

# Modeling and analysis of vector control systems for asynchronous motor

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**Abstract.** The study aims at the analysis of vector control asynchronous electric drive systems. For comparison and evaluation, mathematical models of systems are implemented in the environment of simulation modeling Matlab Simulink. The evaluation criteria selected were: complexity of implementation, energy efficiency of the inverter, accuracy of speed maintenance, torque ripple, reaction speed of the system to disturbances from the side of the drive mechanism, impact on the supply network. Vector control systems by ensuring the maintenance of accuracy of the moment in the entire range of speed control are more widespread. The study of vector systems, the formation of the stator voltage vector in which is carried out using pulse-width modulation. The signal organization during the study was carried out by several methods. At the initial stage, the signal was formed due to relay-vector control in a closed loop for monitoring the instantaneous values of current errors without forced modulation; at the next stage of the study, the signal was generated using sinusoidal pulse-width modulation based on a comparison of control signals with some reference vector, the final stage became a spatial-vector modulation method.

## 1 General information

The basis of vector control of an asynchronous electric drive are differential equations that allow you to describe an electric machine quite accurately in both statics and dynamics. The control of the electromagnetic torque is achieved by controlling the amplitude and instantaneous phase of the stator current or its voltage, which allows achieving complete control of the machine in dynamics and obtaining the desired transients, the quality of which is much higher than in scalar control systems. This fact has ensured the widespread use of vector systems, including in high-precision electric drives [1-15]. The stator voltage vector is formed using pulse-width modulation. At the same time, on the basis of a voltage inverter, pulse-width modulation signal can be obtained in the following ways:

- relay-vector formation of pulse-width modulation in a closed loop for monitoring the instantaneous values of current errors without forced modulation;
- sinusoidal pulse-width modulation based on a comparison of the control signals with some reference signal;
- space-vector modulation method.

### 1.1 Relay-vector control

In the relay-vector control systems, the reference vector is the rotor flux linkage vector (Fig. 1). The system has two control channels: a speed control channel and a rotor flux link control channel. As feedback channels, signals

from current sensors and a speed sensor (in a real system represented by an encoder) are used. The rotor flux linkage value is calculated indirectly. Relay-vector PWM signal is generated by the relay current regulator (Current Regulator). Sequence control of power switching transistors made IGBT- current regulator.

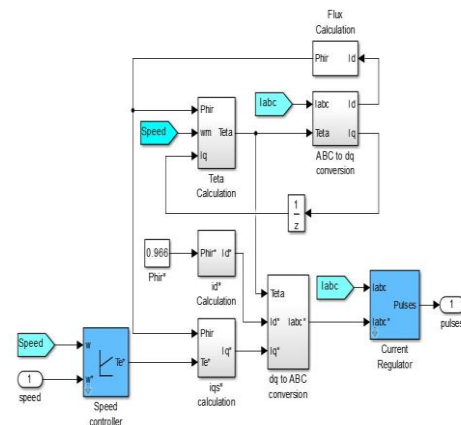


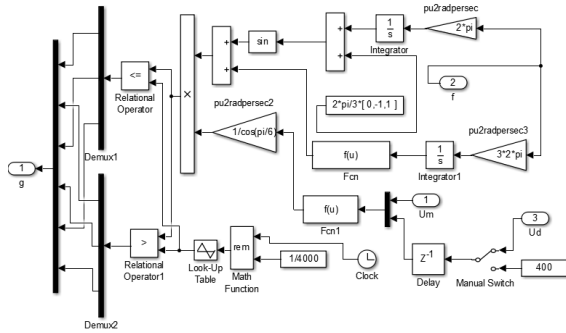
Fig. 1. Relay-vector control.

### 1.2 Vector control with sinusoidal PWM

The main drawback of standard sinusoidal PWM modulation is the underutilization of the DC link voltage by about 14%. This leads to a decrease in the motor torque, an increase in current consumption when working with the rated torque, as well as the

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non-optimal use of high-voltage elements of the power circuit. One way to solve this problem is premodulation with the third harmonic of the line voltage. The idea of the work is that a third harmonic premodulation signal is added to the signal of the fundamental frequency generator, which allows to realize the maximum amplitude of the output voltage. The functional diagram of the generator that implements a sinusoidal PWM with premodulation is shown in Figure 2.

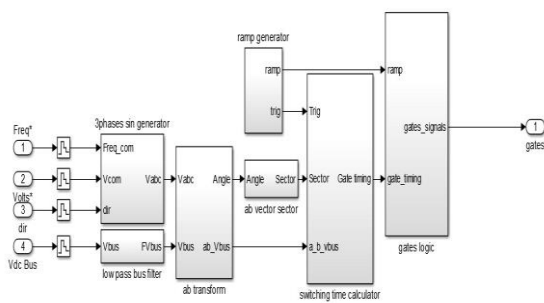


**Fig. 2.** Pre-modulated Sine-PWM Generator.

### 1.3 Vector control with space-vector PWM

The spatial-vector PWM of the voltage vector is implemented using basic vectors in a three-phase coordinate system, with each basic vector characterized by a certain state of the inverter keys (Fig. 3). The speed reference comes to classical PI controller, whose output signals are proportional to the required frequency and voltage magnitude. Based on these signals, a three-phase voltage generating unit generates sinusoids of a given frequency and amplitude. In the sector calculation unit, the sector number in the coordinate system  $\alpha\beta$  is determined.

The calculation of the duration of the inclusion of basic and zero vectors is carried out by the corresponding unit, the conversion of the relative durations into real ones is carried out by the signal of the ramp generator, which determines the carrier frequency of the pulse-width modulation of the inverter. The power driver is controlled directly by the pulse shaper.

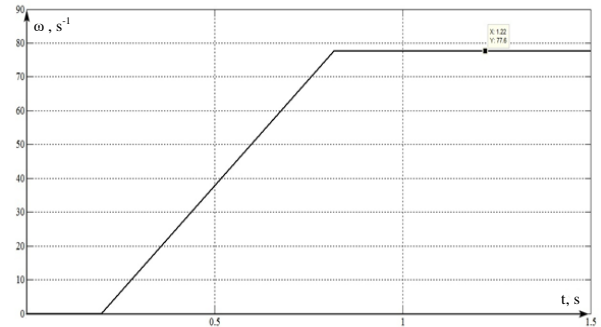


**Fig. 3.** Control system with space-vector PWM.

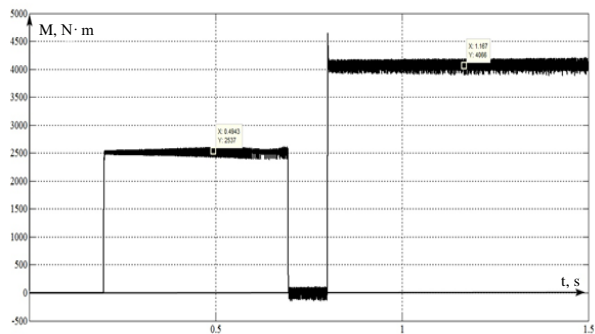
## 2 Simulation results

### 2.1 Vector system (relay-vector control)

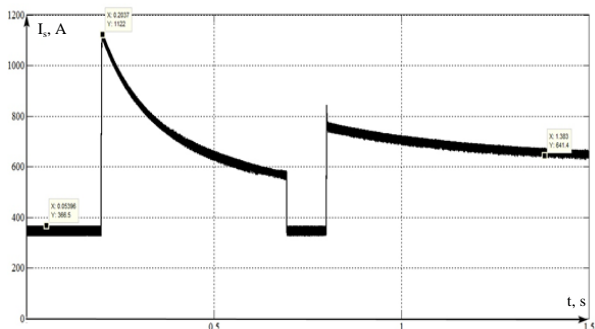
The characteristics obtained during modeling are presented in Figures 4-6.



**Fig. 4.** Transition process of the torque.



**Fig. 5.** Transient process of the stator current.

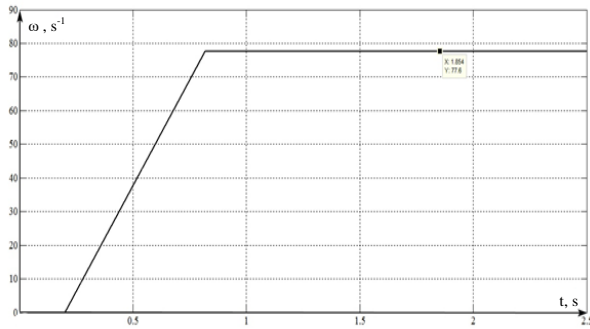


**Fig. 6.** Transient process of the speed.

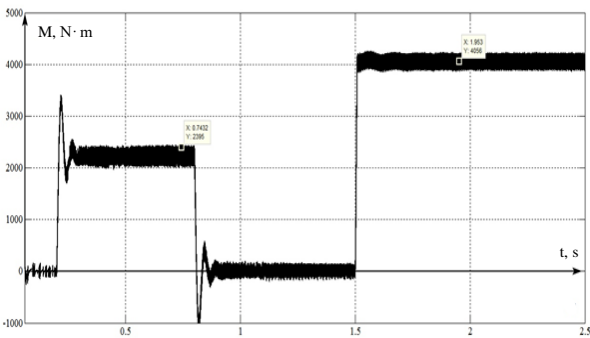
As can be seen from the oscillogram of the stator current, at a time when there is no speed reference, a voltage is applied to the stator windings, causing a magnetizing current of 366 A to flow, which is necessary to create a nominal rotor flux linkage. At a time of 0.2 s, a speed reference is received through the intensity controller. During acceleration, a constant dynamic torque of 2500 Nm is maintained. At a moment of time of 0.8 s, a load surge occurs, while there is no subsidence of speed, and the torque is formed with a slight overshoot. So, the relay-vector control system allows for full control of the asynchronous motor in dynamics.

## 2.2 Vector system (control with sinusoidal PWM)

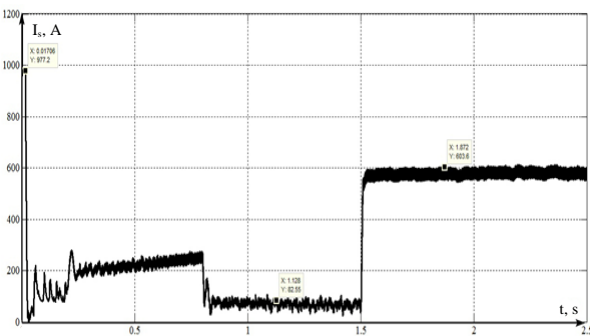
The characteristics obtained during modeling are presented in Figures 7-9.



**Fig. 7.** Transition process of the torque.



**Fig. 8.** Transient process of the stator current.

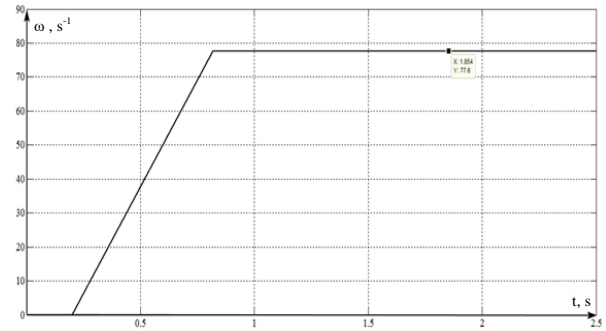


**Fig. 9.** Transient process of the speed.

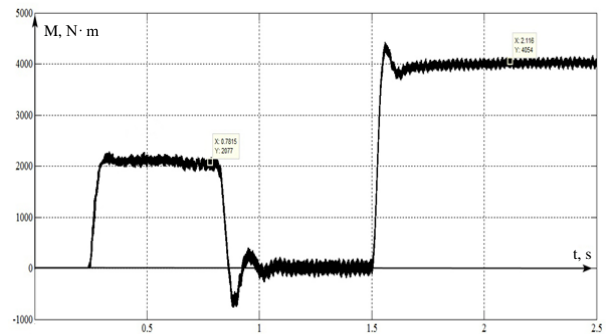
At the initial torque, a magnetization current of 977 A is formed, not exceeding twice the nominal value, necessary to create the nominal rotor flux. In the process of acceleration is maintained constant dynamic torque 2300 Nm. At a moment of time of 1.5 s, a load surge occurs, the torque is formed practically without overshoot. So, a vector control system with a sinusoidal pulse-width modulation algorithm allows to obtain a good quality of transients.

## 2.3 Vector system (control with space-vector PWM)

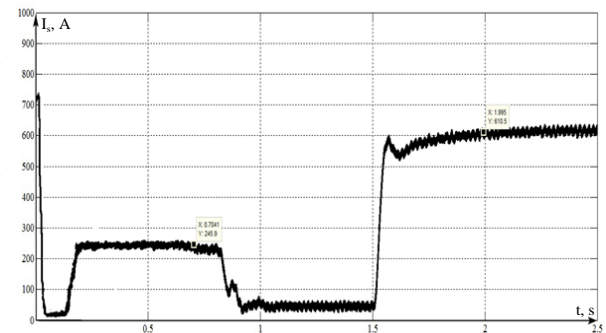
The characteristics obtained during modeling are presented in Figures 10-12.



**Fig. 10.** Transition process of the torque.



**Fig. 11.** Transient process of the stator current.



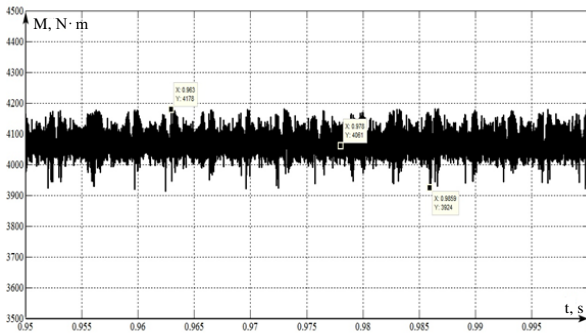
**Fig. 12.** Transient process of the speed.

The rated motor flux is formed by a stator current surge of 735 A; during startup, the current value is 245 A. During acceleration, a constant dynamic torque of 2000 N · m is maintained. At a moment of time of 1.5 s, a load surge occurs, the torque is formed with permissible overshoot. So, the spatial-vector control system allows you to implement the desired transients.

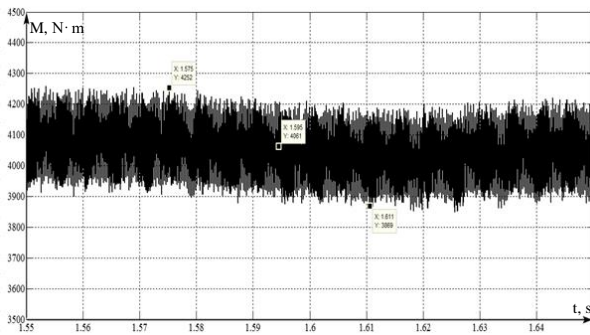
## 3 Comparison of different types of PWM

### 3.1 Torque ripple

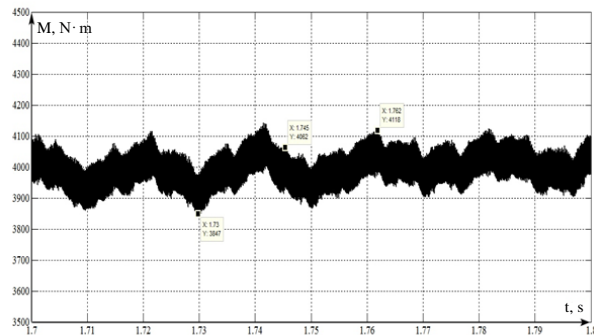
The oscillograms of the electromagnetic motor torque during steady state operation at rated load for different types of PWM type shown in Figures 13- 15.



**Fig. 13.** Transient process for relay-vector pulse-width modulation.



**Fig. 14.** Transient for sinusoidal pulse width modulation.

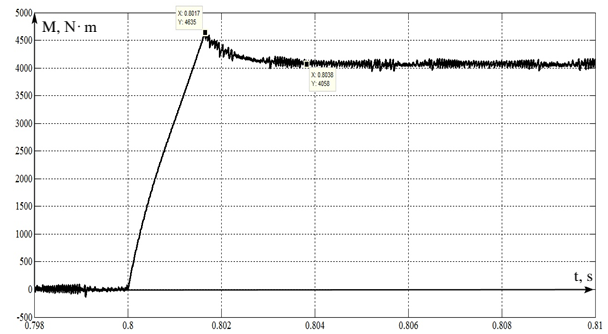


**Fig. 15.** Transient for spatially vector pulse width modulation.

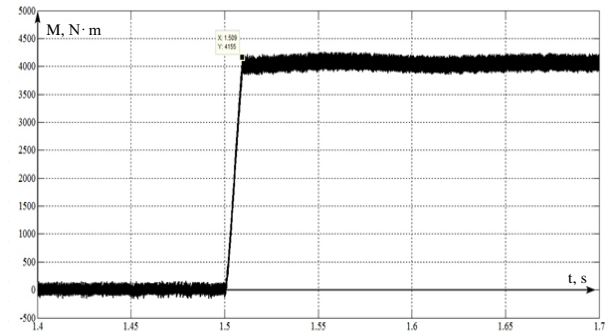
The average amplitude of the pulsations of the electromagnetic torque for the relay-vector and space-vector pulse-width modulation lies in the range of 120 - 130 N · m, for sinusoidal pulse-width modulation in the range of 150 - 160 N · m. So, sinusoidal pulse-width modulation provides a slightly worse quality of the electromagnetic torque, however, the ripple value is still small and does not exceed 7% of the nominal value of the torque.

### 3.2 System response time to perturbation

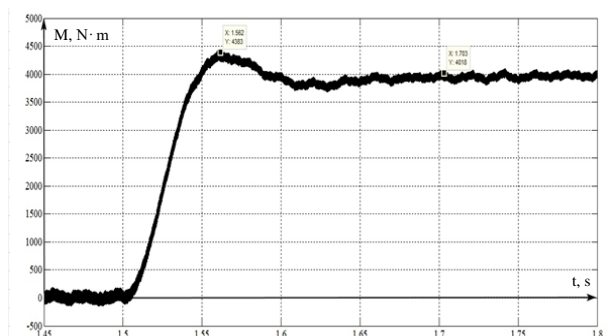
Oscillograms of the formation of the electromagnetic torque of the engine when the rated load is drawn during idling for various types of pulse-width modulation are shown in Figures 16, 17 and 18.



**Fig. 16.** Transient process for relay-vector pulse-width modulation during load transfer.



**Fig. 17.** Transient for sinusoidal pulse width modulation during load transfer.



**Fig. 18.** Transient for spatially vector pulse-width modulation during load transfer.

It is seen from the graphs that the system with ladder-vector control has an order of magnitude higher speed torque control channel that is connected to the lack of a fixed switching frequency keys.

## 4 Conclusion

Vector control systems as a whole make it possible to achieve complete control of blood pressure in both static and dynamic modes. Due to the presence of two control channels, it is possible to separately or jointly control the flow and speed of the machine, which in turn provides complete control over the current and electromagnetic torque of the machine. Since the system is focused on a high-performance microprocessor system, it is very flexible and allows implementing various control laws, methods for modulating phase voltage, and increasing the energy

efficiency of the system as a whole. These positive qualities ensured its wide distribution in a wide range of industrial electric drives.

## Acknowledgements

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