

Simulation of the Current Regulated Inverter Fed Induction Machine in OrCAD Environment

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Abstract – This paper presents a method for simulation a current regulated inverter fed induction machine using PSPICE. The operation mode and simulation results are presented.

Keywords: OrCAD Capture, PSpice, Induction motor, current regulated inverter

I. INTRODUCTION

Current regulated inverter is a PWM technique that has various names such as delta modulation, tolerance band current control, adaptive current control and hysteresis-type current control. The main task of the control scheme in current regulated inverters is to force the currents in a three-phase ac load to follow the reference signals. By comparing the command i_{ref} and measured i_l instantaneous values of the phase currents, the current controller generates the switching state for the inverter power devices, which decrease the current errors. In general, current control implements two tasks: error compensation and modulation [1]. For a current controller to operate properly there must be sufficient voltage to force the line current in the desired direction. For loads with low counter EMF the dc bus is not critical, but as the counter EMF is increased, a point is reached where the current controller is not able to command the desired current. This condition is reached when the line- to-neutral voltages approach a six-step quasi-square wave [2].

II. CURRENT- REGULATED INVERTER

Consider the one leg inverter illustrated in Fig 1.

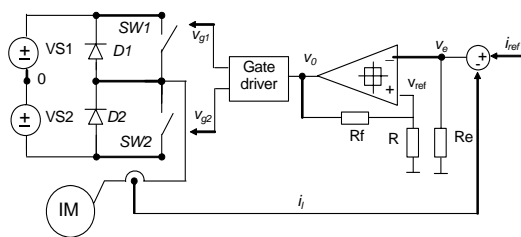


Fig. 1 Current regulated inverter.

It is desired to have a load current similar to a sine-wave reference current, shown in Fig.2a. The actual current is

allowed a tolerance band, as shown by the broken lines either side of the ideal sine wave. The two small preset error limits are called hysteresis limits.

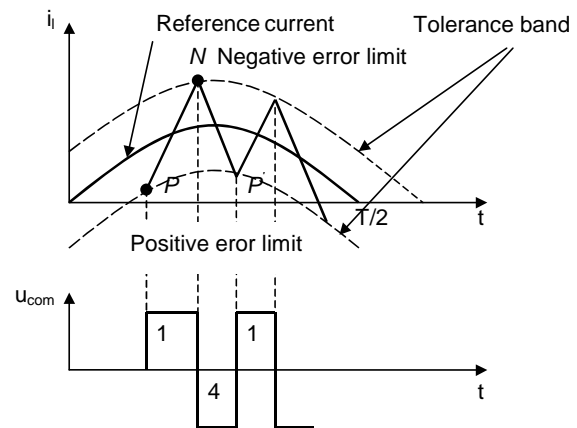


Fig. 2 a) Reference signal and load current.
b) Gate signal to implement strategy.

At some time t the actual current is given by the point P . The current is below the reference value, the error ($i_{ref} - i_l$) is positive so it is required to apply a gate signal to switch $SW1$ (fig.2). With switch $SW1$ on, the load current will tend to increase, and the positive value of the current error tends to reduce to zero. The switch $SW1$ is kept on by to gate signal, the current error becomes negative until it reaches the preset limit of the point N . At this point N must turn off switch $SW1$ (remove its gate signal) and turn on switch $SW2$ (apply its gate signal). Following these actions, the load current will tend to reduce so that the current error becomes less negative. Switch $SW2$ is allowed to remain on until the reduction of load current reaches the predefined positive error ($i_{ref} - i_l$) at the point P' . Here, the cycle repeats; switch $SW2$ is turned off end switch $SW1$ is turned on again. This strategy provides load current with is a sinewave with a small ripple.

The control strategy is to compare the actual load current with a sinewave reference signal. The current error signal ($i_{ref} - i_l$) is almost triangular. Have to convert this triangular wave to square waves that can be used as gate signals to turn on the inverter switches at the triangle "peaks" and "troughs"[3]. The gate signal must to maintained while the triangular wave traverses from peak to trough and vice versa. This can be accomplished with a bistable device such as a Schmitt trigger, since a

Schmitt trigger can be modeled in analogue form in PSpice by a comparator with hysteresis.

Fig. 3a shows the circuit diagram of a comparator that is provided with hysteresis. The input signal v_e (proportional to the current error signals) is applied to the inverting input. At the noninverting input the reference voltage v_{ref} is given by the voltage divider principle to be:

$$v_{ref} = v_0 R / (R + R_f) = kv_0 \quad (1)$$

The comparator works as follows: if the error signal v_e is greater than the reference signal v_{ref} , the output v_0 goes negative. In this application the negative output $-V_{cc}$ is to be a gate signal that will lead to a change (less positive) of the error signal v_e . When the error signal v_e is negative and less than the reference signal v_{ref} (at present $-kV_{cc}$) the comparator output shifts states to $v_0 = +V_{cc}$ and the reference signals becomes $v_{ref} = kV_{cc}$.

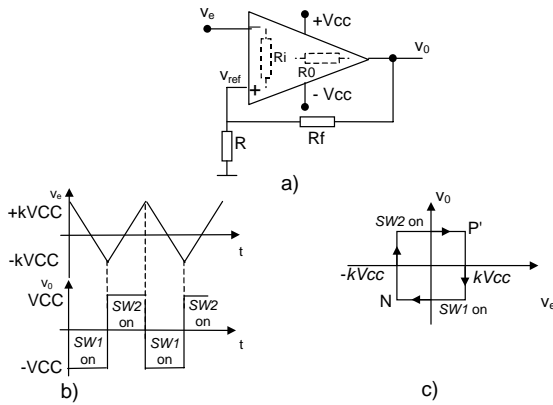


Fig. 3 PWM with preset tolerance
a) Comparator, b) Input and output signals, c) Hysteresis effect.

The reference signals remains at $+kV_{CC}$ until the error signal v_e is greater than v_{ref} , at which point the cycle repeats. While the comparator output is $v_0 = +V_{CC}$, the output is to be a gate signal that will lead to a change (less negative) in the error signal. Fig. 3b shows how the error signal as a function of time is transformed by a comparator square-wave output. The negative output voltage v_0 becomes the gate signal to keep switch $SW1$ of the inverter in the on-state. The positive output voltage v_0 is used to maintain switch $SW2$ on.

Fig.3c shows the comparator output voltage v_0 against the comparator input voltage v_e .

III. ORCAD SIMULATION AND RESULTS

In the Pspice simulation, the phase currents motor has been obtained as current through voltages source zero value V_{ax} , V_{bx} , V_{cx} with goal of current transducer. These voltage sources is in series with current sources G_{ia} , G_{ib} , G_{ic} used for currents transformation two-phase – three-phase system. Figure 4 presents the circuit with that had been obtained command signals for $SW1$ and $SW2$. IRA is the reference current source.

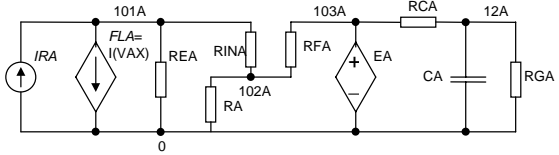


Fig. 4 Circuit for command SW1 and SW2.

The voltage across resistor REA is in fact the voltage error v_e . FLA is a controlled current source with current through V_{ax} source with gain equal to one.

The d-q model of induction machine is presented in Fig. 5. 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.

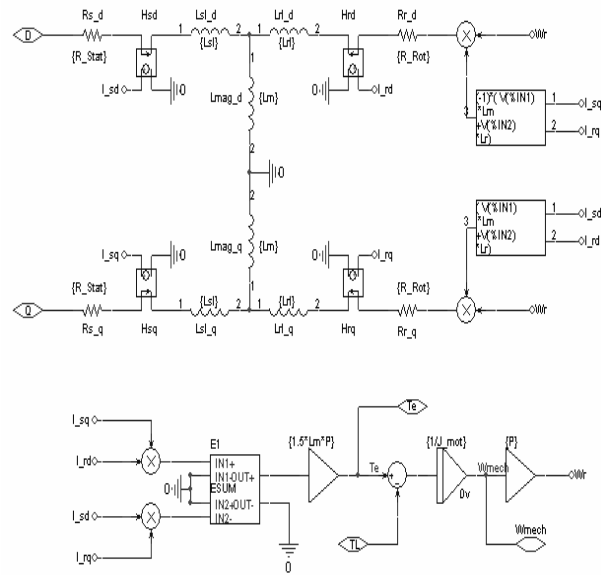


Fig. 6 Subcircuit for d-q induction motor model.

The 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.

The induction motor parameters are: nominal power $P_n = 3\text{KW}$; numbers of pole pairs $p = 2$; stator resistance $R_s = 5.5\Omega$; rotor resistance $R_r = 5.5\Omega$; mutual inductance $L_m = 64\text{mH}$; stator leakage inductance $L_{os} = 29.9\text{mH}$; rotor leakage inductance $L_{or} = 28.2\text{mH}$; moment of inertia $J = 2 \cdot 10^{-3}\text{Kg}\cdot\text{m}^2$; viscous coefficients of the motor $F_s = 10^{-3}\text{Ns/rad}$. The inverter is supplied from $V_s = 380\text{V}$ and the reference currents have the amplitude $IR_{MAX} = 10\text{A}$.

The simulation results are presented in Fig.6. The motor start from standstill. Steady state is attained at moment $t_1=200\text{ms}$. At the moment $t_2=250\text{ms}$ the load torque steps from 0 N.m to 5 N.m. The voltage $V(dq1)$ is numeric equal with the speed of rotor, the current $I(Gme)$ is numeric equal with electromagnetic torque of the motor and $I(Imr)$ is numeric equal with load torque. $I(IRA)$ is the reference current for the phase "a" of the motor and $I(Vax)$ is the motor current through phase "a". $V(as)$ is the phase voltage.

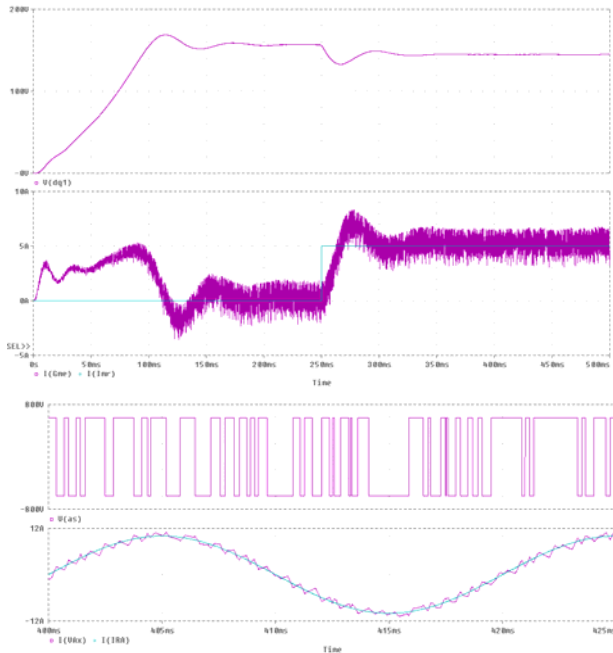


Fig. 6 Simulation results for current regulated inverter fed induction machine.

III VECTOR CONTROL OF INDUCTION MACHINE FED BY CURRENT REGULATED INVERTER

The basic idea of field oriented control is to inject currents into the stator of an induction machine such that the magnetic flux level and the production of electromagnetic torque can be independently controlled and the dynamics of the machine resembles that of a separately excited dc machine without armature reaction [5], [10], [11]. Using induction motor model for the synchronous reference frame, the D input of the induction machine would correspond to the field current that produces the flux, and Q input to the current component that produces electromagnetic torque. The frequency of ac voltages and currents that fed induction motor are mostly determined by the rotor speed to a small extent by the commanded torque. We still supply dc values representing the commanded flux and torque but we transform these dc values to appropriate ac values. We will assume that we can measure the actual rotor speed with a sensor. If we add the slip speed, that we determine mathematically from the torque command, to the measured rotor speed, we obtain the synchronous

speed for the given operating point. With this synchronous speed we can transform the dc flux and torque command values from the synchronous reference frame to the stationary reference frame. We accomplish this by using a rotational transformation according to the matrix equation (3) [4]. θ angle can be interpreted as the momentary rotational displacement angle between two Cartesian co-ordinate systems; one containing the input values and the other one the output values. This angle is obtained by integration of the angular velocity which the co-ordinate systems are rotating.

$$\begin{bmatrix} V_{D_out} \\ V_{Q_out} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} V_{D_in} \\ V_{Q_in} \end{bmatrix} \quad (3)$$

Fig. 7 shows the top level of a simulation example that implements vector control for induction machine with a stationary reference frame.

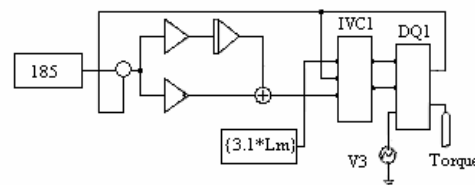


Fig. 7 – Indirect vector control.

The objective of the speed loop is to keep the speed at its initial value of 182 rad/sec, in spite of the load torque disturbance at $t=0.1\text{s}$. It was supposing that induction motor work in steady state with load torque $T_L=12.64\text{ Nm}$ and at time $t=0.1\text{s}$ T_L suddenly goes to one half of initial value. We will design the speed loop with a bandwidth of 25 rad/sec and a phase margin of 60 degrees [6].

Fig. 7 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.

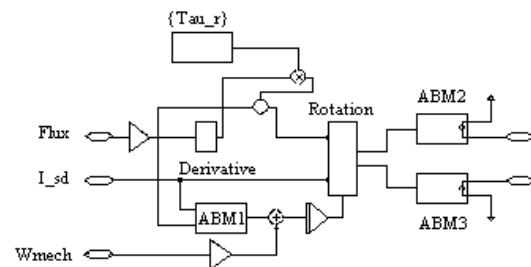


Fig. .8 – Sub-circuit for indirect vector control.

In the D axis, a differentiator is used in a compensation element which assures that the actual flux in the machine follows the commanded signal without delay.

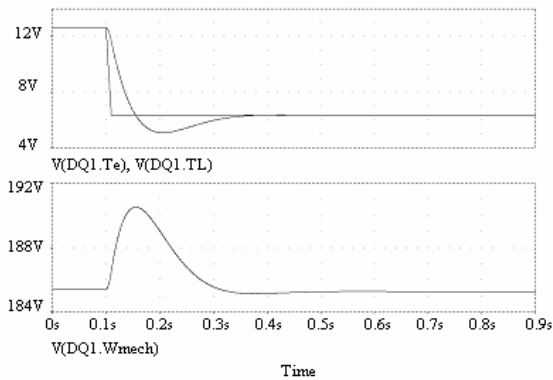


Fig.9 – PSpice™ simulation results.

PSpice simulation results are presented in Fig.9 for electromagnetic torque, load torque, and speed variation.

PSpice can't accomplish the start of simulation from steady state because it can't calculate the initial values of the currents and fluxes for this state. As a result, for visualization the steady state in PSpice, the length of simulation will be chosen sufficiently large, so that this state occurring.

IV. CONCLUSIONS

A OrCAD simulation of the current regulated inverter fed induction machine has been presented. Simulation method, allows analyse of the commutation process to the semiconductor devices. This simulation method WAS used to simulate the indirect vector control for induction machine [7].

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