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Research article

Improving the Speed Control of the Induction Motor Using Pulse Width Modulation Technique

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ABSTRACT

In this research, the improvement of the speed control of the induction motor using the pulse width modulation (PWM) technique was carried out. The induction motor is subjected to characterization to evaluate its essential parameters of functionality. The speed characterization of the induction motor was obtained by the application of the phase angle control method under the two operating conditions. The induction motor was operated at a setpoint speed 2830RPM and rated with torque 10Nm. In the second part, the induction motor was operated at 50% of rated torque (5Nm) and a speed setpoint of 50% of the rated speed (1415 RPM). It was observed that the torque obtained is inversely proportional to the speed. At about 0.15 seconds the speed rose to a maximum of 3152.9RPM, which represents an overshoot of about 10.24% with a settling time of 0.3 7sec. While the setpoints speed at 50% of the rated speed and loaded mark with 50% of the rated torque, it took the induction motor a long time to match the speed setpoint. The settling time is about 0.44sec while the overshoot recorded is about 26.60%. Due to faster settling time and favourable overshoot obtained by the induction motor in the study, the speed response characteristics exhibited higher efficient operation and better energy utilization.

Keywords: *Speed Setpoint, Induction Motor, Torque, Pulse Width Modulation*

1. Introduction

Induction motors are the most common motors used in industrial control systems. Low cost simple and rugged design, as well as low maintenance, are the main advantages of induction motors. Generally, induction motors are specifically designed to run at rated speed when connected to the main power supply. Maximum utilization of these induction motors does not need a fast response but also speed control. Therefore, many techniques have been used for induction motor speed control.

Pulse with modulation technique is one of the most popular methods and its utilization which dated back to the 1960s was mainly in the control of VFD-fed AC motors [1,2]. However, the variable speed drives are faced with many limitations such as poor efficiencies, unstable control, large space consumption, etc. In recent decades, much effort has been put up by various researchers toward the appropriate methods for optimizing the speed control of induction motors. Due to growing concern in these areas of accuracy and effective energy utilization in speed control, the enormous work carried out involving different techniques/methods which include Genetic Algorithm (GA), Particle Swarm Optimization (POS), Artificial Neural Networks (ANN), Fuzzy logic and Neuro-Fuzzy logic (NFL) were geared towards providing the needed solution [3,4]. Remarkably, the general review of all the past works reveals that the speed response of the induction motors has been not evaluated under the combined variation of speed and torque set-points [5]. Therefore, this research effort on the pulse width modulation technique is intended toward achieving the desired objective by employing the method of the setpoint of speed and torque rated values using the speed controllers of phase angle and pulse width modulation.

Modeling of Pulse Width Modulation Control for Varying the Supply Voltage Applied to the Induction Motor

The induction motor is controlled via a drive circuit. The motor drive circuit comes as a power electronics converter. The drive circuit consists of switches that have to be switched to vary the output voltage to the converter. In this work the speed of the induction motor is controlled, using PWM, via a matrix converter (the drive circuit). The block diagram of the system configuration is shown in figure 1

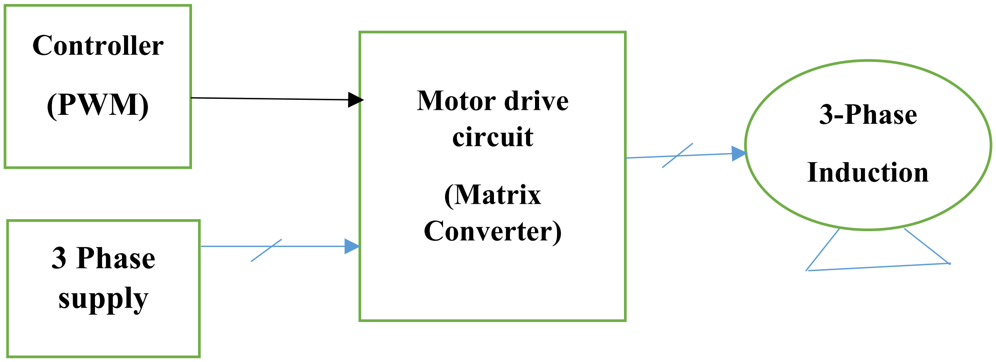

Figure 1: Block Diagram of Matrix Converter Induction Motor Drive System Controller Using PWM

The matrix converter is a direct power conversion device that converts three-phase AC line voltages to variable-voltage variable-frequency three-phase outputs. The variable voltage at the output of the matrix converter is used to control the speed of the induction motor. The output voltage of the motor diver circuit (i.e the matrix converter) is generated from the input voltage by the nine bidirectional switches of the matrix converter. The switching sequence (switching pattern) is generated using PWM. That is, the switches are pulse width modulated. The switching pattern is established via the PWM technique to vary the output voltage of the power electronics converter to control the speed of the induction motor.

The goal of the modeling carried out in this section is to obtain the mathematical model of using the PWM technique to generate the sinusoidal switching function to the drive circuit for control of the induction motor via voltage variation. The matrix converter is an AC to AC power converter having no direct current (DC) link. Figure 1.2 shows the schematic circuit of the converter.

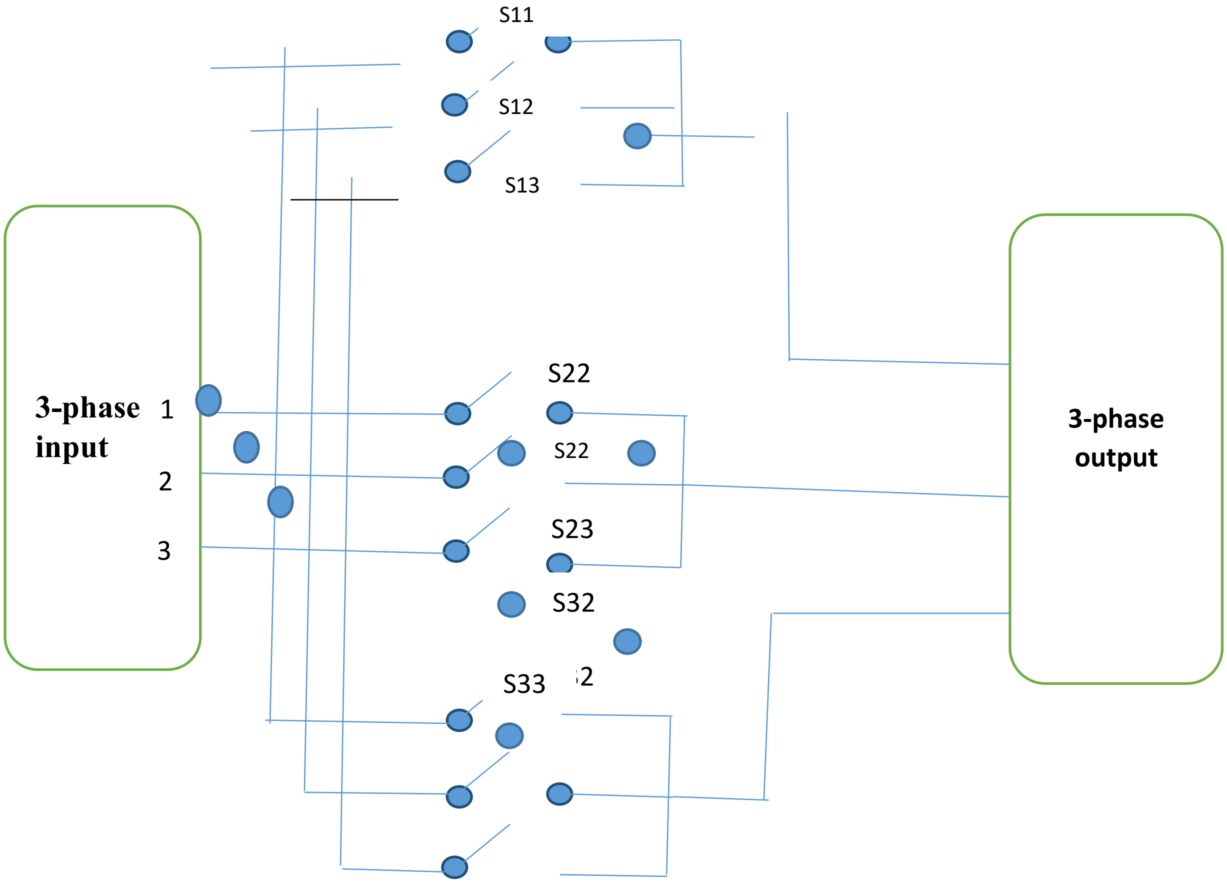

Figure 2: 3-Phase Matrix Converter Having Nine (S_{ij}) Bidirectional Switches

The analytical expression for the PWM spectrum switching function to control the matrix converter to control the speed of the 3-phase induction motor will be obtained by using the one-dimensional Fourier series of a pulse train.

2. Model of the Induction Motor

For obtaining the model of the induction motor, a dynamic d-q model of a three-phase induction motor in state-space form is developed. This is based on a dynamic d-q model of the induction motor. Furthermore, the dynamic model in state-space form is useful to carry out simulation studies of the induction motor in the MATLAB/SIMULINK programme [6,7]. In the induction motor model development carried out here, the state space equation of the motor in a rotating frame is considered and the three-phase to two-axis transformation is used.

From the formulations of the three-phase voltages supplies to the induction motor, motor stator, and rotor circuits and their variables represented in a rotating frame, flux leakage in terms of current, and then the flux linkage in terms of stator and rotor reactances, the final equations obtained are expressed as [5,8,9]

$$\frac{dFqs}{dt} = \omega b\left[Vqs - \frac{\omega eFds}{\omega b} + \frac{Rs}{Xls}\left\{\frac{FqrXm}{Xlr} + Fqs\left(\frac{Xm}{Xls} - 1\right)\right\}\right] \qquad (1)$$

$$\frac{dFds}{dt} = \omega b\left[Vds - \frac{\omega eFqs}{\omega b} + \frac{Rs}{Xls}\left\{\frac{FdrXm}{Xlr} + Fds\left(\frac{Xm}{Xls} - 1\right)\right\}\right] \qquad (2)$$

$$\frac{dFqr}{dt} = \omega b\left[\left(\frac{\omega e-\omega r}{-\omega b}\right)Fdr + \frac{Rr}{Xls}\left\{\frac{FqsXm}{Xls} + Fqr\left(\frac{Xm}{Xls} - 1\right)\right\}\right] \qquad (3)$$

$$\frac{dFdr}{dt} = \omega b\left[\left(\frac{\omega e-\omega r}{\omega b}\right)Fqr + \frac{Rr}{Xls}\left\{\frac{FdsXm}{Xls} + Fdr\left(\frac{Xm}{Xls}-1\right)\right\}\right] \qquad (4)$$

MATLAB/Simulink Model of the Induction Motor

The MATLAB SIMULINK model of the induction motor is obtained by using appropriate SIMULINK blocks to represent the mathematical expressions of the induction motor.

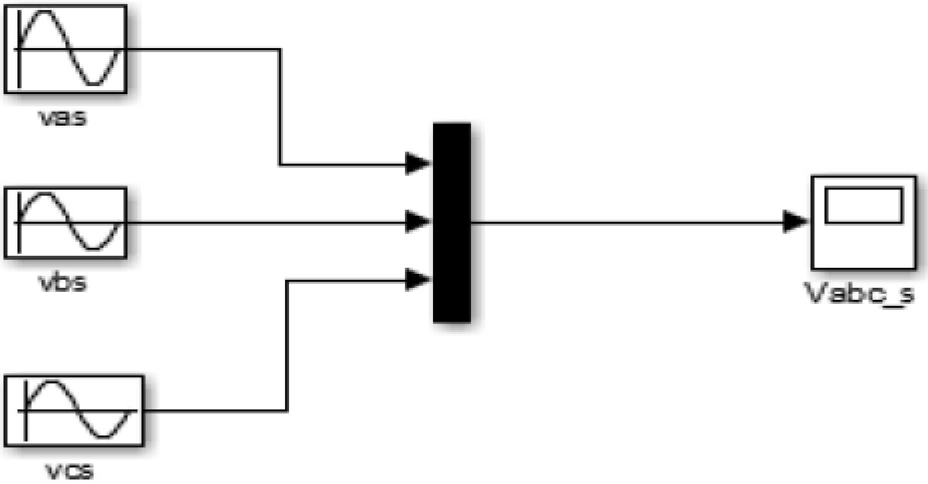

Figure 3: SIMULINK Model of the 3-Phase Power Supply to the Motor

The overall SIMULINK model of the induction motor was obtained as shown in figure 4 [10,11,12].

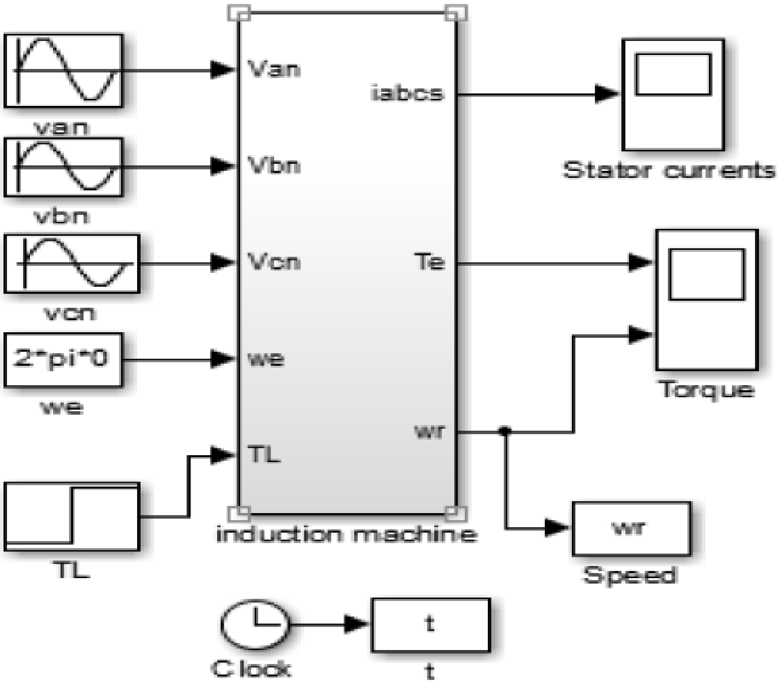

Figure 4: The Overall SIMULINK Model of the Induction Motor

3. Method, Design, and Implementation

The determination of the characteristics of a 3-phase induction motor under phase control method was used to establish the reference situation by which the performance improvement achieved by the proposed Pulse Width Modulation (PWM) control techniques is based. The mathematical model of the 3-phase induction motor was employed to obtain the MATLAB/SIMULINK model of the motor. The SIMULINK model of the induction was used to carry out simulation studies to evaluate the performance of the proposed PWM speed control method. A computer running the Windows operating system of 2.15 gigga hertz clock speed, 4GB of RAM, 500 GB of HDD is used to run the MATLAB/SIMULINK programme for the simulation studies carried out.

The speed response of the induction motor was simulated and evaluated under two different speed setpoints and torque loading. The proposed Pulse Width Modulation control scheme for the speed control of the 3-phase induction motor was implemented in the simulation carried out as MATLAB M-file programme code. The PWM programme carries out a signal exchange with the SIMULINK model of the induction motor using the MATLAB s-function block and the MATLAB workspace structure.

For the mathematical model of the PWM scheme developed, the matrix converter was used as the drive interface of the PWM to the induction motor. Fourier transform and Fourier series were utilized for the modeling of the PWM control signal generation process, to show how the PWM is generated and to modulate the 3-phase voltage input to the induction motor to control the motor’s speed.

4. Result and Discussion

Characterization of the Speed Response of the Induction Motor Based on the Existing Phase Angel Controller

To characterize the speed response of the 3-phase induction motor, the MATLAB SIMULINK simulation of the d-q model of speed response characteristic is obtained based on the use of the phase angle control as the benchmark controller. The MATLAB m-file programme code of the phase angle controller and the SIMULINK model of the induction motor are integrated via the MATLAB s-function block.

The speeds response characteristics of the induction motor were obtained for two operating conditions. In the first case, the induction motor operates at setpoint speed 2830 RPM (ie the rated or nominal speed) and loads with rated torque 10Nm. The second is the case of the induction motor operating at 50% of the rated torque and speed setpoint of 50% of the rated speed. The speed trajectory and the corresponding torque of the induction motor for the phase angle controller for the various conditions investigated are given in figures 3.1 to 3.5 respectively.

It was observed, generally, that the speed of the motor rose past the speed setpoint of 2830 RPM, then reduced but later increased to the rated value and thereafter maintained constant for some time. The speed reduced and matched the setpoint speed. The settling time which is the time taken to match the setpoint was obtained as 0.37 sec. The motor speed exceeded the setpoint and at about 0.15 sec, the speed rose to about 3152 RPM. This represents an overshoot of about 10.24%. The torque characteristics of the motor followed a somewhat opposite trajectory. Low speed is associated with high torques and vis versa. It was observed from figures 3.1 and 3.2 that the basic criteria of torque-speed relation are satisfied as torque is inversely proportional to speed.

The speed trajectory and the corresponding torque of the induction motor for the case of the setpoint speed at 50% of the rated speed (ie 1415 RPM) and loaded with 50% of the rated torque (ie 5Nm) were obtained as given in figures 3.3 and 3.4 respectively. It can be observed that it took the induction motor a longer time than in the first case for the speed to match the speed setpoint. The settling time is about 0.44 sec. The percentage overshoot is higher than in the first case probably due to the reduced impact torque and speed on the system. The overshoot is about 26.60%. The speed rose past the setpoint by 26.60%, at the corresponding value of 1927 RPM, with the setpoint at 1415 RPM. However, the rise time of about 0.08 sec, is shorter than in the first case. It can be seen that the speed oscillation about the setpoint is more pronounced than in the first case. This is also due to a longer settling time. The effect of this speed profile can be observed with the corresponding torque trajectory.

Evaluation of the Performance of the Induction Motor under the Control of the Pulse Width Modulation Controller

The speed and torque responses of the induction motor under the PWM controller were equally obtained for the same operating conditions as the phase angle controller previously characterized. Simulation is carried out to obtain the response of the proposed controller for the case of the induction motor operating at: (i) The setpoint speed of 2830 RPM (ie loaded with rated torque, and (ii) the case of the induction motor operating at speed setpoint of 50% of rated speed and 50% of rated torque.

The MATLAB m-file script code that implements the PWM controller induction motor is given in figures 3.5 - 3.8. These responses of the induction motor are obtained for the PWM controller for the various conditions of speed and torque investigated.

The trajectory of the speed with the PWM controller at the same setpoints has similarity with a controlled response via phase angle controlled which was discussed earlier on. From figure 3.5, the PWM controller did not allow the speed to exceed a maximum of 3077 RPM. Based on the speed setpoint value, the overshoot is 247 RPM, which represents a percentage of 8.73%. The settling time commanded by this controller is about 0.32 sec. In figure 3.6, it can be seen that at the initial stage, torque supplied by the motor varied. It took the PWM controller about 0.31 sec to supply a balanced torque.

Responses of the induction motor under the PWM controller for the case of the setpoint speed at 50% of the rated speed (ie 1415 RPM) and loaded with 50% of the rated torque (ie 5Nm) are given in figures 3.7 and 3.8 for speed and torque respectively. In figure 3.7, the variation in speed reached a maximum of 1740.32 RPM. Considering the speed setpoint of 1415 RPM, the controlled speed overshoot is 325.32 RPM. This represents an overshoot of about 11.49%. The settling time is at 0.38 sec. As observed in figure 3.8, the PWM controller achieved the balanced torque at 0.44 sec.

A high overshoot often leads to oscillation of the speed trajectory about the desired setpoint. This affects the finish time and quality of the industrial process in which the induction motor is applied. For instance, it produces errors in machine-cutting operations, as well as in rotating and industrial positioning operations that are driven by the induction motor. In an electric vehicle, in which the induction motor is mostly applied, it leads to a less smooth ride and increased motor battery usage with its impact on the distance the electric device could travel on a full battery charge. This results in less efficient electric care operations.

The performance of the setpoint of the speed controller affects the time taken for the motor to reach a steady speed at any torque loading. The longer the settling time, the higher the transient, the speed, and the torque fluctuations, thus the more jerky the operations of the induction motor. For a high-performance speed controller, the speed rise time should be as short as possible, while the overshoot should also be as small as possible. In the same vein, the oscillations about the speed setpoint should be as low as possible. From the speed response characteristics of the motor, it can be observed that the system has more tendencies to overshoot for lower setpoint speeds than for higher setpoint speeds.

5. Conclusion

From the results of the speed response characteristics of the inductor motor, it is generally observed that the system has more tendency to overshoot while the settling time exhibits an undesirable higher extension of the period for a lower setpoint speed than for the higher setpoint speed counterpart. The PWM controller also achieved a higher degree of efficiency in the reduction of overshoot and the settling time as well as the display of higher effective load balancing when compared to the phase angle controller.

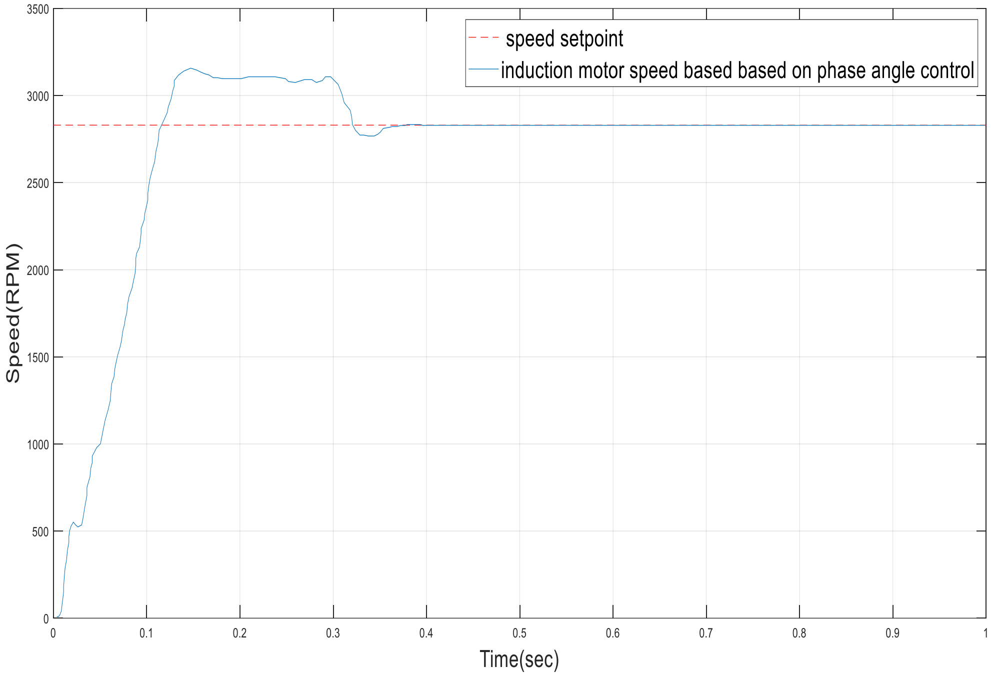

Figure 5: The Speed Trajectory of the Induction Motor Under Phase Control for the Case of the Setpoint Speed at the Rated Speed of 2830rpm and Loaded with Rated Torque of 10nm

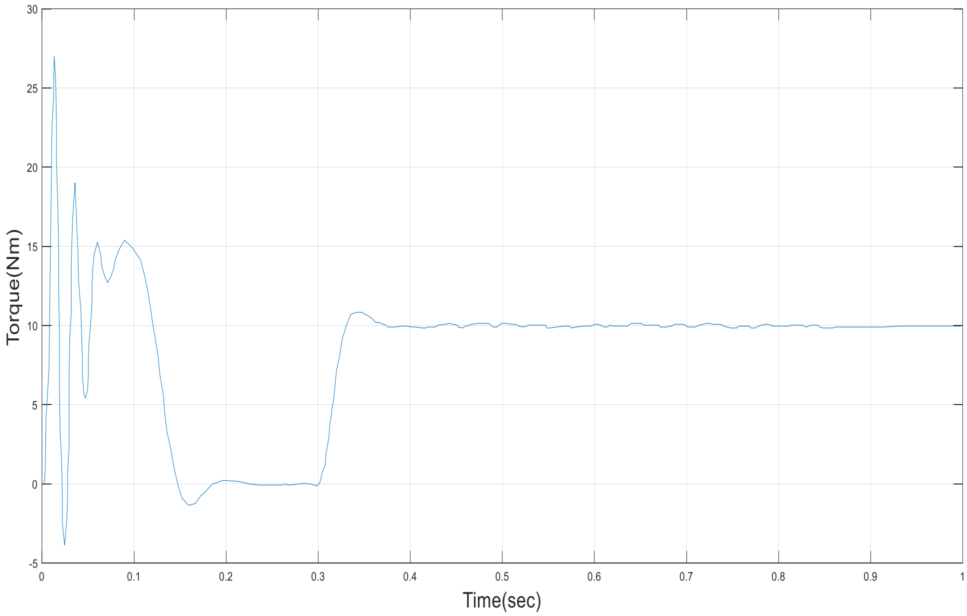

Figure 6: The Torque Variation of the Induction Motor Under Phase Control for the Case of the Setpoint Speed at the Rated Speed of 2830rpm and Loaded with Rated Torque of 10nm

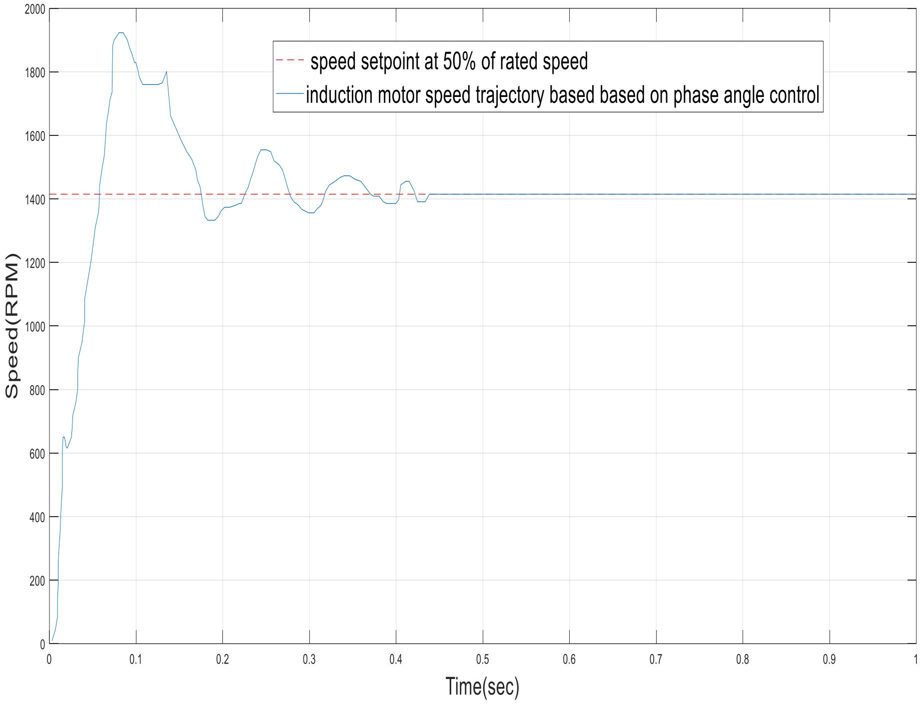

Figure 7: The Speed Trajectory of the Induction Motor Under Phase Control for the Case of the Setpoint Speed at 50% of the Rated Speed and Loaded with 50% of Rated Torque

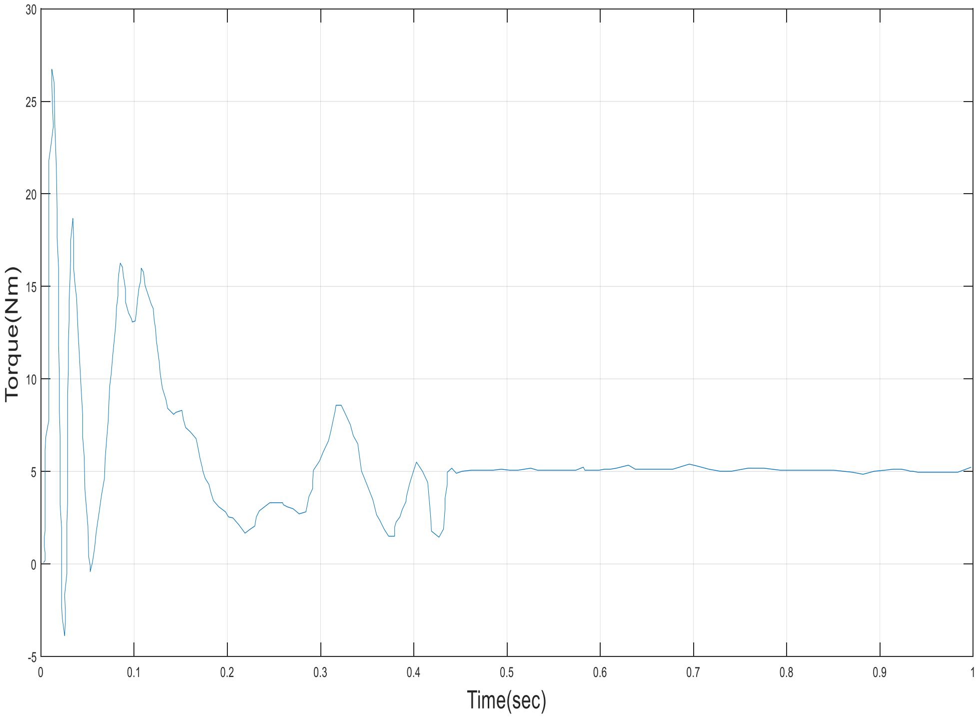

Figure 8: The Torque Variation of the Induction Motor Under Phase Control for the Case of the Setpoint Speed at 50% of the Rated Speed and Loaded with 50% of Rated Torque

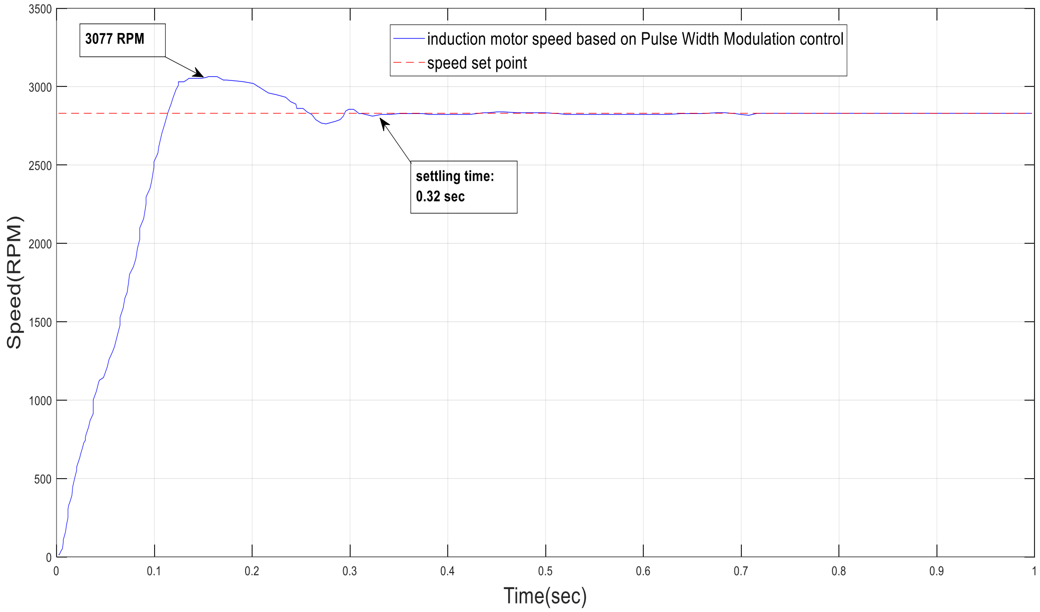

Figure 9: The Speed Trajectory of the Induction Motor Under Pulse Width Modulation Control for the Case of the Setpoint Speed at the Rated Speed Of 2830rpm and Loaded with Rated Torque of 10nm

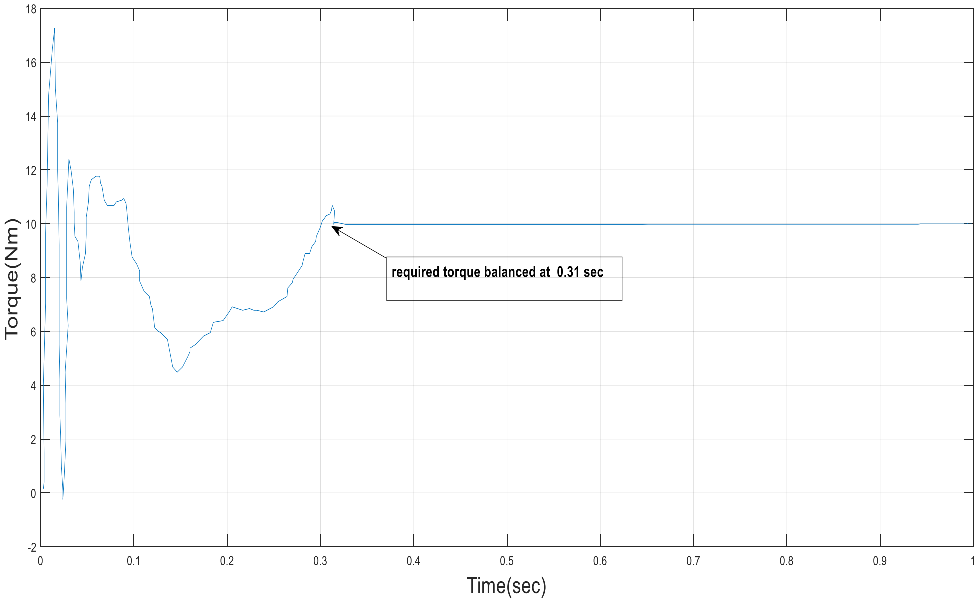

Figure 10: The Torque Variation of the Induction Motor Under Pulse Width Modulation Control for the Case of the Setpoint Speed at the Rated Speed of 2830rpm and Loaded with Rated Torque of 10nm

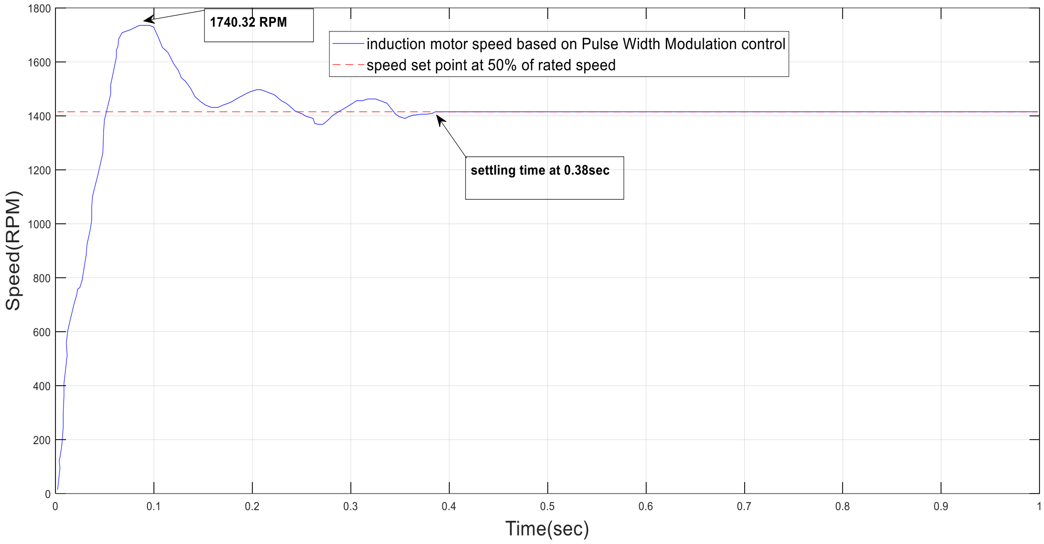

Figure 11: The Speed Trajectory of the Induction Motor Under Pulse Width Modulation Control for the Case of the Setpoint Speed at 50% of the Rated Speed and Loaded with 50% of Rated Torque of 10nm

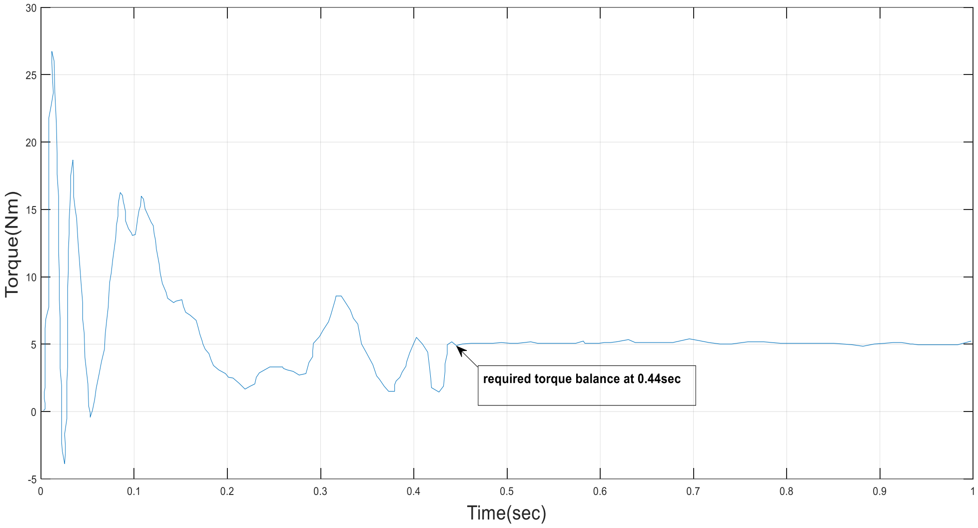

Figure 12: The Torque Variation of the Induction Motor Under Pulse WiDth Modulation Control for the Case of the Setpoint Speed at 50% of the Rated Speed and Loaded with 50% of Rated Torque

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