a technological process.

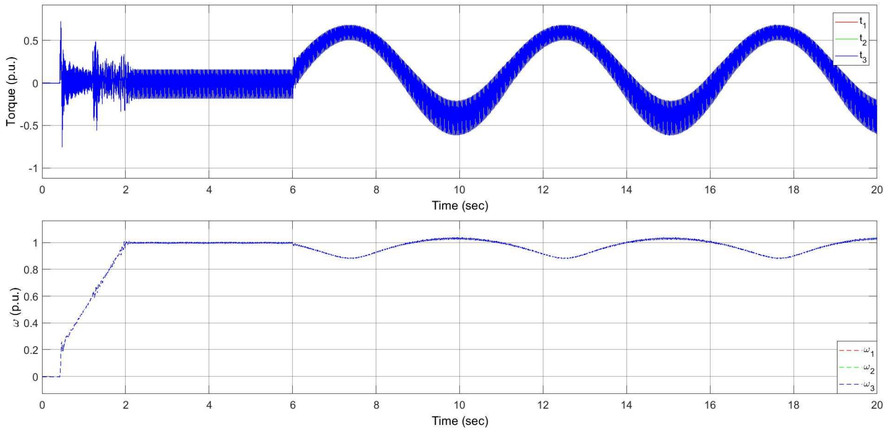

Figure 3. Graphs of torques and speeds of all electric drives in one phase of operation

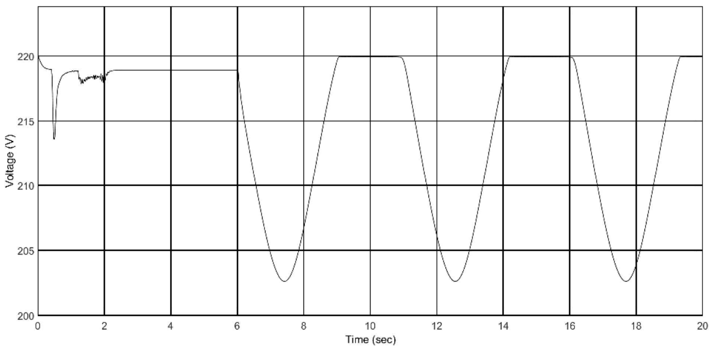

Figure 4. Graph of the root-mean-square phase mains voltage when the drives are operating in the same phases

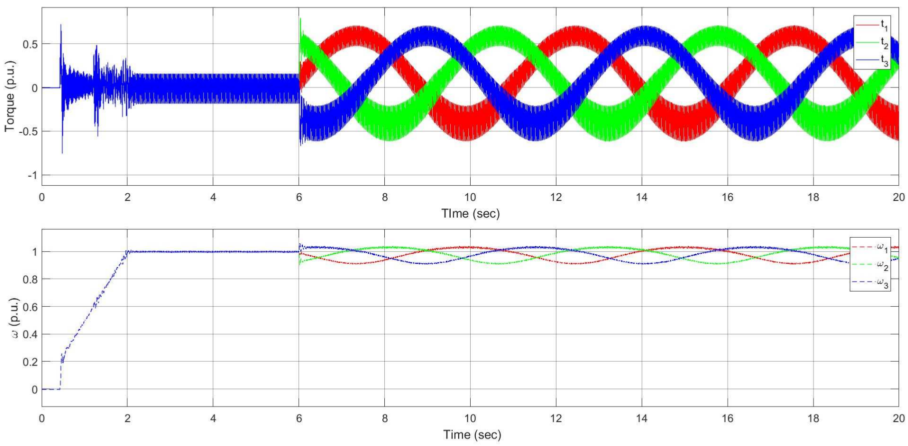

Figure 5. Graphs of torques and speeds of all electric drives with phases of operation equal to 0, 90 and 180

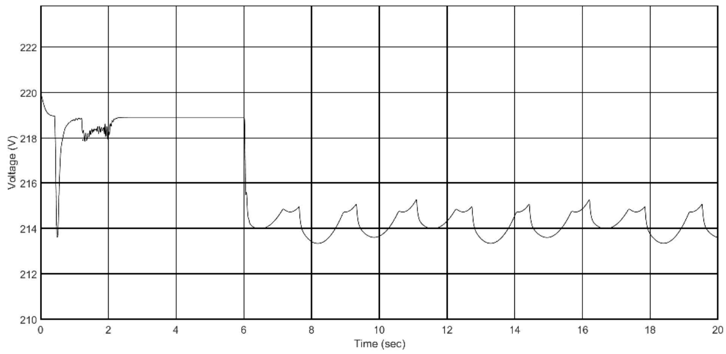

Figure 6. Graph of mains voltage with the phases of operation of electric drives equal to 0, 90 and 180

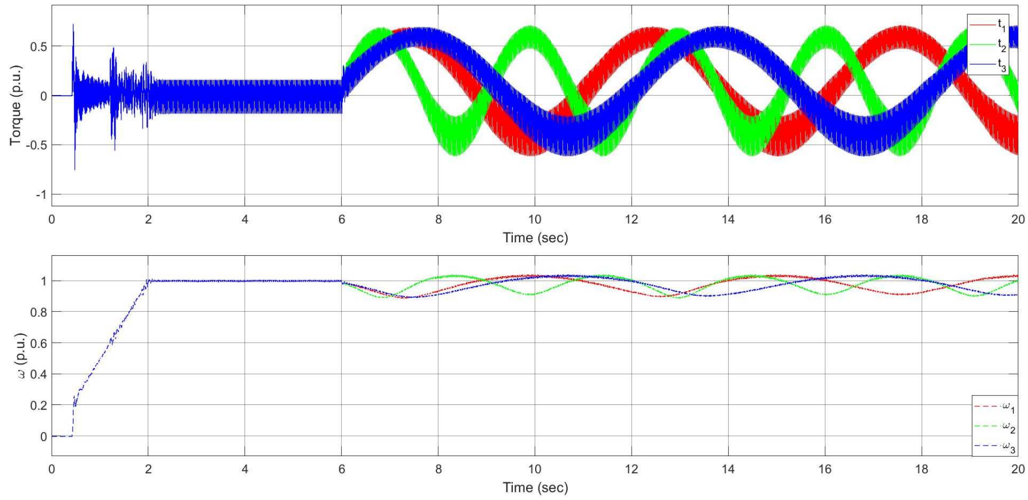

Figure 7. Graphs of torques and speeds of all electric drives with different periods

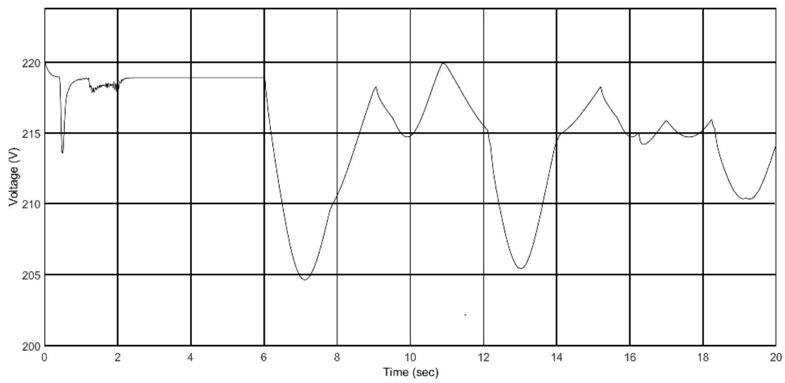

Figure 8. Graph of the root mean square phase mains voltage with different periods of operation of electric drives

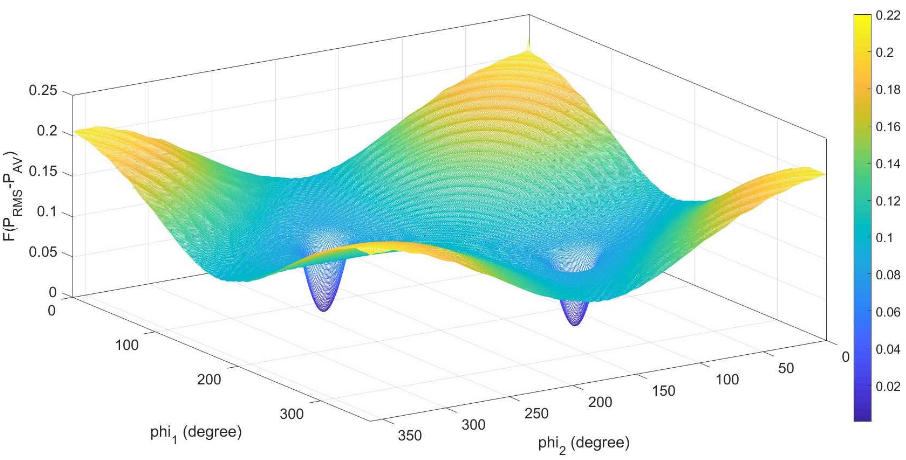

Figure 9. Dependence of the optimization criterion on the assigned parameters

Disadvantages:

- High cost (compared to the first method);

Thus, the second method is preferred.

VI. Conclusion

Analytical approaches to assessing the network load mode are considered.

A model of a plant's electrical network was synthesized, consisting of a power source of limited power and a group of independent electric drives with a periodic sinusoidal load.

A comparison is made of the effect of the operation of a group of electric drives on the mains voltage at different initial phases of the load. During the operation of mechanisms in one phase, a voltage drop exceeding the level permissible by Russian standards was noted, as well as the occurrence of power surges that have a negative effect on the transformer. Different initial phases significantly reduced the impact of these effects.

Comparison of the two methods for ensuring the phase shift has shown that the most preferable method is using a variable electric drive.

The analytical optimization method based on the analysis of the power curves of electric drives with periodic load showed the optimal phases of operation of each mechanism.

In the future, it is planned to create a regulator that analyzes in real time the power graphs of a group of electric drives with a periodic load and ensures the constancy of the optimal phases by the method of phase control by short-term speed reference correction.

References

[1] I.Elker, T.Kara, "Modelling and Simulation of Water Supply Systems for Feedback Control", Rev. Energ. Ren.: Power Engineering (2001), pp. 49-55, 2001.

[2] M. Rodic, K. Jezernik and M. Trlep, "Dynamic emulation of mechanical loads - approach based on nonlinear control," 2005 European Conference on Power Electronics and Applications, Dresden, 2005, pp. 10 pp.-P.10, doi: 10.1109/EPE.2005.219287.

[3] Z. Hakan Akpolat, G. M. Asher and J. C. Clare, "Dynamic emulation of mechanical loads using a vector-controlled induction motor-generator set," in IEEE Transactions on Industrial Electronics, vol. 46, no. 2, pp. 370-379, April 1999, doi: 10.1109/41.753776.

[4] Ануфриев И.Е. Matlab 7 / И.Е.Ануфриев, А.Б.Смирнов, Е.Н.Смирнова. СПб.: БХВ-Петербург, 2005. 1104 с.

[5] Черных И.В. Моделирование электротехнических устройств в Matlab, SimPowerSystems и Simulink / И.В.Черных. М.: ДМК Пресс; СПб.: Питер, 2008. 288 с.

[6] Валеев, Р.Г. Моделирование электрической сети напряжением 380 В с воздушными линиями в программной среде Matlab-Simulink / Р.Г.Валеев, А.В.Млоток, А.И.Сидоров, А.М.Ершов, // Проблемы энергетики. 2013. № 9–10. С. 116–128.

[7] A. N. Ladygin, D. D. Bogachenko, V. V. Kholin and N. A. Ladygin, "Method of Efficient Control of the Sucker-Rod Pump Electric Drive," 2020 27th International Workshop on Electric Drives: MPEI Department of Electric Drives 90th Anniversary (IWED), Moscow, Russia, 2020, pp. 1-4, doi: 10.1109/IWED48848.2020.9069584.

[8] Patent RF №RU 2 686 304 C1 Method of control of the jack pump frequency-regulated electric drive with the induction motor / Anatoly N. Ladygin, Dmitry D. Bogachenko, Nikolay A. Ladygin, Vladimir V. Kholin. Bulletin of inventions. 2019. № 5.