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Abstract

The article considers the problem of ensuring reliable operation of DC electric drives under short-term overloads, when the installed power of the electric motor is limited. It is shown that the use of traditional current cutoff units does not allow for the effective use of the maximum permissible overload capacity of the motor when changing the reference speed. The dependence of the permissible overload current on the rotation speed is analyzed, and the limitations of the existing control schemes are identified. In this paper, the existing schemes of automated electric drives equipped with traditional current cutoff units are considered and their main disadvantages are identified. As a solution, a current limiting system with automatic regulation of the cutoff current is proposed, aimed at increasing the reliability and energy efficiency of adjustable electric drives. The key feature of the proposed system is to adapt the cutoff current value depending on the rotation speed of the motor, which allows dynamically matching the electromechanical characteristics of the drive with the permissible overload curve of the motor. A current limiting circuit for a DC electric drive is proposed, in which the cutoff current setting is automatically changed depending on the value of the specified speed. The circuit ensures full use of the maximum permissible overload capacity of the electric motor at all values of the setting voltage.

Keywords: electric motor, current limiting system, cut-off current, setting voltage, electromechanical characteristics, reliability

I. Introduction

For mechanisms in which short-term large overloads are observed, and the installed capacity of the DC electric drive is limited, it is necessary to fully utilize the maximum permissible overload capacity of the drive electric motor.

In [1], a brief analysis was carried out of the provision of known circuits of automated DC electric drives for full use of the maximum overload capacity of the drive motor and some shortcomings of these circuits were identified.

Fig. 1, a shows a simplified version of the DC electric drive circuit, where the motor overload is limited by a conventional current cutoff unit used in automation circuits. The controlled energy converter C, feeding the DC motor M with independent excitation, contains a control signal adder with identical windings CW1 and CW2.

The equation of the electromechanical characteristic of such a system can be represented as:

$$\omega = \frac{k_g(U_\Sigma)}{k\phi} \cdot U_s - \frac{r_c + r_m}{k\phi} \cdot I - \frac{k_c(U_\Sigma) \cdot r_s}{k\phi} \cdot (I - I_c) \cdot l(\Delta I) \tag{1}$$

Where $k_g(U_\Sigma)$ and r_c are the gain of the total input voltage and the output resistance of the converter, respectively; I and r_m are the current and resistance of the motor armature circuit,

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respectively; U_s – setting voltage; I_c – cut-off current, I_c=const; U_r – reference voltage; k – electromagnetic constant; ϕ – motor excitation flux ϕ=const.

For different values of U_s, the electromechanical characteristics of the drive, constructed according to equation (1) at ϕ=const, will have the form shown in Fig. 1, b [2].
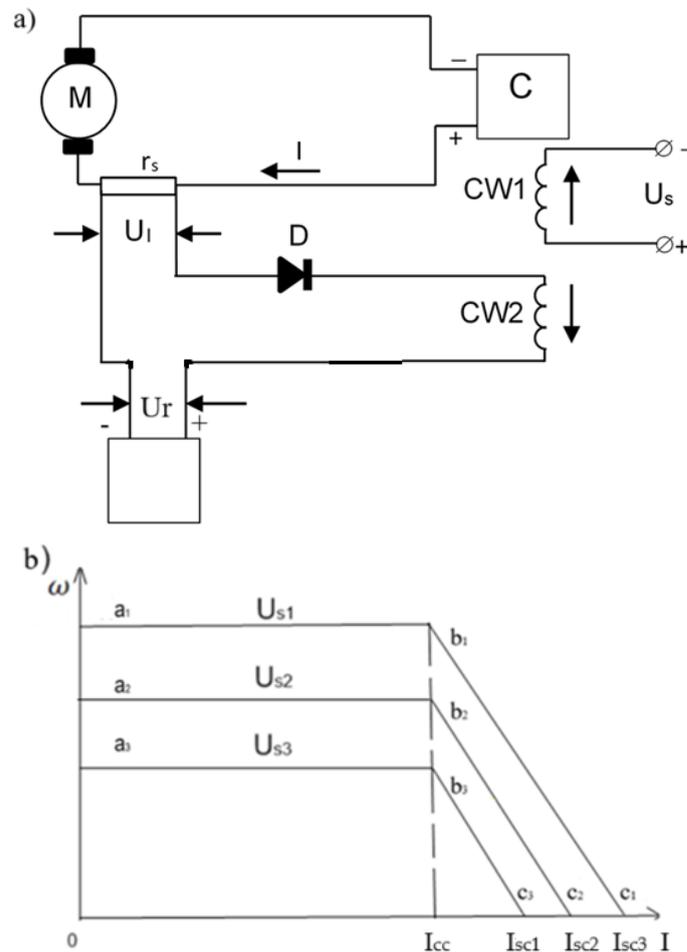

Figure 1: *Current limiting circuit (a) and electromechanical characteristics (b)*

As is known, the maximum permissible overload capacity (or maximum permissible current) of a DC electric motor changes depending on its speed - with decreasing speed, the maximum overload capacity increases. Usually, in practical problems, this dependence is assumed to be linear. To fully utilize the maximum overload capacity of an electric motor, the falling part of the electromechanical characteristic of the drive (for example, line b_1c_1 for U_{s1}) must be combined with the dependence curve of maximum permissible currents mentioned above. This can easily be done by selecting the parameters of the current limiting unit.

However, the overload limiting unit configured for one value of the setting speed does not ensure full use of the motor by permissible current at other values of the setting speed. For example, at U_{s2} and U_{s3}, automatic limitation of the overload current will pass along lines b_2c_2 and b_3c_3, which lie below line b_1c_1. Consequently, the use of a conventional current limiting unit in adjustable DC electric drives does not ensure full use of the maximum overload capacity of the drive motor at different values of the set speed [3-8].

In this regard, a new current limiting circuit was proposed for adjustable DC electric drives in [1], in which the comparison voltage does not remain constant, but changes as a function of the

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motor speed. This was achieved by introducing an additional signal from the speed sensor into the current limiting circuit. However, as was noted there, such a solution to the problem has some of its own drawbacks: the presence of a tachogenerator and some dependence of the stop current on the value of the setting signal.

II. Materials and methods

In connection with the above, a slightly different current limiting circuit is proposed, a simplified version of which is shown in Fig. 2, a. Here, a signal of the setting voltage U_s in reverse polarity relative to the reference voltage U_r is additionally introduced into the circuit of the current limiting unit. The setting signal U_s, subtracted from the reference voltage U_r, forms a comparison voltage U_c, the value of which increases as the setting signal (or the specified engine speed) decreases, due to which the cutoff current becomes a function of the specified engine speed. At the moment of the start of the cutoff, the following voltage balance takes place:

$$U_I = U_c = U_r - U_s = I_{cc}r_s$$

Cutoff current:

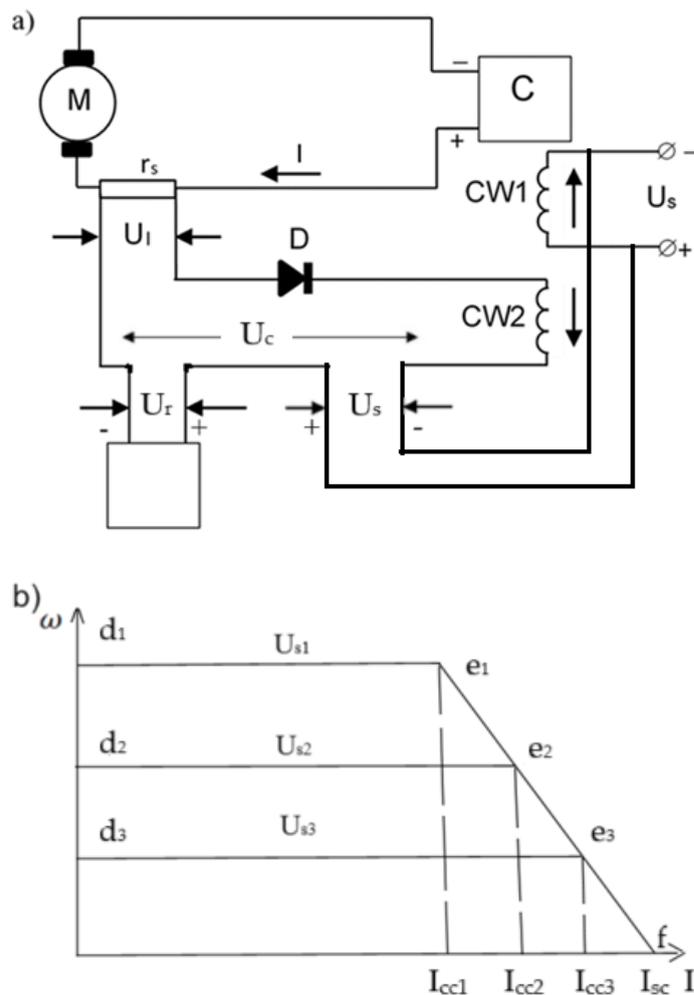$$I_{cc} = \frac{U_r - U_s}{r_s} \qquad (2)$$

Figure 2: *Self-adjusting current limiting circuit (a) and corresponding electromechanical characteristics (b)*

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Fig. 2, b shows the graphs of the electromechanical characteristics of the proposed electric drive circuit. These graphs are constructed for different values of U_s according to the equation:

$$\omega = \frac{k_c(U_\Sigma)}{k\phi} \cdot U_s - \frac{r_c + r_m}{k\phi} \cdot I - \frac{k_c(U_\Sigma)}{k\phi} \cdot (Ir_s - (U_r - U_s) \cdot l(\Delta I)) \tag{3}$$

While $U_I = Ir_s \leq U_c = U_r - U_s$, no current flows through the CW2 winding, and the electric drive operates on the working section of the speed characteristic. When $U_I > U_c$, current begins to flow through the CW2 winding, as a result of which the motor overload is limited. For reduced U_s values, U_c increases and the overload limitation start points, self-adjusting, move to the right, that is, the cutoff current in this circuit automatically increases to the values of I_{cc2} or I_{cc3}, corresponding to the setting signals U_{s2} and U_{s3} [9-15].

By selecting the parameters of the current limitation unit, it is easy to ensure that the movement of the initial cutoff points and the current limitation slope coincide with the line of dependence of the maximum permissible motor currents on the speed. Then the automatic overload limitation, regardless of the value of the set speed, is always obtained along the line of maximum permissible motor currents and, therefore, its maximum overload capacity is fully realized at all values of the setting signal. For example, for values of the reference signal equal to U_{s2} and U_{s3}, the electromechanical characteristics of the drive are obtained as d_2e_2f and d_3e_3f (Fig. 2, b).

The magnitude of the stop current can be determined from equation (3):

$$I_{sc} = \frac{k_c(U_\Sigma)U_r}{r_c + r_m + k_c(U_\Sigma)r_s} \tag{4}$$

As can be seen from equation (4), the stop current I_{sc} for the proposed current limiting circuit does not depend on the magnitude of the setting signal, which is the main advantage of this circuit [16-19].

It should be noted that equation (3) was derived for a simplified version of the electric drive circuit, where there is feedback only on the motor armature current and when the control windings of the signal adder are identical. In the applied automated electric drive systems, different types of feedback often operate simultaneously and the control windings of the signal adder differ in parameters. For these electric drives, it is also possible to derive an equation of the electromechanical characteristic taking into account the presence of specific feedbacks together with the attached current-limiting circuit. For example, below is the equation of the electromechanical characteristic of an automated electric drive system that has feedback on the armature voltage and the current-limiting unit using a circuit for the full use of the maximum overload capacity of the motor:

$$\omega = \frac{k_c(U_\Sigma)}{k\phi[1 + k_c(U_\Sigma)k_u]} \cdot U_s - \frac{r_c + [1 + k_c(U_\Sigma)k_u]r_m}{k\phi[1 + k_c(U_\Sigma)k_u]} \cdot I - \frac{k_c(U_\Sigma)k_{\omega I}}{k\phi[1 + k_c(U_\Sigma)k_u]} \cdot (Ir_s - (U_r - k_s U_s) \cdot l(\Delta I))$$

In this case, the following equations are obtained for the cutoff current and for the stop current:

$$I_{cc} = \frac{U_r - k_s U_s}{r_s}$$

$$I_{sc} = \frac{k_c(U_\Sigma)k_{\omega I}U_r + k_c(U_\Sigma)(1 - k_{\omega I}k_s)U_s}{r_c + [1 + k_c(U_\Sigma)k_u]r_m + k_c(U_\Sigma)k_{\omega I}r_s} \tag{5}$$

From equation (5) it follows that in the case of identity of the adder control windings, i.e. when $k_{\omega I} \neq 1$, to achieve complete independence of the stop current from the value of the U_s signal, the coefficient ks must be taken so that $k_{\omega I}k_s = 1$. This can be easily achieved by using a potentiometer or intermediate amplifier in the circuit for introducing an additional signal from U_s into the current limiting circuit [20-24].

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III. Conclusions

To ensure full utilization of the maximum permissible overload capacity of a DC electric motor in systems with variable speeds and limited installed drive power, it is crucial to apply a current limiting circuit that dynamically adjusts the cutoff current based on operating conditions. Traditional current limiting units with a constant comparison voltage fail to provide optimal overload protection at all speed settings, resulting in underutilization of the motor's capabilities.

The proposed improved circuit introduces a variable comparison voltage that depends on the setting voltage U_s, thereby automatically adjusting the cutoff current in accordance with the motor speed. This enables the electromechanical characteristics of the drive to align with the curve of maximum permissible motor currents, ensuring optimal use of overload capacity across the entire speed range.

Furthermore, the proposed system can be adapted for more complex feedback configurations, such as combined voltage and current feedback loops. With appropriate parameter tuning, including the use of a compensation coefficient k_s, the stop current can be made independent of the setting signal, which is a major advantage over previous solutions.

Overall, the proposed circuit provides a simple yet effective method for maximizing motor performance and reliability in adjustable DC electric drives, especially in applications where high short-term overloads occur.

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