Three-Phase Variable Speed Drive using ARM Cortex-M3

Muhamad Aiman Muhamad Azmi, Hamdan Daniyal, Mohd Shafie Bakar, Abu Zaharin Ahmad

SuPER, FKEE, Universiti Malaysia Pahang, Malaysia
MEL13001@stdmail.ump.edu.my

Keywords: VSD, IM, Sine-PWM, V/Hz, Arduino DUE.

Abstract

This paper focuses on the design and development of variable speed drive (VSD) for induction machine (IM) application. The estimation of frequency or speed produced in the voltage source inverter (VSI) will express the reliability and the efficiency of the system. The usage of renowned ARM Cortex-M3 processor embedded in Arduino DUE is selected as a controller for easy implementation and minimal computational power. The sinusoidal pulse width modulation (Sine-PWM) technique is used to drive the VSD with constant torque configuration to analyze the variation of speed towards the performance of the IM system. The experimental verification was conducted in open loop Volts per Hertz control (V/F).

1 Introduction

As the increased renewable energy penetration nowadays, the potential of the power electronic device development has rapidly expanded. Since most of renewable energy sources are dynamic in nature, the efficiency and performance of energy generation and drive mainly rely upon on the capability of the controller unit in the system used [1]. Most of the renewable energy technology applications are powered by an AC machine that has been replaced the DC machine. An extensive research for variable speed, variable frequency drive control technique for the AC machine drive technology such as IM become essential [2,3]. There are several types of inverter topology that have been applied to the VSD system design classified with a number of phases, power of the switching device, commutation of the fundamental machine, the drive of the switching scheme (PWM) and the output waveform generated [4]. This paper highlighted the implementation of the controller using the common SPWM technique to generate the gating signal for the 2-level 3-phase VSD using the 32-bit ARM Cortex- M3 processor embedded in the Arduino DUE board. The target three PWM signals will have fixed switching frequency with 120° phase shifted among each other, in compliance with the mathematical equation of three-phase voltage. The desired frequency input is adjusted by using a potentiometer towards the Arduino DUE will change the speed of the IM application. The adjustable supply frequency is directly proportional towards the synchronous speed of the IM expressed the VSD design system employment even for below or above the nominal full speed rated required. The V/Hz control of IM is introduced to fulfill the torque-speed curve.

2 Variable Speed Induction (Asynchronous) Machine Drive

Variable speed or frequency drive (VSD) of squirrel cage induction motor or machine (IM) becomes prominent. The VSD IM application may enhance the speed variation, heavy load inertia starting, high starting torque requirement, low starting current requirement with high efficiency even at low or above rated speed and high power factor utilization. However, the VSD applied could influence the overall system design, performance and reliability of the IM. Therefore, the VSD design must ensure the stability of the IM with operating point applied complies to the IM based on the load speed-torque curve while the motor voltage is limited to its nominal rated voltage and current produced at the variation of speed should be controlled [2,3]. This paper expresses the experimental verification with scalar control known as V/Hz profile with constant torque test condition on the 3-phase squirrel cage IM to observe the produced current and torque characteristic with the variation of the frequency based on the design of the VSD. Sine-PWM technique with open loop direct control realization on Arduino DUE is applied. Figure 1 shows a block diagram of VSI with Intelligent Power Module (IPM) used in the VSD IM drive system. The common 2-level 3-phase VSI topology is shown in the Figure 2. The six switches (IGBT) of any leg of the inverter (A+ an A-, + and B- or C+ and C-) are the PWM signal presented to the positive side of the IGBT is generated from the microcontroller while the negative side is the inverted PWM signal with dead band time implemented as a safety precaution to protect from the short-circuit occurred in the system that could damage the inverter.

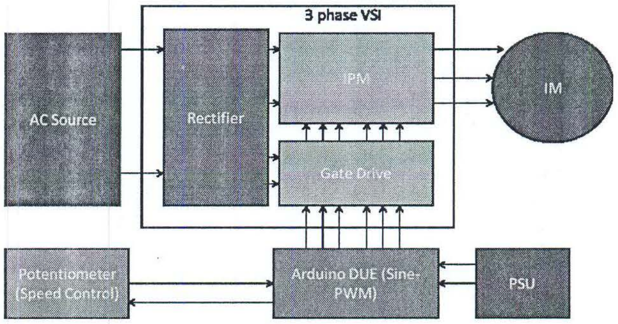

Figure 1: Block Diagram for IM VSD system

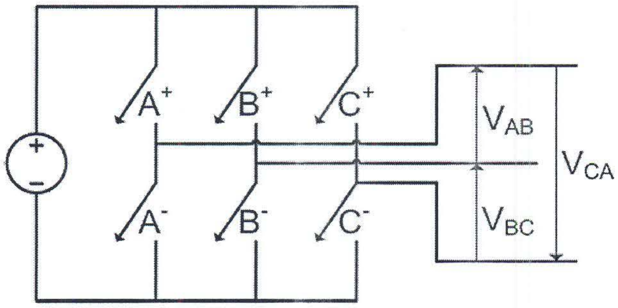

Figure 2: 2-level 3-phase VSI topology

TABLE 1. Arduino DUE specification summary

Microcontroller	AT91SAM3X8E
Operating Voltage	3.3V
Digital I/O Pins	54 (of which 12 provide PWM output)
Analog Input Pins	12
Analog Outputs Pins	2 (DAC)
Flash Memory	512 KB
SRAM	96 KB
Clock Speed	84 MHz

3 Scalar Control (V/F)

In 3-phase IM, the speed motor can be controlled by varying the frequency of the induction machine. The basic control method for 3-phase squirrel cage IM is scalar control knows as Volts per Hertz (V/F) ratio. It denotes that the torque produced in the IM is directly proportional towards the magnetic field in the stator winding. Equation 1, shows that the Volts per Hertz affect the magnetizing flux produced in the IM can be kept constant by varying the ratio. This paper presents 3.5 V/F ratio employed in the VSD system to generate constant torque with variable speed control. The 20% of base speed is selected as the maximum frequency range with supply voltage of 240 Vac presented in the experiment [2,3,5]. The current produced is kept constantly to verify the VSD requirement.

$$\text{Stator Voltage (V)} \propto [\text{Stator Flux } (\phi)] \times [\text{Angular Velocity } (\omega)] \quad (1)$$
$$V \propto \phi \times 2\pi f$$
$$\phi \propto V/f$$

4 Arduino DUE

ARM known as an Advance Reduced Instructed Set Computing (RISC) Microprocessor makes the programming code become simplified. ARM provides a three main profile architecture component as their initial where "A" stand for application target, "R" stand for real-time application and "M" for microcontroller technology. The ARM Cortex-M3 processor is a 32-bit microcontroller that offers a small size, low cost and ultra-low-power processor without sacrificing the performance and efficiency required. Arduino platform as an open source integrated development environment (IDE) features, encourage many research with a multi discipline background to design and develop their system using the Arduino board application [6,7]. Therefore, Arduino DUE evaluation board microcontroller based on the ARM Cortex M-3 processor is selected to perform the necessary programming application in this paper to drive the 3-phase VSD system. The Arduino DUE specification summary is shown in Table 1.

5 Sinusoidal Modulated PWM

There are many PWM techniques that have been developed for the VSI based application such as a square wave PWM, Sine-PWM carrier based, Selective Harmonic Elimination (SHE) PWM, Third Harmonic Injection PWM, Space Vector PWM and etc [8,9]. This paper highlighted the Sine-PWM technique as the code writing is easy to be implemented by using the Arduino DUE to generate the target sinusoidal waveform towards the VSI with varying frequency of the fundamental signal. The high switching frequency will sampling the reference signal in the look-up table to represent the duty cycle of the PWM gating signal for the VSD. The sinusoidal representation is defined as equation 2 and the specification of the design principle is based on the Table 2. The analog-to-digital converter (ADC) is 10-bit or varying value from (0 to 1023) need to be converted to the following equation 3 as the delay angle for duty cycle from time execution is exercised to generate the variation of the fundamental frequency in the look-up table to be defined in the Arduino programming. Maximum fundamental value of the sinusoidal signal in array table corresponds to the input of the ADC feed the change of voltage in potentiometer towards the Arduino DUE board. The expected waveform for sine-PWM is shown in Figure 3. The 3-phase shifted waveform generated from this driving scheme validate the 2-level 3-phase VSI topology. Furthermore, the comparative value of the amplitude of the carrier signal and fundamental signal can be denoted as modulation index which controlled the output voltage.

$$Va(t) = Vm \sin(\omega t) \quad (2)$$
$$Vb(t) = Vm \sin(\omega t - 120^\circ)$$
$$Vc(t) = Vm \sin(\omega t + 120^\circ)$$

$$\text{ADC Value} = \text{Analog input} * (\text{Maximum Fundamental value}) / 1023 \quad (3)$$
$$\text{Desired Frequency} = 1 / (\text{ADC value in } \mu s) * 360$$

TABLE 2. VSD design specification

Switching Frequency	5 kHz
No. of Sine Table Sample	360
Amplitude of Sine Sample	4095
Amplitude of Carrier Signal	12-bit
Amplitude of ADC	10-bit
Amplitude of DAC	12-bit
Minimum Fundamental Signal	8 Hz
Maximum Fundamental Signal	80 Hz

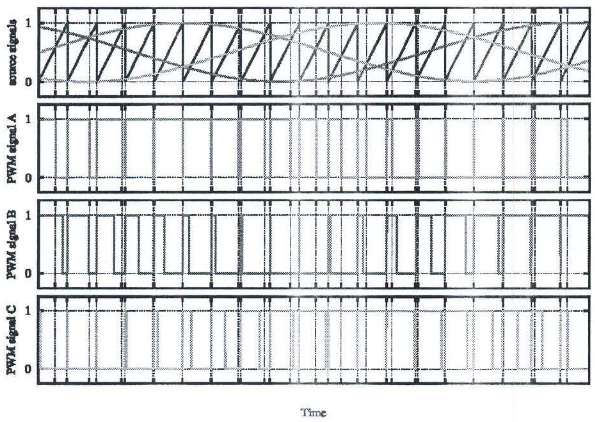

Figure 3: Three-Phase PWM gating signal waveform

6 Experimental Result and Discussion

The result from the Arduino DUE board towards the VSD IM system designed is presented in this section where the digital implementation generated from Arduino DUE display the sinusoidal behavior in the digital-to-analog converter (DAC) pin waveform. Figure 4 shows the test bench for the system and Figure 5 show the 3-phase squirrel cage induction machine nameplate. The experimental result waveform acquired is shown in Figure 6 and 7 respectively.

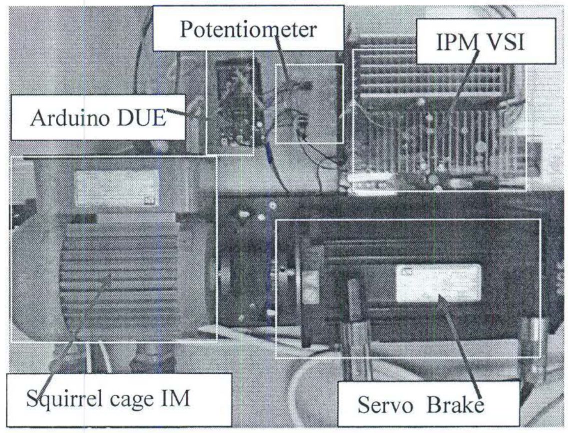

Figure 4: The experimental setup for the VSD system

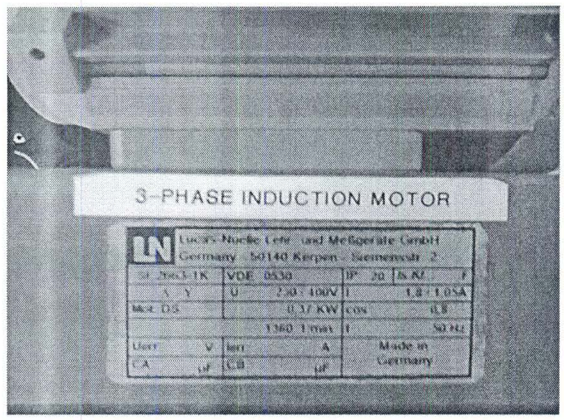

Figure 5: 3-Phase Induction Motor Nameplate.

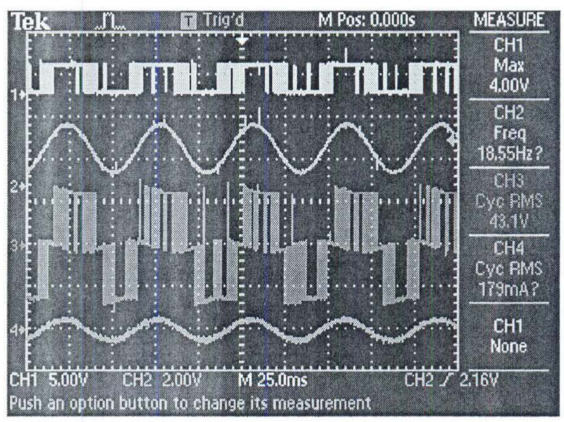

Figure 6: PWM waveform (CH1), DAC output (CH2), Phase Voltage AB (line-line) (CH3) and Current waveform (CH4) for Phase A of IM.

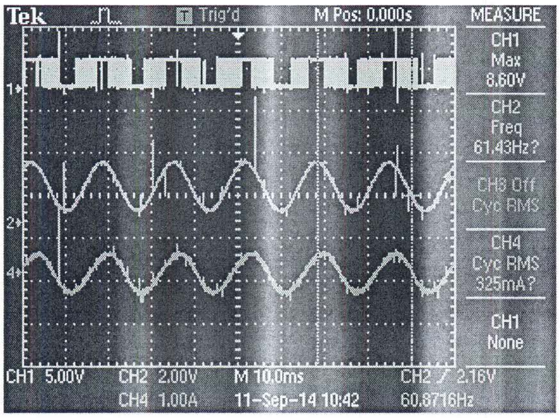

Figure 7: PWM waveform (CH1), DAC output (CH2), and Current waveform (CH4) for Phase A of IM at 60 Hz.

From the Figure 6, the driving scheme of the sine-PWM technique generated towards the targeted VSD system using the Arduino DUE is presented. The VSD system operates at above the nominal speed value or in the field weakening operation can generate a significant of current induced in the machine. The current output of the motor can generate excessive heat as result from over-current produce in the coil could reduce the lifetime of the IM indicate the reliability of the system designed.The current obtained from the Figure 7 shows that minimal differences between the reference sinusoidal signal and the actual signal value in the experimental result. This validate the efficiency of the system designed. Table 3 presents the VSD IM characteristic result obtain from the V/F ratio for the torque, current and speed generated. The current induced in the machine is kept constant same with the torque in accordance with the V/F ratio. The data result expresses that the VSD IM implementation in constant torque variable speed can be applied in the system is verified.

TABLE 3. Experimental results for 3.5 V/F ratio

V/f ratio	Torque (N-m)	Vs (V)	Fs (Hz)	Speed (RPM)	Current I (A)
3.5	0.2	70	20	430	292m
3.5	0.2	87.5	25	615.2	298m
3.5	0.2	105	30	776.6	298m
3.5	0.2	122.5	35	919.5	300m
3.5	0.2	140	40	1093	303m
3.5	0.2	157.5	45	1253	297m
3.5	0.2	175	50	1402	298m
3.5	0.2	192.5	55	1550	303m
3.5	0.2	210	60	1710	310m

7 Conclusion

The Arduino DUE provides a simplified programming code that eases the computing requirement and reduces time execution while keeping the performance and efficiency of the system. The verified result of a VSD IM system using Sine-PWM technique provides an essential knowledge of the IM characteristic for constant torque variable frequency The VSD IM system satisfied the standard reliability requirement based from the current produced in the machine. As for the possible further research are towards full-load test and the space vector PWM (SVPWM) technique, perhaps for motor control application is highly recommended as the implemented using the microcontroller gives more DC bus utilization compared to the Sine-PWM in 3-phase VSI system to analyze the performance capability for the system design.

Acknowledgements

Gratitude towards financial assist of the research grant RDU130607 from Universiti Malaysia Pahang. The research is conducted in the Sustainable Energy and Power Electronics Research (SuPER) Laboratory in Fakulti Kejuruteraan Elektrik & Elektronik, UMP Pekan.

References

[1] M. B. Everett, and R.P Joseph, "Convert your home to solar energy". USA, The Taunton Press, (2010).

[2] Bahram Amin. "Induction Motors Analysis and Torque Control". Springer, pp. 12-64, (2001).

[3] R. Krishnan, "Electric Motor Drives (Modeling, Analysis, and Control)". Prentice Hall, Inc. (2001).

[4] Holmes, D Grahame, Lipo Thomas "A. Pulse width modulation for power Converters". USA: IEEE Press, (2003).

[5] M. S. Aspalli, Asha.R, P. V. Hunagund, "Three Phase Induction Motor Drive Using IGBTs and Constant V/F Method". International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 1, Issue 5, Nov. 2012.

[6] Website: www.arduino.cc

[7] J. Yiu, "The Definitive Guide to ARM Cortex-M0". USA, Elsevier Science, (2011).

[8] Jacobina CB, Nogueira AM, Cabral ER, Cunha RN, Seixas PF. "Digital scalar pulse-width modulation: a simple approach to introduce non sinusoidal modulating waveforms". IEEE Trans Power Electron, (2011).

[9] Bin Wu. "High-power converters and AC drives". IEEE Wiley Press, (2006).