

Synchronous Current Control of Three phase Induction motor by CEMF compensation

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Abstract: *The performance of the machine largely depends on quality of applied current control strategy. Hysteresis-band PWM current control is one of the methods whose task is to force the actual current to track reference wave by means of switches. In low speed region of the machine, when CEMF is low, there is no difficulty in current controller tracking. However at higher speed, the current controller will saturate in part of the cycle due to higher CEMF and will be less and its phase will lag with respect to command current. PWM frequency is not constant (varies within a band) and as a result non-optimum harmonic ripple is generated in machine current. Fundamental current suffers a phase lag which increases at higher frequency. This phase deviation causes problems in high performance machine control. Synchronous Current Control is implemented using MATLAB/SIMULINK*

Key words: Hysteresis-band PWM current control, CEMF, Synchronous Current Control

1. INTRODUCTION

Among all types of ac machines, the induction machine, by a considerable margin, the most widely used ac motor (almost more than 90 percent of the mechanical power used in industry is provided by a 3-phase induction motor). The reasons are its low cost, simple and rugged construction, absence of Commutator, good operating characteristics (reasonably good power factor, sufficiently high efficiency and good speed regulation).

The control and estimation of ac drives in general is considerable more complex than those of dc drives. This complexity increases substantially if high performance is demanded. The main reasons for this complexity are the need of variable-frequency; harmonically optimum converter power supplies the complex dynamics of ac machines, machine parameter variations and difficulties of processing feedback signals in presence of harmonics.

2. INDIRECT VECTOR CONTROL

There are generally two methods of vector control. One is called Direct or Feedback method and the other known as Indirect or Feed-forward Method.

The Direct method of Vector Control is difficult to operate successfully at very low frequency because of following problems: At low frequencies, voltage signals are very low and

integration becomes very difficult. The parameter variation effect of resistances and inductances tend to reduce accuracy of estimated signals.

Indirect vector control strategy has been implemented using following equations:

$$\theta_e = \int \omega_e dt = \int (\omega_e + \omega_{st}) dt = \theta_r + \theta_{sl}$$
$$\frac{d\psi_{dr}}{dt} + R_r i_{dr} - (\omega_e - \omega_r) \psi_{qr} = 0$$
$$\frac{d\psi_{qr}}{dt} + R_r i_{qr} - (\omega_e - \omega_r) \psi_{dr} = 0$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds}$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs}$$

$$i_{dr} = \frac{1}{L_r} \psi_{dr} - \frac{L_m}{L_r} i_{ds}$$

$$i_{qr} = \frac{1}{L_r} \psi_{qr} - \frac{L_m}{L_r} i_{qs}$$

Figure below shows block diagram of Indirect Vector Control. A Hysteresis Band Current Controller is used.

The speed control loop generates torque component of current i_{qs}^* . The flux component of the current i_{ds}^* for the desired rotor flux is derived from equations above.

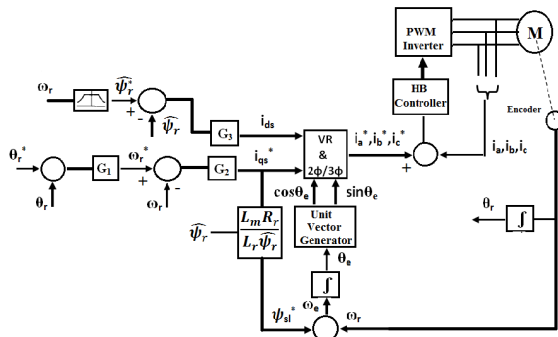


Fig.1 Control block diagram for hysteresis-band PWM

The slip frequency w_{sl} , which is generated from i_{qs} in feed forward manner is added with speed signal w_r to generate frequency signal w_e . The unit vector signals \cos and \sin are then generated from w_e by integration and look up tables. The speed control range in Indirect Vector Control can easily be extended from standstill to field weakening region. The addition of field weakening control is shown by dotted block diagram.

3. HYSTERESIS CURRENT CONTROL

In a machine drive system, control of machine current is important because it influences the flux and developed torque directly. High performance drives invariably require current control. For a voltage fed inverter with voltage control PWM, a feedback current loop can be applied to control the machine current.

Hysteresis-band PWM is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a hysteresis-band.

Fig 1 explains the operating principle of hysteresis band PWM for a half bridge inverter

The control circuit generates the sine reference current wave of desired magnitude and frequency and it is compared with actual phase current wave. As the current exceeds a prescribed hysteresis band, the upper switch in half bridge is turned OFF and lower switch is turned ON. As a result, the output voltage transitions from $+0.5V_d$ to $-0.5V_d$ and the current starts to decay. As the current crosses the lower band limit, the lower switch is turned OFF and the upper switch is turned ON.

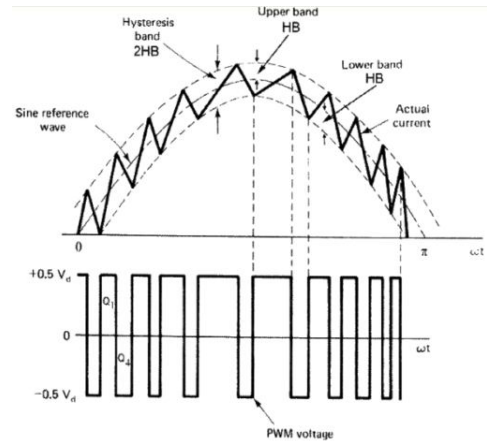


Fig.2 Principle of hysteresis-band current control

A lock-out time is provided at each transition to prevent a shoot through fault. The actual current is forced to track the sine reference wave within the hysteresis band by back and forth switching of upper and lower switches. The inverter then essentially becomes a current source with peak-to-peak current ripple, which is controlled within the hysteresis band irrespective of V_d fluctuations.

An optimum band that maintains a balance between the harmonic ripple and inverter switching loss is desirable. In low-speed region of the machine, when CEMF is low, there is no difficulty in current controller tracking. However at higher speed, the current controller will saturate in part of the cycle due to higher CEMF and will be less and its phase will lag with respect to command current

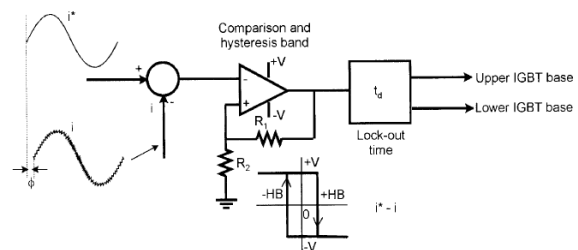


Fig.3 Control block diagram for hysteresis-band PWM

Fig.2 shows the simple control block diagram for a hysteresis-band PWM implementation.

The hysteresis band is very popular because of its simple implementation, fast transient response, direct limiting of peak current. However there are few drawbacks. PWM frequency is not constant (varies within a band) and as a result non-optimum harmonic

ripple is generated in machine current. Fundamental current suffers a phase lag which increases at higher frequency. This phase deviation causes problems in high performance machine control.

All these problems can be solved in a Synchronous Current Controller.

4. SYNCHRONOUS CURRENT CONTROL

Hysteresis band PWM current control has been used, but its harmonic content is not optimum. Besides, at higher speeds, the current controller will tend to saturate because of higher CEMF.

In this condition the fundamental current magnitude and its phase will lose tracking with the command current. Thus vector control will not be valid. All these problems are solved in a synchronous current controller.

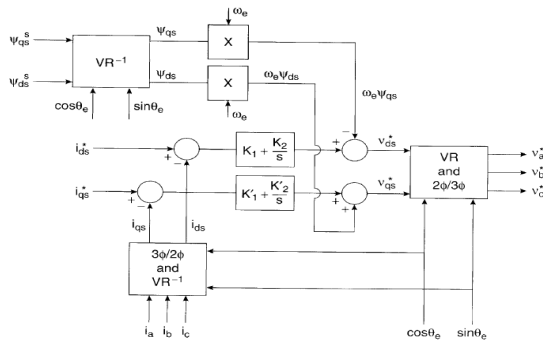


Fig.4 Synchronous current control with feed-forward CEMF compensation

Command currents i_{ds}^* and i_{qs}^* in vector control are compared with respective i_{ds} and i_{qs} generated by transformation of phase currents ($3\phi-2\phi$) with the help of unit vectors. The respective errors generate the voltage command signals V_{ds}^* and V_{qs}^* through P-I compensators.

These voltage commands are converted into stationary frame phase voltages. The synchronous current control with P-I controller assure amplitude and phase tracking of currents.

The introduction of feedback loops brings with it a small amount of coupling effect. To enhance the loop response, feed-forward CEMF signals are injected in the respective loops. Signal $\omega_e \psi_{ds}$ is added in i_{qs} loop, whereas signal $\omega_e \psi_{qs}$ subtracts from i_{ds} loop.

5. SIMULINK CIRCUITS

Both Hysteresis Current control & Synchronous Current Control (Proposed method) are implemented using MATLAB/SIMULINK. The speed response of Induction motor is compared and THD (Total Harmonic Distortion) levels of Input Voltage as well as Input Current of Induction Motor are compared.

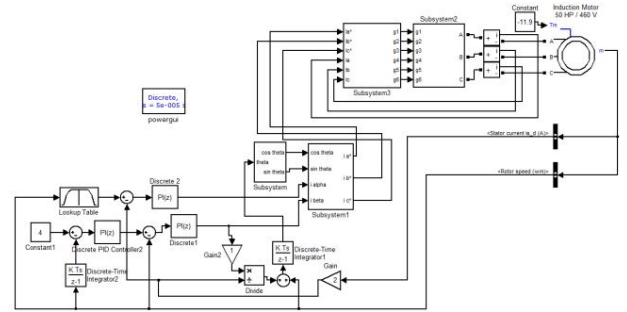


Fig. 5 The simulation circuit of Indirect Vector Control with Hysteresis Controller

Here the reference angle and actual angle are compared and processed through PI Controller and rotor flux is compared with estimated flux and processed through PI Controller to produce reference currents with help of unit vectors.

This signal is given to HB Controller which is given to the inverter connected to Induction machine.

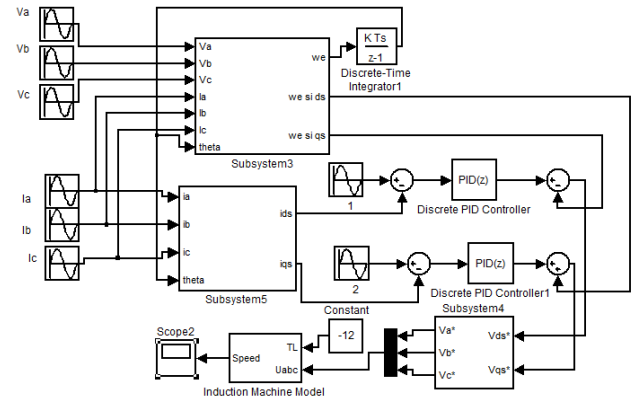


Fig. 6 Simulink circuit of Synchronous current control

With the help of Currents and Voltages, Flux linkages are calculated. These currents are compared with command currents processed through PI controller. Here feed forward CEMF signals are injected to enhance loop responses. Due to introduction of these loops, it produces command

voltages which are again converted to three-phase Voltages which has been connected Induction motor.

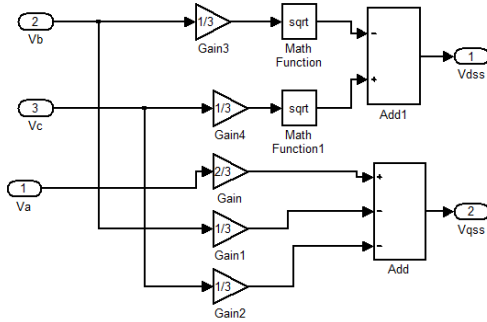


Fig. 7 Sub circuit of Conversion of 3-phase voltages (abc) to 2-axis Voltages (Stationary Frame d-q)

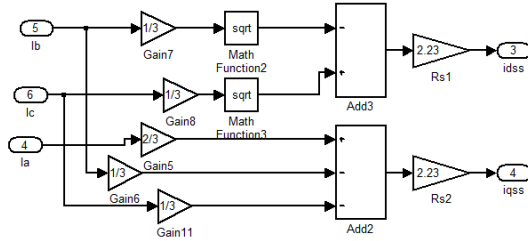


Fig. 8 Sub circuit of Conversion of 3-phase currents (abc) to 2-axis Currents (Stationary Frame d-q)

By Park's Transformation, 3-phase voltages and currents (ABC) are converted into 2-phase voltages and currents (Stationary Frame d-q) using these equations.

$$V_{ds}^s = \frac{-1}{\sqrt{3}} V_b + \frac{1}{\sqrt{3}} V_c$$

$$V_{qs}^s = \frac{2}{3} V_a - \frac{1}{3} V_b + \frac{1}{3} V_c$$

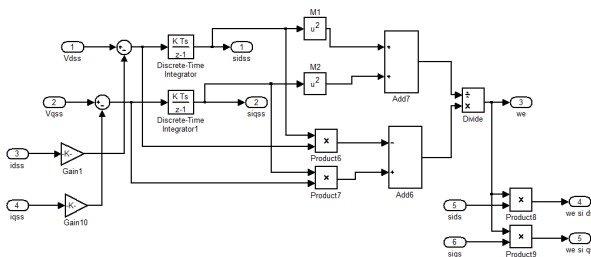


Fig.9 Sub circuit of Feed forward CEMF signals

Introduction of feed forward CEMF signals enhances loop response. Signal $\omega_e \psi_{ds}$ is added in i_{qs} loop, whereas signal $\omega_e \psi_{qs}$ subtracts from i_{ds} loop.

Feed forward CEMF signals are injected in their

respective loops using these equations

$$\widehat{\psi}_s = \sqrt{(\psi_{ds}^s)^2 + (\psi_{qs}^s)^2}$$

$$\omega_e = \frac{(V_{qs}^s - i_{qs}^s R_s) \psi_{ds}^s - (V_{ds}^s - i_{ds}^s R_s) \psi_{qs}^s}{\widehat{\psi}_s^2}$$

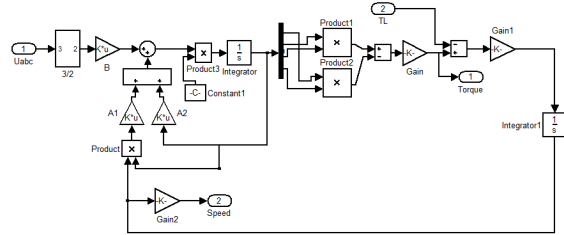


Fig.10 Mathematical Model of Induction Motor

Electrical sub-model of three phase induction motor is shown. The three-phase to two-phase axes voltage transformation is achieved using following equation. Where V_{as} , V_{bs} , V_{cs} are the three phase stator voltages, while V_{ds} , V_{qs} are two axis components of stator voltage.

In two-axis stator reference frame, the electromagnetic torque T is given by

$$T = \frac{PL_m}{3} (i_{dr} i_{qs} - i_{qr} i_{ds})$$

Mechanical sub-model of induction motor from torque balance equations and neglecting viscous friction, the rotor speed may be obtained as follows:

$$\omega_o = \int_{\tau=0}^t \frac{T - T_L}{J} d\tau$$

Where J is moment of inertia of rotor and load & TL is load torque.

Machine parameters are as follows:

Function Block Parameters: Induction Machine model	
Subsystem (mask)	
Parameters	
Stator resistance	2.7
Stator inductance	0.3562
Rotor resistance	2.23
Rotor inductance	0.3562
Mutual inductance	0.3425
Friction coefficient	0.00825
No. of pair of poles	2

Fig.11 Parameters of Induction Motor

VII. SIMULATION RESULTS

The speed response of Induction motor using HB Controller is shown

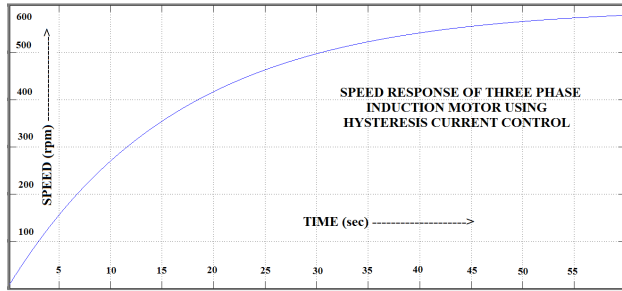


Fig.12 Waveform of Speed Response of Induction Motor (using HB Controller).

It can be observed that response is sluggish i.e. it takes a lot of time for the speed to settle down.

THD Graph of both Input Voltage and Current to the Induction motor are shown

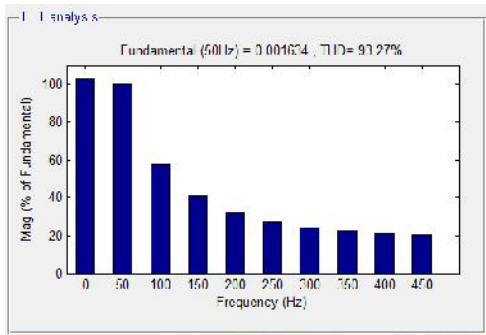


Fig.13 THD Graph of Input Voltage of Induction Motor (HB Controller)

The THD Graph depicts that input voltage harmonic content is 93.47%

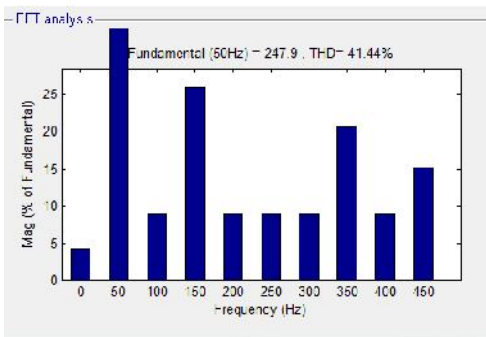


Fig. 14 THD Graph of Input Current of Induction Motor (HB Controller)

The THD Graph depicts that input current harmonic content is 41.44%

The speed response of Synchronous Current Control is shown.

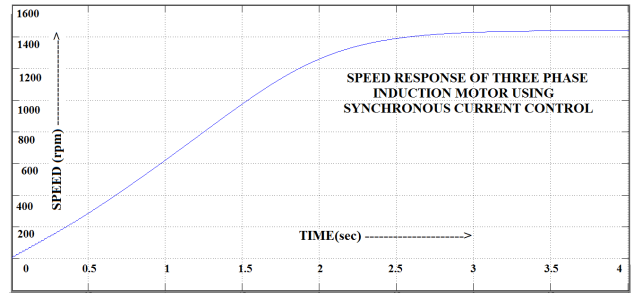


Fig.15 Waveform of Speed Response of Induction Motor (Synchronous Current Controller)

On comparing both the speed responses, we can see that speed has reached steady state at a much earlier time in case of Synchronous Current Control when compared to Indirect Vector Control using HB controller.

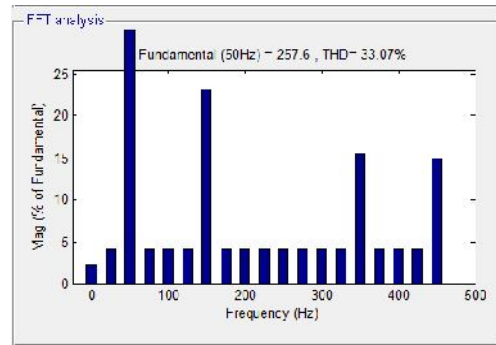


Fig.16 THD Graph of Input Voltage of Induction Motor (Synchronous Current Control)

The THD Graph depicts that input voltage harmonic content is 33.07%

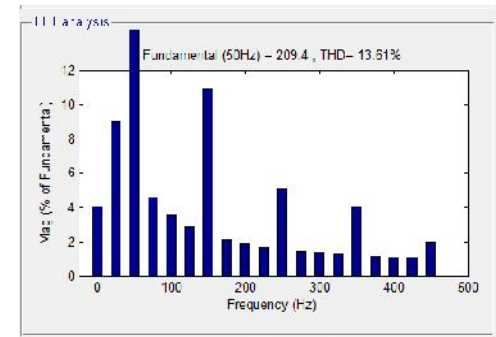


Fig.17 THD Graph of Input Current of Induction Motor (Synchronous Current Control)

The THD Graph depicts that input voltage harmonic content is 13.61%

THD graph of input voltage and current is obtained and on comparing those with that obtained using Indirect Vector Control. We can observe that THD level of input voltage and current is less in case of synchronous current control when compared to the case of indirect vector control. So we can conclude that response has been improved.

VIII. CONCLUSION

The performance of machine largely depends on quality of applied current control strategy.

Hysteresis current control has been used in indirect vector control of Induction motor drives. Its speed and THD graph of both input voltage and input current has been observed. The harmonic content is not optimum.

To overcome this Synchronous Current Control is proposed. Both the circuits are simulated and compared using MATLAB/SIMULINK. It is observed that Synchronous Current Control has improved Steady State Response.

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