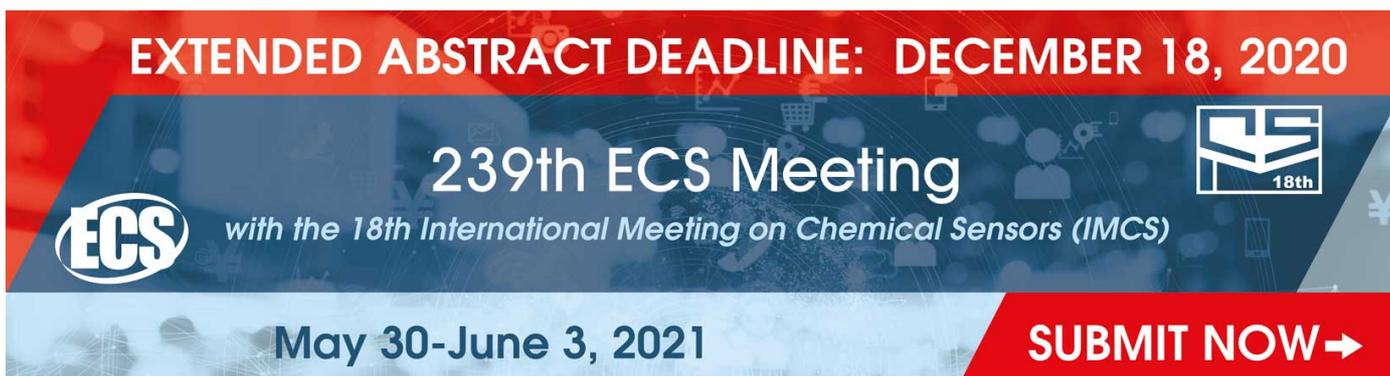


PAPER • OPEN ACCESS

Operational algorithm of logical control system for electric drive of a lifting installation based on a doubly-fed induction machine

To cite this article: V Yu Ostrovlyanchik and I Yu Popolzin 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **865** 012008

View the [article online](#) for updates and enhancements.



EXTENDED ABSTRACT DEADLINE: DECEMBER 18, 2020

239th ECS Meeting
with the 18th International Meeting on Chemical Sensors (IMCS)

May 30-June 3, 2021

SUBMIT NOW →

The banner features a red top section with white text, a dark blue middle section with white and light blue text, and a light blue bottom section with a red right-side button. The ECS logo is on the left, and a stylized 'ECS' logo with '18th' is on the right. The background includes faint icons of a shopping cart, a person, and a yen symbol.

Operational algorithm of logical control system for electric drive of a lifting installation based on a doubly-fed induction machine

V Yu Ostrovlyanchik and I Yu Popolzin

Siberian State Industrial University, 42 Kirova str., Novokuznetsk, 654 007, Russia

E-mail: eidoline@yandex.ru

Abstract. Using of a doubly-fed machine circuit is a promising way to upgrade existing electric drives of hoist installations based on wound-rotor induction motors. Power connection of induction motors according to the scheme of a doubly-fed machine with control of machine coordinates in the rotor circuit allows to increase the energy efficiency of the drive, organize the recovery of energy, which is usually uselessly dissipated in the rotor circuit, as well as increase the reliability of the drive. To achieve a wide range of speed change while maintaining the overload capacity of the machine by the torque, it is necessary to combine various methods for controlling the amplitude, phase and frequency of the auxiliary voltage on the rotor. These parameters are controlled by a logical control system. So it is necessary to develop an operational algorithm of the logical control system to organize this way of control. This paper is devoted to the development of the operational algorithm of the logical control system for the electric drive of a lifting installation based on a doubly-fed induction machine, which allows combining different modes of operation of the machine to achieve a wide range of speed control.

1. Introduction

Doubly-fed machine (DFM) in the general case is a wound-rotor induction motor (WRIM) with auxiliary voltage supply in a rotor circuit from an external source with the options to control the amplitude, frequency and phase of additional voltage [1].

The use of DFM in adjustable-speed drives has significant advantages over the use of WRIM with auxiliary resistors in the rotor circuit, since it allows controlling the flow of slip energy and achieving high energy efficiency. Nevertheless DFM operation in electric drive systems requires switching of its operation modes depending on the rotor speed. The switching of modes is carried out by the logical control system of the electric drive.

Since the modernization of complex technological complexes should not affect their operability [2], the use of a DFM scheme is the best way to modernize existing lifting systems based on WRIM.

In [3] it was shown that in order to achieve a wide range of DFM speed change it is necessary to combine its operation modes. A general algorithm of the drive functioning for this case was obtained in [4].



2. Electric drive structure

The algorithmic structure of the electric drive of a lifting installation with DFM was obtained in [6] and [6]. The structure shown in figure 1.

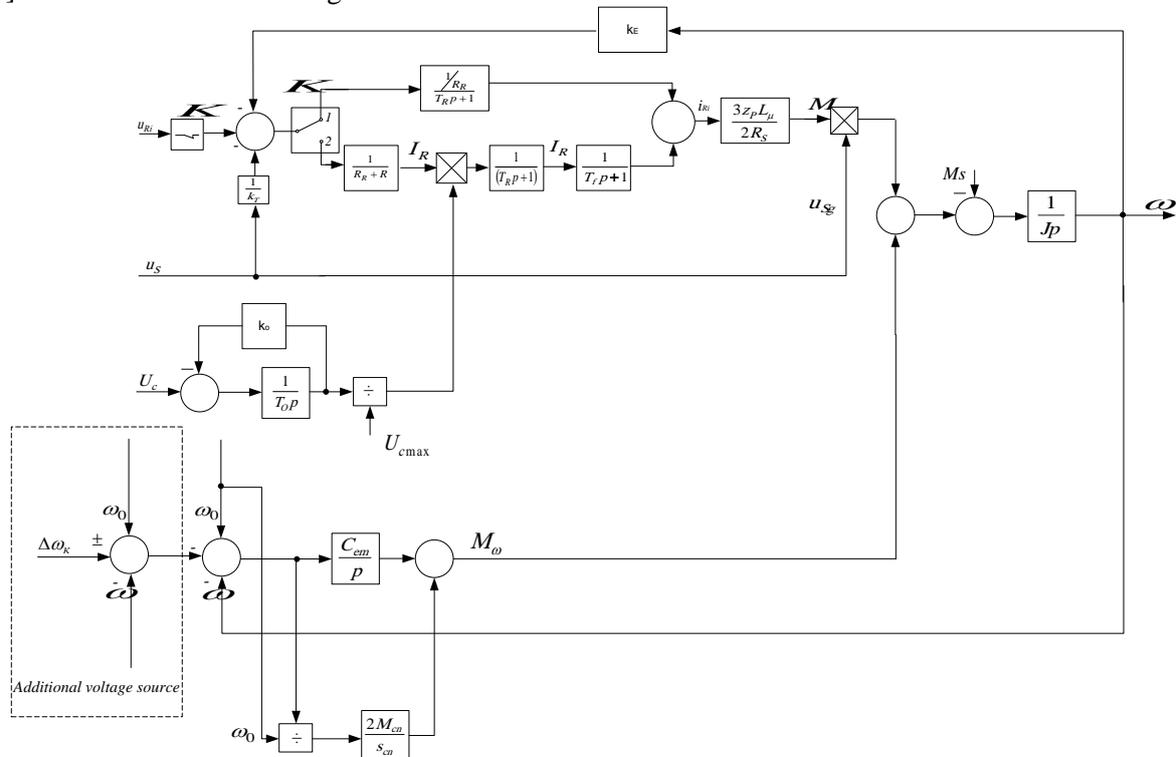


Figure 1. The algorithmic structure of the electric drive of a lifting installation with DFM.

Notation for figure 1: u_{Ri} - active component of the additional voltage on the rotor; R_R - rotor intrinsic resistance; T_R - electromagnetic time constant of rotor circuit; k_E - rotor EMF internal feedback coefficient; i_{Ri} - active component of rotor current; z_p - the number of pole pairs of the motor; L_μ - mutual inductance between the stator and rotor; R_S - stator intrinsic resistance; u_{Sg} - stator voltage (phase-to-neutral); U_C - control voltage of the additional active resistance in the rotor circuit; C_{em} - electromagnetic stiffness; M_{cn} - critical torque on the WRIM natural mechanical characteristic; s_{cn} - critical slip on the WRIM natural mechanical characteristic; k_T - WRIM transformation ratio; M - electromagnetic torque; M_c - load torque (static torque); J - the total moment of inertia of the mechanical part of the installation reduced to the rotor axis; ω - rotor angular velocity; ω_0 - synchronous angular velocity; $\Delta\omega_k$ - additional voltage frequency increment; K - a logical function that determines whether the drive operates in doubly-fed mode from a controlled voltage converter (CVC) or in a controlled current converter (CCC) mode [7].

Let us assume that position 1 of key K corresponds to logical 0, and 2 corresponds to logical 1. In this case, the DFM operation modes are determined by the following expressions:

$$\begin{cases} K = 0 - CVC ; \\ K = 1 - CCC. \end{cases} \quad (1)$$

We introduce the following notation: ω_n - rated speed of the DFM on a natural mechanical characteristic; ω_t - DFM speed set by the control system; $\omega_{cr} = 0,5\omega_0$ - speed corresponding to the switching from asynchronous to synchronous mode; A - maximum rate of change in the amplitude of the additional voltage on the rotor, V/s; U_R - effective value of the additional voltage on the rotor. It is possible to draw up rules for controlling the additional voltage on the rotor of the machine, based on

the analysis of the mechanical characteristics of the machine in various modes. The control rules assume that the working area of the DFM mechanical characteristics is divided into sections within the mechanical characteristics of the machine do not change in a qualitative way.

A special mode of operation of the machine is brake release, in which the drive provides a torque when the rotor is locked. This mode occurs when a mechanical brake is applied to the drum of a lifting machine, what is mathematically equivalent to the condition $J=\infty$. This mode is described by the following system of equations:

$$\begin{cases} e_{SgRi} = u_S \frac{\cos \varphi_S}{k_T}, \\ \Delta u_{Ri} = u_{Ri} + e_{SgRi}, \\ i_{Ri} = \Delta u_{Ri} \cdot \frac{1/R_R}{T_R p + 1}, \\ M_a = \frac{3z_p L_\mu}{2R_S} i_{Ri} u_{Sg}. \end{cases} \quad (2)$$

System of equations (2) can be associated with the structural scheme of a DFM with a locked rotor, shown in figure 2.

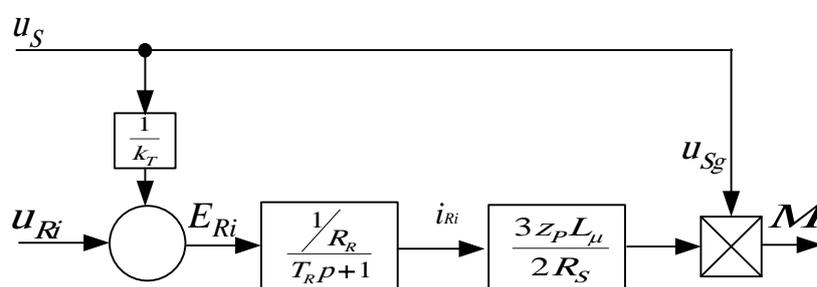


Figure 2. Structural scheme of a DFM with a locked rotor.

In the structures shown in Figures 1 and 2, two parts can be distinguished: variable one, which determines the dependence of the electromagnetic torque of the machine on the parameters of the additional voltage on the rotor or its active resistance $M=f(U_R, \delta, R_R)$, that is, characterizing the electromechanical conversion of energy in a machine; and non-variable one, determining the dependence $\omega=f(M)$, i.e. mechanical energy conversion. Thus, the main idea of controlling a combined drive is to change the method of electromechanical energy conversion in a machine while maintaining the mechanical conversion method.

3. Functional algorithm

In accordance with the known sections of the working cycle of the lifting installation, we can formulate the rules for switching inside and between them and compose analytical and logical expressions describing the algorithm of the logical control system.

We additionally introduce the following variables for the description of proposed algorithm:

I_{Ra} – active component of rotor current;

$f(K)$ – rotor circuit key closure variable;

S – a variable that takes a value of 1 in the presence of a drive start signal from a stopped state and a value of 0 in the absence of this signal;

B – a variable that takes a value of 1 in the presence of a brake signal of the drive and a value of 0 in the absence of this signal;

S_t – a variable that takes a value of 1 in the presence of a drive stop signal and a value of 0 in the absence of this signal;

Rev – a variable that takes a value of 1 in the presence of a drive reverse signal and a value of 0 in the absence of this signal;

CR – variable taking value 1 when switching the reverser;

$ES = \begin{cases} 1 & \text{when } \omega = \omega_t, \text{ – variable determining the machine reaches a given rotor speed;} \\ 0 & \text{when } \omega \neq \omega_t \end{cases}$

$CD = \begin{cases} 1 & \text{when } \frac{dI_{Ra}}{dt} = 0, \text{ – variable determining the equality of 0 time derivative of the active} \\ 0 & \text{when } \frac{dI_{Ra}}{dt} \neq 0. \end{cases}$

component of the rotor current;

$CS = \begin{cases} 1 & \text{when } I_{Ra} > 0, \text{ – variable determining the sign of the active component of the rotor current;} \\ 0 & \text{when } I_{Ra} \leq 0. \end{cases}$

$SC = \begin{cases} 1 & \text{when } \omega \leq \omega_{KP}, \text{ – variable determining the machine reaches a critical rotor speed} \\ 0 & \text{when } \omega > \omega_{KP}. \end{cases}$

$ZS = \begin{cases} 1 & \text{when } \omega = 0, \text{ – variable determining the machine reaches zero rotor speed.} \\ 0 & \text{when } \omega \neq 0. \end{cases}$

Taking into account the introduced notation, the functioning algorithm of the combined electric drive of the lifting machine based on DFM can be formulated as follows:

1) Brake release and acceleration:

a) Voltage supply connection:

$$\begin{cases} \bar{E}_S = \bar{E}_R + \bar{U}_R, \\ \delta = \psi_{E_R} + 180^\circ, \\ \dot{I}_R = 0, \\ f(K) = 1. \end{cases} \quad (3)$$

b) Brake release:

$$\text{At } (\omega = 0) \wedge (M = M_c): \begin{cases} K = 1, \\ S = 1 \\ \frac{d\dot{I}_R}{dt} > 0, \\ M > M_c. \end{cases} \quad (4)$$

c) Acceleration:

$$\begin{aligned} \text{At } 0 < \omega \leq 0,1\omega_0: & \begin{cases} K = 1 \\ \dot{I}_R = \text{const.} \end{cases} \\ \text{At } 0,1\omega_0 < \omega \leq \omega_0: & \begin{cases} K = 0, \\ \Delta\omega = \frac{M_H s_{KPe} \omega_0 - 0,5(\omega_0 - \omega) M_{KPe}}{2M_{KPe}}, \\ -A \leq \frac{dU_R}{dt} < 0, \\ \delta = \text{arctg}\left(\frac{s}{s_{KPe}}\right). \end{cases} \end{aligned} \quad (5)$$

Section end condition: $ES \wedge CD \wedge CS = 1$.

2) Movement at low speed:

$$At \quad 0 < \omega \leq 0,1\omega_0 : \begin{cases} K=1 \\ \dot{I}_R = const. \end{cases}$$

$$At \quad 0,1\omega_0 < \omega \leq 0,5\omega_0 : \begin{cases} K=0, \\ \Delta\omega = \frac{M_H s_{KPe}\omega_0 - 0,5(\omega_0 - \omega)M_{KPe}}{2M_{KPe}}, \\ \dot{U}_R = const, \\ \delta = arctg\left(\frac{s}{s_{KPe}}\right). \end{cases} \quad (6)$$

Section end condition: $ES = 0$.

3) Movement at maximum speed:

$$At \quad \omega = \omega_3 : \begin{cases} K=0, \\ \bar{U}_R = 0. \end{cases} \quad (7)$$

Section end condition: $B=1$.

4) Slowdown:

$$At \quad 0 \leq \omega \leq \omega_0 : \begin{cases} K=0, \\ 0 < \frac{dU_R}{dt} \leq A, \\ f_R = \frac{\omega_0 - \omega}{\omega_0} f, \\ \delta = arctg\left(\frac{s}{s_{KPe}}\right). \end{cases} \quad (8)$$

Section end condition: $ES \wedge CD = 1$;

5) Movement at low speed:

$$At \quad 0 < \omega \leq 0,1\omega_0 : \begin{cases} K=1 \\ \dot{I}_R = const. \end{cases} \quad (9)$$

Section end condition: $St=1$;

6) Stopping:

$$\begin{cases} K=1 \\ \frac{d\dot{I}_R}{dt} < 0. \end{cases} \quad (10)$$

Section end condition: $ZS \wedge CS = 1$;

7) Reverse: reversing switch when

$$\begin{cases} \bar{E}_S = \bar{E}_R + \bar{U}_R, \\ \delta = \psi_{E_R} + 180^\circ, \\ \dot{I}_R = 0, \\ f(K) = 1. \end{cases} \quad (11)$$

The proposed algorithm (3-11) can be transformed into a block diagram or transition graph.

4. Conclusion

The algorithm involves the regulation of the active component of the rotor current as the basis for regulating the motor torque and maximizing it. To increase the drive efficiency and reduce the total power consumed by DFM, it is also possible to regulate the reactive component of the rotor current or stator current. The logical control system (LCS) implements this algorithm together with a programmable task and control apparatus, which performs the calculation of logical functions based on signals from the electric drive system and generates control actions for the LCS.

References

- [1] Onishchenko G B and Lokteva I L 1979 *Asynchronous Valve Stages and Double-fed Motors* (Moscow: Energiya) p 200
- [2] Myshlyaev L P et al 2018 *IOP Conference Series: MSE* **354** 012008
- [3] Ostrovlyanchik V Yu et al 2018 *IOP Conference Series: EES* **206** 142714
- [4] Ostrovlyanchik V Yu et al 2018 *IOP Conference Series: EES* **206** 012040
- [5] Ostrovlyanchik V Yu and Popolzin I Yu 2019 *IOP Conference Series: EES* **377** 012042
- [6] Ostrovlyanchik V Yu and Popolzin I Yu 2019 *IOP Conference Series: EES* **377** 012041
- [7] Ostrovlyanchik V Yu et al 2019 *Mining Equipment and Electromechanics* **1** 40–46