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Simplified Low-Speed Operation Of Space Vector Modulated Current Source Inverter Fed Induction Motor Drive

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Abstract

Most research work in current-source inverter (CSI) fed motor drives has focused on various control methodologies, harmonic elimination techniques, pulse width modulation schemes, methods for reduction in switching losses and efficiency evaluation. This project, however, is dedicated to investigating simplified low speed operation characteristics of CSI-fed induction motor drives (IMDs). Low-speed operation can greatly increase the competitive value of the drive and expand its range of applications to include cranes, hoists, and draglines. The induction motor (IM) is fed from three phase bridge inverter which is operated with space vector modulation (SVM) Technique. Among- the various modulation strategies Space Vector Modulation Technique is the efficient one because it has better spectral performance and output voltage is more closed to sinusoidal. Unlike voltage source inverter-based drives, filter capacitors are required at the output of the CSI for current commutation and harmonics filtering. The influence of these capacitors on the system dynamic performance is comprehensively evaluated.

1. Introduction

Power electronics has changed rapidly during the last thirty years and the number of applications has been increasing, mainly due to the developments of the semiconductor devices and the microprocessor technology. An overview of different power devices and the areas where the development is still going on is presented in Fig.1. The voltage source inverter (VSI) fed drives are most widely used in low and medium

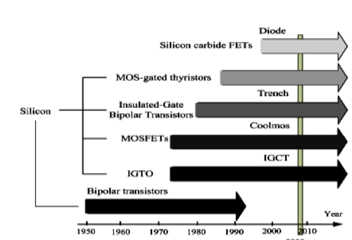

Fig.1. Development of power semiconductor devices since 1950

Power applications, but not used widely in high power applications. Now a days, current source inverter (CSI) fed motor drives are increasingly used for medium-voltage high-power applications where fast dynamic response is not needed because of the following advantages:

- Simple converter topology,
- Inherent four quadrant operation,
- Reliability,
- Motor friendly waveforms with low dv/dt.

Recent work has focused on control strategies, PWM schemes, topologies, and efficiency, for high-power current-source converters and drives, where significant improvements have been achieved, such as harmonic distortion minimization, high input power factor, minimized dc-link current, and reduced switching frequencies. However, it seems that low-speed operation of space vector modulated CSI driven induction motor has seldom been reported. Low speed operation plays an important role in applications such as cranes, hoists, and traction drives, where maintaining the desired torque down to low speed or starting the load with a high torque from low speed is highly desirable versions of their papers. This paper is therefore dedicated to exploring the low speed operation characteristics of space vector modulated CSI driven induction motor.

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2. CSI-fed induction motor drive

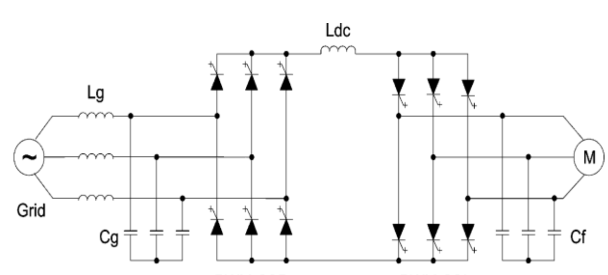

Fig. 2. PWM current-source converter-based motor drive.

In this paper, the drive is controlled by closed loop with PID controller. The system structure shown in Fig.2. The present day CSI drives employ Metal Oxide Semiconductor Field Effect Transistor (MOSFETs) instead of SCRs as in the past. Pulse width modulation (PWM) techniques can be used to get improved output currents and voltages. Even though a relatively high switching frequency PWM will result in near sinusoidal output voltages and currents, at higher power levels the CSI is switched at low frequency (200 Hz), to reduce switching losses. In the system structure, filter capacitors are connected at the output of the CSI to assist with current commutation and harmonics filtering. The impact of the capacitors on the drive dynamic performance is systematically analyzed.

3. System control scheme

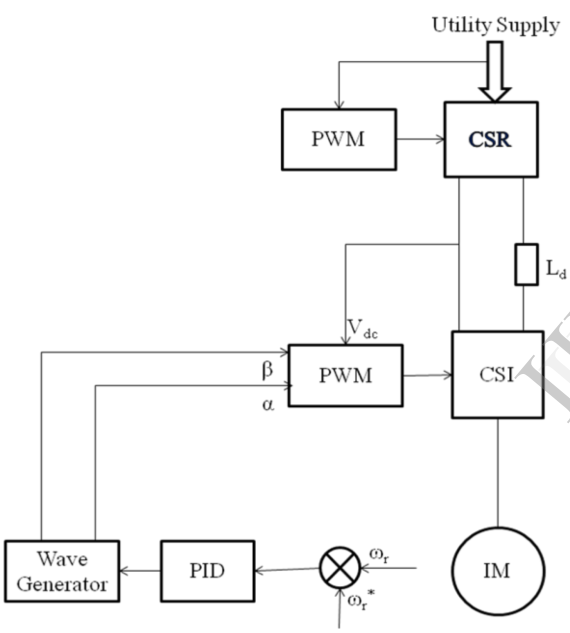

Fig. 3.Motor control scheme

The induction motor control scheme is shown in Fig. 3, where closed loop with PID controller is employed. Actual speed ω_m is compared with the reference speed ω_m^*.The speed error is processed through a PID controller and wave generator. SVPWM is generated from this output. There are several ways to implement the modulation for the CSI, including mapping method from voltage-source inverter modulation, space vector modulation, and so on.

4. Space vector modulation

In Fig 4(a) the typical power stage of the three phase inverter and the equivalent circuit of a machine are presented. As shown in this figure, the currents applied to machine is defined as $I_{an,bn,cn}$ and the $I_{aN,bN,cN}$ denote the pole currents produced in the inverter stage. And, the available eight different switching states of the three phase inverter are depicted in the Fig 4(b). Note that all the machine terminals are connected to each other electrically and no effective currents are applied to machine when the zero vectors presented by I_o and I_7 are selected. Therefore the six current vectors can be

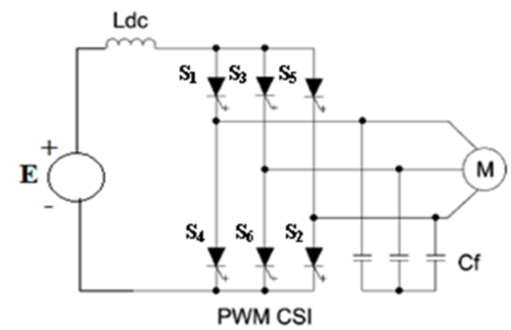

Fig.4(a). Three phase inverter fed induction motor

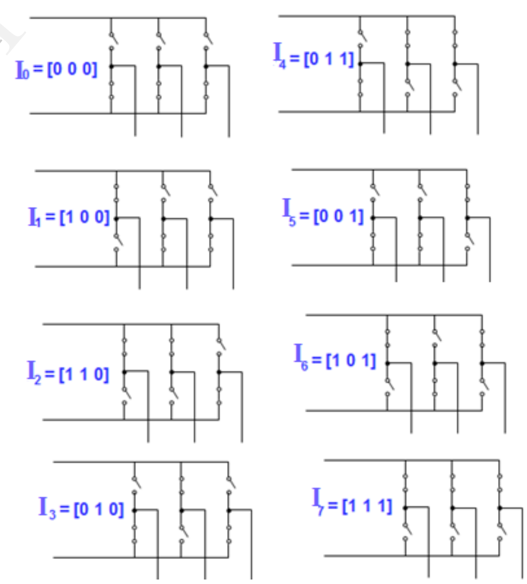

Fig.4(b). Switching state diagram with eight switching states

selected to apply an "effective current" to the machine and these vectors can be located on the vector space represented with the stator fixed d-q reference frame as shown in the fig 5. If a constant reference current vector I^*or I_{ref} is given in one sampling period, this vector can be generated using zero vector (I_0 or I_7) in combination with only two nearest active vectors (I[n] and I[n+1]). These two active vectors are considered as

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the effective vectors to generate desired output current. From the average current concept, the reference vector can be written as followings during one sampling period.

$$I^* = (T_1 . I_n + T_2 . I_{n+1})/T_3 \text{ ----------------------- } (1)$$

(Where T_1, T_2 are the applied effective times corresponding to the active vectors.)
And, the effective time can be deduced as,

$$T_1 = \frac{\sqrt{3} \cdot T3 \cdot |\bar{I}ref|}{I_{dc}} \left(\sin\frac{n}{3}\pi\cos\alpha - \cos\frac{n}{3}\pi\sin\alpha \right) - - (2)$$

$$T_2 = \frac{\sqrt{3} \cdot T_3 |\bar{I}ref|}{I_{dc}} \left(-\cos\alpha \cdot \sin\frac{n-1}{3}\pi + \sin\alpha \cdot \cos\frac{n-1}{3}\pi \right) - - - (3)$$

$$T_0 = T3 - T_1 - T_2 \text{ ---------------------- } (4)$$

Where T_0 is the time corresponding to null vector I_{DC} is the DC linkage Current and T_3 is sampling time.

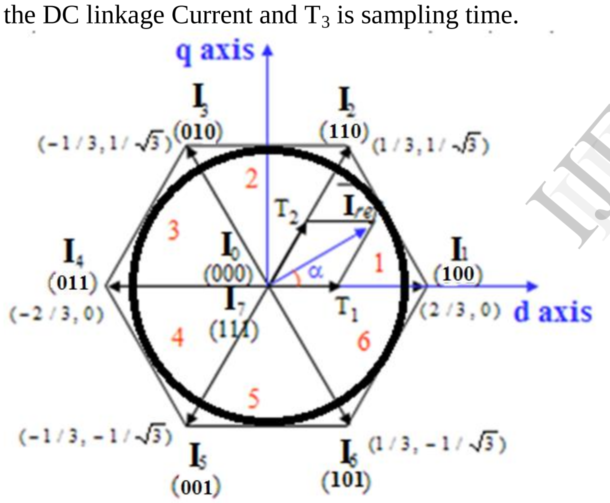

Fig.5.Space vector diagram of the effective vectors

Note that, in fact the effective time doesn't imply the actual switching time. The switching time complies with the time delay from the initial point of one sampling period the activation time of switching device. Therefore in order to evaluate the active switching times, the effective times should be recombined to the location of the reference vector. In fig 6, the relationship between the effective times and the actual gating times is depicted when the reference vector is located in the Sector-1. In this case the I_1 vector is applied to the inverter during T_1 interval, and consequently I_2 vector is applied during T_2 interval. In the three phase symmetry modulation method, the zero sequence current vectors is distributed symmetrically in one sampling period to reduce the current ripple. Thus, in general, the switching sequence is given by 0-1-2-7-7-2-1-0 within two sampling periods. With the point of view of the upper switching devices of one inverter leg, the former sequence (0-1-2-7 sequence) is called 'ON' sequence, and the latter (7-2-1-0) is called 'OFF' sequence in this paper. Therefore, the actual switching times corresponding to the case of sector -1 can be written as,

On gating Sequence	Off Gating Sequence	
$T_{ga}=T_0/2$	$T_{ga}= T_0/2+T_1+T_2$	--- (5)
$T_{gb}=T_0/2+T_2$	$T_{gb}=T_0/2+T_2$	
$T_{gc}=T_0/2+T_1+T_2$	$T_{gc}=T_0/2$	

From this analysis, the conventional space vector modulation task can be solved into following steps to make the actual PWM pattern.

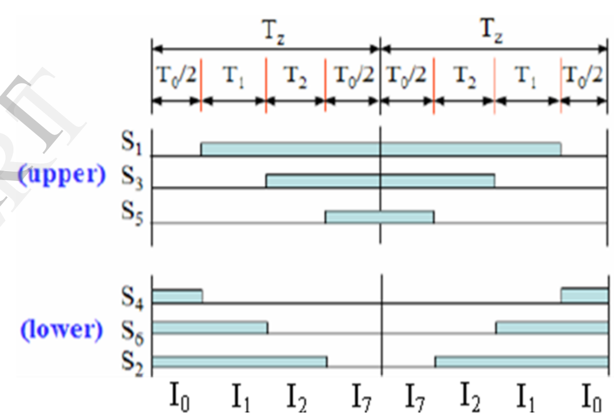

Fig.6.Actual gating signal pattern of the space vector PWM (in the case of the sector -1)

Step: 1) Sector Identification: By comparing the stationary frame α-β components of the reference voltage vector, the sector where the reference vector is located is identified.
Step: 2) Calculating the Effective Timer: Using the α-β components of reference vector and the DC link voltage information, the effective times T_1, T_2 are calculated.
Step: 3) Determining the switching Times: using the corresponding sector information the actual switching time for each inverter leg is generated from the combination of the effective times and zero sequence time.

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The space vector modulation is employed where active and zero vectors are calculated. The typical three-segment sequence is then used to obtain the gating signals for each switching devices. The corresponding advantages include a reduction in switching frequency, which leads to a reduction in switching losses, and reduced complexity for switching scheme implementation. A fixed modulation index of 1 is adopted for the CSI to reduce the dc-link current and operating losses.

5. Simulation results

In order to illustrate the feasibility of the low-speed operation control scheme, a CSI-based ac drive model is developed with MATLAB/Simulink to feed a 1250-hp 4160V six-pole induction motor.

Table I
System parameters

Converters	
Grid voltage:4160V(line to line),60Hz	Grid side capacitor:66.2μF
Dc inductance:42.5mh(1 pu)	Motor side capacitor:63μF
Switching frequency(CSR and CSI):540Hz	
Induction motor	
Rated voltage:4160V	Stator self inductance:160.2mH
Rated current:150A	Rotor resistance:0.146Ω
Pole pairs:3	Rotor self inductance:160.2mH
Moment of Inertia:440kgm2	Magnetizing inductance:155mH
Rated Torque:7490Nm	Rated speed:1189rpm

System parameters are shown in Table I. The drive performance under step torque variation is shown in Fig. 7. The stator flux is initially established through dc current, while the stator *q*-axis current is zero. At 0.5 s, a rated load torque is suddenly addressed and the stator *q*-axis current is increased to handle it. The stator *d*-axis current varies a little and recovers quickly. This verifies that the coupling between stator *d*, *q*-axis currents has negligible impact on the system control. The motor speed drops 12r/min and goes back to steady state within 0.3 s Thus, the speed drop here is not obvious.

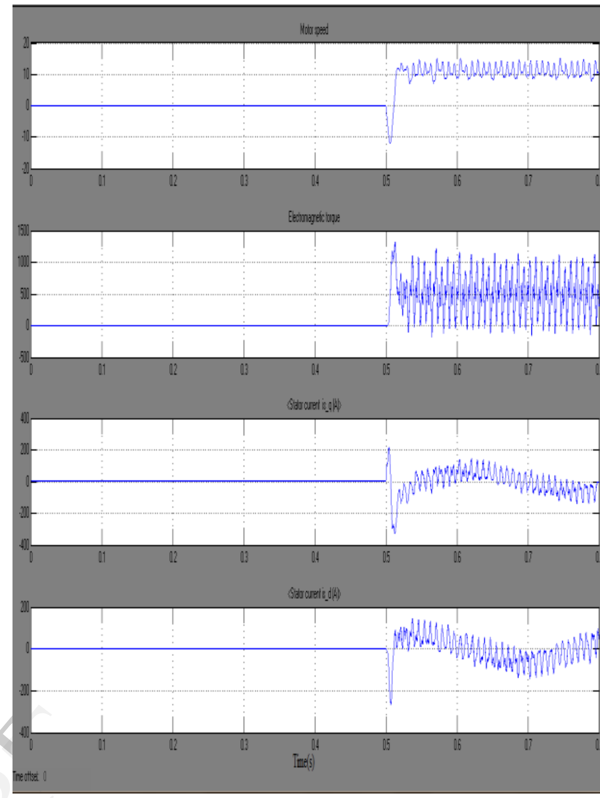

Fig.7. Motor performance under step load torque variation. (speed ,torque and Stator *d*, *q*-axis currents.)

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6. Conclusion

In this paper, the low-speed operation of space vector modulated CSI-fed IMD is investigated. The motor is controlled by closed loop with PID controller. Space vector modulation leads to a reduction in switching frequency, reduction in switching losses, and reduced complexity for switching scheme implementation. Due to the CSI-side filter capacitors, the stator currents are a portion of the inverter output currents. Simulation shows that the CSI-fed IMD works well at low speed with promising speed dynamic performance.

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