MODELING OF THE PROCESSES IN THE PROPULSION SYSTEM OF AN ELECTRIC VEHICLE

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***Abstract*— In this paper we make modeling of process in driving system of electric vehicle with realization of a particular assignment state of departure. The realization is made by the utilization of the specialized software Multisim, through which hardware implementation of the model is simple, fast and unified. Conclusions are made for the necessary energy from the power source for the implementation of the selected mode acceleration at the departure state.**

Keywords—Modeling; Multisim; Electric Vehicle; BLDC; Power electronics; Intelligent Motion

I. INTRODUCTION

Brushless motors with permanent magnets have some major advantages such as: high torque, power output with high density, efficiency and excellent movement. Because of their features they are widely utilized in various industrial devices, high-current servomechanisms, as well as several particular applications where size and weight are limited, such as in electrically powered transportation vehicles [1].

The object of this work is to create a model of the propulsion system of an electric vehicle of a power source, electronic transformer, motor and control system and automatic regulation.

II. DESCRIPTION OF THE MODEL

In the literature [1,4,11] are described different methods for the control and systems of power electronic converters. Below are presented the most commonly used with their descriptions, advantages and disadvantages.

The main characteristic of the predictive control is the use of the model of the system for the prediction of the future behavior of the managed variables. This data is used by the control unit to obtain optimal actuation, compared to a predetermined criterion for optimization.

The diversity of predictive control can be deadbeat, hysteresis, trajectory-based and model predictive control. It is divided into two types with a finite and infinite set of points.

The criterion for optimization in hysteresis based predictive control is to maintain the variables within the limits of the predefined hysteresis loop area while in the trajectory based control, they are forced to follow a predefined such.

In deadbeat control, the optimal actuation is what makes the error equal to zero in the sample time. A more flexible criterion is used in the model predictive control (MPC), as it is expressed with a cost function which must be minimized.

The MPC describes a wide range of controllers without a concrete strategy for control. This structure has several important advantages [16, 17]: The concept is very intuitive and easy to understand, can be applied in different types of systems, the multivariable systems may be taken into consideration, the dead time can be compensated, easy inclusion of non-linear in the model, easy processing of restrictions and it is suitable for the inclusion of variation, depending on the different applications.

Despite all the advantages it has weaknesses, for example the large number of calculations in relation to the classic controllers. The main ideas in this type of control are the use of the model for the prediction of the behavior of the variables and cost function which represents the desired behavior of the system. The model used is discrete - time and can be expressed by the following equations:

$$x(k+1) = Ax(k) + Bu(k) \tag{1}$$

$$y(k) = Cx(k) + Du(k) \tag{2}$$

The cost function which represents the desired behavior of the system must be defined. It shall include the connections, future status and future actions:

$$J = f(x(k), u(k), \dots u(k+N)) \tag{3}$$

Brushless motors with permanent magnets are entirely composed of three-phase stator windings and iron rotor with permanent magnets attached to it. They can be attached to the surface of the rotor or in its core. Thus, the magnetic field is fixed to the position of the rotor. Concerning the design speed of the rotor is strictly dependent on the frequency of the stator and a variable speed operation is required supply voltage inverter [2, 3].

In the description of vectors of states are displayed the following equations for V_s- voltage of the stator, I_s – current of the stator and Ψ_s– the magnetic flux.

$$V_s = \frac{2}{3}(v_{sa} + a v_{sb} + a^2 v_{sc}) \tag{4}$$

$$I_s = \frac{2}{3}(i_{sa} + a i_{sb} + a^2 i_{sc}) \tag{5}$$

$$\Psi_s = \frac{2}{3}(\Psi_{sa} + a\Psi_{sb} + a^2\Psi_{sc}) \tag{6}$$

The dynamics of the stator are described with the following equation:

$$V_s = R_s i_s + \frac{d\Psi_s}{dt}, \tag{7}$$

where R_s is the resistance of the stator.

Magnetic flux of the stator Ψ_s is generated from the magnetism of the rotor and self-flux linkage of currents in the stator and it is described with this equation:

$$\Psi_s = L_s i_s + \Psi_m^{e^{j\theta_r}}, \tag{8}$$

where L_s is self-inductance of the stator, Ψ_m is magnetic flux in the stator, θ_r – the position of the rotor.

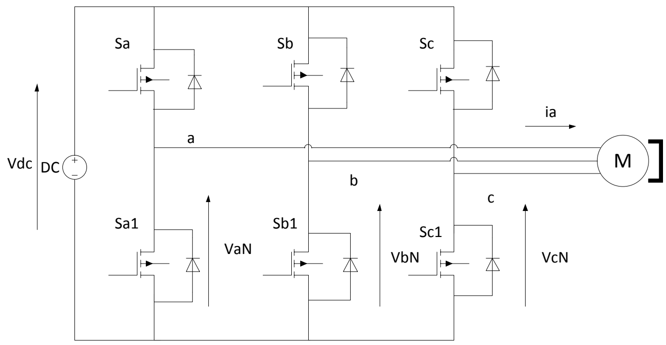

Fig. 1. Scheme of converter and motor with permanent magnet

The most frequently used are few structural schemes for the control of the synchronous machine with permanent magnets [6, 7, 9]. Well established methods are field oriented control and direct torque control. The quality of the scheme controlled by the field depends on the implementation of current control units that most often used PI controllers with a pulse width modulation. Other schemes for the control as hysteresis and deadbeat-based control are also represented.

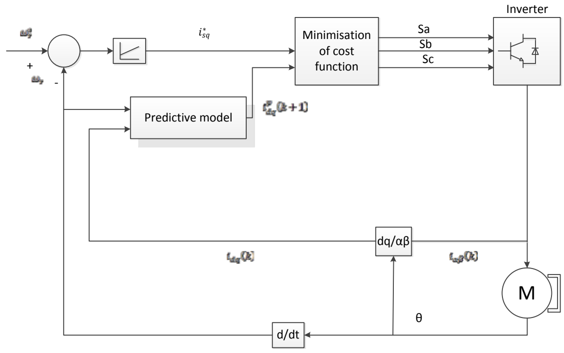

Fig. 2. Block scheme for control for field oriented control

In Fig.2. is shown the motor with permanent magnets with predictive current control. Here, the PI controller is used to control the speed and generates the reference of the works current i_{sq}^* at torque. Predictive current control is used for tracking the reference current. In the block diagram of predictive control, discretely-time model of the machine is used for the estimation of the current of the stator for seven different voltages expressed by vectors generated by the converter. The voltage vector that minimizes the cost function must apply throughout the full interval of time.

The cost function g is expressed by the following equation:

$$g = \left(i_{sd}^{p}(k+1)\right)^2 + \left(i_{sq}^{*} - i_{sq}^{p}(k+1)\right)^2 + \\ +\hat{f}\left(i_{sd}^{p}(k+1), i_{sq}^{p}(k+1)\right), \tag{9}$$

where the first part of the equation described the minimization of the reactive power, which allow the optimization of torque, the second part described the current thought this moment, the third part is non-linear function for limit the amplitude of currents in the stator.

Through the use of the rotation d-q transformation, field oriented to magnetic core of the rotor, each current component of the stator has physical meaning. The imaginary component i_{sq} is proportional to electric torque until the actual component i_{sd} is proportional to the reactive power. In this way the control of the motor shall be applied as the current control of the scheme, where current references are generated by the external for the speed control of the feedback.

The model of the motor is used for the prediction of the behavior of the currents in the stator and by the cost function must be predict for the error between the given and the estimated currents.

The block diagram of predictive speed control is shown in Fig.3. Discretely-time model of the motor is used for the calculation of the estimated speed of the rotor and currents in the stator for the seven different voltage vectors generated by the converter. These data's are evaluated by the cost function which defines the desired behavior of the system. The voltage vector that minimizes this function is selected and shall be applied to the machine for the entire interval of time. Due to the disturbance of the measurement of speed and high frequencies that are usually necessary in this type of schemes to be used Kalman filter (EKF), for estimation of the rotor speed [14].

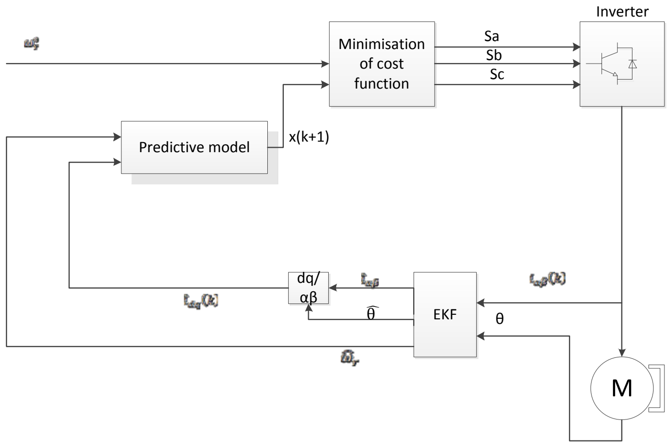

Fig. 3. Predictive speed control

This scheme can be described wish followed cost function:

$$g = \lambda_{\omega}\left(\omega_r^* - \omega_r^p(k+1)\right)^2 + \lambda_i\left(i_{sd}^p(k+1)\right)^2 + $$
$$+\lambda_{if}\left(i_{sqf}^p(k+1)\right)^2 + \hat{f}\left(i_{sd}^p(k+1), i_{sq}^p(k+1)\right), \qquad (10)$$

where in the first part of equation is described the predicted speed error and ω_r^* is the reference speed. In the second part the current i_{sd} is minimized, to optimize the torque. In the third part the filtered value of the current i_{sq} is checked. A high-frequency filter is used to eliminate high frequencies in order to improve the behavior of torque to the motor. The last part of the equation describes the non-linear function which restricts the currents in the stator, thus not allowing the voltage vectors to pass through the borders of the predicted currents.

The particular model shows the use of a specific regulator, shown in Fig.4. In the workflow of the regulator the Park and Clark transformation is used. Those are mathematical transformations, which rotate the reference frame of the three-phase systems in order to simplify the analysis and modeling of the electrical schemes. For the motor these transformations convert the magnitudes of the rotor and stator in a rotating frame in order to eliminate periods of ranging inductance [2].

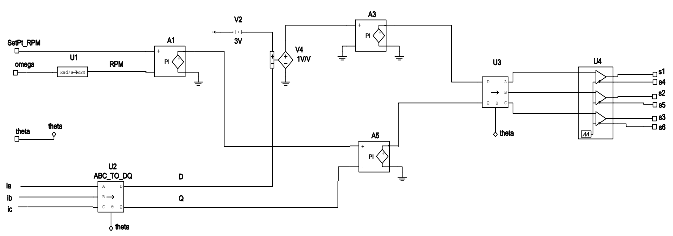

Fig. 4. Scheme of control system

To reduce losses in power converters, it is necessary to select suitable materials for the realization of the magnetic components. It is appropriate to use the studies described in [19, 20].

III. RESULTS

Studies performed to the propulsion system of the electrically powered vehicle in a state of acceleration based on the proposed model. Using the mentioned bellow initial model conditions: input voltage V1= 260V. The speed will reach the 80 RPM set point at 250 us (Fig. 5). The power will reach about 14 kW for the same time (Fig. 6).

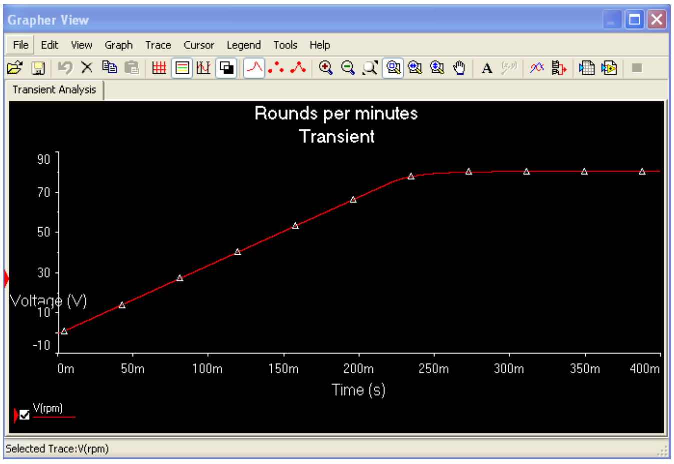

Fig. 5. Results for rounds per minute

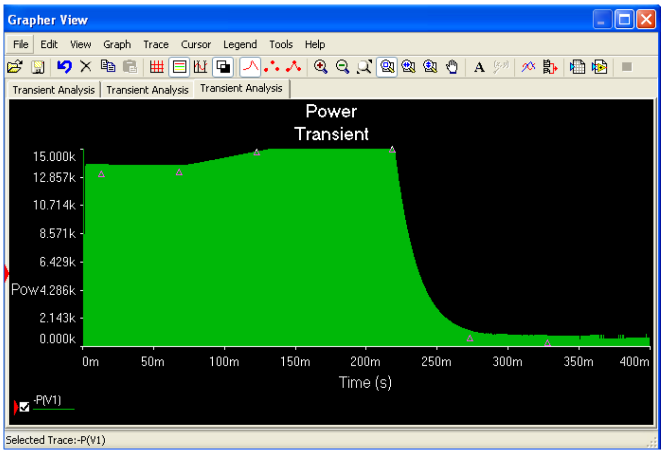

Fig. 6. Results for the power

Fig. 7. shows the results of the study, when the parameters of the motor with permanent magnets is changed and the field oriented control is used. Ah the diagrams is shown a faster down speed than the previous (Fig. 5 and Fig.6.) - for about 115ms.

These studies demonstrate the efficiency of the converter under various parameters of the motor. The implemented control method allows management of the process without adjustment of the supply voltage. This improves the energy performance of the converters.

The system has a reserve in robustness as the variations of the values of the variables are significantly slower in the real process than those used in our studies.

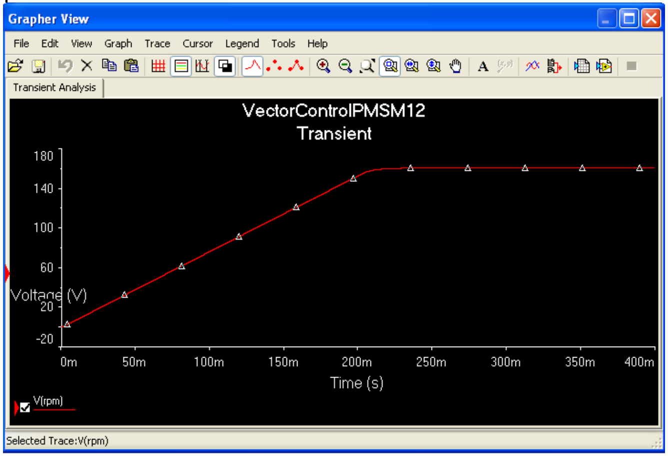

Fig. 7. Results for rounds per minute

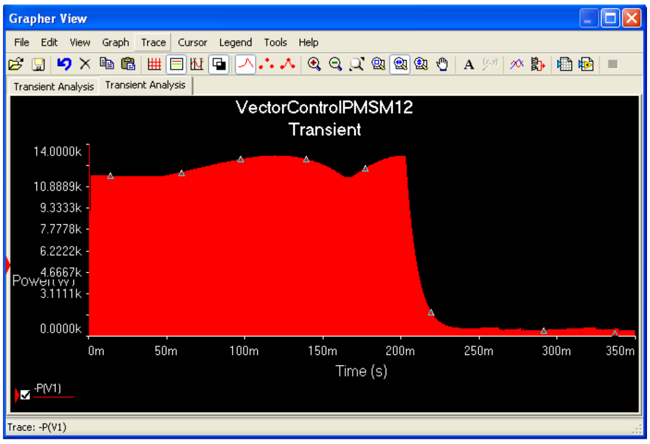

Fig. 8. Results for the power

IV. CONCLUSIONS

The content of this publication represents study results based on a model of the dynamics of electromechanical system of an electrically powered vehicle in the departure mode. Based on the methodology provided in this study the possibility to research in other modes of braking energy recovery, etc. is provided. NI Multisim environment is particularly suitable for this type of research, for ease of integration with other modern means of research in the field of power electronics such as NI LabVIEW, MathWorks Simulink, and also with the hardware resources of National Instruments and companies.

As a result of the above, it is found that the system is designed properly and comply with the requirements. Achieved appropriate control, with guaranteed quality and high energy performance.

A useful future research would be one for the behavior of the system considering the non-linearity of the inductive elements and thus expanding the applicability in other technological objects such as induction heating, welding and rectifier, etc.

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