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The Variant of Vectorial Self - control of the Induction Machine Supplied by a PWM Inverter

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Abstract – The paper presents a method for the vectorial self - control of an induction motor supplied by a PWM inverter with IGBT transistors. Very good performances are obtained.
Considering the dynamic regime for the induction machine, its equivalent circuit is presented according to the suggested method. To analyze the performances obtained with the proposed control technique, transient response simulation results are given, in comparison with SPWM control technique.
Keywords: pulse width modulation, inverter, induction machine, dynamic performances

I. INTRODUCTION

Before the appearance of power electronics, the control of the motors was scalar and much easier, since the dc machines used in most of the applications were represented by scalar quantities. With the advent of thyristors and power transistors, power electronics began to penetrate the area of variable speed electrical drives.

The ac machines are represented by vectors and their control is more complex. The conception of inverters with technical and economical performances allowed a vectorial control characteristics for ac motors both in steady state and transient regime. The ac motors – especially the induction ones- are , by now, in the favorable position to be able to replace the dc motors in the variable speed drives.

The vectorial control of the induction machines, that allows very good dynamic performances, was suggest ten years before, but only recent developments of software and electronic circuits has made it possible to be used [1]-[4]. The vectorial control (or field oriented control) consists in controlling the flux and torque components of the statoric current.

The vectorial self - control method proposed in this paper, has the same object as the vectorial control, but it is based upon a certain transient regime behavior of PWM inverter that supplies the induction machine, thus simplifying the hardware and software of the controller.

Due to the adequate method of controlling the inverter semiconductor devices, supplemental voltages appear at the terminals of the induction machine in the transient regime, resulting in a very fast damping of the transient currents [5]-[7].

In the text, SPWM represents a sinusoidal PWM command method for a three-phased inverter used for the field oriented control of induction machines

II. DESCRIPTION OF THE VECTORIAL SELF - CONTROL METHOD

In the following, a method for field self acceleration, by mean of a PWM inverter, is described. Fig.1 presents the basic diagram of a static frequency converter, with three-phase inverter using IGBT transistors. We shall denote by v_{U0}, v_{V0}, v_{W0} the instantaneous phase voltages of the stator windings, by i_U, i_V, i_W the phase currents and the notation i_K, i_L,

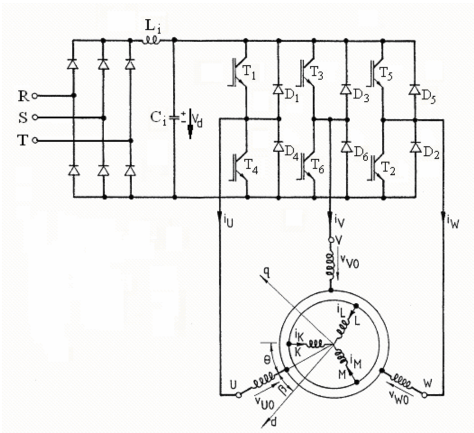

Fig. 1 Basic diagram of a static frequency converter with three – phase inverter

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i_M will be for the rotor instantaneous currents.

The inverter operation based on sinusoidal Pulse Width Modulation [5] – [7], is described in the following. The inverter allows the control of the amplitude of the output voltage fundamental for different output frequencies f_1 lower than the maximum frequency f_{1max} (f_{1max} can be 50 or 60Hz).

For frequencies higher than f_{1max} the inverter keeps the output voltage to a constant value.

For $f_1<f_{1max}$, in order to modify both the output voltage and frequency, one must vary the inverter pulse frequency f_p. The frequencies f_p and f_1 are in a fixed ratio denoted with m. For example, the wave forms of the output voltages v_{U0}, v_{V0}, v_{W0} together with those of the fundamentals of the stator currents $i_{U(1)}$, $i_{V(1)}$, $i_{W(1)}$ are presented in Figs.2(a), (b) and (c), in the case of m=18 pulses, while Fig.2(d) shows the T_1-T_6 transistors command sequences for an output voltage period. The ratio m can have the following values:

m=18, 36, 72, 144 and 288

as shown in Fig.2(e).

Studying these transistor command sequences, one can see that only two transistors are controlled to conduct within the pause intervals, T-τ, between the output voltage pulses.

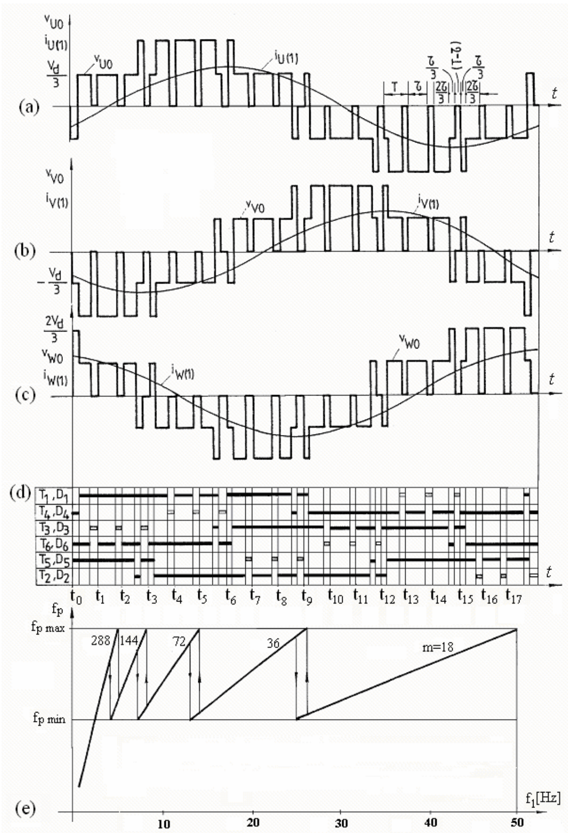

Fig.2(a), (b), (c): Output voltages of 18 pulse PWM inverter with self-control; (d) Controlling program for transistors; (e) Relationship between the carrier frequency and the inverter output frequency

The effect of the transistors control pattern on the waveforms of the output phase voltages v_{U0}, v_{V0}, v_{W0} during the operation of the induction machine supplied by the PWM inverter with self - control, can be seen in Fig.3.

Figs 3(a), (b) and (c) present the waveforms of the output voltages $v_{U0}^{(2)}$, $v_{V0}^{(2)}$, $v_{W0}^{(2)}$ after changing the supply frequency from f_1 to f_2 ($f_2<f_1$), and those of the steady state stator currents $i_{U(1)}^{(1)}$, $i_{V(1)}^{(1)}$, $i_{W(1)}^{(1)}$ at the frequency f_1.

Fig. 3(d) shows the currents $i_{U(1)}^{(1)}$, $i_{U(1)}^{(2)}$ and the supplemental voltage Δv_{U0} applied at the U phase during the transient regime, supposed to last more than a period $1/f_2$. One can see that during the transient regime, when the difference between the current $i_{U(1)}^{(1)}$ (that can be considered as the measured current) and the current $i_{U(1)}^{(2)}$ (that can be considered as the prescribed current) is not zero, a supplemental voltage Δv_{U0} appears as pulses, that trends to annul the difference $\Delta i_{U0}=i_{U(1)}^{(1)}-i_{U(1)}^{(2)}$. When the steady state is reached at the frequency f_2, the current $i_{U(1)}$ becomes equal to $i_{U(1)}^{(2)}$ and the supplemental voltage Δv_{U0} vanishes.

The supplemental phase voltages (shown hatched in Figs.3 (a), (b), (c) appear only in the transient regime and they play a double part. First, they induce a faster damping of the transient components of the stator currents i_U, i_V, i_W. Second they produce an increase of the fundamental components of the phase voltages v_{U0}, v_{V0}, v_{W0} and hence an acceleration in establishing the excitation current i_0 at the frequency f_2, corresponding to the new steady state of operation.

Better performances are obtained at lower frequencies, since the pause intervals between the output voltage pulses are longer, so the supplemental voltage represents a higher percent of the output voltage. The process of damping the transient stator currents also occurs when the supply frequency changes from f_1 to f_2 (this time $f_2>f_1$). The T equivalent diagram of the induction machine in the dynamic regime is presented in Fig.4, where $X_{\sigma 12}$ and $X_{\sigma 21}$ are stator and rotor leakage reactance respectively, and X_{11} is the cyclical stator self-reactance. One can notice in this diagram the presence

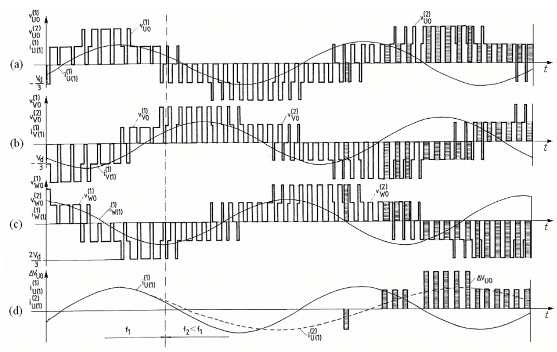

Fig. 3: Operation waveforms obtained in the vectorial self - control method for f2<f1.

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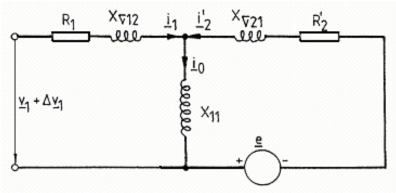

Fig.4: Equivalent diagram of the induction machine in the dynamic regime

of the voltage e, given by:

$$\underline{e} = -j\omega_m L_{11} \underline{i}_1 - j\omega_m \left(L'_{\sigma 21} + L_{11}\right) \underline{i}'_2 = \\ = -j\omega_m \left(L_{11} i_0 + L'_{\sigma 21} \underline{i}'_2\right) \quad (1)$$

where ω_m is the rotor angular speed. The supplemental voltage Δv_1, added to the input voltage v_1 was defined according to Fig.3. On the steady state of operation of the induction machine, the voltage e becomes e_S:

$$\underline{e}_S = r_2 \frac{1-s}{s} i_2 \quad (2)$$

where s is the rotor slip, and the supplemental voltage vanishes.

Evidently, the ratio m between the frequencies f_p and f_1 may also vary according to other patterns that are one shown in Fig.2(e).

On conclusion, the method of vectorial self - control of the induction machine supplied by a PWM inverter consists in the turn on of two transistors during the zero voltage gap time, when the phase voltages v_{U0}, v_{V0}, v_{W0} should be zero.

III. SIMULATION RESULTS

An inverter-fed induction motor drive system according to Fig.1 was simulated, using the electrical circuit simulation code PSPICE. In order to analyze both the inverter behavior and the induction machine dynamic behavior under different control techniques, the inverter was introduced as a circuit and not as an analog input source. Controlled switches were used for the IGBT devices.

The PSPICE model of the induction machine is based on the dq model in the synchronously rotational reference frame. The input dq voltages are obtained from three phase inverter output voltages through dq transformation.

In order to model non-electrical parameters, such as torque and angular speed, the governing equations were written and generic electrical integrators were used to solve them. Thus the electromagnetic torque appears as a voltage controlled source and the rotor angular speed appears as a current through an independent voltage source. Since the induction machine is modeled in a biphasic system and the inverter needs a three phase load, the link is based on the stator voltage equations in the three phase system and the dq reverse transformation of the stator and rotor currents.

The induction motor used for computation is a 480V, 4-pole, 3-phase, 15hp, 60Hz machine, with the following parameters:

stator phase resistance 0.25Ω

rotor phase resistance 0.3Ω

stator entire cyclical inductance 83.2mH;

rotor entire cyclical inductance 84mH;

rotor-stator mutual inductance 80mH.

To analyze the performances of the proposed control technique, simulation waveforms of stator current, electromagnetic torque and rotor angular speed have been plotted for a 50% step decrease in inverter frequency. Figs.5 show transient responses of the system under constant load torque in the cases: (a) PWM with self - control technique and (b) SPWM control technique. In case (a) from inverter frequency f_1=55.555Hz; m=18; modulation index m_a=0.926 the command sequence changes to f_2=27.777Hz; m=36; m_a=0.463. In case (b) from inverter frequency f_1: modulation index m_a=0.926; frequency modulation ratio m_f=9, the command sequence changes to f_2=27.777Hz; m_a=0.463; m_f=15. In Fig.5 waveforms are shown for load torque T_l=60Nm, system inertia J=0.8 kgrm^2.

One can observe that the rotor always reaches the angular speed corresponding to f_2 in a significantly shorter time when the PWM with self - control technique is used.

The difference is more evident at higher moments of inertia. When the load torque is closer to rated torque, the braking is accelerated.

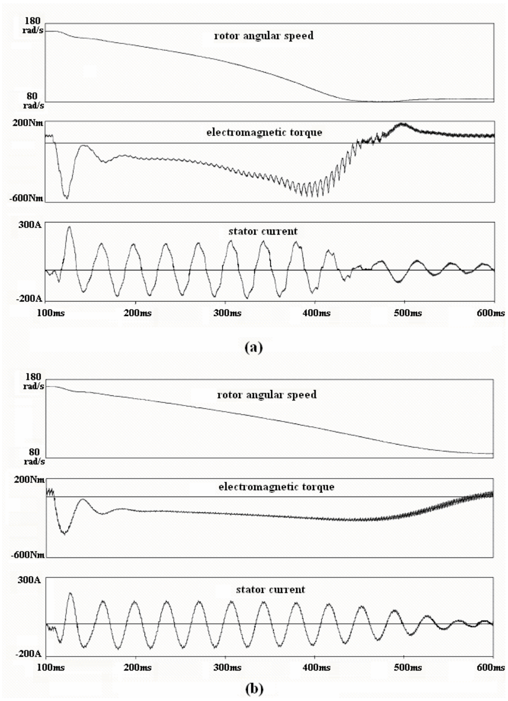

Fig. 5: Simulation waveforms of the machine driven by (a) PWM inverter with self-control and (b) SPWM inverter, for 50% step decrease in inverter frequency, in the case Tl=60 Nm, J=1.2 kgr m2.

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IV. CONCLUSION

By choosing a certain control program of the semiconductor switching devices of the PWM inverter with self - control, high dynamic performances can be obtained in the transient operation of the induction machine that is supplied, due to the appearance of supplemental voltages at the inverter output. These voltages result in a faster damping of the transient currents in the machine, as well as in accelerating the process of establishing the excitation current i_0 at the value corresponding to the new steady state of operation.

The method of vectorial self - control of the induction machine supplied by a PWM inverter consists in the turn on of two transistors during the zero voltage gap time, when the phase voltage v_{U0}, v_{V0}, v_{W0} should be zero.

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