Effect on Indirect Matrix Converter Due TO Field-oriented Control OF Induction Motor

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ABSTRAC: The rectifier and inverter are used in vector control of induction motor. The most shortcomings are that exist a big capacitor and energy pass only from power sources to load. This paper details a novel matrix converter—indirect matrix converter. It is used in vector controlling research of induction motor and displaced for conventional inverter to supply power for induction motor. Because switches are bidirectional in the rectifier, it can realize bidirectional pass of the energy and decrease pollution of harmonic wave. Meanwhile bidirectional switches can act in zero current. Four step commutations don't be needed so that it decreases complexity of control process.

In addition, indirect matrix converter which compared with direct matrix converter has the same advantages but it is simpler in controlling strategy. Main circuit topology and control strategy are introduced in this paper. Lastly, simulation result is given with MATLAB.

I. INTRODUCTION

Because of their easy implementation and low cost, indirect field oriented (IFO) induction machine drives are finding numerous industrial applications. Most of the industrials motors are used today are in fact induction motors. Induction motors have been used in the past mainly in applications requiring a constant speed because conventional methods of their speed control have either been expensive or highly inefficient. This type of control scheme uses more mathematical calculations and algorithms, which involves heavy computing and needed efficient and costly controllers. Here we introduce a novel theory to improve the performance of the motor running it at optimum voltage and frequency for optimum motor efficiency at different points. This is an offline method and not for online and real-time control. A computer MATLAB program is developed for getting the ratio of optimum voltage and frequency. The motor flux is in the ratio of the ratio of optimum voltage and frequency. So this flux is compared with the reference flux and generates the error signal and control the action of the induction motor.

II.NEED FOR THE ELECTRICAL DRIVE

Apart from the nonlinear characteristics of the induction motor, there are various issues attached to the driving of the motor. Let us look at them one by one.Earlier motors tended to be over designed to drive a specific load over its entire range. This resulted in a highly inefficient driving system, as a significant part of the input power was not doing any useful work. Most of the time, the generated motor torque was more than the required load torque. For the induction motor, the steady state motoring region is restricted from 80% of the rated speed to 100% of the rated speed due to the fixed supply frequency and the number of poles. When an induction motor starts, it will draw very high inrush current due to the absence of the back EMF at start. This results in higher power loss in the transmission line and also in the rotor, which will eventually heat up and may fail due to insulation failure. The high inrush current may cause the voltage to dip in the supply line, which may affect the performance of other utility equipment connected on the same supply line. When the motor is operated at a minimum load (i.e., open shaft), the current drawn by the motor is primarily the magnetizing current and is almost purely inductive. As a result, the PF is very low, typically as low as 0.1. When the load is increased, the working current begins to rise. . This means the customer is forced to maintain the full-load condition for the entire operating time or else pay penalties for the light load condition. While operating, it is often necessary to stop the motor quickly and also reverse it. In applications like cranes or hoists, the torque of the drive motor may have to be controlled so that the load does not have any undesirable acceleration (e.g., in the case of lowering of loads under the influence of gravity).. Also, mechanical brakes require regular maintenance. The supply line may experience a surge or sag due to the operation of other equipment on the same line. If the motor is not protected from such conditions, it will be subjected to higher stress than designed for, which ultimately may lead to its premature failure. All of the previously mentioned problems, faced by both consumers and the industry, strongly advocated the need for an intelligent motor control.

2.1VARIABLE FREQUENCY DRIVE (VFD)

The VFD is a system made up of active/passive power electronics devices (IGBT, MOSFET, etc.), a high speed central controlling unit and optional sensing devices, depending upon the application requirement. A typical modern-age intelligent VFD for the three phase induction motor with single-phase supply is shown in Figure below.

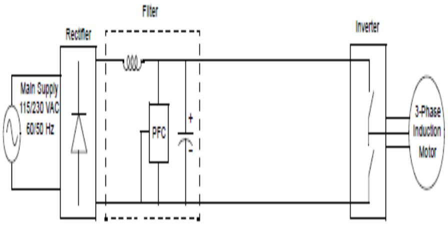


Fig. 1: Typical Variable Frequency Drive

The basic function of the VFD is to act as a variable frequency generator in order to vary speed of the motor as per the user setting. The rectifier and the filter convert the AC input to DC with negligible ripple. Additional features can be provided, like the DC bus voltage sensing, OV and UV trip, over current protection, accurate speed/position control, temperature control, easy control setting, display, PC connectivity for real-time monitoring, Power Factor Correction (PFC) and so on. The base speed of the motor is proportional to supply frequency and is inversely proportional to the number of stator poles.

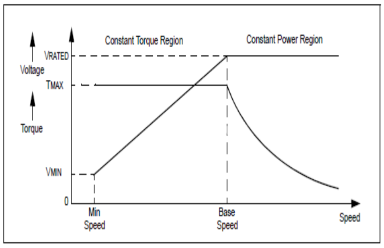


Fig. 2: V/F Curve

As seen in Figure 2.1, the voltage and the frequency are varied at a constant ratio up to the base speed. The flux and the torque remain almost constant up to the base speed. Beyond the base speed, the supply voltage can not be increased. Increasing the frequency beyond the base speed results in the field weakening and the torque reduces. Above the base speed, the torque governing factors become more nonlinear as the friction and windage losses increase significantly. Due to this, the torque curve becomes nonlinear. Based on the motor type, the field weakening can go up to twice the base speed. This control is the most popular in industries and is popularly known as the constant V/f control.By selecting the proper V/f ratio for a motor, the starting current can be kept well under control. This avoids any sag in the supply line, as well as heating of the motor. The VFD also provides over current protection. This feature is very useful while controlling the motor with higher inertia.

III.VECTOR CONTROL

This control is also known as the “field oriented control”, “flux oriented control” or “indirect torque control”. Using field orientation (Clarke-Park transformation), three-phase current vectors are converted to a two-dimensional rotating reference frame (d-q) from a three-dimensional stationary reference frame. The “d” component represents the flux producing component of the stator current and the “q” component represents the torque producing component. These two decoupled components can be independently controlled by passing though separate PI controllers. The outputs of the PI controllers are transformed back to the three-dimensional stationary reference plane using the inverse of the Clarke-Park transformation. The corresponding switching pattern is pulse width modulated and implemented using the SVM. This control simulates a separately exited DC motor model, which provides an excellent torque-speed curve.

The transformation from the stationary reference frame to the rotating reference frame is done and controlled with reference to a specific flux linkage space vector (stator flux linkage, rotor flux linkage or magnetizing flux linkage). In general, there exists three possibilities for such selection and hence, three different vector controls. They are:

- ➢ Stator flux oriented control
- ➢ Rotor flux oriented control
- ➢ Magnetizing flux oriented control

As the torque producing component in this type of control is controlled only after transformation is done and is not the main input reference, such control is known as “Indirect torque control”. The most challenging and ultimately, the limiting feature of the field orientation, is the method whereby the flux angle is measured or estimated. Depending on the method of measurement, the vector control is divided into two subcategories: Direct and Indirect Vector Control. In direct vector control, the flux measurement is done by using the flux sensing coils or the Hall devices. This adds to additional hardware cost and in addition, measurement is not highly accurate. Therefore, this method is not a very good control technique. The more common method is indirect vector control. In this method, the flux angle is not measured directly, but is estimated from the equivalent circuit model and from measurements of the rotor speed, the stator current and the voltage. One common technique for estimating the rotor flux is based on the slip relation. This requires the measurement of the rotor position and the stator current.

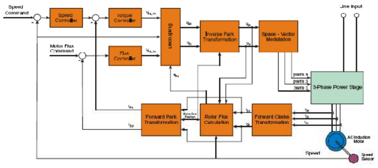


Fig.3: Complete block diagram of Vector Control

3.1Implementation of Vector Control

Vector control is the most popular control technique of AC induction motors. In special reference frames, the expression for the electromagnetic torque of the smooth-air-gap machine is similar to the expression for the torque of the separately excited DC machine. In the case of Induction machines, the control is usually performed in the reference frame (d-q) attached to the rotor flux space vector. That’s why the implementation of vector control requires information on the modulus and the space angle (position) of the rotor flux space vector. The stator currents of the induction machine are separated into flux- and torque-producing components by utilizing transformation to the d-q coordinate system, whose direct axis (*d*) is aligned with the rotor flux space vector. That means that the *q*-axis component of the rotor flux space vector is always zero:

$$\Psi_{rq} = 0 \text{ and } \frac{d}{dt}\Psi_{rq} = 0$$

To perform vector control, follow these steps:

- Measure the motor quantities (phase voltages and currents).
- Transform them to the 2-phase system (α ,β) using a Clarke transformation.
- Calculate the rotor flux space vector magnitude and position angle.
- Transform stator currents to the d-q coordinate system using a Park transformation.
- The stator current torque- (i_{sq}) and flux- (i_{sd}) producing components are separately controlled.
- The output stator voltage space vector is calculated using the decoupling block.
- An inverse Park transformation transforms the stator voltage space vector back from the d-q coordinate system to the 2-phase system fixed with the stator.
- Using the space vector modulation, the output 3-phase voltage is generated.

The components $i_{s\alpha}$ and $i_{s\beta}$, calculated with a Clarke transformation, are attached to the stator reference frame α, β In vector control, all quantities must be expressed in the same reference frame. The stator reference frame is not suitable for the control process. The space vector i_s is rotating at a rate equal to the angular frequency of the phase Currents. The components $i_{s\alpha}$ and $i_{s\beta}$ depend on time and speed. These components can be transformed from the stator reference frame to the d-q reference frame rotating at the same speed as the angular frequency of the phase currents. The *isd* and *isq* components do not then depend on time and speed. The component *isd* is called the direct axis. Component (the flux-producing component) and *isq* is called the quadrature axis component (the torque-producing component). They are time invariant; flux and torque control with them is easy.

IV VECTOR VERSUS SCALAR CONTROL OF AC MOTORS

Scalar control involves controlling only the magnitude of the control variables with no concern for the coupling effects between these variables.

Conversely, vector or field orientated control involves adjusting the magnitude and phase alignment of the vector quantities of the motor. Scalar control, such as the Constant Volts/Hertz method when applied to an AC induction motor is relatively simple to implement but gives a sluggish response because of the inherent coupling effect due to torque and flux being functions of current and frequency. Vector control de-couples the vectors of field current and armature flux so that they may be controlled independently to provide fast transient response. Accurate position control is not possible with scalar control since this requires instantaneous control of the torque. This requires either, instantaneous change to the stator currents, which is not possible due to energy storage effects, or instantaneous change to the rotor current which in the case of scalar control is controlled indirectly via the stator currents. Similarly, whilst scalar control may provide acceptable steady state speedcontrol, precise and responsive speed control due to load changes requires accurate and responsive torque control. The vector approach overcomes the sluggish transient response when using scalar control of AC motors.

4.1 Vector Control concept

In a typical AC induction motor, 3 alternating currents electrically displaced by 120^0 are applied to 3 stationary stator coils of the motor. The resulting flux from the stator induces alternating currents in the ‘squirrel cage’ conductors of the rotor to create its own field these fields interact to create torque. Unlike a DC machine the rotor currents in an AC induction motor can not be controlled directly from an external source, but are derived from the interaction between the stator field and the resultant currents induced in the rotor conductors. Optimal torque production conditions are therefore not inherent in an AC Induction motor due to the physical isolation between the stator and rotor. Vector control of an AC induction motor is analogous to the control of a separately excited DC motor. In a DC motor (see Fig.3) the field flux Φ_f produced by the field current I_a is perpendicular to the armature flux Φ_a produced by the armature current I_a . These fields are decoupled and stationary with respect to each other. Therefore when the armature current is controlled to control torque the field flux remains unaffected enabling a fast transient response.

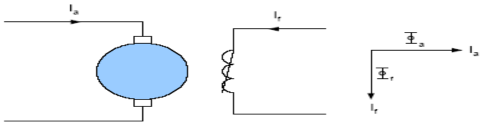


Fig.4: Separately excited DC motor

Where torque (T) $\infty\square I_a I_f$ and where I_a represents the torque component and I_f the field.

Vector control seeks to recreate these orthogonal components in the AC machine in order to control the torque producing current separately from the magnetic flux producing current so as to achieve the responsiveness of a DC machine.

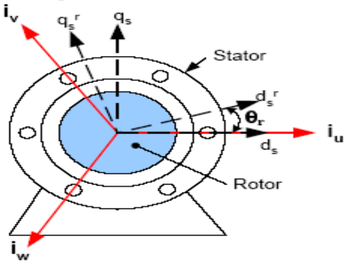


Fig.5: D-Q axis flux distribution in 3 phase induction motor

Traditional control methods, such as the Volts-Hertz control method described above, control the frequency and amplitude of the motor drive voltage. In contrast, vector control methods control the frequency, amplitude and phase of the motor drive voltage. The key to vector control is to generate a 3-phase voltage as a phasor to control the 3-phase stator current as a phasor that controls the rotor flux vector and finally the rotor current phasor. Ultimately, the components of the rotor current need to be controlled. Indirect vector control of the rotor currents is accomplished using the following data:

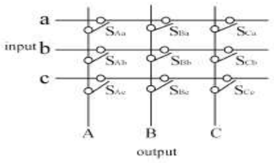
- Instantaneous stator phase currents, i_a, i_b and i_c
- Rotor mechanical velocity
- Rotor electrical time constant

The motor must be equipped with sensors to monitor the 3-phase stator currents and a rotor velocity feedback device.

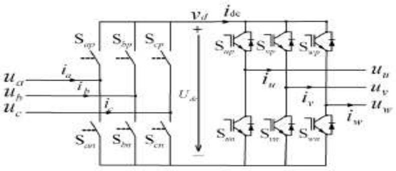
V.MATRIX CONVERTERS

With the development of power electronics and electric transmission, AC-DC-AC converter has already been used in frequency control system. Especially after vector control technique is adopted, output performance of frequency control system is greatly improved. However when output performance of the system is required to be better, AC-DC link in AC-DCAC converter has a big capacitor to filter and produced a lot of harmonic pollution in the line side. This becomes a very difficult problem to drive areas.

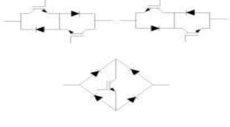
Matrix converter has a good prospect in frequency control system because it don't need filter capacitor and it has bidirectional energy pass, small harmonic pollution and a good controllability[2].Matrix converter can be divided direct matrix converter (DMC) and indirect matrix converter (IMC) in the structure. The main topology of DMC and IMC and the structure of bidirectional switches ar.



(a) Direct matrix converter



(b) Indirect matrix converter



(c) Bidirectional switches

Fig 6: Main circuit topology of matrix converter

In comparison of other power converter, DMC has many advantages such as sinusoidal PWM output voltage and input current, controllable input power factor, bidirectional energy pass, no big capacitor and so on[3,4]. So DMC has already become a hot spot of power electronics areas at home and abroad. Up to now, the research of DMC is still stayed on the experiment stage because its control is complex and effort computation is too large. Four commutation methods increased the difficulty of control and reduced the reliability of the system. Meanwhile switches are in numbers so that the cost of the system is higher. If DMC is replaced by IMC, the problem can be resolved very well. In comparison of DMC, IMC has many advantages:

1. a good input and output performance, unit input power factor, bidirectional energy pass, no DC storage element;
2. switches can communicate in zero current in line side and control process is simple;
3. under some constraint conditions, the number of switches can be reduced;
4. the method of space vector pulse width modulation (SVPWM) can be used and it is simplified to control.

During the advantages the zero current commutation is very important because it immensely simplify the complex commutation problem in DMC. Nowadays most of the scholars are engaged in the research of DMC and they are known a little about IMC. Especially IMC is rarely used in frequency control system. The combination of IMC and vector control frequency system is proposed in this paper and the simulation research of induction motor vector control based indirect matrix converter is given. The simulation result with MATLAB/Simulink verified the feasibility of the proposed system.

5.1. INDUCTION MOTOR VECTOR CONTROL BASED INDIRECT MATRIX CONVERTER

A. The Strategy of IMC

Supposing the expression of input voltage is:

$$u_a = V_m \cos(\omega_i t)$$

$$u_b = V_m \cos(\omega_i - \frac{2\pi}{3})$$

$$u_c = V_m \cos(\omega_i t + \frac{2\pi}{3})$$

We can divide three phase input voltage into six parts so that there is a positive DC voltage in DC side and we can get a biggest output voltage and a smaller switch loss. Each sector has the same performance that is absolute value of one phase is largest and others have opposite polarity. The period of each PWM can be divided two section and two positive polarity voltage are output in the two sections. So two effective space vector voltage of rectifier can be created in a period and zero vectors can't be produced just like Fig.

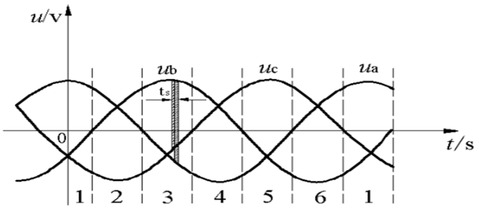


Fig 7: Six sectors of three-phase input voltage and the combinations of DC bus voltage

For example, in the third sector *u*b is positive and maximal, then phase *b* is always conducted in rectifier circuit. Phase *a* and phase *c* are modulated.

So the mean value of DC voltage in one period is:

$$\overline{U_{dc}} = d_{cb} \cdot u_{cb} + d_{ab} \cdot u_{ab}$$

$$d_{cb} + d_{ab} = 1$$

In the equation, *dbc, dba* is duty ratio of *ucb* and *uab* in one period.

1). In Figure., when phase *c* is modulated, Scn and Sbp will conduct. Output voltage in the rectifier is *Udc=ub-uc*.

The duty ratio of phase *c* and phase *b* is:

$$d_{cb} = -\cos\theta_c / \cos\theta_b$$

2). When phase *a* is modulated, San and Sbp will conduct. Output voltage in the rectifier is *Udc=ub-ua*.

The duty ratio of phase a and phase b is:

$$d_{ab} = -\cos\theta_a / \cos\theta_b$$

Table. 1 Duty cycle and switching pattern of the rectifier

θ_a	$-\frac{\pi}{6}\sim\frac{\pi}{6}$		$\frac{\pi}{6}\sim\frac{\pi}{2}$		$\frac{\pi}{2}\sim\frac{5\pi}{6}$	
sector	1		2		3	
Turning on switches	S_{ap}		S_{cn}		S_{bp}	
Modulation switch	S_{bn}	S_{cn}	S_{bp}	S_{ap}	S_{cn}	S_{an}
Duty ratio	d_{ba}	d_{ca}	d_{bc}	d_{ac}	d_{cb}	d_{ab}

After confirming the switch conduction thing of rectifier, all kinds of PWM control method of can be used, especially space vector pulse width modulation (SVPWM). In this SVPWM is used to modulate inverter. We can get the maximal output voltage 3 / 2 *m V* in rectifier. So supposing expecting output voltage vector in the inverter is:

$$\overline{V_{0\_ref}} = k \cdot (\frac{3 \cdot V_m}{2}) \angle\theta_0$$

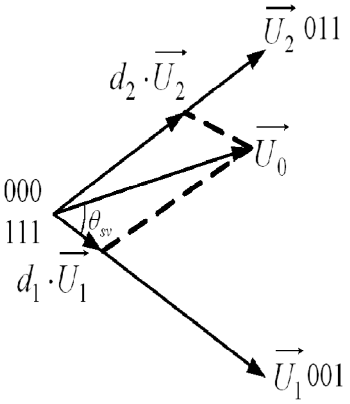


Fig 8: Output voltage Space vector PWM for inverter

In the SVPWM of inverter, zero vectors should be inserted in each PWM period so that expecting value is reached in the output. Meanwhile when zero vectors are inserted in the inverter, the switches is commutated in the rectifier.It makes sure that commutation is reliable and the control strategy is very simple. Combining PWM of rectifier with SVPWM of inverter, we can get the conduction thing of the switches in one period like Fig. shown.In the Fig. shown, *d1* and *d2* is duty ratio of modulated switches in rectifier in one period.

$$t'_1 = t_{com} - d_1 t_0 / 2$$

$$t'_2 = t'_1 - d_1 t_1$$

$$t'_3 = t'_2 + d_1 t_1$$

$$t''_1 = t_{com} + d_2 t_0 / 2$$

$$t''_2 = t''_1 + d_2 t_1$$

$$t''_3 = t''_2 + d_2 t_2$$

$$t_{com} = t_{start} + d_1 t_s$$

$$t_{end} = t_{start} + t_s$$

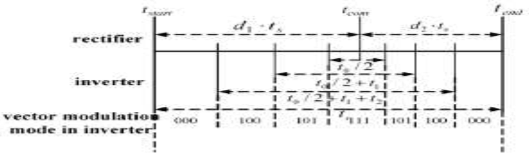


Fig 8: SVPWM sequence for the indirect converter

B. Induction Motor Vector Control Based Indirect Matrix Converter

The block diagram of induction motor vector control system based IMC is shown in Fig.

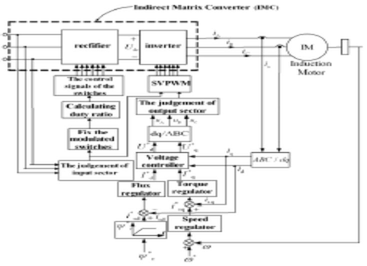


Fig 9: Induction motor vector control system block diagram of indirect matrix converter

According to the principle of IMC and induction motor vector control system, at first stator current *Is* is divided *Id* component and *Iq* component. Then the value of *Id* component and *Iq* component is controlled separately. That is the instantaneous value of three phase current *isu* , *isv* and *isw* is controlled. In comparison with expecting value *Id** and *Iq** , through speed regulator and flux regulator we can get three phase voltage *uu*, *uv* and *uw* after anti-transformed coordinate system. Through judging that output voltage *uu*, *uv* and *uw* is in the sector, we can determine the control signals of the switches in the inverter.

VI.SIMULATION DIAGRAMS& WAVEFORMS

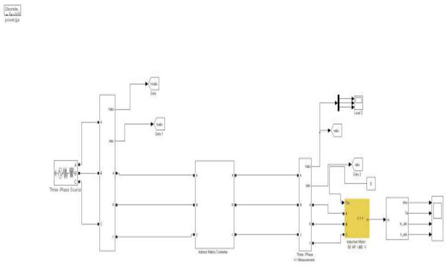


Fig 10: Indirect matrix converter-without load

Fig. is showing output line voltage, the instantaneous value of DC voltage in rectifier simulation waveform in one period when induction motor is running steadily and output frequency 60Hz.

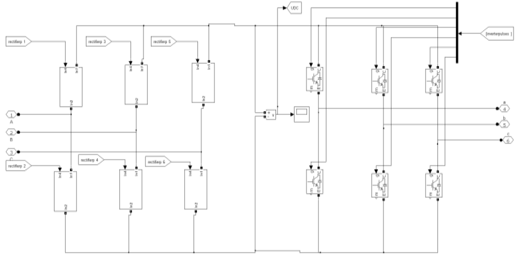


Fig 11 : Indirect matrix block diagram

The above fig shows the block diagram of indirect matrix converter.

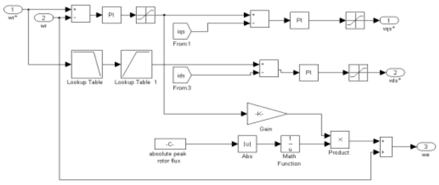


Fig 12: Internal block diagram of vector control

From the simulation we can see sinuous waveform of amplitude regulated is got through rectifying and inverting process of IMC. Meanwhile it can supply to induction motor. Because the switches are bidirectional, the energy can be bidirectional pass when induction motor is electric generator. In Fig. shown when induction motor is zero loads, the simulation waveforms of the three stator current, rotor angular velocity and magnetic torque are shown.From Fig. we can see that when induction motor is zero loads, input reference speed is 150rad/s and this is a steady process step by step. Meanwhile phase current is basically constant and that is 45A or so.

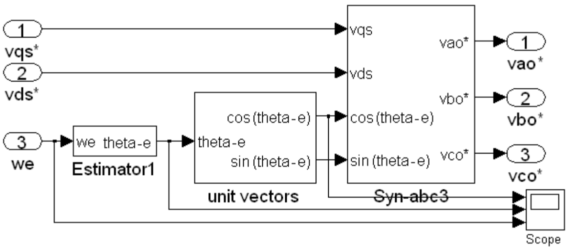


Fig 13: Internal block diagram of line voltage

Fig13. output line voltage, the instantaneous value of DC voltage in rectifier simulation waveform in one period

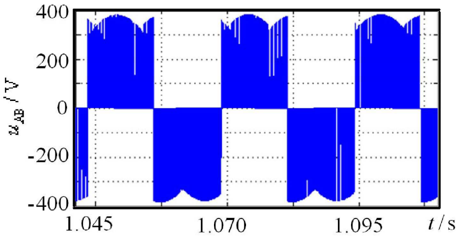


Fig 15: Line voltage simulation waveform of inverter side

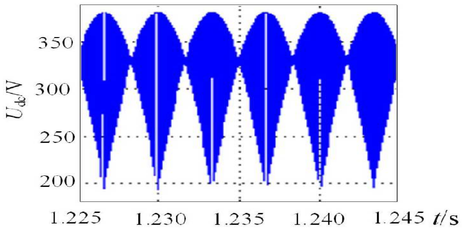


Fig 16: DC voltage instant value simulation waveform of rectifier side

Fig15the simulation waveforms of the stator current, rotor angular velocity and magnetic torque when induction motor is zero loads

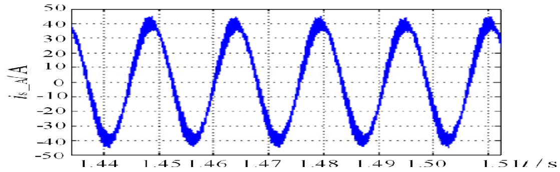


Fig 17: Stator current simulation waveform of induction motor

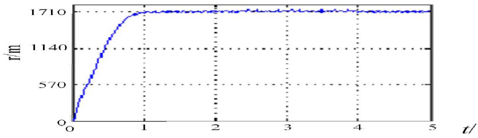


Fig 18: Rotor angle speed simulation waveform of induction motor

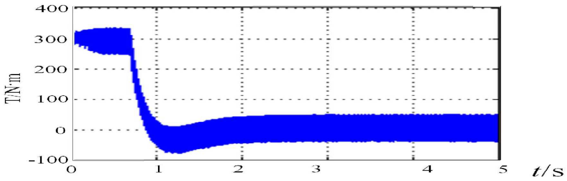


Fig 19: Torque simulation waveform of induction motor

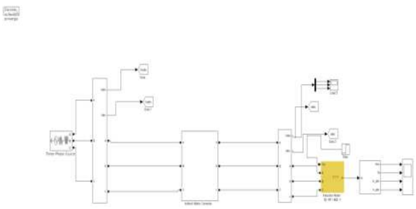


Fig20: Indirect matrix converter-with load

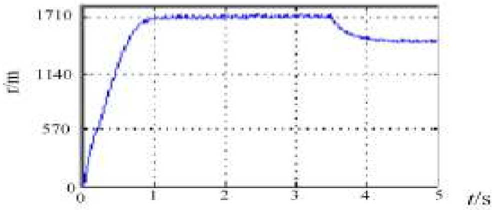


Fig 21: Rotor angle speed simulation waveform of induction motor

From the Fig. we can get the magnetic torque is changing from initial value 0N•m to final value 200N•m.

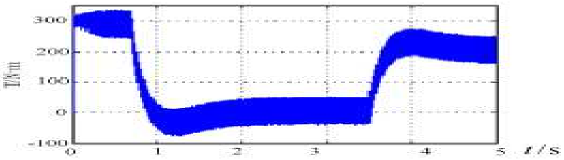


Fig 22: Torque simulation waveform of induction motor

VII. CONCLUSION

Indirect matrix converter based on investigations of vector control for induction motor is introduced in this paper. The main topology structure, control strategy and simulation are given through analyzing the principle of indirect matrix converter and induction motor vector control. From the simulation we can know that induction motor can reach stabilization after a stage of transient state. So IMC replaced traditional DC/AC inverter is feasible in induction motor. Meanwhile the energy pass is bidirectional because the switches of rectifier are bidirectional. The harmonic pollution is reduced also. In addition, the complexity of commutation is largely simplified because of no four step commutation. So it has important research meaning and application value.

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