Control system of electric traction drive of electric vehicle

N V Pechenkina

1LLC STC Privodnaya tekhnika, 19, 40-letiya Oktubrya St., 454007, Chelyabinsk, Russia

E-mail: office@momentum.ru

Abstract. The growth rate of electric transport production is increasing every year, so the issues of its improvement and development are relevant. The development of a traction electric drive control system that would meet all the requirements, it is the aim of the article. There is a strong weakening of the field, providing a quick change in torque. The results of the created electric drive system are obtained with simulation in the MATLAB. The control system provides the engine in traction mode, recovery mode, reverse, and also allows you to develop high torque at low speeds. The result is a trapezoidal velocity diagram and an almost rectangular moment diagram. When operating at higher speeds up to 400 rad/s, the system works stably. At higher speeds, moment fluctuations appear and dynamics deteriorates. Fluctuations in flux linkage are observed at a speed of more than 700 rad/s. The modeling also showed that the system maintains a constant voltage in the field weakening mode. The development of the control system in order to increase the torque at low speeds is possible due to the introduction of the controller of the balances of the real current of the machine and the current calculated in the engine model. The introduction of a dynamic field attenuation circuit serves to provide high torque when it is not possible to further increase the voltage of the motor stator.

1. Introduction

The current environmental situation in the world requires a gradual abandonment of internal combustion engines and the transition to the use of electric vehicles. They have a number of positive qualities, such as the practically absence of harmful emissions into the atmosphere during its operation, which is relatively simpler. But at the same time, electric vehicles have a number of disadvantages: a limited power reserve resulting from the insufficient energy consumption of batteries, high cost, and lack of the required infrastructure (charging stations, for example), the difficulty of disposing of used batteries, lack of energy for an increasing number of electric vehicles. But, despite these shortcomings, issues of development and improvement of electric transport are relevant today.

Ensuring high momentum dynamics, field weakening mode is assigned to the traction electric drive control system, as well as the implementation of all other electric drive operation modes. Therefore, the purpose of this article is to develop a control system that would implement all the operating modes required by the traction engine and the features of an electric vehicle.

The modern AC electric drives have two main control methods: scalar and vector control. Details of these methods are described in [1, 2].

A sharp decrease in load capacity at low frequencies, the inability to simultaneously control torque and speed, as well as a small range of speed control do not allow the use of scalar control systems for electric transport.
Direct Torque Control (DTC) systems are widespread. More details about these systems are given in [3]. DTC systems provide good control performance, excellent dynamic torque characteristics, but they are not widely used in traction electric drives. This is due to the fact that DTC systems are optimized for medium power drives, and they use high switching frequencies of power switches. Therefore, a group of scientists from the Ruhr University (Germany), headed by M. Depenbrock, created a control system optimized for traction electric drive and called Direct Self Control (DSC), which is described in more detail in [4].

To increase the performance of DSC – systems in the field of low speeds, a group of scientists from the Ruhr University (Germany), led by A. Shteimel, proposed the Indirect Self Control method (abbreviated ISC). This system operates with a circular path of motion of the stator flux linkage vector and incorporates a PWM voltage modulator, which fundamentally distinguishes it from DTC and DSC systems, therefore this system does not apply to direct torque control systems. Modern ISC systems satisfy the high demands put forward by the traction electric drive of electric vehicles. This provides high torque at low speeds and a wide range of speed changes above the nominal due to the weakening of the field [5]. This control method most satisfies the requirements put forward to the control system of the traction electric drive of an electric vehicle. Therefore, it is the ISC system that will be the subject of further work [6].

2. Materials and Methods

The main parameters of the developed electric vehicle are presented in Table 1.

| Characteristics                          | Magnitude |
|-----------------------------------------|-----------|
| Maximum vehicle speed, km/h, not less   | 80        |
| Minimum steady speed, km/h, no more    | 3         |
| Cruising range, km, not less            | 150       |
| Reverse speed no more, km / h           | 10        |

A power electric drive is shown in Fig. 1 which connected through a filter to a battery. The inverter power from the traction battery causes its limitations. This is mainly expressed in the fact that the voltage range of the DC link can be large. The influence of the internal resistance of the battery itself and the connecting wires also contributes to this. As a result, there will be a large range of changes in the load current [7].
Table 2. Main characteristics of power drive.

| №  | Name                                      | Parameters                |
|----|-------------------------------------------|---------------------------|
| 1  | Type                                      | three-phase               |
| 2  | Nominal battery voltage, V                | 500 - 528                 |
| 3  | Operating voltage, V                      | 100 - 550                 |
| 4  | Minimum voltage, V                        | 100                       |
| 5  | Maximum voltage, V                        | 550                       |
| 6  | Maximum current consumption, A.           | 250                       |
| 7  | Short-term (30 s) power on the output shaft at rated voltage, kW | 80                       |
| 8  | Continuous power, kW                      | 60                        |
| 9  | Maximum moment, Nm                        | 275                       |
| 10 | Nominal rotation speed, rpm               | 2100                      |
| 11 | Maximum rotation speed, rpm               | 8000                      |
| 12 | Efficiency not less than, %               | 92                        |
| 13 | Nominal supply voltage of the control system, V | 12                      |
| 14 | Operating voltage supply SU, V            | 8 - 15                    |

3. Results

The control system (CS) of the traction electric drive must ensure uninterrupted and stable operation of the electric motor in the entire range of modes, when the electric car moves with banks, rises and descents of at least 20%. Thus, it is necessary to provide the following basic technical requirements for the control system of a traction electric drive of an electric vehicle: ensuring all operating modes of the electric motor; realization of strong field weakening; providing a quick change in torque, which is highly important for creating safe operation of an electric vehicle [8].

To ensure high control dynamics of the ISC system, accurate calculation of stator and rotor flows is required [9]. To do this, the observer is used in the system, the input of which receives voltage signals from the inverter model, converted into a fixed coordinate system α and β, and also, since the speed feedback sensor is used in this system, the signal is in speed. The observer must calculate the estimates of the electromagnetic moment M, as well as the components of the stator and rotor flux linkages in the coordinates α and β. The basis for constructing the observer are the equations of a generalized machine in a fixed coordinate system [10].

It should be noted that to ensure ease of control, speed feedback was introduced. The speed controller (SC) is selected proportional-integral type (PI controller), the channel parameters of which are adjusted based on the conditions of support, the required accuracy and speed. The speed loop forms the task of the moment. First, the set and actual (coming from the observer) torques are converted into an increment of the angular velocity of rotation. The task is limited at the moment by using the block of restriction (BR).

The stator flux linkage vector increment is formed using two controllers: a proportional flow regulator (P-regulator) and the proportional-integral regulator (PI-regulator), which forms the dynamic component of the stator flux linkage vector increment ΔχCdin. In the steady state, the advanced control carried out gives a stable result and deviations of the moment from the set value are not observed. In this mode, the increment ΔχCdin is equal to zero [11]. In dynamics, regulation is carried out mainly due to the proportional channel, while the integral channel eliminates errors.

The modulus of the stator flux linkage vector is changed by changing the coefficient kΨ(i) [12]. At the input of the flow circuit, the predetermined flow is compared and the actual flow (coming from the observer), the error obtained, amplified by the P-regulator of the flow, is this coefficient. In addition, it is necessary to add one to it so that, in the case of equal flows at the input, kΨ(i) is not equal to zero.
Dividing the projections of the stator flux linkage vectors of the stator by the modulation period $T_M$ allows us to obtain projections on the same axis of the resulting voltage vector. Subtracting from which the corresponding voltage drops on the stator, we obtain the projections of the voltage vector on the stator, which are fed to the PWM spatial vector system (SVPWM).

The control system must provide all the modes of operation of the electric motor (traction, regenerative braking, reverse), a strong weakening of the field for work in the field of high speeds and small moments, as well as the development of high torque at low speeds [13]. It is necessary to illustrate that the control system satisfies all of the above requirements. First, we show the operation of the drive in traction mode, regenerative braking mode and during reverse. The value are applied to the system are given in table 3.

| Value   | Time of apply value, t.s |
|---------|--------------------------|
| $\omega$, rad/s | 0 | 0.2 | 0.4 | 0.6 |
| $M$, Nm       | 210 | 0  | -30 | 0   |
| $\Psi_C$, Wb  | 50  | -50| -50| 50  |

Table 3. Apply a value

Note that the reverse speed of the machine is limited to 12.5% of the maximum according to the table. 1. The transients of speed and moment are showed in the figure 2.

It can be seen that good dynamics were obtained in the tuned system - the velocity curve has a trapezoidal shape, and the moment curve is rectangular. At the beginning of acceleration, a gap of zero speed is visible, during which time the engine develops enough energy to start moving. The moment builds up in a short time [14]. The first 0.2 s of movement is characteristic of the traction mode. When a reference of zero speed and a negative static moment is applied, the engine goes into the second quadrant at a constant speed. Regenerative braking occurs, speed decreases with constant torque. At $t = 0.4$ s, the task of negative speed and negative static moment arrives. The engine goes into the third quadrant [15]. The reverse is carried out. At $t = 0.6$ s, the task of zero speed and a positive static moment arrives, the engine at a constant speed goes into the fourth quadrant. Regenerative braking is carried out, the speed decreases to zero with constant torque. In this case, the flow remains constant and equal to the specified one. The trajectory of the flux linkage vector is shown in Fig. 3. It has a circle shape.
Figure 2. Wave forms $\omega = f(t)$ and $M = f(t)$ in accordance with the task.

Figure 3. Stator flux link vector trajectory at $\Psi_C = 1$.

The phase voltage curves are showed in the figure 4. A decrease in speed causes a decrease in the frequency of the voltage and its amplitude, and an increase, respectively, on the contrary. Thus, the control system provides the engine in traction mode, recovery mode, reverse, and also allows you to develop high torque at low speeds, which is evident when working in the fourth quadrant when reversing [16].
Figure 4. Oscillograms of phase voltages corresponding to the task.

Now look at the operation of the control system in the field weakening mode. We will control the task of speed and the corresponding flux linkage, which are given in table 4. It is working of idling.

| Value       | Time of apply value, t.s |
|-------------|-------------------------|
| \(\omega\) rad/s | 0.2 | 0.3 | 0.5 | 0.8 | 1.0 | 1.5 |
| \(\Psi_c\), Wb | 1 | 0.72 | 0.62 | 0.52 | 0.42 | 0.365 | 0.345 |
| \(M\), Nm | 0 |

The oscillograms can be used to trace how field weakening affects the quality of transients. When accelerating to a speed of 400 rad / s inclusive, we get a trapezoidal speed curve, a rectangular curve of the moment. Although when accelerating to a speed higher than the nominal, slight and rapidly dying oscillations are observed in the moment curve. But when accelerating to speeds above 400 rad / s, an increase in acceleration time and the occurrence of overshoot caused by fluctuations in torque are observed. This is due to the poor dynamics of the regulators in the high frequency region.

We can note the high dynamics of the stator flux linkage; the characteristics are practically rectangular. Oscillations occur during acceleration to a speed of 700 rad / s and higher. The change in the flux linkage of the rotor is more inertial, when the flux linkage of the stator changes, the flux linkage of the rotor tends exponentially to align with it.

The trajectory described by the stator flux linkage vector is showed in the figure 5.
According to the described trajectory, it is possible to trace how the modulus of the stator flux linkage vector changes with respect to the decrease in the radius of the circle. It is also seen along the trajectory when the moment increased and when it was equal to the steady-state value in increment of the angle of rotation of the vector.

4. Discussion
The control system provides the engine in traction mode, recovery mode, reverse. Also allows you to develop high torque at low speeds. The result is a trapezoidal velocity diagram and an almost rectangular moment diagram. When operating at higher speeds up to 400 rad/s, the system works stably. At higher speeds, moment fluctuations appear and dynamics deteriorates. Fluctuations in flux linkage are observed at a speed of more than 700 rad/s. The modeling also showed that the system maintains a constant voltage in the field weakening mode. The development of a control system with the aim of increasing torque at low speeds in the presence of errors associated with fluctuations in the DC link voltage and a change in the stator resistance with a change in temperature is possible due to the introduction of a real-current machine balance controller and current calculated in the engine model. The introduction of the dynamic field attenuation circuit serves to provide high torque when it is not possible to further increase the voltage of the motor stator.

5. Conclusions
It is established that in traction electric drives the control system provides the engine in traction mode, recovery mode, reverse, and also allows you to develop high torque at low speeds.

It is shown that for traction electric drives, the introduction of a dynamic field attenuation circuit serves to provide high torque when it is impossible to further increase the motor stator voltage.
References

[1] Gorozhankin A N, Gryzlov A A, Tsirkunenko A T and Zhuravlev A M 2018 Russian Electrical Eng. 89(4) 217
[2] Belykh I A and Grigorev M A 2019 Russian Electrical Eng. 90(5) 370
[3] Belousov E V, Grigor’ev M A and Gryzlov A A 2017 Russian Electrical Eng. 88(4) 185
[4] Grigor’ev M A 2017 Russian Electrical Eng. 88(4) 189
[5] Gryzlov A A, Grigor’ev M A and Imanova A A 2017 Russian Electrical Eng. 88(4) 193
[6] Gorozhankin A N, Bukhanov S S, Gryzlov A A and Grigorev M A 2019 Russian Electrical Eng. 90(5) 357
[7] Khayatov E S and Grigor’ev M A 2017 Russian Electrical Eng. 88(4) 197
[8] Zhuravlev A M and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 222
[9] Chupin S A and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 240
[10] Naumovich N I and Grigorev M A 2019 Russian Electrical Eng. 90(5) 380
[11] Chupin E S and Grigorev M A 2019 Russian Electrical Eng. 90(5) 375
[12] Belykh I A and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 234
[13] Gryzlov A A and Grigorev M A 2019 Russian Electrical Eng. 90(5) 364
[14] Gryzlov A.A. and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 245
[15] Belykh I A, Grigor’ev M A and Belousov E V 2017 Russian Electrical Eng. 88(4) 205
[16] Men’shenin A S and Grigor’ev M A 2018 Russian Electrical Eng. 89(4) 228