

Simulation of the Induction Motor Drives in OrCAD Environment

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Abstract – *This paper shows how induction motor drive, can be simulated with modern simulation programs. The focus will be on OrCAD, which is one of the most widely used general-purpose simulation programs. Static power converters can be analyzed by means of widely available circuit simulation software packages such as PSpice. However, they are usually modeled as a set of real switches, which results in long execution times and possible convergence problems in the case of complex circuits. This paper presents a model to simulate a sinusoidal pulse width modulation (SPWM) for three-phase inverter fed induction machine using PSpice. The proposed model are based on converter switching function rather than actual circuit configuration, and they are suited for steady state and large signal transient analysis at system level. The operation mode and simulation results are presented.*

Keywords: *OrCAD Capture, PSpice, Induction motor drives.*

I. INTRODUCTION

The PSpice circuit simulation program that nowadays is included in OrCAD environment, has become an industry standard. The major advantage of using PSpice is that, with the same software, a particular circuit can be designed and analyzed at different system and subsystem levels, i.e. at the levels of the power switch, the converter circuit, and control systems, including feedback control [1].

PSpice contains models for basic circuit elements (R; L; C, independent and controlled sources, transformer, transmission line), switches, and most common semiconductor devices: diodes, bipolar junction transistors (BJT's), junction field-effect transistors (JFET's), insulated gate bipolar transistors (IGBT's), MESFET's, and MOSFET's.

PSpice is mainly applied to simulate electronic and electrical circuits for different analyses, including dc, ac, transient, distortion, sensitivity, and noise. PSpice uses the nodal approach with a variable-time-step integration algorithm so that it can correctly simulate switching power electronic circuits. Using the analog behavioral modeling (ABM) blocks facilitates the simulation of control systems in PSpice.

However, there are no specific models for electrical machines, circuit breakers, surge arresters, etc. To simulate a power system, the user has to build the needed models using SPICE primitives and basic elements.

For higher levels of simulation, simplified models for the switch and the converter must be implemented, in order to minimize convergence problems and reduce the run times. General functional model for three-phase PWM inverter has been proposed. A functional model produces a dramatic simplification of the total converter circuit. Moreover, it allows a converter to be modelled as a multiport circuit that consists only voltage controlled voltage source, and current controlled current sources connected at the input and output ports. The signals controlling these sources are two level switching functions defined by PWM technique.

II INVERTER MODEL

Using transfer functions derive analytical model for the inverter.

The inverter as a non-linear multiport network has three ports: dc, ac, and control. The dc port is input and ac ports is output. The control port consists only of inputs. The transfer function is the instantaneous relation between the dc input and the ac output variables. An inverter has a current and voltage transfer function, both defined by the same switching function applied to the control port. The transfer function of this multiport network can be easily simulated on PSpice by using controlled sources in the Analog Behavioral Modeling option (ABM) [2]. The signal applied to the control input port is two level switching functions shown in Fig.1.

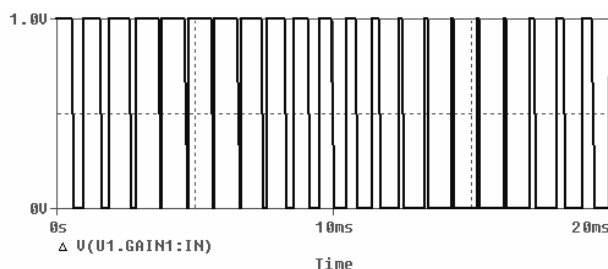


Fig.1. Two-level switching function.

The switching function is derived by comparing a sinusoidal signal named modulator signal with a triangular signal named carrier signal. The carrier signal is obtained with VPULSE source.

A switching function is used to generate the ac output leg voltage in a voltage source inverter. By using the concept of switching functions, and with the assumption of no losses and no parasitic reactive element in the inverter, the functional representation is derived, as shown in the next.

In the voltage source inverter, the output voltage is generated by reflecting simultaneously the instantaneous input voltage to the output, and the instantaneous output line current to the input during intervals defined by the switching function. These two processes can be formulated in analytical form by the following equations [4]:

$$\begin{aligned} I_i &= [i_a(t) \ i_b(t) \ i_c(t)]^T [s_a(t) \ s_b(t) \ s_c(t)] \\ v_a(t) &= V_i * s_a(t) \\ v_b(t) &= V_i * s_b(t) \\ v_c(t) &= V_i * s_c(t) \end{aligned} \quad (1)$$

where $i_a(t)$, $i_b(t)$, $i_c(t)$ are the three-phase instantaneous output line currents and $v_a(t)$, $v_b(t)$, $v_c(t)$ are the three instantaneous output voltages. Also, I_i and V_i are instantaneous input current and voltage respectively (dc quantities), and $s_a(t)$, $s_b(t)$, $s_c(t)$ are two-level switching function for each leg of the inverter.

Using the ABM Library in OrCAD Capture, the implementation of the inverter models is shown in Fig. 2.

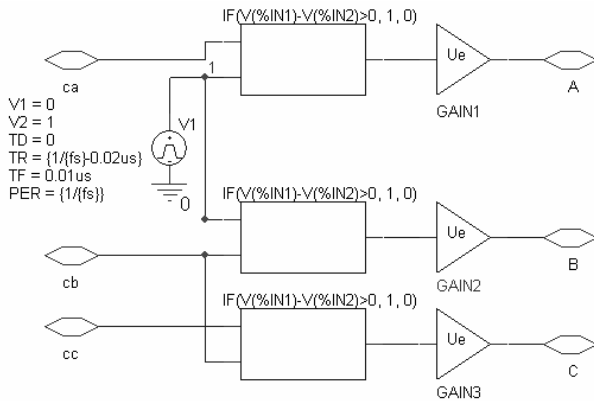


Fig. 2. Proposed models of three-phase inverter.

The SPWM modulation requires a comparator circuit to generate switching function. The model for a comparator is implemented by means of ABM2 part from ABM Library. EXP1, the field of ABM2 part, contain the expression:

$$\text{IF}(V(\%IN1)-V(\%IN2)>0, 1, 0) \quad (2)$$

This means that the output of ABM2 part is 1 V when the modulator signal is greater than carrier signals and 0 contrariwise. The Gain parts have the gain equal with inverter voltage fed.

Fig. 2 is the hierarchic down level of component named *INVERTER*. The symbol of *INVERTER* part is

presented in Fig. 3.

The *A*, *B* and *C* are the inverter outputs, and *ca*, *cb* and *cc* are the inputs where the modulator signals are applied.

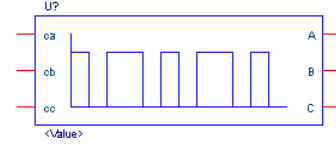


Fig. 3. The symbol of *INVERTER* part.

II SIMULATION OF INDUCTION MACHINE

The induction motor symbol represents the electromechanical model of an induction motor. The model is suitable for studies of electrical and mechanical transients as well as steady state conditions. The induction motor model has been derived for a two-phase equivalent motor. Attached to the motor is a bi-directional two-phase to three-phase converter module. This module is voltage and current invariant. This means that the voltage and current levels in the two-phase and the three-phase machine are equal. Consequently, the power in the two-phase machine is only 2/3 of the power in the three-phase circuit.

In Fig. 4 the motor is represented by a custom symbol called *Motor*. A simple hierarchical block could have been used for the motor, but a custom symbol has been created to achieve a more realistic and pleasing graphical representation. The symbol can be easily created with the symbol editor, which is build into the regular schematics editor. The editor provides standard graphical elements: lines, rectangles, circles etc. so that professional looking symbols can easily be created.

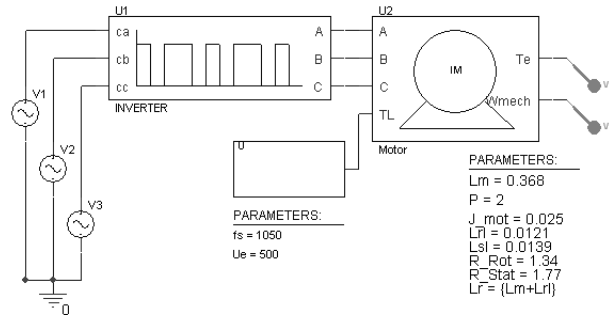


Fig. 4 Induction motor start-up with proposed model inverter.

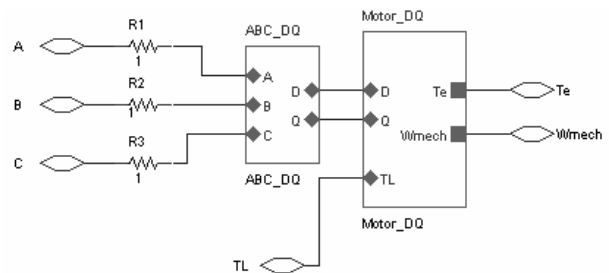


Fig. 5 The subcircuit of the *Motor* block.

The subcircuit of the *Motor* block contains the

subcircuit for ABC-DQ transformation called *ABC-DQ* and the *Motor_DQ* block.

The d-q model of induction machine is presented in Fig. 6. The upper portion of this subcircuit represents the electrical model. The task of the electrical model is to calculate the stator and rotor currents, where the stator voltages and the mechanical speed of the machine are input parameters.

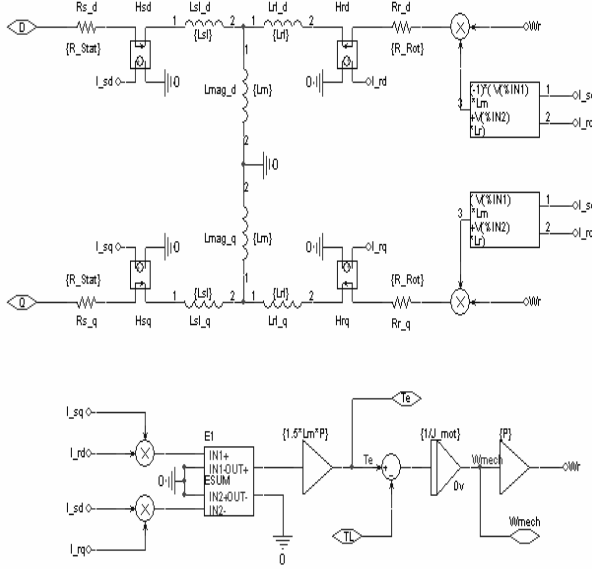


Fig. 6 Subcircuit for d-q induction motor model.

The equation system for the electrical model is given by equation (1). The theory for this equation system is derived in [4]. The equation system and the model are formulated for the stationary reference frame.

$$\begin{bmatrix} V_d \\ V_q \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_{stat} + pL_s & 0 & pL_m & 0 \\ 0 & R_{stat} + pL_s & 0 & pL_m \\ pL_m & \omega_e L_m & R_{rot} + pL_r & \omega_e L_r \\ -\omega_e L_m & pL_m & -\omega_e L_r & R_{rot} + pL_r \end{bmatrix} \begin{bmatrix} I_{sd} \\ I_{sq} \\ I_{rd} \\ I_{rq} \end{bmatrix} \quad (1)$$

$L_s = L_m + L_{ls}; L_r = L_m + L_{lr}; p = d/dt.$

The bottom of Fig. 6 represents the mechanical model. This circuit calculates the internally generated electro-magnetic torque using the stator and rotor currents as input values. The equation for the torque is given by (2) [4]:

$$T_e = (3/2)p(I_{sq}I_{rd} - I_{sd}I_{rq}). \quad (2)$$

Using the generated torque, the load torque and the moment of inertia, the angular acceleration can be calculated. Integration of the angular acceleration yields the rotor speed, which is used in the electrical model. Since typical induction machines are three-phase machines, it is often desirable to have a machine model with a three-phase input. Therefore a bi-directional two-phase to three-phase converter module, which can be attached to the motor, has been developed. A subcircuit for this module is shown in Fig. 7. This circuit is truly bi-directional, meaning that the circuit can be fed with voltage or current sources from either side. An interesting detail of the subcircuit is the three-phase switch on the input. This switch is necessary to ensure a

stable initialization of the simulator in case the machine is fed with a controlled current source. The switch provides an initial shunt resistor from the three-phase input to ground. Soon after the simulation has started, the switch opens and leaves only a negligible shunt conductance to ground.

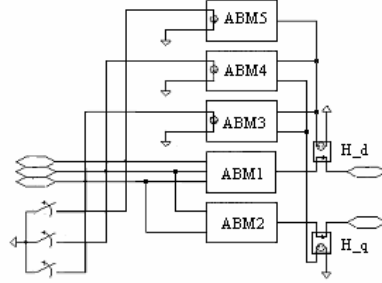


Fig. 7 Subcircuit for ABC-DQ transformation.

Fig. 7 shows the results for the start-up of the induction motor for the circuit of Fig.4. The motor's parameter is presented in Fig.4. The top trace in Fig. 7 shows the developed electromagnetic torque. The scale for this graph is 1V = 1 Nm. The graph below shows the mechanical angular velocity with a scale of 1 V = 1rad/s. Below the graph for the rotor speed, all three input currents are shown. Input voltage is the PWM waveform shown in the bottom graph.

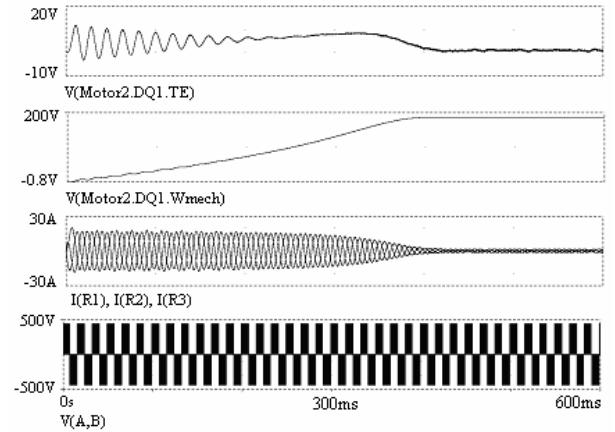


Fig. 8 Induction machine with three-phase inverter.

III SIMULATION OF VECTOR CONTROL

Figure 9 shows the subcircuit for the vector control unit. The central part is a vector rotator for positive direction. This element transforms the dc reference values for the flux (D axis) and the torque (Q axis) to the stationary reference frame. The input angle for the vector rotator is the integral of the synchronous angular velocity. The signal called "Wmech" is the measured rotor speed. This speed is multiplied with the number of pole-pairs to obtain the electrical angular velocity. Then the slip value appropriate to the torque command is added and the resulting signal is routed through an integrator to generate the input angle for the vector rotator.

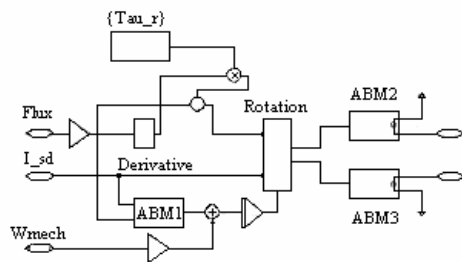


Fig. 9 Subcircuit for indirect vector control.

Fig. 10 presents indirect vector control of induction machines with current excitation.

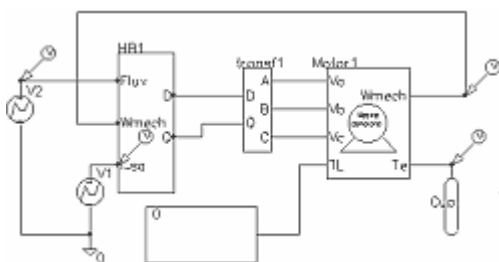


Fig. 10 Circuit for indirect vector control with current excitation.

Fig. 11 shows the results obtained for the circuit shown in Fig. 9 with perfect tuning of the vector controller, meaning that the controller precisely knows all motor parameters. The trace in the diagram on top of Fig. 11 represent the trace for Q input signals of the vector rotator.

The graph below shows the reference value for the flux. Below the flux reference is the graph for the mechanical angular velocity. It can be seen that the machine accelerates whenever torque is developed and slows down due to the load when the torque command is driven to zero. The graph on the bottom of Fig. 11 provides the easiest way to judge the quality of the correct field orientation. This graph shows the traces of the commanded and the actually produced torque and in this case they are perfectly on top of each other at all times.

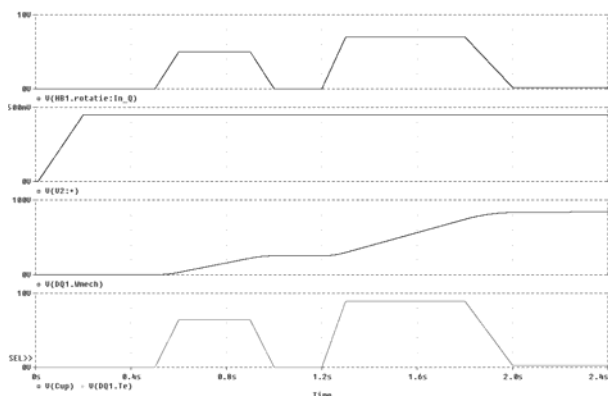


Fig. 11 Results for indirect vector control with perfect tuning.

IV CONCLUSIONS

This paper shows how, electric motors and drives, can be simulated in OrCAD environment. The PSpice simulations of induction machine and of indirect vector control of induction machine with closed loop speed control and with current excitation, when exact motor parameters are known are presented. The simulation of induction motor using hierarchically structures is in detail presented. For asynchronous motor was used the stator reference frame.

V REFERENCES

- [1] N.Mohan, W.Robbins, T.Undeland, Simulation of Power Electronic and Motion Control Systems - An Overview, Proceedings of the IEEE, No.8, August 1994
- [2] Boldea I. and Nasar S.A. Vector Control of AC Drives CRC Press Inc., 1992.
- [3] Trzynadlowski A. M. The Field Orientation Principle in Control of Induction Motors Kluwer Academic Press, Boston, 1994.
- [4] Novotny D.W. and Lipo T.A. Vector Control and Dynamics of AC Drives, Clarendon Press, Oxford, New York, 1996
- [5] Ong Chee-Mun Dynamic Simulation of Electric Machinery Using MATLAB/SIMULINK Prentice Hall PTR, Upper Saddle River, New Jersey, 1998
- [6] Bose, B. K. (2002) Modern Power Electronics and AC Drives Prentice Hall PTR, Upper Saddle River.
- [7] Casadei D., Profumo F., Serra G., Tani A. FOC and DTC: Two Viable Schemes for Induction Motors Torque Control IEEE Transactions on Power Electronics, Vol. 17, no. 5, pp. 779-787, 2002.
- [8] Şchiop A. Analysis and Design of Speed Controller for Vector Controlled Induction Motor Drives EMES, Oradea, pp.122-128, 2003.
- [9] A. Şchiop, Contribuții la studiul convertoarelor utilizate la acționarea motoarelor asincrone, Editura Politehnica, Timișoara 2007.