UDC 621.314

D. Kulagin, PhD.,
B. Chernetskiy

ANALYSIS OF MODES TRACTION FREQUENCY CONVERTER

Annotation: *Results of research of energy flows circulating through the traction Converter of frequency. The results obtained can be used in the synthesis and development of systems of automated control of traction power for a typical transport and load-lifting systems of electric drives.*

Keywords: *automatic control system, traction inverter, traction transmission, recuperation*

Д. А. Кулагин, канд. техн. наук,
Б. С. Чернецкий

АНАЛИЗ РЕЖИМОВ РАБОТЫ ТЯГОВОГО ПРЕОБРАЗОВАТЕЛЯ ЧАСТОТЫ

Аннотация: *Приведены результаты исследования энергетических потоков, циркулирующих сквозь тяговый преобразователь частоты. Полученные результаты можно использовать при синтезе и разработке систем автоматического управления тяговых электропередач для типовых транспортных и грузоподъемных систем электроприводов.*

Ключевые слова: *система автоматического управления, тяговый инвертор, тяговая электропередача, рекуперация*

Д. О. Кулагін, канд. техн. наук,
Б. С. Чернецький

АНАЛІЗ РЕЖИМІВ РОБОТИ ТЯГОВОГО ПЕРЕТВОРЮВАЧА ЧАСТОТИ

Анотація: *Наведено результати дослідження енергетичних потоків, що циркулюють крізь тяговий перетворювач частоти. Отримані результати можливо використовувати при синтезі та розробці систем автоматичного керування тягових електропередач для типових транспортних та вантажопідйомних систем електроприводів.*

Ключові слова: *система автоматичного керування, тяговий інвертор, тягова електропередача, рекуперація*

Statement of the problem. In the system of traction power traction Converter can perform the role of a source of voltage or current. The provision of a traction Converter of properties similar to the properties of an ideal voltage source (DC) is provided by the introduction of the internal control loops of feedback voltage or current of the Converter. The quality of the conversion of electrical energy one can assess the ability of the traction inverter to reproduce the change of control actions with minimal distortion [1 – 3]. When you build structures and traction control systems with frequency converters need to consider the electromagnetic transients, the nature of which is determined by the mode in which the traction Converter [4 – 6]. Therefore, such studies are relevant. Noteworthy features traction drive in comparison with industrial drive: often this is a standalone from a shared supply network of the device, and pulling the actuator is limited to the maximum torque and power to the drive shaft. The limitation of the maximum torque is primarily due to the requirements defined by power electronics (maximum current of the power Converter); limit the hyperbole capacity is determined by the onboard power source (engine, buffer storage).

The purpose of the study. The study of energy flows in a traction drive system to improve the management efficiency of the traction Converter.

The main material. At no load induction motor consumes current, conventionally divided in the theory of electrical machines [7] for the reactive component, which is determined mainly by the magnetizing current and the active component, which is determined by the time of idling and loss in the engine. The reactive component in the system of the Autonomous voltage inverter – asynchronous motor closed contour: the filter capacity of the inverter and motor windings, or in accordance with the selected equivalent circuit, the magnetizing circuit. The active component of current flows through the rectifier. In addition, the rectifier provides charging of the filter capacitor, compensating for the loss of flow through the filter reactive current component and leakage currents.

That is, flows through the rectifier, the total current determined by the load and the losses in the Converter. In the generator mode of the induction motor changes the direction of the active current component that defines the following modes when braking, which are determined by the rate of change of frequency inverter (slip frequency), the magnitude of the primaries of mass and static moment on the motor shaft:

– the energy stored in the rotor of the motor and the traction elements transmission, the braking process is completely dissipated in the active resistance of the windings of the motor and the traction elements of the Converter without exceeding the values of currents and voltages in excess of the permissible;

– the energy stored in the rotor of the motor and the elements of the traction power returns to the power source, causing an increase in the voltage on the filter capacitor and the currents through the keys of the traction inverter voltage in excess of acceptable values [8].

The first mode is a characteristic for the case of slow changes in the frequency of the stator with a significant static torque given to the motor shaft [9]. The second mode, as a rule, emergency and requires special measures to prevent failure of the circuit elements. This mode occurs when significant primaries masses and rapid changes of frequency inverter, which causes a sharp increase in the slip [10]. The active component of the stator current that is proportional to the slip increases the charge of the filter capacitor, which leads to saturation of the motor and further growth of the reactive component of the stator current. During recovery in the traction system on the basis of the Autonomous voltage inverter can distinguish four distinct phases, as shown in Fig. 1.

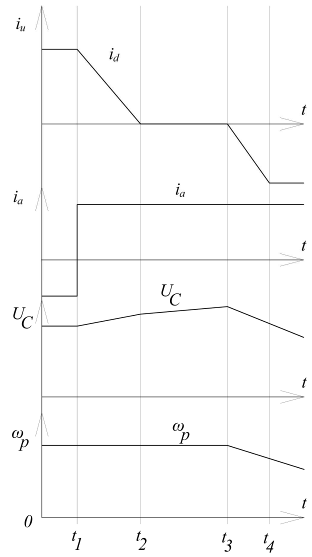

Fig. 1. The selection characteristic areas of traction power in the process of recuperation:
i_u – current of the inverter; i_a – the active component of the current; U_C – voltage filter capacitor; ω_p – frequency

In this case we assume that the variation of slip occurs abruptly at time t_1. Thus, the active component of the stator current (current of the traction inverter) i_a changes sign. Then the filter capacitor capacity $C_ф$, decreasing charging current of the rectifier i_d and the current of the inverter i_a.

The section from time t_1 to time instant t_2 the fair the following system of equations:

$$\begin{cases} \dfrac{di_d}{dt} + \dfrac{i_d}{T_d} = \dfrac{1}{L_d} \cdot \left[U_1(t) - U_\phi(t) \right]; \\ U_\phi(t) = \dfrac{1}{C_\phi} \displaystyle\int_{t_1}^{t_2} (i_d + i_a)\, dt, \end{cases} \tag{1}$$

where T_d – is the time constant of the filter of the DC traction Converter with an inductance;

$U_ф(t)$ – the function of changing the voltage on the filter capacitor with time;

$U_1(t)$ – function voltage change at the output of the traction rectifier with time.

In most cases, part of the participation of the rectifier in the charging of the capacitor for practical calculations can be neglected due to the fact that the descending current from time t_1 to time t_2 is considerably less time no-current pause from time instant t_2 to time instant t_3. The section from time t_2 until time t_3, the capacitor is charged by a current of the traction inverter. We also believe that the slip of the motor is unchanged. Then the charging current of the capacitor is constant. The influence of the ripple current due to reactive energy exchange between the windings of the traction asynchronous motor and the capacitor, the voltage on the capacitor is neglected due to their smallness.

Taking into account the foregoing and on the basis of the system of expressions (2) we write the following:

$$U_\phi(t) = \frac{I_a}{C_\phi} t + U_{C0}, \tag{2}$$

where U_{C0} – is the initial value of the voltage on the filter capacitors.

From the expression (2) can determine the condition for determining the permissible value no-current pause $T_{\max}$:

$$T_{\max} \le \frac{U_\phi^{\max} - U_{C0}}{I_a^{\max}}, \tag{3}$$

where $U_\phi^{\max}$ – the maximum allowable value of the voltage on the filter capacitor; $I_a^{\max}$ – maximum current of the inverter during recovery.

The section from time point t_3 to time point t_4 turns on the traction inverter starts operation.

When installed aboard the complex electrical energy storage it is possible to regulate the amount of current consumed by the traction synchronous generator, enabling a storage device in the following modes:

– the mode in which the storage device is discharged in the traction electricity since the launch of the power plant;

– the antialiasing mode of the current consumed by the traction synchronous generator. In this mode, the accumulator is charged during braking electrical complex, and when driving on the coast. The discharge drive occurs as the electrotechnical complex of a certain current setpoint, providing a more uniform shape of the current in the traction power supply. Given the long-standing mode of operation, the traction power of the generator can be obtained via the so-called free power diesel. In operation, electrical complex each of these quantities varies continuously. Additional automatic control of a diesel engine with a power of rejecting at least one of the three quantities (power of the traction generator, the effective power of a diesel engine or the power required for the operation of auxiliary drives of machines and equipment), ensures the change of the excitation of the traction generator in such a way as to establish compliance with the specified capacity steady-state operating conditions of electrical engineering complex. This ensures full utilization of diesel engine power and not allowed to overload.

When pulling electrical engineering complex of the traction generator consumes significant current. In such a process to reduce the load on the generator and provide some form of current in the traction network, it is appropriate to connect the drive energy.

Conclusions

The results of a study of energy flows circulating through the traction inverter. The obtained results may be used in the synthesis and development of automatic control systems, traction power model for transport and lifting. When installed aboard the complex electrical energy storage it is possible to regulate the amount of current consumed by the traction synchronous generator, ensuring the operations of the storage device during all modes of operation of the traction electric drive, while providing uniform loading of power plants and resource saving.

References

1. Kulagin D.O., Proektuvannya sistem keruvannya tyagovimi elektroperedachami motorvagonnikh poyizdiv : monografiya [Designing of Control Systems of Traction Electrical Transmission EMU-trains], (2014), Berdyans'k, Ukraine, *FOP Tkachuk O. V.*, 154 p. (In Ukrainian).

2. Kulagin D.O., Sposib aproksimatsiyi krivoyi namagnichuvannya tyagovogo asinkhronnogo dviguna [Method of Approximation of a Curve of Magnetization Asynchronous Traction Motor], (2013), Zaporozhye, *Elektrotekhnika ta Elektroenergetika,* No. 2, pp. 66 – 70 (In Ukrainian).

3. Ali Emadi, (2004), Energy-Efficient Electric Motors: Selection and Applications, New York, *Marcel Dekker*, 424 p.

4. Boldea Ion, and Syed A. Nasar, (2002), Induction Machines Handbook, *CRC Press Boca Raton*, London, New York, Washington, D.C, 845 p.

5. Choi J., Boroyevich D., and Lee F., (1999), A Novel ZVT Three-phase Inverter with Coupled Inductors, London, *Power Electronics Specialists Conference, 30th Annual IEEE*, Vol. 2, pp. 975 – 980.

6. Ferreira De Jesus J.M., (1988), A Model for Saturation in Induction Machines, London, *Energy Conversion, IEEE Transactions*, Vol. 3, Issue 3, Sep., pp. 682 – 688.

7. Keyhani A., and Tsai H., (2009), IGSPICE Simulation of Induction Machines with Saturable Inductances, London, *IEEE Transactions on Energy Conversion,* March 2009, Vol. 4, No. 1, pp. 118 – 125.

8. Petrov L.P., (1980), Die Modelierung der Energieverluste in Asynchronmotoren unter Beachtung der Elektromagnetischen Ubergangsprozesse, Berlin, *Elektrik*, Vol. 34, No. 7, pp. 375 – 379.

9. Wasynczuk O., Sudhoff S.D., Corzine K.A., Tichenor J.L., Krause P.C., Hansen I.G., and Taylor L.M., (1998), A Maximum Torque Per Ampere Control Strategy for Induction Motor Drives, *IEEE Transactions on Energy Conversion*, London, Vol. 13, No 2, pp. 163 – 169.

10. Yuan X., Barbi I., (2000), Fundamentals of a New Diode Clamping Multilevel Inverter, London, *IEEE Transactions on Energy Conversion*, Vol. 15, No. 4, pp. 711 – 718.

Received 29.05.2015

References

1. Кулагін Д. О. Проектування систем керування тяговими електропередачами моторвагонних поїздів : монографія [Текст] / Д. О. Кулагін. – Бердянськ : ФОП Ткачук О. В., 2014. – 154 с.

2. Кулагін Д. О. Спосіб апроксимації кривої намагнічування тягового асинхронного двигуна [Текст] / Д. О. Кулагін // Електротехніка та електроенергетика. Запоріжжя : – 2013. – № 2. – С. 66 – 70.

3. Ali Emadi, (2004), Energy-Efficient Electric Motors: Selection and Applications [Text], New York, *NY: Marcel Dekker*, 424 p.

4. Boldea I., and Syed A. Nasar, (2002), Induction Machines Handbook [Text], *CRC Press Boca Raton:* London, New York, Washington, D.C, 845 p.

5. Choi J., Boroyevich D., and Lee F., (1999), A Novel ZVT Three-phase Inverter with Coupled Inductors [Text], *Power Electronics Specialists Conference, 30th Annual IEEE,* Vol. 2, pp. 975 – 980.

6. Ferreira De Jesus J.M., (1988), A model for saturation in induction machines [Text], *Inst. Superior Technical, Lisbon, Portugal, Energy Conversion, IEEE Transactions,* Vol. 3, Issue 3, Sep. 1988, pp. 682 – 688.

7. Keyhani A., and Tsai H., (2009), IGSPICE Smulation of Induction Machines with Saturable Inductances [Text], *IEEE Transactions on Energy Conversion,* March 2009, Vol. 4, No. 1, pp. 118 – 125.

8. Petrov L.P., (1980), Die Modelierung der Energieverluste in Asynchronmotoren unter Beachtung der elektromagnetischen Ubergangsprozesse [Text], *Elektrik,* Vol. 34, No. 7, pp. 375 – 379.

9. Wasynczuk O., Sudhoff S.D., Corzine K.A., Tichenor J.L., Krause P.C., Hansen I.G., and Taylor L.M., (1998), A Maximum Torque per Ampere Control Strategy for Induction Motor Drives [Text], *IEEE Transactions on Energy Conversion,* London, Vol. 13, No. 2, pp. 163 – 169.

10. Yuan X., and Barbi I., (2000), Fundamentals of a new Diode Clamping Multilevel Inverter [Text], *IEEE Transactions on Power Electronics,* Vol. 15, No. 4, pp. 711 – 718.

Kulagin
Dmitro Olexandrovich, candidate of technical Sciences, associates Professor, Zaporizhzhya national technical University (ZNTU), Senior Lecturer of the Department “Electrosupply of the industrial enterprises” of Zaporozhye national technical University, Zaporizhzhya, Ukraine.
E-mail: kulagindo@gmail.com

Chernetskiy
Bogdan Sergeevich, graduate student, Department “Electrosupply of the industrial enterprises” of Zaporozhye national technical University, Zaporizhzhya, Ukraine.
E-mail:
Bogdan_chernetskiy@yandex.ru