Three-Phase Induction Motor Controller Design Based on Hysteresis Voltage Control

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Abstract. This paper describes a controller for Three-Phase Induction Motor. Induction motor is an electromechanical actuator widely used due to its reliability and relatively low maintenance cost. However, the control problem of an induction motor is complex due to nonlinearities, load torque perturbation, and parameter uncertainties. An element included in this study is voltage source control, which is to control the voltage fed from three-phase inverter to Three-Phase Induction Motor. Hysteresis Controller was proposed in this paper to minimize voltage error. Hysteresis controller is seen as an input–output phase lag corrector. The implementation of the designed hysteresis controller is performed in simulation using MATLAB/Simulink. The result proved that the proposed controller design can minimize the line voltage error of the induction motor, preventing the line voltage from being kept low hence avoiding excess current at low speeds.

1. Introduction

Induction motors, either single phase or three-phase are widely used in industry due to their reliability and low cost. However, three-phase induction is the most interesting and has been attracted the attention of many researchers due to their non-linearity [1]. Many controllers have been developed and can be classified into passive and adaptive power controls. The example for passive power control is hysteresis, relay, and sliding mode control. Examples for adaptive power control are PID, fuzzy, and P-resonant controller [2]–[5].

Basically, motor is driven by an inverter. Inverter is a device which supplies various frequencies of power supply to equipment [6]. Based on this function, motor revolution speed can be controlled causing reduction in energy consumption. One of the ways of how it functions is voltage source inverter (VSI) where it takes in a fixed voltage from a device, such as a dc power supply, and converts it to a variable frequencies AC supply [7].

Other papers have discussed the strategy of controller for induction machine. Yassine Kali et al. [8] have found a good performance in terms of current tracking by proposing a robust nonlinear current controller of a six-phase induction motor drive. The technique proposed is a combination of Discrete-
time Sliding Mode Control and the Time Delay Estimation method for the inner current control loop of an Indirect Rotor Field-Oriented Control of a six-phase induction motor drive. The proposed technique provides high accuracy in estimation of uncertainties, perturbations, and unmeasurable rotor current.

The low saturation effect was resulted by using Fuzzy-Anti Windup PID controller for induction motor controller as discussed by Premkumar et al. [9]. The technique considered a fuzzy based proportional (kp), fuzzy base integral (ki), and fuzzy based derivative (kd). In simulation results, the authors found that the proposed technique yielded better performance in providing settling time, overshoot, undershoot, peak, and peak time compared to PI controller and Anti windup PID controller. However, this technique drawback on lower speed and is time consuming.

Hichem Hamla et al. [10] presented a modified direct torque control for induction motor drives based on variable hysteresis band current control with a considerable improvement of its characteristics. This technique was proposed to control the stator currents and the torque and magnitude of stator flux. In comparison to the conventional direct torque control, this technique has proven to be superior as it included one more parameter on the controller, provided better quality of stator current waveforms, and reduced torque ripples.

In this paper, hysteresis voltage control is proposed due to its ability to perform variable frequency switching, very fast response, and simple operation compared to other control methods. The main principle is to switch the motor “on” and “off” very rapidly. The AC output of the inverter can be controlled in both amplitude and frequency which are the requirements of induction motor at any desired point of operation [11]. The switching operation in inverter is to connect the power switches when line voltage is low and disconnect when it is high. In addition, Arduino will be used as a digital signal processing (DSP) [12]. All simulation works was done in MATLAB Simulink.

2. Research Methodology

2.1. The Proposed Controller (Hysteresis Controller)
Hysteresis controller derives the switching signals of the inverter power switches in a manner that reduces the voltage error. The switches are controlled so that they follow the references. The voltage ramping up and down between two limits is illustrated in figure 1. When the voltage through the induction motor exceeds the upper hysteresis limit, a negative voltage is applied by the inverter to the induction motor. This causes the voltage in the induction motor to decrease. Once the voltage reaches the lower hysteresis limit, a positive voltage is applied by the inverter to the induction motor and this causes the voltage to increase and the cycle repeats.

The voltage controllers of the three phases are designed to operate independently. Each voltage controller determines the switching signals to the inverter. The switching logic for phase A is formulated as below:
If $V_a < (V_a \text{ ref} - \text{HB})$ upper switch is OFF and lower switch is ON
If $V_a < (V_a \text{ ref} + \text{HB})$ upper switch is ON and lower switch is OFF

In the same action, the switching of phase B and C are derived. However, they happen in different phase shifts which are phase B in $120^\circ$ shift and phase C in $240^\circ$ shift.

2.2. The Proposed Block Diagram of Controller

Figure 2 describes the overall simulation block diagram. The main setup is the input as in DC source, three-phase inverter, and the Three-Phase Induction Motor. Arduino is employed as the voltage sensor which then sends the data to MATLAB Simulink for simulation. The controller setup is at the feedback of the system, starting from voltage reading from connection between three-phase inverter and Three-Phase Induction Motor. The reading will then be compared with reference voltage. The error from that comparison will be sent to Hysteresis Controller. The Hysteresis Controller will control the PWM (Pulse Width Modulation), increasing and decreasing the voltage based on references to the three-phase inverter.

2.3. Hysteresis Controller Design

Hysteresis controller is the main part in the controller design. The output of the hysteresis controller is in PWM signal. These PWM signals will be used by the gate control for each of the power switches in three-phase inverter. In the project, there are three hysteresis controllers that create six PWM. Three of them are the PWM of each phase, and the other three are the inverted signals of the first three PWMs. Figure 3 (a) and (b) show hysteresis controller block and how to get PWM and its inverse.
The error voltage which is the input to the hysteresis controller is 2VAC. It was cut by constant 0.1 as a sampling signal. From this action, the PWM and its inverse of “Phase A” were created.

### 2.4. Hysteresis Controller Model

Figure 4 above shows the controller for phase A in MATLAB Simulink environment. The same arrangement is found for phase B and C with difference phase shift. V line is the input voltage or feedback voltage from the line voltage inverter to induction motor. ADC is the analog to digital converter and DAC is the digital to analog converter. The MATLAB Simulink model created 6 pulse PWM signals, where each phase has 2 pulses. The first two signals are at 0° (phase A), then the next two signals are at 120° (phase B) and at 240° (phase C). The voltage line (V line) is set to 18Vac and the voltage reference (V ref) is set to 20Vac. This means that the error carried is 2Vac.

### 3. Results and Discussions

Discrete second order filter was used, with the cut off frequency at 100Hz and the damping factor zeta is 0.707 of lowpass filter. The result of the simulation is illustrated in figure 5.
Figure 5. The three-phase component for reference voltage signal (voltage vs time).

Figure 6. The voltage error after hysteresis controller (voltage vs time).

The waveform in figure 6 shows the error voltage as 2Vac. It comes from the comparison of 18Vac as the analog input with 20Vac as the reference voltage.

Figure 7. The PWM and invert PWM for phase A (voltage vs time).

Figure 7 depicts the PWM for Phase A and Invert Phase A. Similar depiction could be found for Phase B and Phase C with difference in phase shift. From here, 6 pulse PWMs were created for the switching of the inverter.
The output voltage of the inverter is in nonsinusoidal waveform depicted in figure 8(a). It is normal and complies with the output voltage of the inverter; the waveform is in square wave. The result was derived from the switching of the MOSFET. Therefore, after placing the filter, the waveform was turned into approximately sinusoidal as shown in figure 8(b).

The function of the transformer is to scale down the voltage to follow the analog characteristic of Arduino. In the model, the ratio of the transformer is 20:1 hence, 20Vac will be scaled down to 1Vac. The output of the transformer, which is the same pattern as the output of the inverter, is nonsinusoidal as shown in figure 9(a). With the same filter application, figure 9(b) shows the waveform as approximately sinusoidal.

4. Conclusion
This paper introduced hysteresis controller with voltage control technique based on three-phase inverter switching fed to an induction motor. The switching frequency of the inverter is presented using the proposed hysteresis controller in MATLAB Simulink model. The method minimizes the line voltage error of the induction motor preventing the line voltage from being kept low hence will be able to avoid excess current at low speeds. Lastly, implementing the MATLAB Simulink model using a three-phase inverter provides flexibility of control.

5. Future recommendation
Further studies can be carried out by implementing hardware setup to prove the proposed method with real time situation. Arduino can be used to create prototypes, to carry out the duty of controller to control the switching of three phase inverter.

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