Choice of braking method of asynchronous electric motor for using in electric drives of conveyor equipment

Vyacheslav Lobov

PhD, Associate professor of Computer Science, Automation and Control Systems department State Higher Educational Institution "Kryvyi Rih National University", Ukraine

Karina Lobova

PhD - student of Automation and Control Systems department State Higher Educational Institution "Kryvyi Rih National University", Ukraine

Abstract

Method, which allows estimating the intensity of braking of asynchronous electric motors with different power schemes and identifying recommendations for their use in automated electric drives of mechanisms of conveyor equipment, is suggested.

Comparative analysis of different braking schemes is fulfilled. The results showed that while braking of reverse asynchronous motor it is necessary to use a controlled bridge rectifier scheme and for irreversible, the scheme that realizes vector-pulse way of dynamic braking.

Scientific novelty is that the proposed research method allows to select a power scheme for braking electric drives of any industrial mechanism.

Use of existing converters in stator of asynchronous motor, allows to realize electric drives braking without increasing their cost, so this has practical value.

Key words: CONVEYOR, ELECTRIC DRIVE, ASYNCHRONOUS MOTOR, CHARACTERISTICS OF BRAKING PROCESS.

The problem and its connection with science and practical tasks.

Choice of automated electric drive for any mechanism of conveyor equipment is extremely important and complicated task. One of the important reqirements for asynchronous electric drive (AED) is to provide braking modes. A variety of technical requirements for electric drives, on the one hand and considerable amount of power converter circuits from another, - all it requires development of specific recommendations on the use of devices that realize methods of induction motor braking (IM). Wherein the preference is given to the simplest devices with parametric control of IM, which provide the necessary intensity and braking time of the working body of conveyor installation, which allows to generate the necessary laws of motion of working bodies. Wherein braking circuits that are realized without using of additional gates, based on the original structure of the converter, are of appropriate use.

For rational use and correct choice of required braking method of IM for conveyor mechanisms it is necessary, to determine the place of every braking method among known ones. So, carrying out of comparative analysis of methods and circuits that implement braking of IM is an actual problem.

Analysis of research and publications. There used different power braking schemes of IM. Anti-current braking, schemes with single-phase controlled and semi-controlled rectifier bridge, with damping circuit, half-period current rectifier and others are related to them [1-17]. It seems possible to implement effective irreversible inhibition of IM without the use of additional power components in converters with the help of combined methods of braking, one of which is vector-way dynamic braking pulse induction motor, which is named as (VPDB) [13-17].

Comparison of power circuits that implement different ways of IM braking is performed using harmonic analysis of straightened currents during changing the opening angle of thyristors and phase angle of equivalent load with which, asynchronous machine can be represented [1-6]. Further we are able to determine the components of points from direct current and each harmonic. This will reveal the effectiveness of comparable braking schemes. However, this way of solution of this problem for all braking circuits without exceptions, even in static mode and assumption constancy of parameters of IM (excluding the impact of saturation and displacement current) is connected with great difficulties. First of all this connected with the complexity of IM presentation by equivalent active-inductive load and a large amount of calculations required to determine the current harmonics at variable opening angle of thyristors and phase angle of equivalent load [7,8-10, 15].

Problem statement. Work objective is the need to substantiate the creation of a method to estimate the intensity of braking of IM using different schemes of stator circuits supply and determine recommendations for their use in automated electric drives of conveyor mechanisms and other equipment. Moreover, for qualitative comparison of different braking schemes, let us use basic indicators of effectiveness of braking, nature of change in braking moment, allowable number of breakings per unit of time, reliability and economy of braking devices. It allows not only compare the existing methods, but also to determine the most rational areas of their application.

Presentation of the material and results. Let us define braking time for vector-pulse mode of IM dynamic braking. This parameter determines the intensity of braking. Let us use during comparison of various schemes of converters. Full braking time t_B at VPDB is determined as the sum of the two times of braking t_1 and t_2 [14-15]. Time t_1 defines out-of-current pause of motor since its stator disconnection from the power supply at initial frequency of rotation, equal $\omega_{r\ \mathrm{in}}$. During this time, the speed of the rotor n_r decreases by overrun and when it becomes equal to n_r', there comes the moment of coincidence of phase vectors of mains voltage and EMF in the stator, and the process of electric braking begins. Time t_2 in fact consists of components. The first one is determined by the time of action of the first phase of VPDB, namely vector-pulse braking. The second component is determined by the action of the second phase of VPDB, namely dynamic braking.

Considering that the angular velocity of vector network ω_c is equal to the angular velocity of EMF stator after disconnecting of stator windings from the power supply network and motor slip S_1 at the time of disconnection from the network, the angular speed of the EMF after the engine is shutdown equals $\omega_c = (1-S_1) K$, where K – is the coefficient taking into account the reduction in speed when stopping. $K = (t_{stpg} - t) / t_{stpg}$. Here t_{stpg} and t – stoppage of rotor after disconnection from the supply network and the current time. Basing on the condition that the difference of path vector of network and vector EMF until the convergence by phase equals π, time of the break during feed necessary for creation the initial conditions will be:

$$t_1 = \frac{-S \pm \sqrt{S^2 + \dfrac{2\pi}{(1-S)\omega_c t_{stpg.}}}}{\left(\dfrac{1-S}{t_{stpg.}}\right)}, \qquad (1)$$

where S - current slide of IM

Time t_2 of electric braking is determined:

$$t_2 = \frac{J_\Sigma \omega_r}{M_S + M_B},$$

where J_Σ – moment of inertia of electric drive, consolidated to the motor shaft;

ω_r - angular speed of rotor.

As a result full braking time t_B to a complete stop of rotor under effect of braking moment M_B and static moment Mc is determined according to the following formula:

$$t_B = \frac{t_{stpg}(M_S + M_B(-S \pm \sqrt{S^2 + \frac{2\pi}{(1-S)\omega_c t_{stpg.}}} + J_\Sigma \omega_r{}'(1-S)}{(1-S)(M_S + M_B)} \quad (2)$$

As for other known methods of dynamic braking for induction motors, at VPDB, as coming from (2), braking time of AED depends on braking electromagnetic moment, synchronous and rated speed of rotation of the electric motor and as well as the static moment and the total moment of inertia drive.

VPDB increases its efficiency by reducing the length of the pause without power. This is possible by controlling the spatial location of voltage vector supply just like with vector-pulse control.

Main criteria of efficiency is braking time and braking distance of rotor of IM.

Braking time is determined by the average amount of braking torque. The path is also characterized by the character of its change.

At comparative analysis of the brake schemes of IM we will use, besides indicators of the time and braking way, the magnitude of shock moments and currents, electrical losses of IM during braking process and some other values, necessary for determining the efficiency of braking [1, 5-7, 12-15].

Investigations showed that indicators of efficiency are better to express in relative units, because there obtained averaged indicators for sufficiently large groups of IM. For ease of use of generalized indicators, indicators of one scheme are required to be accepted as basic ones. Indicators of the scheme that realizes one of the classic methods - braking against the current, named henceforth as AC, taking it as a baseline.

For comparative analysis, except AC circuit, the schemes with single-phase controlled and semi-controlled rectifier bridge (RB) are selected. Schemes AC and RB are presented in Figure 1, a, b respectively.

Let us also use the schemes with damping circuit (DC) - Figure 1, c and single half-period rectified current (ORC) - Figure 1, d, e. Marking of the elements on the schemes are adopted in accordance with generalized scheme parametric control provided in [13,16].

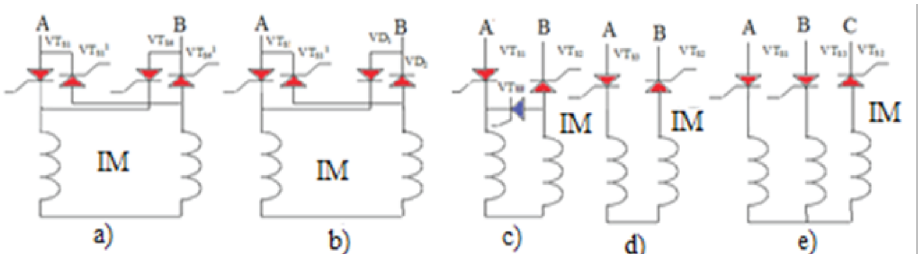

Figure 1. Power connection schemes of stator elements of IM, selected for evaluation of braking intensity.

For comparison of braking scheme let us distinguish two groups from a single unified series IM. These schemes are for electric conveyors. The first group comprises electric drives with low power IM up to 5 kW (from first to fourth dimensions of a single series) and low total moment of inertia, equal in value no more than double moment of inertia of the rotor IM. The second group consists of electric drives with IM power from 5 to 15 kW (fifth and sixth dimensions) with a total moment of inertia exceeding the three-time moment of inertia of rotor of electric motor.

For the first group of low-inertia electric drives, relative efficiency of comparable schemes of braking is characterized by average values, the values of which are displayed in Figure 2. Performance indicators of methods for low-inertia electric braking are compared with braking by opposite current.

Submitted charts are compiled according to calculations and experiments for IM, that running idle (without load).

Precision of time and braking path characterized by values of maximum and minimum deviation.

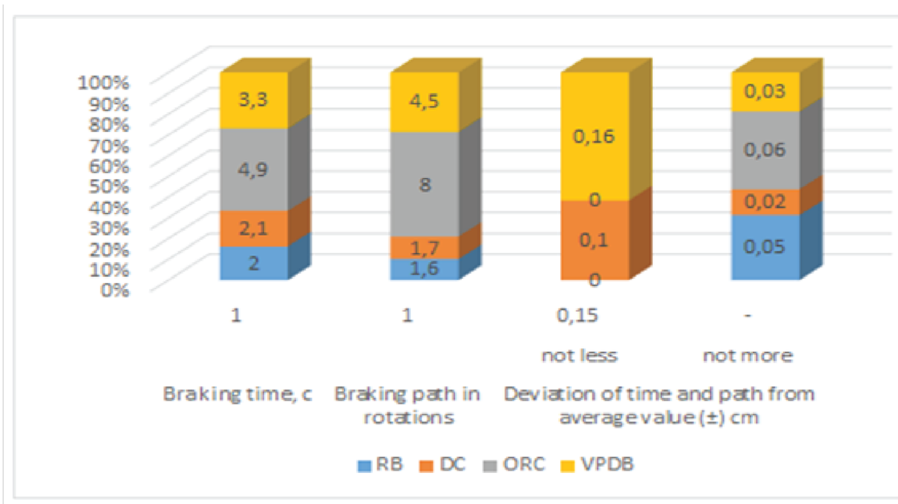

Figure 2. Comparison of braking methods of IM with power up to 5 kW.

Thyristors opening angle involved in the regulation of IM braking process is adopted such, at which there achieved the maximum intensity. The results presented in Figure 2, show that for the group of low inertial drives at selected parameters all the dynamic braking circuits are less effective than the scheme of opposite current of braking.

Schemes of dynamic braking of IM differ with that they provide various time and path of braking. Braking time of IM rotor for RB and DC circuits is practically the same, but it is 2.5 times smaller than in the ORC scheme. Moreover braking path of rotor for RB and DC circuits, 3.4 times smaller than in VPDB schemes and 5 times than for ORC. Braking under the VPDB scheme provides fewer braking time and smaller braking path that is 1.5 more than times in comparison with the ORC scheme.

For the second group of electric motors 15 kW, data of changes of relative efficiency of braking during increase of power and electric drives inertia are depicted in Figure 3.Here relative parameters of braking schemes are the same as for previous group. Data displayed in Figure 3 shows, that time and path of IM braking by increasing of power and total inertia moment of AED is growing.

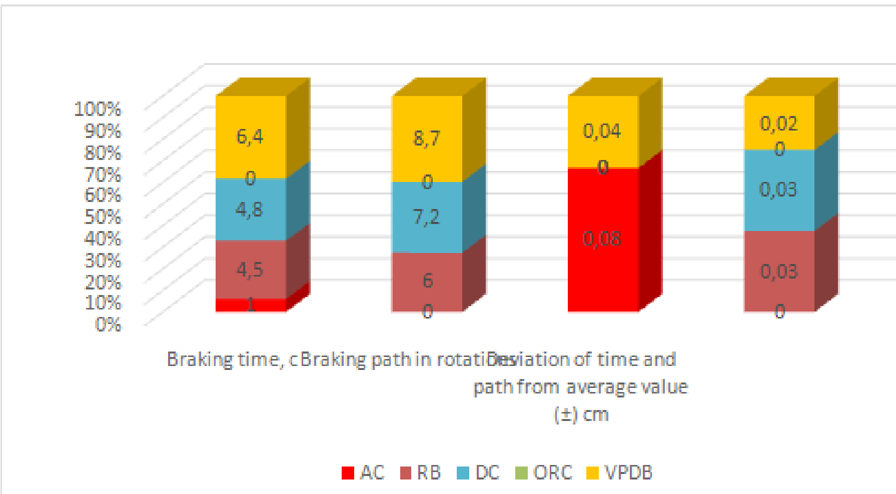

Figure 3. Comparison of braking methods of IM with the power up to 15kW

Moreover, braking intensity is significantly reduced for the VPDB scheme, as compared to AC scheme and in comparison with RB and DC schemes. However, this scheme is quite effective even with increasing total moment of AED inertia, while ORC scheme does not provide any braking. Moreover, intensity of braking decreases for VPDB scheme as in comparison with AC, RB and DC schemes. This is because of that in low slip zone during electromagnetic braking moment there is motion component and constant component is negligible.

As it was previously noted, time t_B and path S_B of braking dependent on the angle of opening of thyristors α_3, regulating the intensity of braking. The values of shock current *Isc* and shock moment *Msm*, as well as loss of electricity *W* in IM while braking depend on this angle. Figure 4 presents universal dependences:

$$t_B = f(\alpha_S),\ S_B = f(\alpha_S),\ Isc = f(\alpha_S),\ Msm = f(\alpha_S),\ W = f(\alpha_S),$$

These dependencies are used during design and adjustment of series mechanisms of conveyor systems that require brake modes.

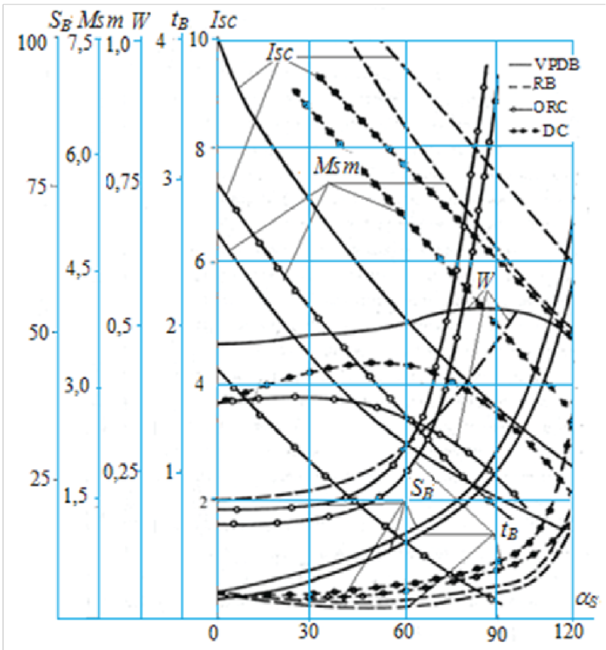

Figure 4. Universal dependencies: $t_B = f(\alpha_s)$, $S_г = f(\alpha_s)$, $Jsc = f(\alpha_s)$, $Msm = f(\alpha_s)$, $W = f(\alpha_s)$.

Comparative indicators are typical for electric motor of single series 4A, MTF, MTK with power up to 50 kW. Value of shocking current and moment and loss of electricity in Figure 4 are presented in shares respectively, nominal current, nominal moment and nominal loss of electricity.

Angle α_s time t_B, and path S_B are expressed in electrical degrees, seconds and rotations respectively. As it is seen from the Figure 4, the biggest shock current and moment of IM are in schemes with single-phase controlled rectifier bridge, next coming schemes with damping circuit, vector-pulse braking mode and with single half-period rectified current. At the same time to ensure maximum braking intensity in all schemes - opening angle of thyristors must be such, at which there achieved the greatest intensity of braking [1].

Because of significant value of the variable component of rectified current, dynamic braking scheme with power supply of single half-period rectified current gives the lowest braking efficiency even at rational values of open angle of thyristors. At its decreasing in the area of low slip, motor torque increases as well as motor braking time and at high angles rotor IM does not brake at all. Bridge circuit has the best harmonic composition of current [1, 4] that leads to braking of IM with nominal time. Smoothing of pulsation and increasing of the constant component of current using damping circuit, allows significantly increase braking intensity in comparison with VPDB and ORC.

The most rational adjusting range of opening angle of thyristors, as follows from the shown graphs, for RB and DC schemes is at the limit from 30^0 to 90^0, ORC - from 0^0 to 30^0 and VPDB- from 0^0 to 60^0. Increasing of the opening angle of thyristors higher than limit one for all without exception schemes leads to the decrease of intensity and other parameters of braking.

To perform more complete comparative analysis, it is necessary to estimate additionally the efficiency of braking schemes, ways of determining coefficients, quality of static characteristic (*Kst*), dynamic (*Kd*) and energy (*Ke*) efficiency, pulsations of energizing current (*Kpc)* and schemes (*Ksch*). Using analytical expressions, given in [8] and a number of experimental data, obtained at researching of different braking methods, there determined recalculated coefficients for comparable braking schemes. Values of obtained coefficients are shown in Figure 5.

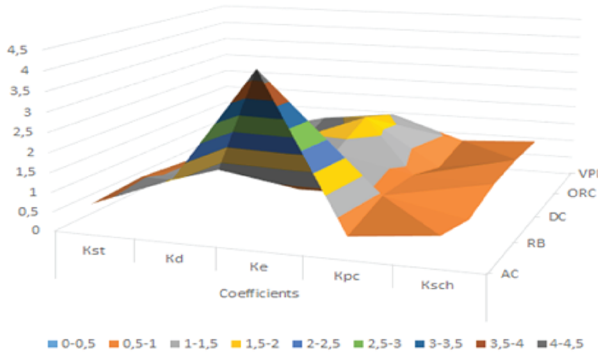

Figure 5. Full comparative analysis of braking schemes

Data in Figure 5 shows, that simple scheme of single half-period dynamic braking of ORC is low-effective. In irreversible electric drives the greatest increase of braking efficiency is achieved by using schemes with damping circuits or vector-pulse method of dynamic braking of IM, which have quite high values of braking efficiency. However, the scheme with damping circuit DC must necessarily include additional damping valve (thyristor or diode), that significantly worsens weight and size parameters of braking device.

According to the characteristics shown in Figure 6, we may see that relative values of braking time (1) and losses (2) in the windings of IM of MTF411-8 type while performing VPDB remain much more, than during AC braking.

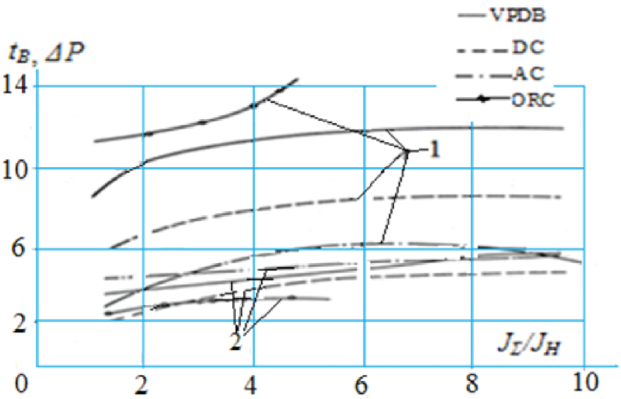

Figure 6. Relative values of braking time (1) and losses (2) in windings of electric motor MTF411-8 at VPDB

Increase of total moment of inertia of electric drive continues braking process at VPDB and it is bigger than while IM braking with the use of DC or AC braking. At the inertia moment of the electric braking up to *4Jim* braking time increased significantly, but further increase of inertia moment over *10 Jim* leads to considerable increase of it.

Relative dependencies between parameters of different braking ways practically remain unchanged with increasing of inertia moment up to *4Jim*. Dependencies $t_B = f\,(J_\Sigma/J_H)$ show that braking time of VPDB is 30-50% higher than braking of AC and on 15-20% than dynamic braking with the use of DC and lower on 20-40% than braking scheme with single half-period rectified current. At the same time losses of electricity at VPDB are lower, than AC and higher than at dynamic braking with the use of DC.

Conclusions

Comparing power schemes of commutators, one may notice that the weight of VPDB commutator as compared with DC is 16% less from total weight of commutator, dimensions are 10% less and the cost is lower up to 20%. So for electric drives that do not require high performance braking, preference should be given to the schemes, realizing vector pulse-way dynamic braking that do not use additional force elements. These braking schemes should be used for electric drives of conveyor equipment mechanisms, especially when there is a need to use converters with reduced weight and overall performance.

It is established that for providing the smallest ways of braking and limits of electromagnetic moments for reverse electric drives of conveyor equipment mechanisms, schemes with controlled rectifier bridges RB are appropriate to use, as they have the best technical, energy and other parameters of braking efficiency. In case of thyristor switches in irreversible electric drives of conveyor equipment mechanisms it is necessary to use vector-pulse dynamic braking, which is the most effective on all technical and economic parameters.

The most advisable range of adjustment of opening angles of thyristors at start of asynchronous electric motors with control parameters is $\varphi \le \alpha_S \le 115°$ and $0° \le \alpha_r \le 180°$. However, at vector-pulse method of dynamic braking, adjustment range of angle α_S must be within $0° \le \alpha_S \le 60°$.

Proposed analytical method for determining of braking time of AED, where IM uses in stator circuits for control of thyristors, indicates that flow of the transition processes in electric drives depends on type of the power circuit and way of control of valves. Moreover, to limit the value of currents and moments at IM braking is the most effective via adjustment of the opening angle of thyristors. The intensity of braking at VPDB is the most conveniently to adjust via the opening angle of phase thyristor, which take part in braking process. However, it can be changed by the number of matches in phase with the voltage vectors with EPS electric motor and by aligning the phase of vectors that can restrict transient electromagnetic processes.

Total inertia moment and static moment AED do not influence significantly on the maximum value of electromagnetic moment, allows choosing the simplest laws of control of braking of electric drive.

The biggest influence they have on the time of the transition process, oscillation frequency of electromagnetic moment and rotation speed of IM, that are recommended to consider when design and implementation in various technological mechanisms and units of mentioned electric drives.

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Pellets Temperature distribution on a conveyor roasting machine

Karina Lobova

PhD - student of Automation and Control Systems department State Higher Educational Institution "Kryvyi Rih National University", Ukraine