Idvc Based Hysteresis Controller For Three-Phase Induction Motor Drive

S. Sangeetha¹, Dr. R. Mahalakshmi², D. Poornima³

¹ Assistant Professor, Department of EEE, Sri Ramakrishna Institute of Technology, Coimbatore, Tamil Nadu, India, sangeetha.eee@srit.org
² Professor, Department of EEE, Sri Ramakrishna Institute of Technology, Coimbatore, Tamil Nadu, India, hod.eee@srit.org
³ Assistant Professor, Department of EEE, Sri Ramakrishna Institute of Technology, Coimbatore, Tamil Nadu, India, poornima.eee@srit.org

Abstract: Induction Motor is the most commonly used motor in industrial applications due to its characteristics like self-starting, reliable and easy speed control. The objective of the proposed system is to provide efficient speed control with lesser current harmonics. The Indirect Vector Control (IVDC) method has been presented for speed control of induction motor due to its high dynamic and low drift property. Though there were many classical methods for speed control like Ward-Leonard method etc.; in later years, power electronics circuits were preferred due to its high efficiency, reliability and accuracy. But the presence of static converter in drive circuits results in harmonics, giving in high feedback complexity. Therefore, the Hysteresis controller with conventional Proportional Integral and Differential (PID) control for speed and PI controller for flux is used to control the current harmonics at the point of common coupling. The simulation for speed control in squirrel-cage induction motor is carried out using the MATLAB/Simulink and the parameters like torque, speed, current and Total Harmonic Distortion are analyzed to show optimal response of drive system.

Keywords: Indirect vector control, Hysteresis controller, current harmonics, PID Controller, PI controller, Squirrel-Cage Induction Motor

1. Introduction
Induction Motors (IM), the workhorse of the modern day industries are the most widely used motors for appliances, industrial control and automation. Among the induction motors, Squirrel Cage Induction Motor (SCIM) is used in various industries due to its high reliability, simple construction, ruggedness, cheap, less maintenance [3,4,5]. Another reason for their widespread use is the availability of efficient control strategies for these motors using power converters [7].

When an induction motor is supplied with AC voltage from mains, it will accelerate quickly and then settle at a fixed speed based on the electrical supply frequency and the motor design. So the squirrel cage induction motor is widely used motor for fixed speed applications. When it is supplied with power at the recommended specifications, it runs at its rated speed. However, many applications need variable speed operations. Historically, mechanical gear systems were used in most of the applications to obtain variable speed [2]; but due to the unbraked deceleration and the difficulty in varying the speed and torque made the usage of this motor very difficult [1]. AC drives with well-designed controllers provide a solution for the above problem by modifying the voltage and frequency of the AC supply given to the motor [8]. Control of motor is achieved by either open loop control or closed-loop control. The design and performance of closed-loop PI and PID based hysteresis current type speed controller with constant PI controller for flux control, in a three phase induction motor were analyzed for variable speed application drives.
Due to advances in power electronics and vector control technologies in recent years, the induction motor drives have become popular and gradually taken the place of DC motor drives. The most important feature which makes the induction motor and alternator as a tough competitor to D.C. machines in the drives field is its cost per KVA, induction machines are approximately one fifty of its counterpart and it possesses higher suitability in complex environment. The various methods for the control of output voltage of inverters are external control of AC output voltage, external control of DC input voltage and internal control of inverter within the inverter itself. The most efficient conventional hysteresis current control inverter is used to compare the current error value with the reference current, due to its quick response and simple implementation. The proposed system has two separate controllers where first controller is used to control the flux and the other is used to control the speed. The flux of the motor is controlled with PI controller and the speed is controlled with PI and PID controller, resulting in the drastic change in THD values. The PI controller (for both torque and flux) with hysteresis comparator measures an average current error at each calculation cycle, and thus generates an average inverter output voltage to make the error to be nil. This controller also has many advantages such as fast deadbeat transient response, simplicity, insensitivity to load parameter variations and direct over current protection.

2. Indirect vector control based speed control

Different speed control platforms are used in the present era for induction motors; we have used the indirect vector control in our proposed system as it is more advantageous. Field oriented control provides a good level of dynamic performance and the motor drive with closed-loop control assures long term stability of the system. It is termed as “indirect torque control” and is shown in Fig.1. This type of control system is of three types: magnetizing flux oriented control, stator flux oriented control and rotor flux control. Induction motors are widely used in different complicated commercial and process applications which requires high performances. In order to achieve the expected performances in these applications, the speed of the motor has to be maintained in a specific reference trajectory regardless of any parameter modifications, unbalanced load and model uncertainties.

The basic schemes of controlling the induction motor speed are the indirect and direct methods of vector control. The direct vector control method is related to the unit vector originated from the stator flux. These vector signals are calculated directly or from the stator voltage and current signals. The components of stator flux are calculated from the stator quantities. To obtain rotor field angle information rotor speed is not required in this scheme. The flux measurement process also adds more extra equipment cost and the measurement is not accurate. This is why vector control technique is not considered to be very adequate technique for speed control. Indirect vector control is more reliable and commonly used method than direct vector control. In this method the unit vectors and rotor field angles are measured indirectly by summation of slip frequency and speed of the rotor.

![Figure 1: Indirect vector control](image)

The hysteresis control is basically an instantaneous feedback current control method where the actual current is continuously tracked with the command current within a specified hysteresis band inverter. It is given in figure 1. The control circuit generates the reference current wave of desired magnitude and frequency, and it is compared with the actual phase current wave. In our mathematical model the reference wave for hysteresis controller is taken as 1 and 0. The current regulator consists of three hysteresis controllers and switches with gain and addition block. The actual current from motor is monitored in the measurement output of the induction machine block. The actual motor current and the reference current are compared and measured in hysteresis type relay and the band switching. The error is then given to a comparator having a hysteresis band. When the error crosses the lower limit of the
hysteresis band, the upper switch of the inverter leg is turned ON; it is represented by constant value 200 in MATLAB/Simulink model. But when the current attempts to become less than the upper reference band, the bottom switch is turned ON, vice versa. This hysteresis controller does not have a specific switching frequency and changes continuously and is related to the bandwidth of the controller arms.

![Figure 2](image)

**Figure 2** MATLAB/Simulink model of current to voltage converter block

The Simulink model of the current to voltage converter is shown in figure 2. The speed controller calculates the difference between the reference speed ($\omega^*$) and the actual speed ($\omega$) producing an error, which is fed to the PI and PID controllers. PI and PID controllers are used widely in motion control systems. The dynamic dq modeling is used for studying the motor during transient and steady state. It is done by converting the variables to three phase currents by using inverse Parks transformation. And we can also imply the PID controller to reduce the harmonics as in our proposed system. In MATLAB/Simulink the inverters are connected with the Hysteresis Current Controller (HCC) but practically it is not interconnected so it is connected to HCC based inverter.

3. Result Analysis

The speed control of the IM drive system is implemented in our proposed system and the response is obtained for indirect vector based method in MATLAB/Simulink software with both PI (Proportional and integral) and PID (proportional integrated and derivative) controllers at the on load condition. The five signature parameters of motor i.e. current, speed, torque, THD (Total Harmonic Distortion), flux are been measured for the analysis purpose. The THD value with PI controller is 45.33% but for PID controller is 5.55%, the drastic change is been witnessed.

3.1. PI based speed control

The PI based model, simulated using MATLAB/Simulink model is as shown in figure 3. By the use of indirect Vector Control (IVC) the flux and speed of 3-phase IM are controlled separately using PI controller. The reference speed of the motor is 300 rpm and the feedback summer output is compared with the reference speed the error is produced.

![Figure 3](image)

**Figure 3.** MATLAB/Simulink block diagram using P-I controller
The summer error is given to the PI controller, which changes the output for a better result. Similarly, the flux is also controlled by giving negative feedback. The reference flux value denoted in the constant block is 0.98 and it is also controlled with the linear PI controller. The hysteresis current for the 3-phase induction motor is also viewed in the results and its corresponding THD value is directly calculated after passing through the low pass filter block. Each signature parameters of 3phase induction motor are as seen in the proceeding section.

3.2. Simulation result of PI controller
The speed of the induction motor drive system can be adjusted based on the application. In our proposed system the set speed is 300 rpm and the output obtained is the same as that of the reference speed for the closed loop system as in figure 4. It is observed that the motor picks up the speed at t=0.0021sec.

![Figure 4. Induction motor speed response](image)

![Figure 5. Performance of load torque in induction motor](image)

The above speed control is simulated with the load torque of 25Nm. Its corresponding result is as shown in figure 5. The vector control method controls the speed and flux using individual controllers. The only difference in the Indirect Vector Control is the slip is considered for the change in speed, it is as discussed below.

![Figure 6. Flux response of Induction motor](image)

![Figure 7. Three phase hysteresis controlled current](image)

The flux response of IVCIM is improved using a PI controller. Here a separate controller is used for flux control as vector control is based on independent factors. The reference flux of 0.98 is obtained as the simulation result from the negative feedback as in figure 6. The Hysteresis Current Control (HCC) is used to control the current in the induction motor drive and the HCC is as shown in figure 7. The conventional HCC is used as it is superior when compared to the multilevel hysteresis controller regarding speed. The current harmonics of the three-phase induction motor is also evaluated with FFT analysis and its THD value, $I_a = 45.33A$ after passing through the Low-pass filter circuit is as shown in figure 8.
Thus the results of signature parameters of IVCIM using the linear conventional PI controllers are as discussed above. Due to the high THD value in a motor phase current the drive system possess inefficient result. So the PID controller is been used in the next section as it is the next improved version of the PI controller where small change in derivative parameter yields efficient output.

3.3. PID based speed control
The block diagram of the PID based IVC model of induction motor is simulated using MATLAB/Simulink model as shown in figure 9.

Using IVC the flux and speed are controlled separately using PI controller and speed using PID controller. The reference speed of the motor is set as 300 rpm and the negative feedback is given in the summer yielding an output. The summer error is given to the PID controller changes the output for a better result. Similarly the flux is also controlled by giving feedback with the reference flux value as 0.98. The speed of the induction motor can be changed based on the application but we have used the same speed to find the difference between the different controllers and their differences. In our proposed system the set speed is the same 300 and the output obtained is same as that of the reference speed. It is observed that the motor picks up the speed at t=0.001sec and is shown in figure10.
The load torque of the induction motor is given as 25N-m and the desired output torque is obtained as in figure 11. It is observed that the distortion in torque is increased compared to the P-I controller. The flux response of IVCIM is done using a PID controller. Here a separate controller is used for flux control as vector control is based on independent factors. The reference flux of 0.98 is obtained in the simulation result shown in the figure 12.

The HCC is used to control the current in the induction motor drive here conventional HCC used as it is superior to the multilevel hysteresis controllers regarding speed but it is also viewed that the THD value also decreases tremendously resulting in low distortion.

The current harmonics of the three-phase induction motor is as shown in figure 13 and the THD value of current in single phase, Ia is 5.55% after passing through the Low-pass filter circuit is as shown in figure 14.
From the above THD analysis, it is found that there is a huge decrease in harmonic distortion. Comparing the PI controller with the PID controller with the same reference values it is observed that the IVC based IM speed drive system with PID controller for speed yields a better speed and harmonic response. It is also observed that the single phase current distortion of a three phase IM matches with the IEC standards with the slight +0.55 variation.

Table 1 shows the Total Harmonic Distortion (THD) after tuning with the proposed PI and PID controller. Thus the following method is said to be more advantageous due to its simplicity and efficient distortion values, though HCC is practically little complex as it mainly depends on the hardware of the whole system.

4. Conclusion
The hysteresis control for three-phase VSI fed IM has been implemented in MATLAB /Simulink. The proposed indirect vector control for motor using PI and PID controller is tested at load torque of 23 N-m, with reference current which changes in real-time applications. The three phase-plane trajectory of the controller shows the convergence of error for various controllers at same load. The PI controlled induction motor yields THD which is around 49% while the PID controlled induction motor offers the THD of 5%, complying with the IEEE 519 standard. From the simulation result it is proven that the constant current hysteresis control technique has good dynamic response and high degree of accuracy in reference tracking capability with reduced harmonics. Hence the proposed control technique could be an attractive solution with ease of implementation along with better performance.

5. References

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| Speed Controller Type | Total Harmonic Distortion |
|-----------------------|--------------------------|
| Hysteresis comparator based PI controller | 45.33% |
| Hysteresis comparator based PID controller | 5.55% |
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