REAL TIME MONITORING AND CONTROL OF WATER PUMP SYSTEM

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ABSTRACT

Common machine is used in industries to transfer liquid is a centrifugal pump that uses an induction motor as a driver. The unexpected error of the machine is the main cause of loss due to cessation of production, and extra cost will be needed for repair and replacement of damaged parts. Therefore, required a system that can monitor and control the machine to know the conditions and avoid the damage of the system. Hence, the objective of this work includes design and development of SCADA based remote control and real-time monitoring of water-pump systems, it is composed of two parts, the first part is motor control and the second part is monitoring systems that implement the IEC 60870-5-101 standard protocol.

This work presents the design and development of water pump monitoring system that uses 3-phase induction motor. Inverter and motor control are designed to run and control the speed of the motor and communicate with the SCADA system. SCADA system is used as monitoring system and process control of fault detection and isolation (FID)**.** The proposed motors control for 3 phase induction motors used space vector pulse width modulation strategy (SVPWM). The v/f strategy (Volt/Hz Control) is used to control the induction motor speed because of its simplicity. The motor control unit drives the motor via an inverter switched by DSP (TMS320F2812). On monitoring side, SCADA has three main parts, namely a remote terminal unit (RTU), the master system, and communication system. RTU collects all the data and make the execution of a command, the master of the proposed system is a software application GUI for water pumping systems according to IEC 60870-5-101 via visual basic.net are low-cost and user-friendly, and the communication system used is the RS232 and RS422 serial communication with the IEC 101 standard protocol.

In this work, the implementation of SCADA system in remote and water-pump monitoring system based on IEC 6870-5-101 has been implemented. The average error between oscilloscope measurement and SCADA system was found to be 1.81%. It can be concluded that the SCADA system with IEC 60870-5-101 standard protocol could be implemented on real time monitoring and remote control of water-pump systems.

ABSTRAK

Mesin yang biasa digunakan dalam industri untuk memindahkan cecair adalah pam sentrifugal yang menggunakan motor induksi sebagai pemacu. Kerosakan yang tidak dijangka pada mesin boleh mengakibatkan kehilangan kos disebabkan oleh gangguan dalam proses, dan kos tambahan berlaku untuk tujuan pembaikan dan tujuan penggantian. Oleh itu, diperlukan sistem yang boleh memantau dan mengawal mesin untuk mengetahui keadaan dan mengelakkan kerosakan sistem. Maka, objektif kerja ini merangkumi reka bentuk dan pembangunan kawalan jarak jauh berasaskan SCADA dan pemantauan masa nyata sistem pam air. ianya terdiri daripada dua bahagian, bahagian pertama adalah pengawal motor dan bahagian kedua ialah sistem pemantauan yang berasaskan protokol piawai IEC 60870-5-101.

kerja ini membentangkan reka bentuk dan pembangunan sistem pemantauan pam air yang menggunakan motor teraruh 3-fasa. Penyongsang dan pengawal motor direka bentuk untuk menjalankan dan mengawal kelajuan motor serta berinteraksi dengan sistem SCADA. Sistem SCADA berfungsi sebagai pemantau sistem dan melaksanakan proses untuk mengesan dan mengasingkan kerosakan, supaya tidak ada kerosakan pada komponen dan bahagian-bahagian lain. Kawalan motor yang dicadangkan adalah menggunakan teknik novel vektor ruang modulasi lebar denyut (SVPWM) untuk mengoptimumkan kuasa. Strategi novel v/f (Volt/Hz Kawalan) digunakan untuk mengawal kelajuan motor aruhan kerana keringkasan. Unit kawalan motor memacu motor melalui penyongsang yang dihidupkan oleh DSP (TMS320F2812). Dari segi pemantauan, SCADA mempunyai tiga bahagian utama, iaitu satu unit terminal jauh (RTU), sistem induk, dan sistem komunikasi. RTU mengumpul semua data dan membuat pelaksanaan perintah, induk sistem yang dicadangkan adalah aplikasi perisian GUI untuk sistem pam air mengikut IEC 60870-5-

101 melalui visual basic 2008, ia berkos rendah dan mesra pengguna, dan sistem komunikasi yang digunakan adalah komunikasi bersiri RS232 dan RS422.

Dalam kerja ini, pelaksanaan sistem SCADA pada kawalan sistem dan pemantauan pam air berasaskan IEC 60870-5-101 telah berjaya dibina. Julat ralat purata antara pengukur osiloskop dan sistem SCADA adalah sebanyak 1.81%. Ini dapat disimpulkan bahawa sistem SCADA ini dengan protokol piawai IEC 60870-5-101 boleh dilaksanakan pada sistem pengkawalan dan pemantauan pam air jarak jauh .

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LIST OF ABBREVIATIONS

AC	:	Alternating Current
ADC	:	Analog Digital Converter
CT	:	Current Transformer
CTA	:	Constant Torque Angle
DAC	:	Digital Analog Converter
DC	:	Direct Current
DMC	:	Digital Motor Control
DSP	:	Digital Signal Processor
DTC	:	Direct Torque Control
emf	:	electromotive force
EMI	:	Electromagnetic Interference
IEC	:	International Electro-technical Commission
IGBT	:	Insulated Gate Bipolar Transistor
PI	:	Proportional Integrator
PC	:	Personal Computer
PSU	:	Power Supply Unit

QEP	:	Quadrature Encoder Pulse
RFI	:	Radio Frequency Interference
SCADA	:	Supervisory Control And Data Acquisition
SCC	:	Signal Conditioning Circuit
SVM	:	Space Vector Modulator
SVPWM	:	Space Vector Pulse Width Modulation
VRC	:	Voltage Reconstruction Calculator
VSD	:	Variable Speed Drives
VSI	:	Voltage Source Inverter

LIST OF SYMBOLS

μ_r	:	Relative permeability of material
B	:	Viscous coefficient of the motor
$e_{d,q}$	:	dq-axis cross-coupling term
f_s	:	Stator frequency
G	:	Gain
$i_{a,b}$	:	Stator currents
$i_{d,q}$	:	dq-axis stator currents
$i_s = i_{\alpha,\beta}$	:	$\alpha\beta$-axis stator currents
J	:	Total moment inertia of the motor
$L_{d,q}$	:	dq-axis inductances
M	:	Modulation index
P	:	Number of poles
p	:	Number of poles pair
R_s	:	Stator resistance
s	:	Derivation (*d/dt)*
$S_{a,b,c}$	:	Switching signal of SVM
T_e	:	Electromagnetic torque
T_L	:	Load torque

T_m	:	Permanent magnet torque
T_r	:	Reluctance torque
T_s	:	Time sampling
$v_{d,q}$	:	dq-axis stator voltages
v_{dc}	:	DC-link voltage
$v_s = v_{\alpha,\beta}$	:	$\alpha\beta$-axis stator voltages
$\lambda_{d,q}$	:	dq-axis stator flux linkages
$\lambda_{d,q}$	:	dq-axis stator flux linkages
ω_e	:	Electrical angular speed
$\omega_{m\ ref}$	:	Mechanical angular speed reference
ω_m*	:	Estimated mechanical angular speed

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CHAPTER 1: INTRODUCTION

1.1 Background

Most of the energy used in the industry is for running the machine. One of the most widely used machines is the induction motor. Centrifugal pump is one that makes the induction motor as a drive. This pump commonly used in industries like; oil and gas, pulp and paper, and mining, etc. (Ahonen, Tamminen, Ahola, & Kestila, 2012; Kini, Bansal, & Aithal, 2008; Stopa, Cardoso Filho, & Martinez, 2014).

The unexpected error of the machine is the main cause of loss due to cessation of production, and extra cost will be needed for repair and replacement of damaged parts. (Kallesoe, Izaili-Zamanabadi, Rasmussen, & Cocquempot, 2004; Soylemezoglu, Jagannathan, & Saygin, 2011; Wolfram, Fussel, Brune, & Isermann, 2001). Therefore, to avoid further damage needed a system that could monitor, detect and protect the occurrence of this failure's damage (Kallesoe, Cocquempot, & Izadi-Zamanabadi, 2006; Soylemezoglu et al., 2011; Stopa et al., 2014).

The sustainable systems require a monitoring system when operating for maintainability and stability purposes. With the existence of this monitoring system, the user will understand the state of the system based on data and events sent to the user. Several types of issues in monitoring system can be classified as follows; detection of fault, response feedback, and performance (Kacur, Laciak, & Durdan, 2011; Schlechtingen & Santos, 2014; Seera, Lim, Nahavandi, & Loo, 2014; Xiangjun, Dong, & Liang, 2013).

Supervisory Control and Data Acquisition (SCADA) is becoming the standard for industrial control and monitoring systems.(Holmes, Russell, & Allen, 2013; Morsi & El-Din, 2014). SCADA systems are used to monitor, control, and save the information about quantity and quality of water at pump stations, water treatment plant, reservoirs and distribution networks in water resource management in big cities.(Dolatshahi-Zand & Khalili-Damghani, 2015). The advantage of SCADA is monitoring and controlling remotely. Hence, a communication system that is structured and reliable is required to maintain stability of SCADA system (Parker & Chadwick, 2011; Schlechtingen & Santos, 2014).

Among the notable works that used SCADA system for monitoring induction motor is Aydogmus et.al (2009). Aydogmus et.al (2009) developed a PLC-based structure to control the system and used an induction motor to validate the system (Aydogmus & Aydogmus, 2009). Meanwhile for the motor drive, it has own controller. The parameters were setup by using the PLC and it has controlled through a GUI on a PC via the SCADA System.

Gonzalez et.al (2011) has constructed a three-phase induction motor with data acquisition and control by using user interface. USB and Ethernet protocols have been put into operation in the user front-end because a high-speed sample frequency is required in order to guarantee the real-time operation of the whole system. A software interface is developed using LabVIEW environment enabling features as filtering voltage, current and power spectrum measurements. Vector-controlled drive is programmed on a digital signal processor (DSP) in order to ensure efficient use of energy in the power stage and proper tracking of the reference at low and high speeds(Gonzalez-Gutierrez et al., 2011).

Work performed by Aydogmus et.al (2009) and Gonzales et.al (2011) are equally perform remote monitoring of induction motor. However, both have different monitoring techniques. Gonzales perform motor drive, remote and monitoring in a single controller is a DSP, while for three-phase induction motors require rapid controller in generating SVPWM and speed control. The SVPWM signal generated could be disrupted if all the work is given to the DSP. Aydogmus et.al (2009) have separated the control and monitoring of induction motors. PLC was used for controlling and SCADA for monitoring. Both of the systems above showed the necessity of separated between the motor drive and remote monitoring of three-phase induction motor to be more effective and efficient. Therefore, it is necessary to separate the motor drive and remote monitoring of three-phase induction motor in a water pump system. One of communication standard protocol for telemetry and telecontrol widely used in industry is IEC 60870-5-101. Compared with the previous circular protocols, it has more powerful function and more efficient (Zhang, Liu, Yang, & Shen, 2010). There are scarcity studies that use SCADA system in real-time monitoring of motor driver and water pump system plant. Hence, it is crucial to develop and validate SCADA implementation in remote control and real-time monitoring of water pump systems based on IEC 60870-5-101 standard protocol.

1.2 Problem Statement

Common machine is used in industries to transfer liquid is a centrifugal pump that uses an induction motor as a driver. The unexpected error of the machine is the main cause of loss due to cessation of production, and extra cost will be needed for repair and replacement of damaged parts. Therefore, required a system that can monitor and control the machine to know the conditions and avoid the damage of the system. Hence, the objective of this work includes design and development of SCADA based remote control and real-time monitoring of water-pump systems, it is composed of two parts, the first part is motor control and the second part is monitoring systems that implement the IEC 60870-5-101 standard protocol. This system would help engineer to monitor and control of motor pump (driver) and water level (plant) thus the data obtained can be used as a reference for perfect and complete in determining the condition of the water pumping system.

1.3 Objectives of Research

The objectives of this study are:

1. To develop hardware and embedded system for 3-phase Induction motor water pump drives.
2. To develop SCADA Master System Application software for Central Supervisory Station via Visual Basic.net based on IEC 60870-5-101 Standard Protocol.
3. To validate SCADA implementation in remote control and real-time monitoring of water pump systems based on IEC 60870-5-101 standard protocol.

1.4 Significant of Study

This work will be advantage as it has several contributions. For industrial purpose, this motor driver can be used to drives induction motor (Pentax Centrifugal Pump 750 W) and this driver also can integrate with remote terminal unit I/O port (part of SCADA system). Therefore, it will be help engineer to monitor condition of motor and plant (water-pump system). The PC-Based software is design and develops for monitoring and control of motor pump (driver) and water level (plant) based on IEC 60870-5-101 standard protocol. So, this system can monitor not only plant level, but also for driver. The software that uses the IEC 101 standard protocol will suitable for all equipment.

1.5 Scope of Study

The scope of this study is the implementation of SCADA in remote control and real-time monitoring of water pump systems based on IEC 60870-5-101 standard protocol.

1.6 Methodology of Research

1. Design and development of hardware for motor drives

There are two main part in the motor drives system: high-voltage part and low-voltage part. The high-voltage part is a three-phase inverter, while the low-voltage side consists of DSP controller, gate drives circuit, and sensors.

2. Firmware development

The algorithm for a three-phase inverter is programmed into DSP controller. The controller will produce signal control for drive IGBTs. SVPWM, PI Control and V/Hz strategy is embedded in this firmware.

3. Hardware and firmware integration

Before integration with hardware, the signal generated by DSP will be previewed by using oscilloscope. Then, hardware is connected to DSP controller. After all connections are installed properly, turn on the power supply and then check the signal on the IGBT first. If the signal looks good, then connect this motor drive to the three-phase induction motor. If the motor rotates, its mean the integration process is ready.

4. Testing and measurement

The actual operating condition and real-time response can be obtained through experimental where testing and measurement should be carried out. The measurement requires high-speed equipment that can capture the actual response during the transient period as well as isolated channel inputs, which enable every point on the circuit to be tested and functioning appropriately.

5. SCADA configuration and setting

At this stage, the SCADA topology is designed to fit the system. After that, setup and configuration RTUs. Make sure the number of IO to be used and store its address point for later use in the software.

6. GUI development

The GUI is developed by using Visual Studio.Net. This master system is developed based on IEC 60870-5-101 standard protocol. The GUI functions as monitoring and control system.

7. System integration

All parts consisting of SCADA and a water pump system are installed. The tank is filled with water. Then, the sensors are installed in the motor drives and in the water-pump plant.

8. System Testing and measurement

The software connected to RTUs, and RTU collect data from motor drives and water-pump plant. It is tested to monitor and control the system. The outputs of the software are data and graph.

9. System validation

To validate the system works properly, benchmarking with a calibrated measuring instrument (oscilloscope) is needed. Then, compare the average error between the two by using the conventional statistical model.

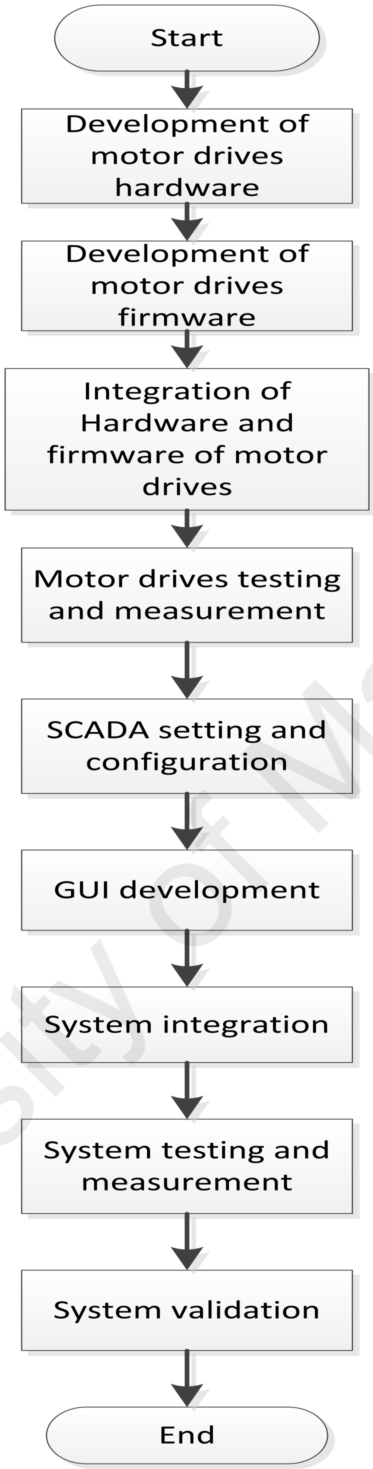


Figure 1.1 Flowchart of Methodology

1.7 Dissertation Organization

The dissertation was organized into five chapters and organized as follows:

Chapter 1 gives an introduction of the thesis and includes a brief background of the research, research scope and objectives, and significant of the study

Chapter 2 contains the literature review of the research. In this chapter, describes a general overview of theory about induction motor drives, control and centrifugal pump. This chapter also describes about SCADA system and IEC 60870-5-101 standard protocol. In this chapter describes: fundamental of SCADA system, SCADA topology, remote terminal unit (RTU) and fundamental of IEC 60870-5-101 standard protocol.

Chapter 3 explains about methodology. This chapter focusing on design and development of the system for remote control and real-time monitoring of water pump systems via SCADA system based on IEC 60870-5-101 standard protocol.

Chapter 4 focusing on results obtained from the system. Discussions on data obtained are further explained in this chapter. In this research, data obtained are displayed in Oscilloscope and SCADA-based to enable other user to monitor the results. Furthermore, calculations on system uncertainty analysis are stated in this chapter.

Chapter 5 states the conclusion of the research. The advantages of SCADA-based remote and monitoring of water-pump system are discussed in this chapter. In addition, future recommendations are also included in this chapter in order to enhance and improve any imperfection of this research.

CHAPTER 2: LITERATURE REVIEW

2.1 Induction Motor Drives, and centrifugal Pump

The largest consumer of electricity energy consumption is spent to meet the needs in the industrial sector. Over 60% of the total energy is being utilized by motor drives, and particularly by three-phase induction motor-driven systems. In general, most consumption of electrical energy among motor-driven systems is used for pumping applications. Pump systems are predominantly used in the domestic, commercial, agricultural and industrial contexts for water pumping, municipal utilities for wastewater transport and many specialized industrial sectors for fluid transportation. Among the various types available, centrifugal pumps are widely used for their versatility in the field of pumping liquids (Kini et al., 2008). In this chapter are described on the motor drive for 3 phase induction motors, also explained about centrifugal pumps.

2.1.1 Induction Motor Description

A three-phase induction motor has two main parts: a stationary stator, and a revolving rotor. The stationary stator is a steel frame that supports a hollow cylindrical core. The revolving rotor is punched laminations, stacked to create a series of rotor slots and to provide space for rotor winding. Two types of revolving rotor exist, different in their construction and application (Bose, 1996; Filippich, 2002). Wound rotor terminals are connected to insulated slip- rings mounted on a shaft, and used in special applications. Whereas, squirrel-cage rotor comprises bare aluminum bars short-circuited by welding on two aluminum end-rings. Its simplicity and robustness make it more popular than wound rotor, which is more expensive and less reliable than its squirrel-cage equivalent. This work thus uses a squirrel-cage motor.

An induction motor runs when voltage is applied to its stator windings, which induces voltage in the rotor windings. The rotor currents produce air-gap flux that rotates at synchronous speed. The stator and the rotor field each rotates synchronously, so they are stationary relative to each other and produce a steady torque, maintaining rotation of the motor (A. E Fitzgerald, 2003).

The difference between induction-motor's synchronous speed n_s and rotor speed n is commonly referred to rotor slip. Slip s is more usually expressed as a fraction of synchronous speed. Fractional slip is:

$$s = \frac{n_s - n}{n_s} \tag{2.1}$$

Rotor speed is thus:

$$n = (1 - s)\, n_s \tag{2.2}$$

Mechanical angular velocity ω_m can be expressed in terms of synchronous angular velocity ω_s and slip s;

$$\omega_m = (1 - s)\, \omega_s \tag{2.3}$$

Relative motions of stator flux and rotor conductors induce voltage of frequency f_r;

$$f_r = s f_s \tag{2.4}$$

Correlation of f_s to n_s is;

$$n_s = \frac{120\, f_s}{P}\, rpm \tag{2.5}$$

2.1.2 Induction-Motor Equivalent Circuit

The equivalent circuit of induction-motor can be seen from the figure below:

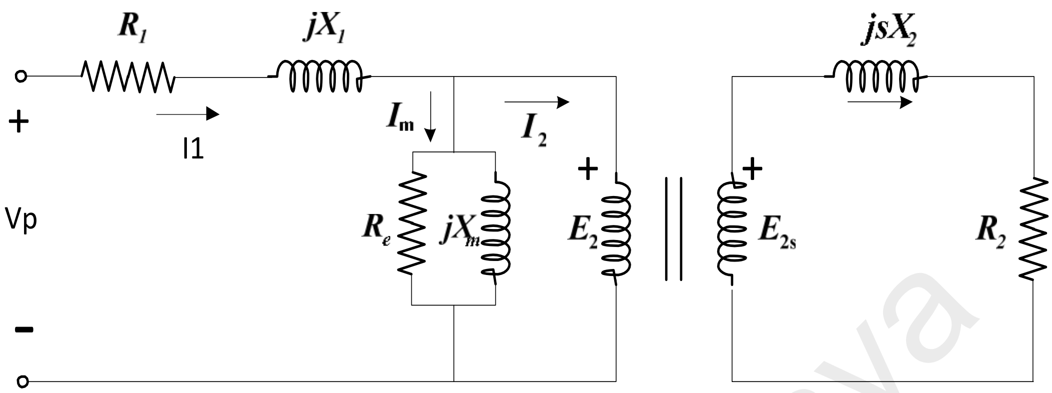


Figure 2.1: Induction-motor equivalent circuit

The induction motor equivalent circuit in Figure 2.1 consists of two circuits that isolated and like transformer equivalent circuit. The left-side circuit is a stator equivalent circuit composed of stator leakage reactance (X_1), stator effective resistance (R_1), core loss resistance (R_e), and magnetizing reactance (X_m). V_p is stator line to neutral terminal voltage, I_1 is stator current, I_2 is rotor current, and I_m is magnetizing current. The right-side circuit is rotor equivalent circuit composed of rotor leakage reactance at slip frequency (sX_2), and rotor resistance (R_2). E_{2s} is voltage induced in the equivalent rotor by the resultant air-gap flux, and I_{2s} is the corresponding induced cı

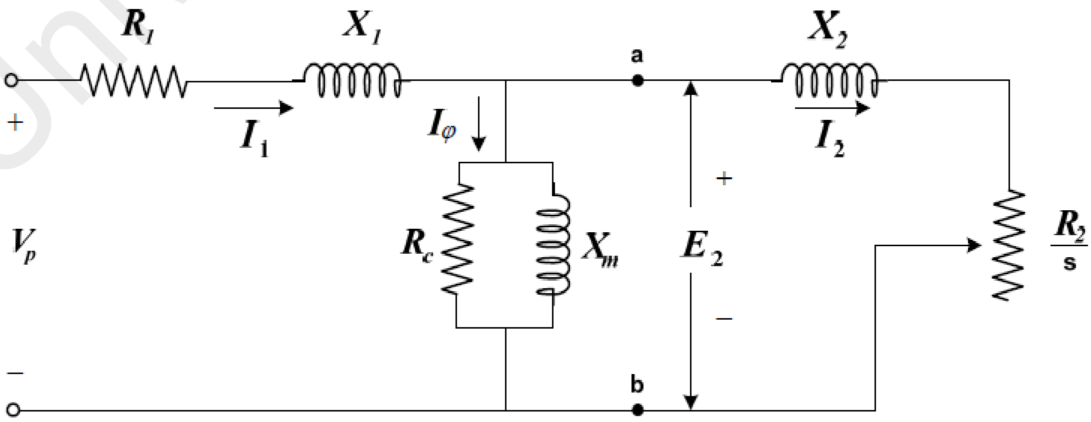


Figure 2.2: Single-phase induction-motor equivalent circuit

Figure 2.2 shows the stator and the rotor circuits in single-phase equivalent circuit. The circuit can be used to determine various steady-state-performance characteristics of induction machines, referring to (A. E Fitzgerald, 2003), total power P_{gap} transferred across air-gap from stator is,

$$P_{gap} = n_{ph}\, I_1^2 \left(\frac{R_2}{s}\right) \tag{2.6}$$

Where n_{ph} is number of stator phase,

And

$$P_{rotor} = n_{ph}\, I_{2s}^2 R_2 \tag{2.7}$$

If $I_{2s} = I_2$, then

$$P_{gap} = n_{ph}\, I_2^2 R_2 \tag{2.8}$$

Therefore,

$$P_{mech} = P_{gap} - P_{rotor} \tag{2.9}$$

$$P_{mech} = (1 - s)\, P_{gap} \tag{2.10}$$

And

$$P_{rotor} = sP_{gap} \tag{2.11}$$

While

$$P_{stator} = 3\, I_1^2\, R_1 \tag{2.12}$$

So,

$$P_{gap} = P_{input} - P_{stator} \tag{2.13}$$

The value of P_{mech} and mechanical angular velocity ω_m can be used to determine electromechanical (T_{mech});

$$T_{mech} = \frac{P_{mech}}{\omega_m} = \frac{P_{mech}}{(1-s)\omega_s} \tag{2.14}$$

Where mechanical angular velocity ω_m is;

$$\omega_m = \frac{4\pi f_e}{P} \tag{2.15}$$

While

$$P_{shaft} = P_{mech} - P_{rot} \tag{2.16}$$

And

$$T_{shaft} = \frac{P_{shaft}}{\omega_m} = T_{mech} - T_{rot} \tag{2.17}$$

Induction motor efficiency is thus

$$\eta = \frac{P_{shaft}}{P_{in}} \tag{2.18}$$

2.1.3 SVPWM Switching Technic for 3 Phase VSI

Several Pulse Width Modulation (PWM) techniques such as: Sinusoidal PWM (SPWM), Third Harmonics Injection PWM (THIPWM) and Space Vector PWM (SVPWM) can be implemented in VSI. However, the SVPWM is the most popular modulation technique among the others. It found widespread use in the industry in the early seventies (Neacsu, 2001). SVPWM offers some advantages such as: less-harmonics and effective utilization of the DC link voltage, 15% higher than SPWM (van der Broeck, Skudelny, & Stanke, 1988).

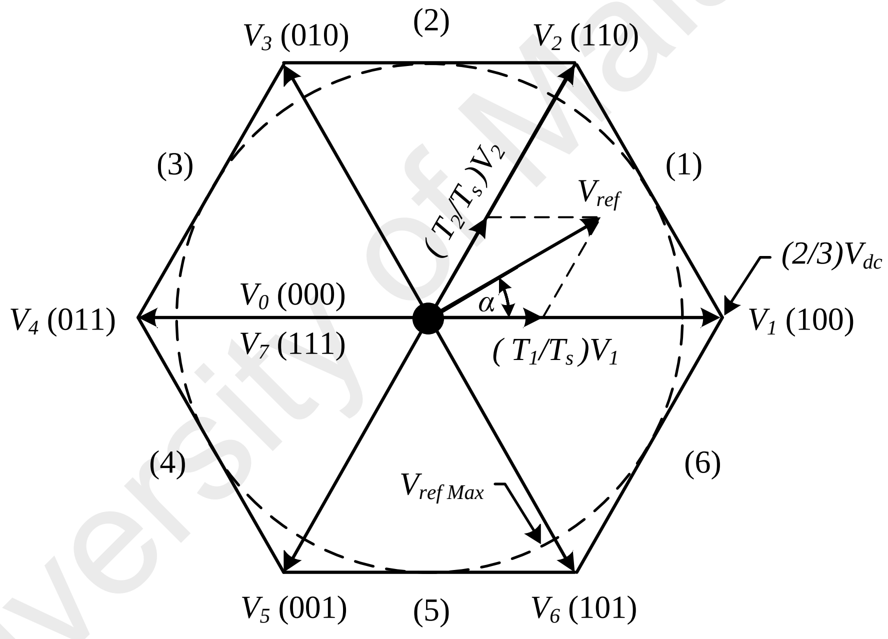


Figure 2.3: Space vectors diagram

The space vector diagram consists of six regions as shown in figure 2.3. There are three steps in the SVPWM process:

- $\alpha\beta$-axis voltage, reference voltage vector and angle calculation
- Time duration calculation
- Switching time determination of each switch

2.1.4 Determination of Switching Strategy of SVPWM for 3 Phase VSI Drive

(a) *Calculation of αβ-axis voltage, reference voltage vector and angle*

The *αβ*-axis voltage **(**V_α, V_β) is obtained from:

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{2.19}$$

The reference voltage vector as V_{ref} and angle (α) is calculated as given in (2.20) and (2.21), respectively:

$$\left|V_{ref}\right| = \sqrt{V_\alpha{}^2 + V_\beta{}^2} \tag{2.20}$$

$$\alpha = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) \tag{2.21}$$

Where maximum V_{ref} = $1/\sqrt{3}$ that is represented by the dash-circle line in Figure 2.3.

(b) *Time duration calculation*

Referring to Figure 2.4, the relationship between time durations (T_S) and voltages vector $\vec{V_n}$ in sector 1 is:

$$\vec{V_{ref}}\, T_S = \vec{V_1}\, T_1 + \vec{V_2}\, T_2 + \vec{V_0}\, T_0 \tag{2.22}$$

Where:

$$\begin{aligned}
\vec{V}_0 &= 0 \\
\vec{V}_1 &= \frac{2}{3} Vdc\, e^{0} \\
\vec{V}_2 &= \frac{2}{3} Vdc\, e^{j\pi/3} \\
\vec{V}_{ref} &= \left| V_{ref} \right| e^{j\alpha}
\end{aligned} \tag{2.23}$$

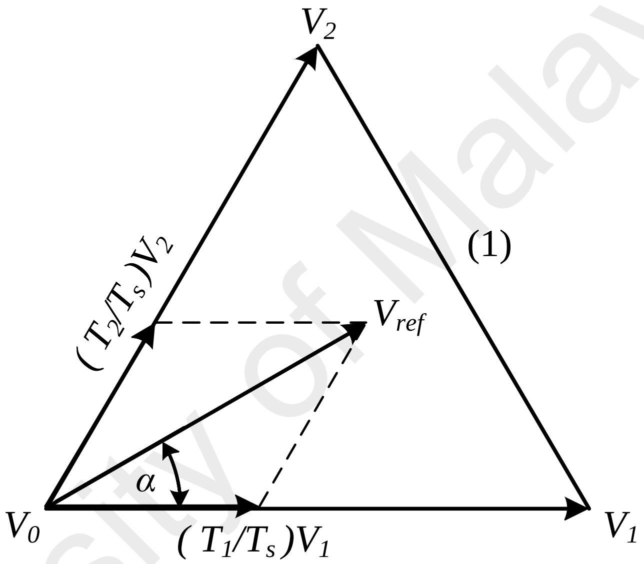


Figure 2.4: Sector 1 of space vector diagram

Substitution of the equation (2.22) and (2.23) yields time duration as given in:

$$T_1 = M\ T_S \frac{\sin\left(\frac{\pi}{3} - \alpha\right)}{\sin\left(\frac{\pi}{3}\right)} \tag{2.24}$$

$$T_2 = M\ T_S \frac{\sin(\alpha)}{\sin\left(\frac{\pi}{3}\right)} \tag{2.25}$$

Where:

$$T_S = 1/f_S$$

$$M = \frac{|V_{ref}|}{2/3 V_{dc}} \tag{2.26}$$

M = Modulation Index

Time duration for any sector n (1 to 6) is formulated as,

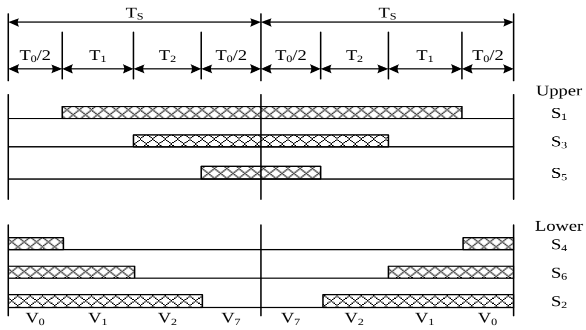
$$T_1 = \frac{\sqrt{3}\, T_S\, |V_{ref}|}{V_{dc}} \left(\sin \frac{n}{3}\pi \cos\alpha - \cos\frac{n}{3}\pi \sin\alpha \right) \tag{2.27}$$

$$T_2 = \frac{\sqrt{3}\, T_S\, |V_{ref}|}{V_{dc}} \left(-\cos\alpha \sin \frac{n-1}{3}\pi + \sin\alpha \cos\frac{n-1}{3}\pi \right) \tag{2.28}$$

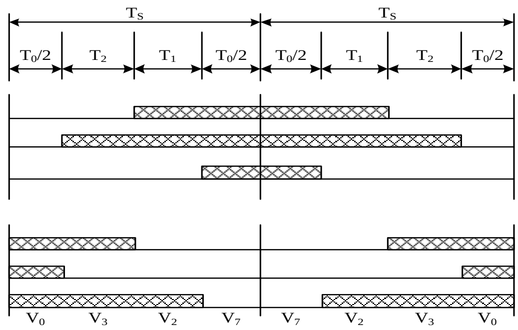
$$T_0 = T_S - (T_1 + T_2) \tag{2.29}$$

(c) *Switching time of each switches*

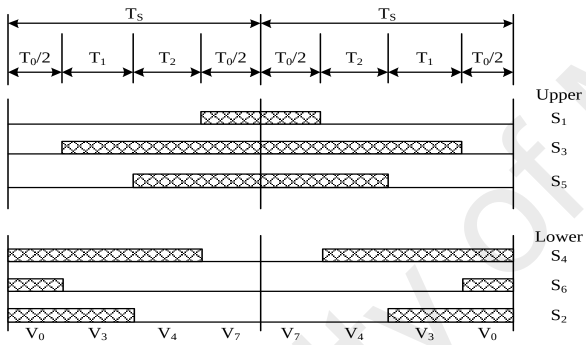
After obtaining the time duration in appropriate sector, the next step is determination of the switching time for each switch: upper (S1, S3 and S5) and lower (S2, S4 and S6) switches of VSI (Voltage source inverter as shown in Figure 2.6). The switching time can be summarized in Table 2.1 and its pattern is illustrated in Figure 2.5.



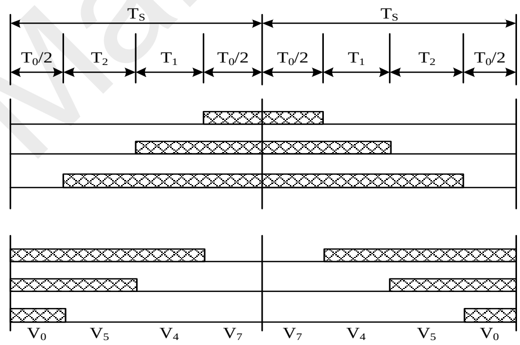
Sector 1 ($0^\circ \le \alpha \le 60^\circ$)



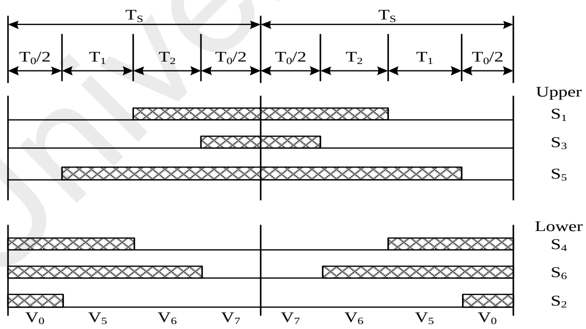
Sector 2 ($60^\circ \le \alpha \le 120^\circ$)



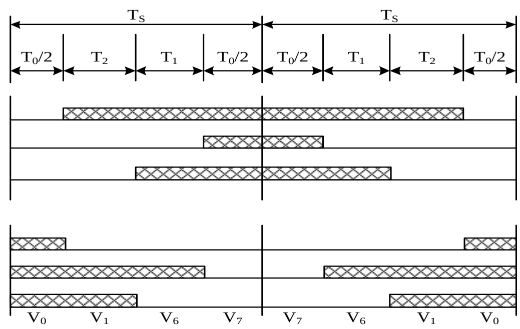
Sector 3 ($120^\circ \le \alpha \le 180^\circ$)



Sector 4 ($180^\circ \le \alpha \le 240^\circ$)



Sector 5 ($240^\circ \le \alpha \le 300^\circ$)



Sector 6 ($300^\circ \le \alpha \le 360^\circ$)

Figure 2.5: Switching pattern for each sectors – n

Table 2.1: Switching time calculation for different sectors

Sector	Upper switches	Lower switches
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_2 + T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_2 + T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_2 + T_0/2$ $S_2 = T_2 + T_0/2$

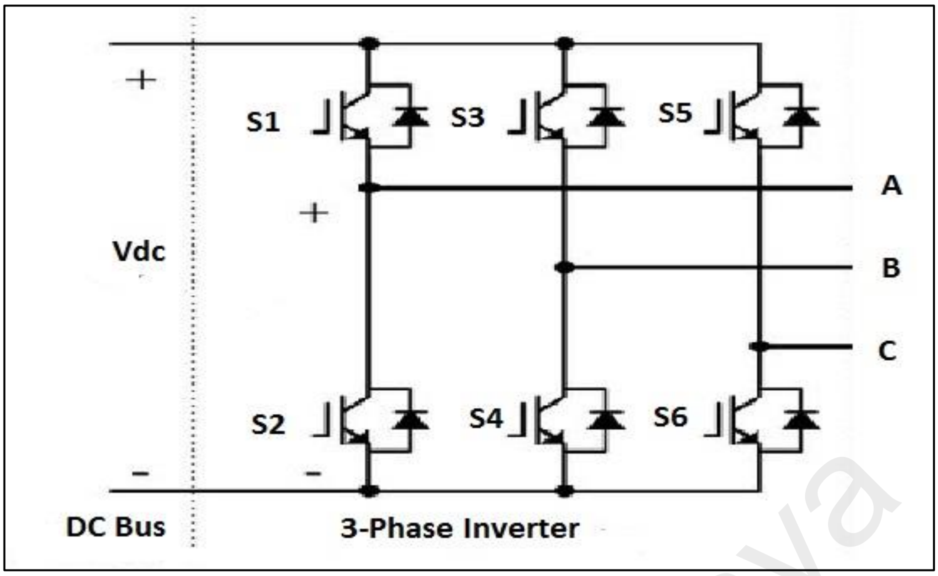


Figure 2.6 Three-phase voltage source inverter

2.1.5 V/f Control for Induction Motor Speed Control

The Volt/Hz control of an induction Motor is by far the most popular method of speed control because of its simplicity, and these types of motors are widely used in industry. For adjustable speed applications therefore voltage is required to be proportional to frequency, so air-gap flux is constant and unsaturated (Bose, 2002).

Air-gap-induced e.m.f. in an ac machine is given by,

$$E_1 = 4.44\, k_{wl} \varphi_m f_s T_1 \tag{2.30}$$

By neglecting stator impedance $R_1 + jX_1$ the induces e.m.f. approximately equals the supply-phase voltage

$$V_{ph} \cong E_1 \tag{2.31}$$

$$\varphi_m = \frac{V_{ph}}{K_b f_s} \tag{2.32}$$

$$K_b = 4.44 k_{wl} T_1 \tag{2.33}$$

$$\varphi_m \cong \frac{V_{ph}}{f_s} \cong K_{vs} \tag{2.34}$$

k_{wl} is stator winding factor,

φ_m is peak air-gap flux,

f_s is supply frequency,

T_1 is number of turns per-phase in stator

K_b is constant flux,

k_{vf} is ratio between V_{ph} and f_s

This method is known as scalar control with control-magnitude variation. It disregards the machine's compiling effects, but includes voltage and frequency.

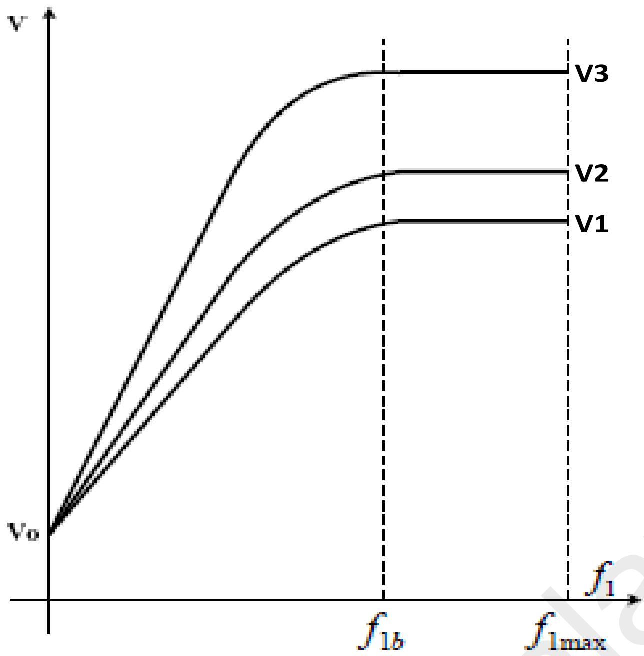


Figure 2.7 V/f curve strategy

This method applies proportional voltage to frequency and flux ($\varphi_s = V_s \,/\, \omega_e$) remains constant, as long as frequency is the primary control variable and phase-voltage command is generated from frequency by gain-factor G. At low speed, frequency get smaller and stator resistance tends to absorb most of stator voltage, weakening flux. Voltage should be boosted to get flux rate, and corresponding full torque becomes available down to zero speed, via:

$$V = V_o + K_o(f_1).\,f_1 \tag{2.35}$$

Where V_o is voltage boost, f_1 is frequency converter, and K_o is constant slope of V/f.

2.1.6 Centrifugal Pump

Pumps provide the means for moving water through the system at usable working pressures. The operation and maintenance of these pumps are some of the most important duties for many water utility operators. There are two basic types of pumps used in water and wastewater systems. The most common type of pump is the centrifugal pump.

Centrifugal pumps is a kinetic device used to move fluids which is transport fluids and liquids through piping systems that come from one reservoir or tank to a different reservoir or tank. A centrifugal pump is a roto-dynamic pump that uses a rotating impeller to increase the pressure and flow rate of a fluid. Centrifugal pumps are the most common type of pump used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward or axially into a diffuser or volute chamber, from where it exits into the downstream piping system. Centrifugal pumps are typically used for large discharge through smaller heads (ahonen, 2011).

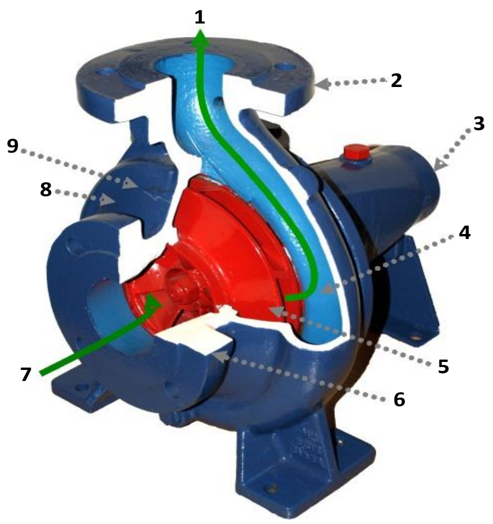


Figure 2.8: Cut-way of centrifugal pump (ref: http://en.wikipedia.org/wiki/Centrifugal_pump)

Information of Figure 2.8:

1. Pressure side
2. Downstream pipe flange
3. Driveshaft flange
4. Volute chamber
5. Impeller
6. Upstream pipe flange
7. Suction side
8. Pump casing
9. Rotating direction indicator

Problems of centrifugal pumps (Bachus, 2003)

- Cavitation—the net positive suction head (NPSH) of the system is too low for the selected pump
- Wear of the impeller—can be worsened by suspended solids
- Corrosion inside the pump caused by the fluid properties
- Overheating due to low flow
- Leakage along rotating shaft
- Lack of prime—centrifugal pumps must be filled (with the fluid to be pumped) in order to operate
- Surge

2.2 SCADA System

2.2.1 Fundamental of SCADA

SCADA is short form for supervisory control and data acquisition system. SCADA system can be interpreted as combination of data acquisition and telemetry. SCADA covers information collection by using remote terminal units, transmit the information to master system, carrying out any necessary analysis and control and then display that information in the form of data or graph on operator screens or GUI. The control actions generated from the data calculations are returned back to the process (Clarke, 2004).

Several advantages of SCADA systems are as follows:

- The master system is recordable and can store large data
- The appearance of data on the master system can be adjusted according to user needs
- The SCADA system can connect to multiple sensors from a wide scope of area
- The user can combine real data simulations into the system
- RTUs can collect different types of data
- The data that has been collected can be viewed from anywhere

Several disadvantages of SCADA systems are as follows:

- The SCADA system is more complicated
- The operators must have the ability to analyze systems and programming skills
- A lot of wire are needed due to many sensors installed

2.2.1.1 SCADA Hardware

On the hardware part, SCADA system consists of remote terminal units (RTUs). The RTU serves to collect data or information from the plant. Then, RTU send the data to a master station by using a communications system. The master station displays the data according user requirement, then the user can control through RTU after analyzing the system.

The following points are five level hierarchical of a complex SCADA system:

- Plant level consist of instrumentation parts and control devices
- Remote terminal units
- Communication system
- The master stations
- Data processing system

The analog and digital sensors located at remote area are connected to RTUs via an I/O interface. Communication system between master system with RTUs has been standardized. This communication arrangement aims to streamline and optimize data transmission. Data transmission can be conducted through cable, radio, fiber optics, and satellite.

RTU consists of several parts, namely; CPU module, analog input module, analog output module, digital input module, and digital output module. Communication port located on CPU module. All data collected begins from I/O of this module then process it inside the CPU module. Then, the data will be sent to the master control station in a standard data packet.

2.2.1.2 SCADA Software

SCADA software is also called the master system. This software works based on an international communication protocol standard. The master system consists of two parts namely; GUI (graphic user interface) and database. in the GUI section describes the monitoring and control functions. while the database serves to store data.

2.2.2 SCADA Network Topologies

There are several possible schemes and network topologies to choose from when planning a SCADA network using RTU. Each has its own benefit as well a drawback. The choice of topology depends on factors contributing its cost and benefit. However, in some cases, it is also influence d by the protocols used in the SCADA network.

2.2.2.1 Basic SCADA Network Topologies

The two most basic SCADA network topologies are point-to-point (or star) network and multi-drop network. These topologies are applicable to most RTUs including Viscon Dua RTU. These topologies are also supported by almost all master-slave communication protocols.

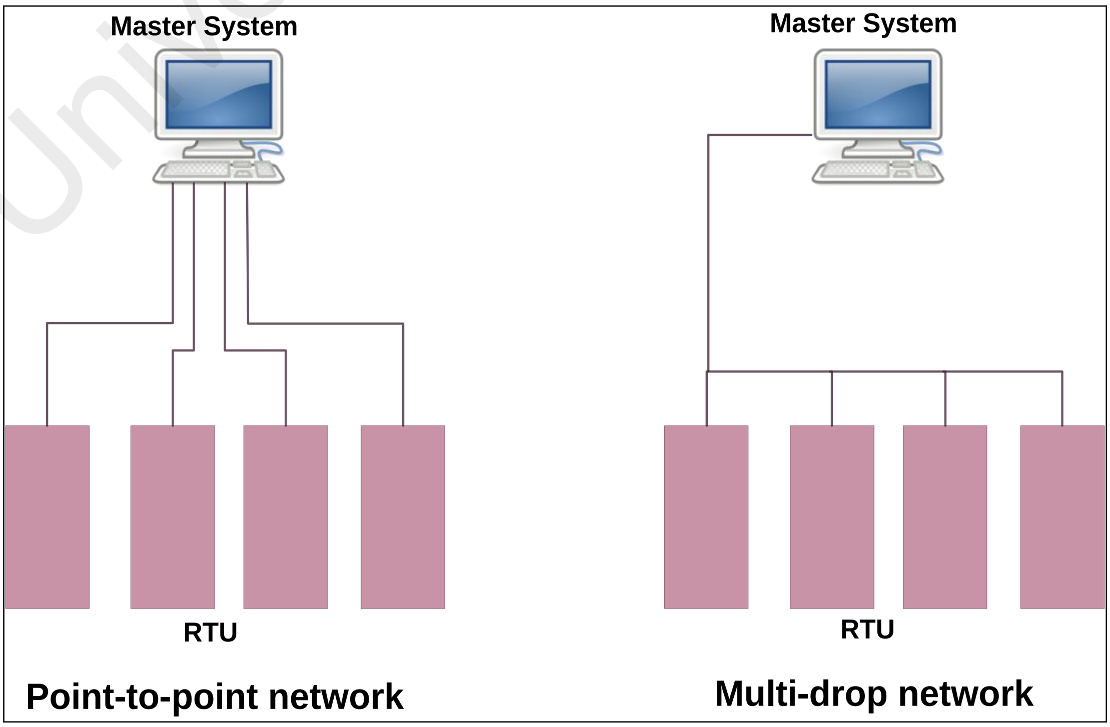


Figure 2.9 Basic SCADA Network Topologies

The simplest form of connection is a point-to-point network. Point-to-point networks have a star topology where each RTU is connected directly to the master system via a dedicated communications channel.

The main advantage of this scheme is that it provides protection of a communications channel from failure on any other channels. It also provides fast response and turn-around time for communications to each RTU since all RTUs may be polled simultaneously.

A multi-drop connection on the other hand shares a communication channel amongst many RTUs to the master system. This saves cabling cost especially when large distances are involved. Multi-drop connections also allow the master system to poll a larger number of RTUs since each communications channel can handle multiple RTUs. The main disadvantage is the reduced turn-around time when polling the RTUs. This is because in a multi-drop network, each RTU has to be polled in sequence.

2.2.2.2 Enhanced SCADA Network Topologies

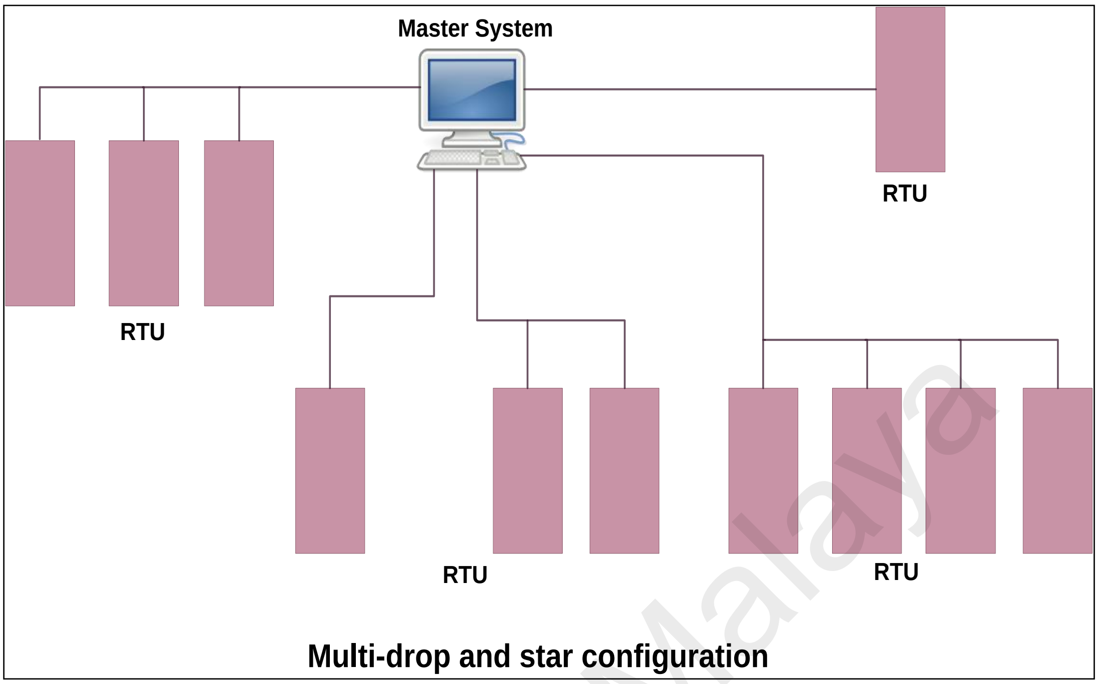


Figure 2.10 Multi-drop in star configuration

To gain the benefit of both basic SCADA network topologies discussed earlier, the multi-drop and point-to-point configurations are normally combined. This is as shown in Figure 2.10. with this combined configurations, the user have the freedom to come up with interconnection plan that considers both implementation cost and system's performance point of view.

2.2.3 Remote Terminal Unit

An RTU (sometimes referred to as a remote telemetry unit or remote terminal unit) is a stand-alone data acquisition and control unit, generally microprocessor based, that monitors and controls equipment at a remote location. Its primary task is to control and acquire data from process equipment at the remote location and to transfer this data back to a central station. It generally also has the facility for having its configuration and control programs dynamically downloaded from some central station. Although, traditionally, the RTU communicates back to some central station, it is also possible to communicate on a peer-to-peer basis with other RTUs. The RTU can also act as a relay station (sometimes referred to as a store and forward station) to another RTU that may not be accessible from the central station(Clarke, 2004).

Small RTUs generally have less than 10 to 20 analog and digital signals; medium sized RTUs have 100 digital and 30 to 40 analog inputs. Any RTU with more inputs is referred to as 'large'.

Typical RTU hardware modules include a control processor and associated memory, analog inputs, analog outputs, counter inputs, digital inputs, digital outputs, communication interface(s), power supply, as well as an RTU rack and enclosure.

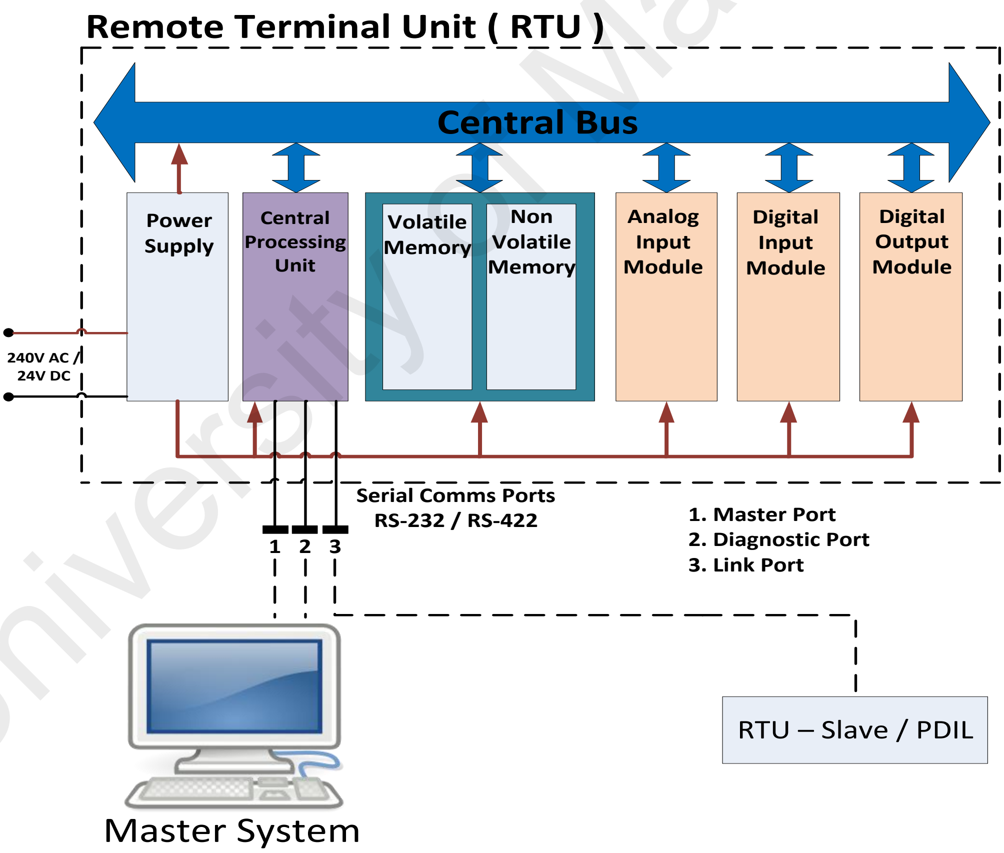


Figure 2.11: Remote Terminal Unit Diagram

A. Control processor unit (CPU)

This is generally microprocessor based (16- or 32-bit) eg 68302 or 80386, and the total memory capacity of 256 kbytes (expandable to 4 Mbytes) broken into three types namely EPROM, RAM and Flash/EEPROM.

Communication ports – typically two or three ports (RS-232/RS-422/RS-485) provide an interface to diagnostics terminals, operator stations, or communications Ethernet link to a central site (e.g. by modem).

Diagnostic LEDs provided on the control unit simplify troubleshooting and diagnosis of problems such as CPU or I/O module failure.

A real-time clock with full calendar is useful for accurate time stamping of events. A watchdog timer provides a check that the RTU program is executing regularly. The RTU program regularly resets the watchdog time and if this is not done within a certain time-out period the watchdog timer flags an error condition (and can reset the CPU).

B. Analog Input modules

There are five main components making up an Analog input module. They are the input multiplexer, the input signal amplifier, the sample, hold circuit, the A/D converter and the bus interface, and board timing system.

A multiplexer is a device that samples several (usually 16) analog inputs in turn and switches each to the output in sequence. The output generally goes to an analog to digital converter (also called an A/D converter or ADC), eliminating the need for a converter on each input channel. This can result in considerable cost savings.

Where low-level voltages need to be digitized, they must be amplified to match the input range of the board's A/D converter. If a low-level signal is fed directly into a board without amplification, a loss of precision will be the result. Some boards provide on-board amplification (or gain), while those with a programmable gain amplifier (PGA) make it possible to select – via software – different gains for different channels, for a series of conversions.

C. Analog output modules

Analog output modules perform the opposite function to that of the analog input modules by converting a digital value (as supplied by the CPU) to an analog value by means of a digital to analog converter (also called a D/A converter or DAC).

Typically the analog output module has the following features:

- 8 analog outputs
- Resolution of 8 or 12 bits
- Conversion rate from 10 μ seconds to 30 milliseconds
- Outputs ranging from 4–20 mA/± 10 volts/0 to 10 volts

Care has to be taken here on ensuring the load resistance is not lower than specified (typically 50 kohm) or the voltage drop will be excessive.

Analog output module designs generally prefer to provide voltage outputs rather than current output (unless power is provided externally), as this places lower power requirements on the backplane.

D. Digital input modules

These are used to indicate such items as status and alarm signals. Most digital input boards provide groups of 8, 16 or 32 inputs per board.

Typically the following would be expected of a digital input module:

- 16 digital input per module
- Associated LED indicator for each input to indicate current states
- Digital input voltages vary from 110/240 VAC and 12/24/48 VDC
- Optical isolation provided for each digital input

E. Digital output modules

Output module drives an output voltage at each of the appropriate output channels with three approaches possible viz. Triac switching, Reed relay switching or TTL voltage outputs.

Typical digital output module specs are:

- 8 digital outputs
- 240 V AC/24 V DC (0.5 amp to 2.0 amp) outputs
- Associated LED indicator for each output to indicate current status
- Optical isolation or dry relay contact for each output

2.2.4 IEC 60870-5-101 Standard Protocol

Communication protocol are the roles through which computer-based devices communicate with one another the way organize, and transmit the bits and bytes of electronic binary signals whose patterns encode data. Simply, a protocol is a set of rules that governs how message containing data and control information are assembled at a source for their transmission across the network and then dissembled when they reach their destination(Clarke, 2004).

One of part of IEC 60870 standards is part 5 which define systems act as tele-control function in electrical engineering applications. (Dorronzoro Zubiete, Medina Rodriguez, Gomez Gonzalez, Romero, & Merino Monge, 2010). The IEC Technical Committee 57 have developed a protocol standard for tele-control, tele-protection, and associated telecommunications for electric power systems. The result of this work is IEC 60870-5(Clarke, 2004).

The IEC 60870 part 5 can be classified into 4 parts as below:

- IEC 101 standard protocol. This part for basic tele-control responsibilities
- IEC 102 standard protocol. This part for the transmission of integrated totals in electric power systems
- IEC 103 standard protocol. Protection system information is described in this part
- IEC 104 standard protocol. This part act as network access for IEC 60870-5-101 using standard transport profiles

IEC 60870-5-101/102/103/104 are companion standards generated for basic tele-control tasks, transmission of integrated totals, data exchange from protection equipment & network access of IEC101 respectively.

IEC 60870-5-101 [IEC101] is a standard for power system monitoring, control & associated communications for tele-control, tele-protection, and associated telecommunications for electric power systems. This is completely compatible with IEC 60870-5-1 to IEC 60870-5-5 standards and uses standard asynchronous serial tele-control channel interface between DTE and DCE. The standard is suitable for multiple configurations like point-to-point, star, multi-dropped etc.

Character format of IEC 60870-5-1 uses 1 start bit, 1 stop bit, 1 parity bit & 8 data bits. This format uses 3 types of frame formats - Frame with variable length ASDU, Frame with fixed length & single character. Single character is used for acknowledgments, fixed length frames are used for commands & variable lengths are used for sending data. The details of variable length frame are given below.

Table 2.2 IEC 101 Frame Format

Data unit	Name	Function
Start Frame	Start Character	Indicates start of Frame
	Length Field (*2*)	Total length of Frame
	Start Character (repeat)	Repeat provided for reliability
	Control Field	Indicates control functions like message direction
	Link Address (*0,1 or 2*)	Normally used as the device / station address
Data Unit Identifier	Type Identifier	Defines the data type which contains specific format of information objects
	Variable Structure Qualifier	Indicates whether type contains multiple information objects or not
	COT (*1 or 2*)	Indicates causes of data transmissions like spontaneous or cyclic
	ASDU Address (*1 or 2*)	Denotes separate segments and its address inside a device
Information Object	Information Object Address (*1 or 2 or 3*)	Provides address of the information object element
	Information Elements (1)	Contains details of the information element depending on the type
Information Object-m	Information Elements (m)	Contains details of the information element depending on the type
Stop Frame	Checksum	Used for Error checks
	Stop Char	Indicates end of a frame

2.3 Previous Research on Monitoring System

Previous studies on real-time monitoring system are focusing on monitoring the induction motors (Aydogmus et.al (2008); Gonzales et.al (2011); Irfan et.al (2013); Sanchez et.al (2013); Sreejeth et.al (2012). Most of the studies use PLC and SCADA system to monitor and control the system (Aydogmus et. al, 2008; Sanchez et.al, 2013 and Sreejeth et.al, 2012). Meanwhile, Irfan et.al (2013) studies only use the PLC to control and monitoring AC Induction motor. Sanchez et.al (2013) stated that one issue in PLC based motor condition monitoring systems is about interfacing the IM to the PLC. Aydogmus et.al (2008) also showed the important of separated between the motor drive and remote monitoring of three-phase induction motor to be more effective and efficient. Therefore, it is necessary to separate between motor controlling and monitoring. The PLC was used for controlling and SCADA for monitoring. There are lacking studies on monitoring and control the induction motor and the water level. Thus, this work aims to develop real time monitoring and control of induction motor and water level using SCADA system.

Table 2.3 Previous study on monitoring system

No.	Author	Objective	Monitoring technique	Object monitoring
1.	Aydogmus (2008)	To build Web-based remote access real-time laboratory using SCADA (supervisory control and data acquisition) control.	• PLC is used to control the operation of the system • A SCADA system is used to monitor and control of the process	Induction motor
2.	Gonzales et.al (2011)	To develop methodology for constructing a user interface for system control and data acquisition of a drive which is suitable for three-phase	• Labview is used to monitor the system	Induction motors

		induction motors.		
3.	Irfan et. al (2013)	To develop an intelligent condition monitoring system for AC induction motors using PLC	• PLC is used to to control the operation of the system	Induction motors
4.	Sanchez et.al (2013)	To develop an open, multilevel condition monitoring system for induction motors (IMs).	• PLC is used to to control the operation of the system • A SCADA program to displays the motor status	Induction motors
5.	Sreejeth et.al (2012)	To monitoring a three phase AC servomotor using PLC and SCADA system	• PLC is used to to control the operation of the system • A SCADA system is used to monitor and control of the process	Induction motor

CHAPTER 3: METHODOLOGY

3.1 Water Pump Condition Monitoring System: Design and Development

3.1.1 Hierarchical of the proposed system

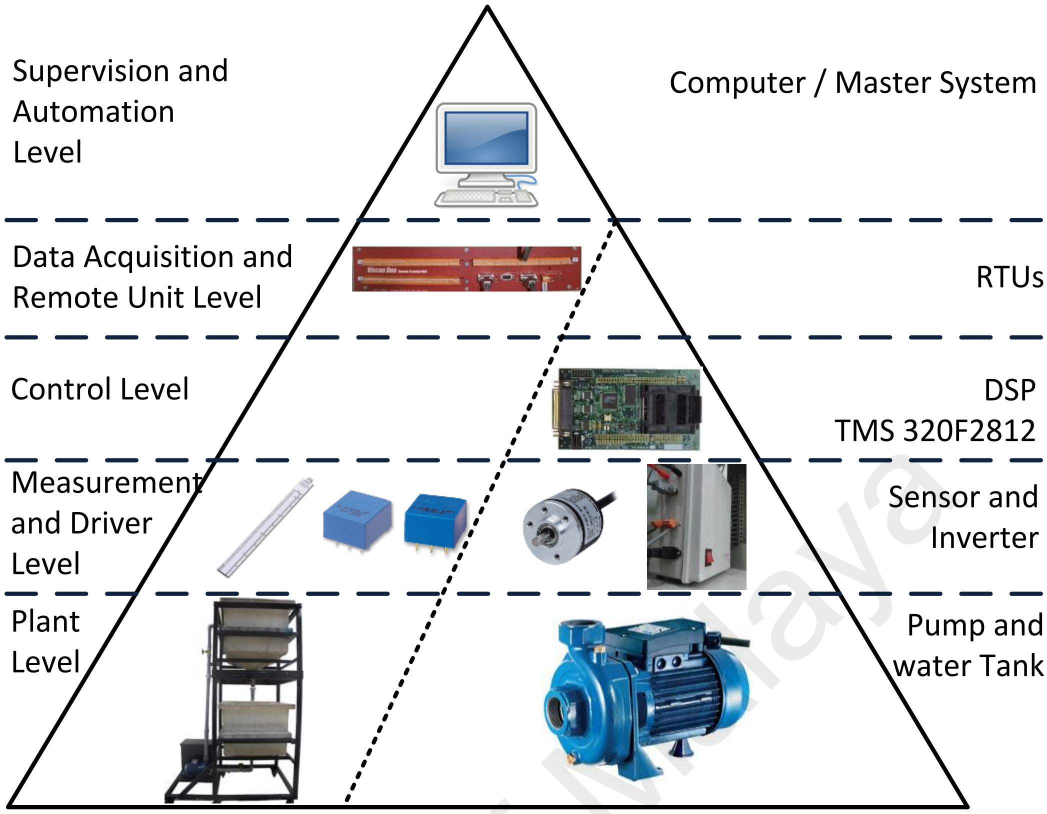


Figure 3.1:Hierarchical, multilevel structure of the proposed system

Hierarchical of the proposed system is multilevel structure as Figure **3.1**. In this structure between water-pump systems with monitoring system located at different pyramid, but between the two would be intertwined. Great Pyramid is part of monitoring or SCADA, while a small pyramid more specifically as a motor-drive. Its structure has been developed following the well-established multilevel, hierarchical organization used in the control and monitoring of water-pump processes, which is divided in five main layers:

1. Plant Level

   This level is the outermost part of the system. This section supervised and controlled by the user using SCADA.

2. Measurement and Driver level

   In this level, there are electronic circuits and sensors which aim to run the induction motor.

3. Control Level

   This level becomes the brain in controlling the work of induction motors. All related data of the motor have processed here.

4. Data Acquisition and Remote level

   Remote terminal units (RTUs) are important part in the data collection and execute commands from the user.

5. Supervision Level

   The closest level to the user is the supervision level. In this part, all the data are collected, and then processed by user or automation system.

The advantage of this system as a hierarchical structure is to divide the work between DSP and SCADA. DSP is used specifically to control the induction motor. While remote supervisory of the system done by SCADA.

3.1.2 Hardware Design and Configuration

Figure 3.2 is the overall system of configuration for real-time monitoring and remote control of water-pump system. This configuration consist of two main systems that is water-pump system (induction motor drives, centrifugal pump and water tank) and SCADA system (Control and monitoring system).

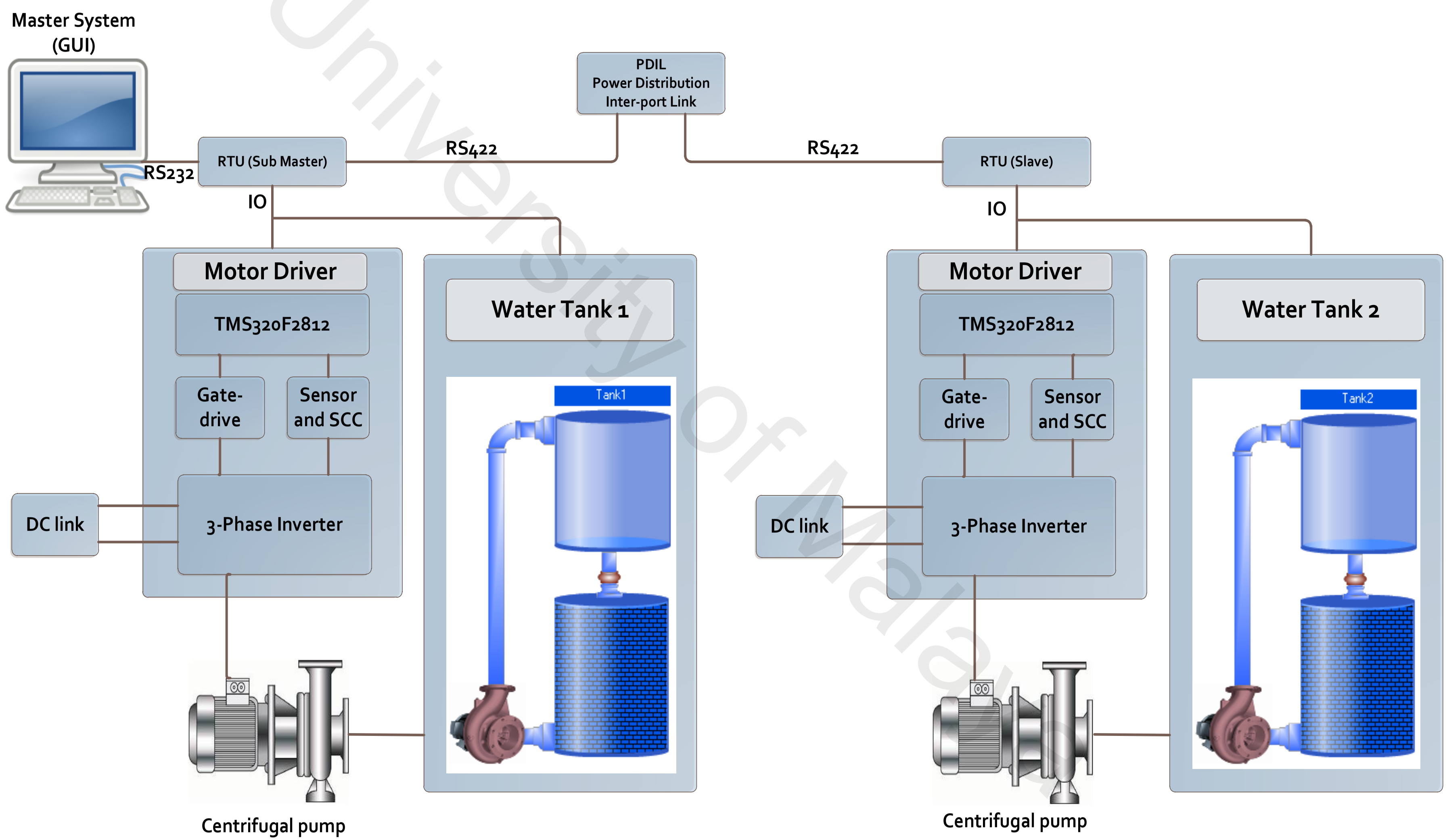


Figure 3.2: Overall System Configuration

3.1.2.1 Motor Drive's Hardware Implementation

This section describes the overall hardware configuration used for the motor drive system in this research. The complete hardware configuration consists of insulated-transformer (T), auto-transformer (AT), single-phase rectifier, three-phase inverter, gate drives, TMS320F2812 EzDSP development board, current sensors, 750 W, 2-poles three-phase induction motor, incremental encoder and signal-conditioning-circuit (SCC).. The detailed information and function of each part is explained in the next section.

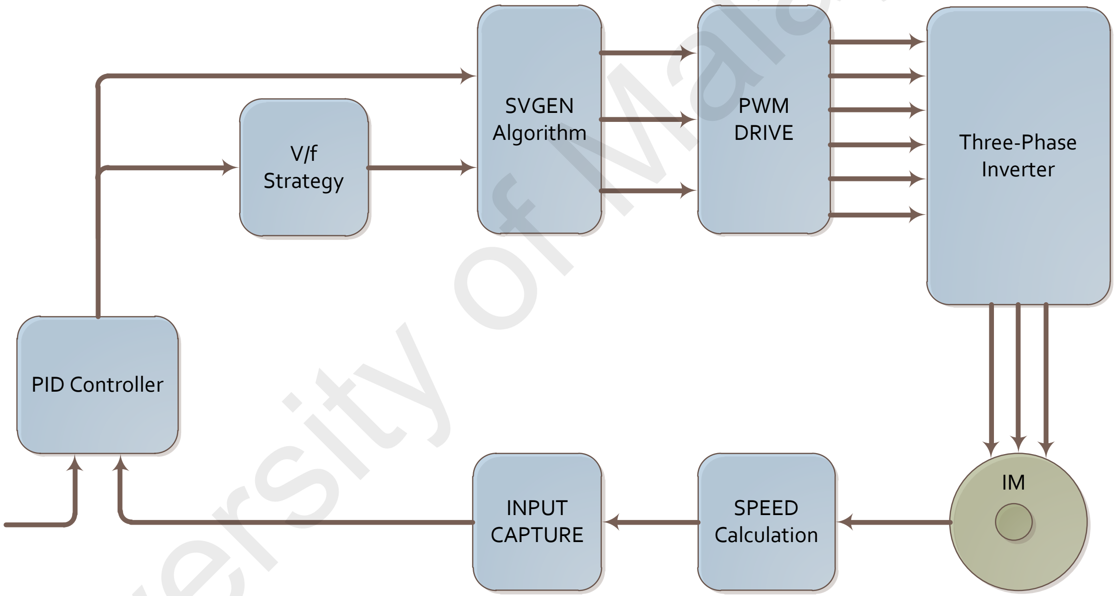


Figure 3.3: Block diagram of the induction-motor drive

(a) ***Rectifier***

A single-phase uncontrolled full-bridge rectifier is used as an input DC supply to the three-phase inverter. As shown in Figure 3.4, this rectifier consists of two different transformers: insulated-transformer and auto-transformer. The insulated-transformer with rating up to 1 kVA, 1:1 winding ratio is used as protection and insulation between the inverter drive system and power line from the grid while the auto-transformer is used to obtain variable AC output from 0 to 240 V AC manually control by user. For rectification, the output of autotransformer is connected to a single-phase full-bridge rectifier and smoothed by a capacitor. As a result, 339 V DC bus voltage (maximum) is produced across the +HVDC and –HVDC terminal when 240 V AC of Vin is applied to the rectifier.

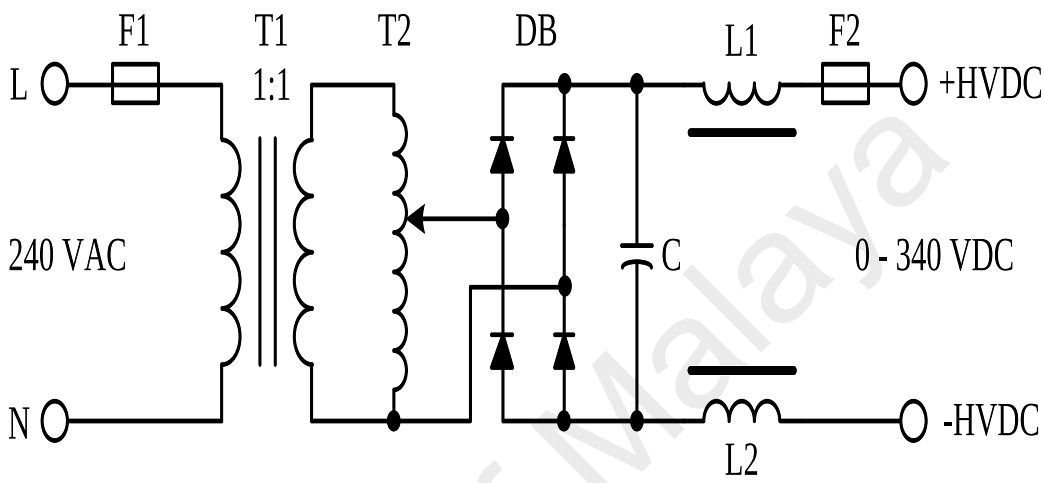


Figure 3.4 DC-link supply circuit

(b) *Three phase VSI*

As power switches, six Infineon's Insulated Gate Bipolar Transistors (IGBTs) with rating up to 1200 V/15 A (IKW15T12) are used to form three phase voltage source inverter (VSI) as shown in Figure 3.5. It was powered with 300 V of DC-link voltage from a single phase rectifier. 300 VDC of the DC-link voltage was selected to run the induction motor up to the nominal speed.

The inverter converts DC voltage into AC voltage with variable frequency output by using space vector modulation for IGBT switching. The lower-IGBT signals are complementary to the upper-IGBTs and a dead band time of 2 μs is added to make sure the upper and the lower-IGBTs in the same IGBT legs are not connected at the same time which would make the DC-link become short-circuited. The signals are shifted by 120 degrees for each IGBT leg. Each IGBT was equipped with RC snubber circuit, 10 Ω / 2 W and 0.001 μF / 1000 V for the resistor and the capacitor values, respectively.

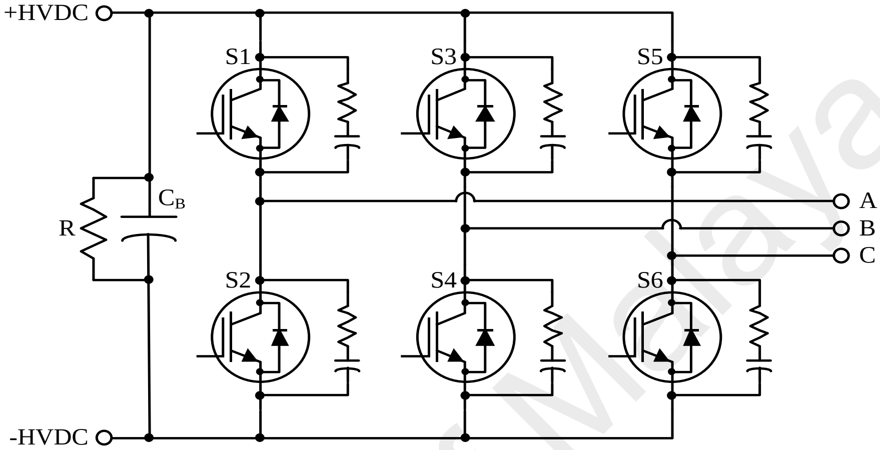


Figure 3.5 Three-phase Voltage Source Inverter

A DC link capacitor is placed as close as possible across the inverter to reduce the line's impedance between the capacitor and the IGBTs. Moreover, for safety reasons, 22 k Ω / 10 W resistor is put in parallel across the capacitor to discharge the capacitor's voltage when the system is turned off for a long period.

(c) *Gate Drive*

Typically, an IGBT requires 15- 20 V input signal level to turn-on, but the DSP can only generate a PWM signal of +3.3 V output level. Although it still can be used, it would give rise to some problems. The IGBTs cannot deliver high-current and high-power rate to the load by applying +3.3 V input signal for the IGBTs.

Due to the insufficient input signal level to the IGBT and the requirement to protect the DSP, gate driver is needed. The complete block of gate drive circuit is shown in Figure 3.6. One side of the opto-coupler is connected to the DSP and the other side is connected to the IGBT, and both sides are separated optically. The gate drive circuit consists of two main parts. The first part is voltage increaser circuit called insulated DC-DC converter and the second part is opto-coupler part.

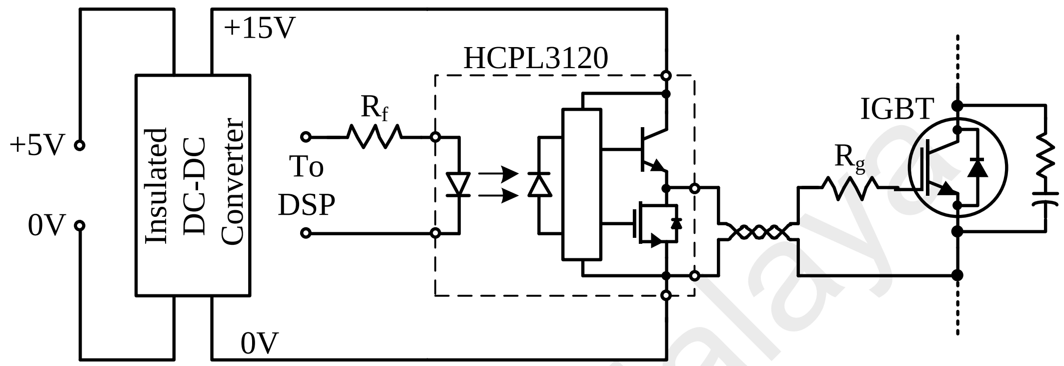


Figure 3.6: Gate drive circuit

The insulated DC-DC converter, as shown in Figure 3.7, increases the DC input voltage from +5 V to +15 V level. First, the oscillator produces high-frequency pulse with +5 V of amplitude and then this pulse amplitude is increased by high-frequency transformer (HFT) with 7:25 winding ratio. The output of transformer is rectified with a full-bridge diode to produce DC output. It has to be maintained at +15 V level by using voltage regulator.

The output of regulator is used to power-up the opto-coupler. In this drive system, HCPL3120 was used as an opto-coupler and IGBT gate driver. HCPL3120 can drive the IGBTs with rating up to 1200 V / 100 A, directly. Furthermore, HCPL3120 is equipped with under voltage lockout (UVLO) that has a function to protect the IGBT when the supply of opto-coupler becomes less than 11 V.

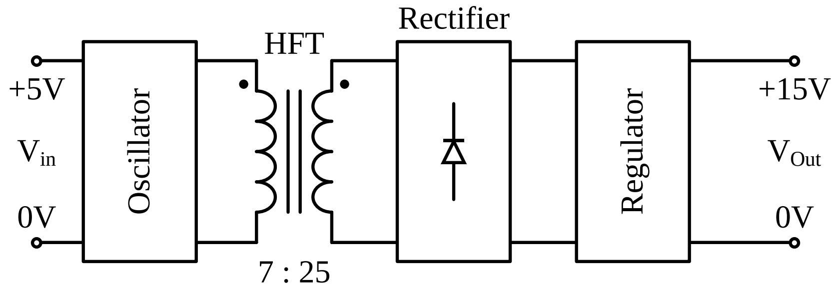


Figure 3.7: Insulated DC-DC converter

The connection between the gate driver and the IGBT should be as short as possible and also twisted or coaxial cables are recommended to prevent the IGBTs from picking up the noises/glitches from inside or outside the system.

(d) *Sensors and Signal Conditioning Circuits*

This section describes the sensors and signal conditioning circuit. There are two kinds of sensors that are used in the motor drive system, i.e. speed sensor and current sensor. Due to DSP input signals being limited to 3.3 V for maximum value and 0 V for minimum value, these signals must be scaled-down by using the signal conditioning circuit. Moreover, the signal conditioning circuit gives protection to avoid DSP damage.

A. Speed Sensor

In this system, the Quadrature Encoder Pulse (QEP) sensor is used because it is commonly used for rotor position and speed measurement of PMSM. Moreover, the QEP is not only cheaper than absolute encoder but also has the same capability as the absolute encoder; it can determine the absolute rotor position as well.

QEP encoder EH60E-5000 series from Autonics (Figure 3.8) is used in this motor drive system. QEP sensor is a kind of incremental encoder and it produces three signals: channel A, channel B, and channel Z or the index signal. Channel A and B are square-wave signal with 90 degrees difference between each other. It can be lagging or leading depending on the direction of rotor rotation. Both signals generate 5000 pulses per one complete rotation. Internally, through the software, these pulses are multiplied by 4 to obtain more accuracy in calculation and avoid missing counting at low speed operation of motor.

Figure 3.8: Autonics QEP EH60E series

The index signal produces a single pulse for every one complete mechanical revolution, as shown in Figure 3.9. It is used as QEP interrupt signal and resets the timer counter before a new round of counting is started.

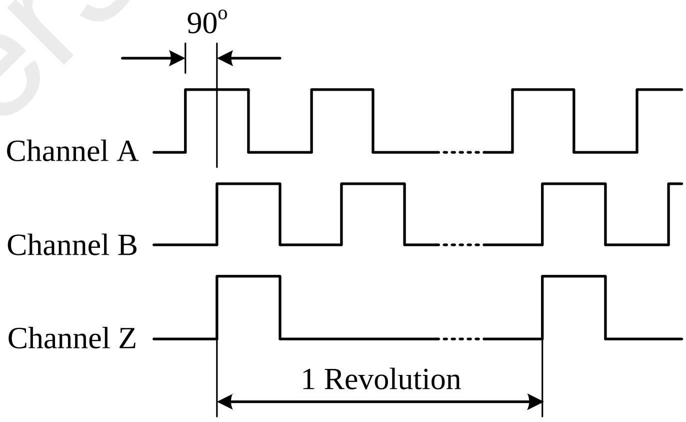


Figure 3.9: Output signal of incremental encoder with index

The QEP sensor must be calibrated before it is used in the motor drive system. A simple calibration method is by measuring the time difference between the QEP index signal and the back-emf waveform using an oscilloscope. Thus, the time difference would be considered as the offset value of the QEP and it is put inside the algorithm as calibration angle value. The motor would draw more current from the DC-link with an incorrect value of calibration angle and the optimum torque production is not achieved in this condition.

Figure 3.10 shows an illustration of rotor position alignment. The notation "θ_{e1}" indicates the incorrect rotor position angle which is obtained from the measurement of encoder and θ_e is the correct rotor position angle after calibration angle is added to θ_{e1}.

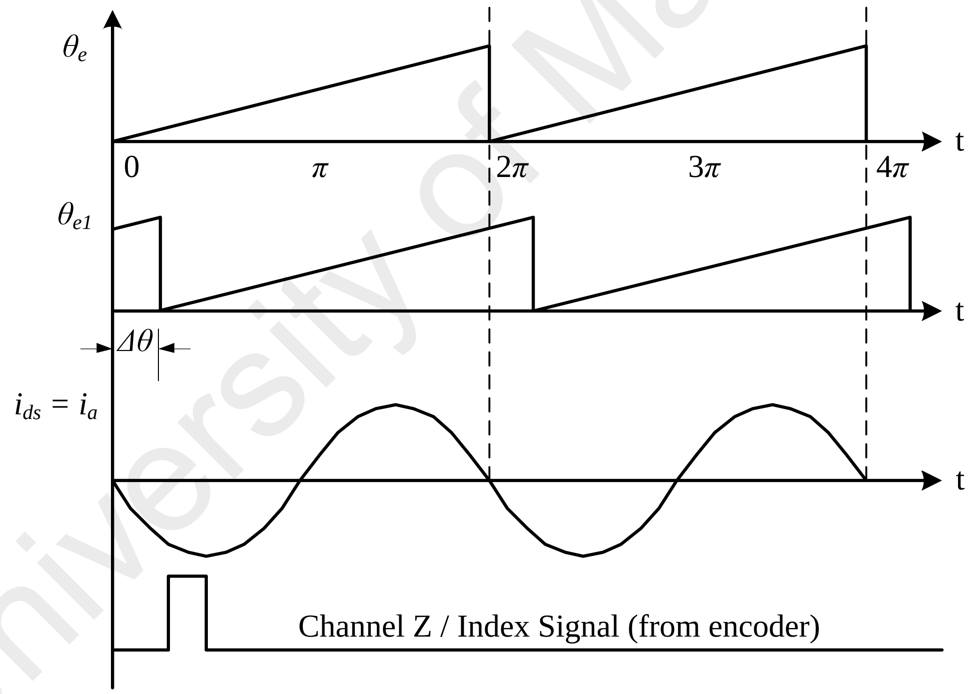


Figure 3.10: Rotor position alignment

The misalignment of rotor position is illustrated in dq-axis current vector as shown in Figure 3.11. The asterisk mark indicates the dq-axis with incorrect rotor position angle.

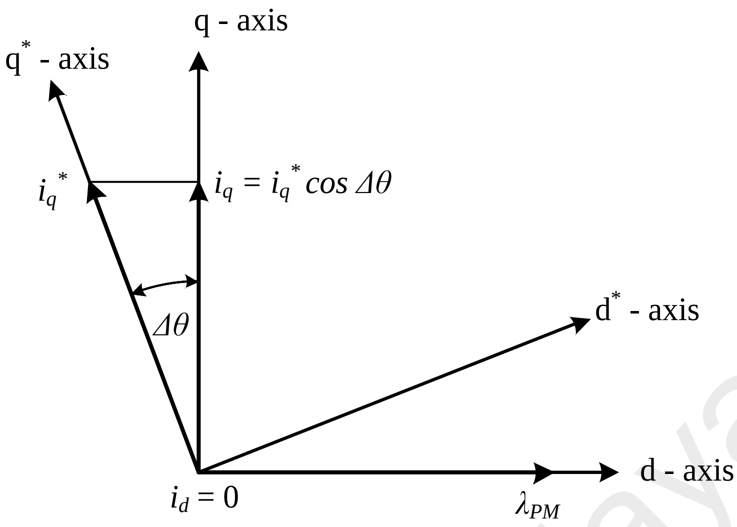


Figure 3.11: dq-axis current vector with misalignment of rotor position

Misalignment of rotor position makes equation 2.44 becomes:

$$T_e = \frac{3}{2}\frac{P}{2}\lambda_{PM}\, i_q^{*}\cos(\Delta\theta) \tag{3.1}$$

Where the rotor angle deviation is defined as,

$$\Delta\theta = \theta_{e1} - \theta_e \tag{3.2}$$

From equation (3.1), by assuming the value of electromagnetic torque (T_e) is equal to the load torque (T_L), which is a constant value, the q-axis current will increase as a result of misalignment of rotor angle. The optimum torque and current can be achieved when the rotor angle deviation is zero.

The QEP has NPN open-collector outputs and each channel need to pull-up by using a resistor connected to +5 V. Then Schmitt triggers (N1 and N2) are used to suppress the glitch and sharpen the pulse. Because only +3.3 V inputs are acceptable for the DSP, a trimmer-potentiometer (VR) is needed as a voltage divider to reduce the signal output from the Schmitt triggers at 3.3 V of maximum amplitude.

Figure 3.12 shows the interface circuit between the QEP and the DSP. The output of the circuit was connected to a special function pin which is dedicated for QEP encoder. Channel-A, B, and Z is connected to QEP1, QEP2, and QEPI1, respectively. The most important thing is that a shield wire (F.G) has to be connected to 0 V of power supply wire (Gnd) and protective-earth (PE) point together. Significantly, it reduces the noise of QEP output. As a result, the error in the measurement of the rotor position can be minimized.

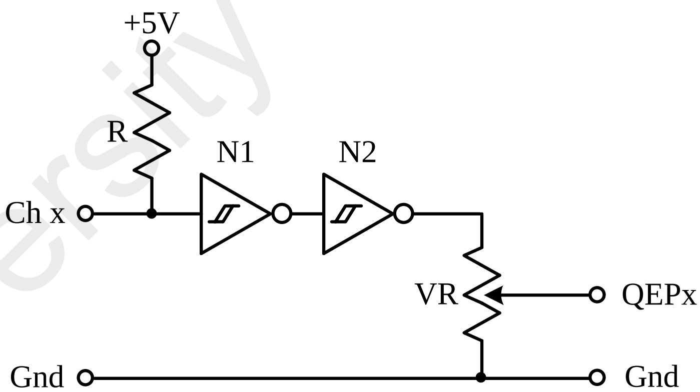


Figure 3.12: QEP's signal conditioning circuit

B. Current Sensor

The actual stator currents are obtained from Hall-effect current sensors. Two LEM Hall-effect current sensors (LA25-NP) are used as current feedback input to the DSP.

Both of the sensors need +/- 15 VDC supply to operate. However, the current measurement output from these sensors cannot be applied to the DSP's ADC directly. In order to fulfil this ADC voltage range, the current sensors output needs a signal conditioning circuit to scale-down to that particular voltage range of signals. Also, the signal is shifted by 1.5 V of DC offset in order to avoid negative voltage. (c)

Figure 3.13 shows the signal conditioning process. In this system, the actual current 8 A (peak) is set equal to 3 V.

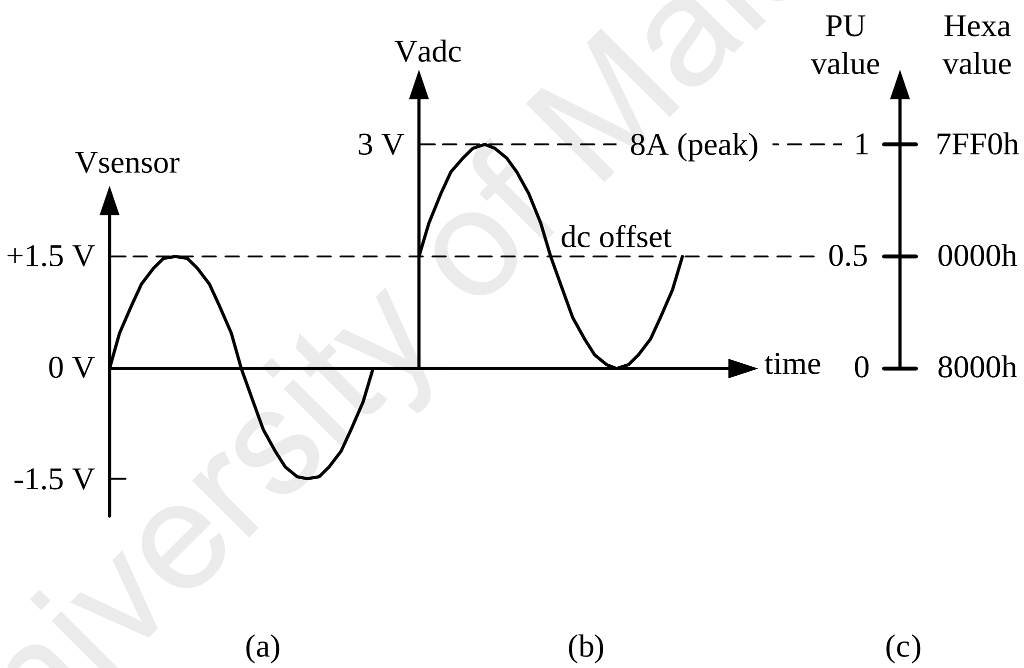


Figure 3.13: Current sensor signal conditioning

(a) scalling-down, (b) shifting-up the signal and (c) hexa number representation

Two clamping-diodes are placed as a backup protection to prevent the ADC's input signal lower or equal to +3.3 V and higher or equal to 0 V (0 V $\leq$ VADC $\leq$ +3.3 V) during the motor start-up, acceleration, or deceleration period. Figure 3.14 shows the configuration of current sensors and signal conditioning circuit. In addition, a simple low-pass-filter (LPF) is placed as close as possible to the ADC input terminal to provide signal filtering.

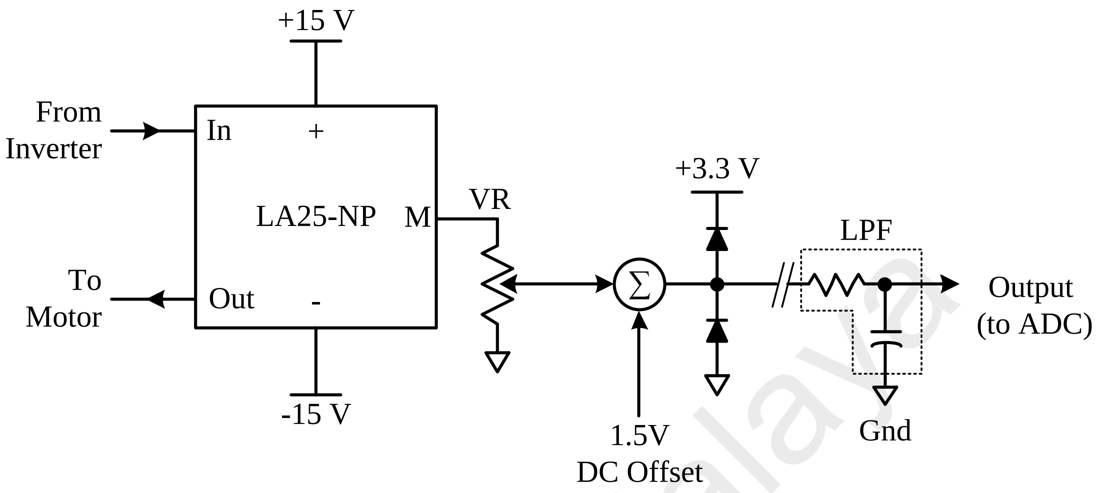


Figure 3.14 Current sensor circuit

C. Voltage Sensor

A voltage sensor LEM LV25P is used to measure the DC-link voltage. The output of the voltage sensor needs to be scaled down from 300 VDC to 3 V as shown in Figure 3.15, before it is applied to the ADC input of DSP. Figure 3.16 shows the circuit diagram of voltage sensor.

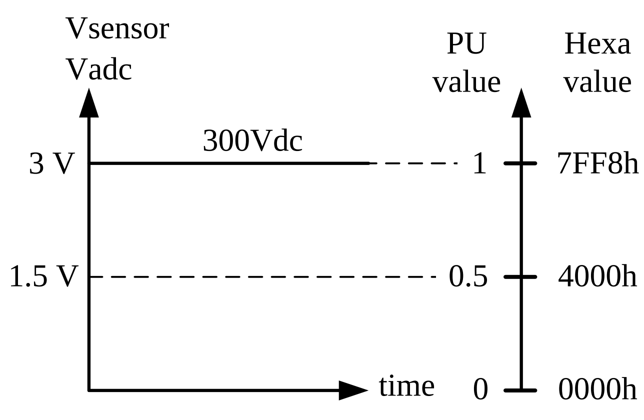


Figure 3.15: Voltage sensor signal conditioning

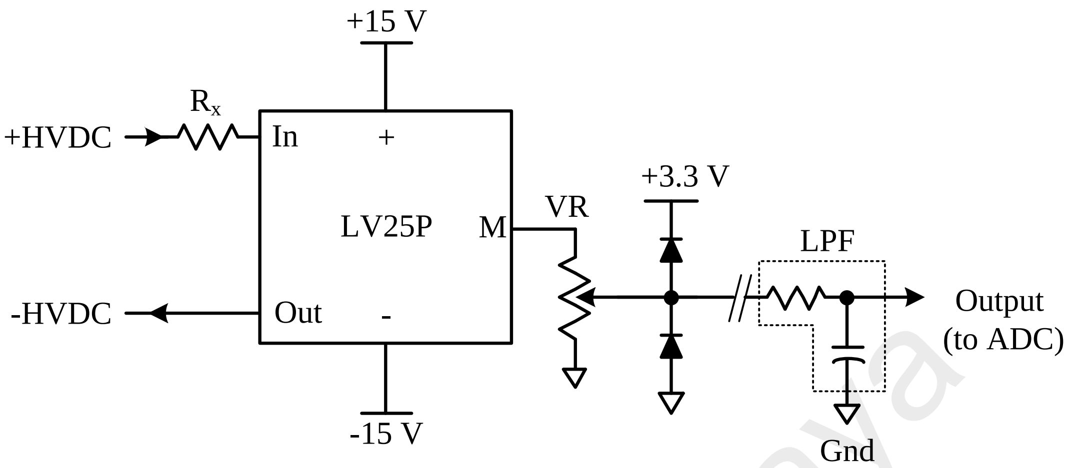


Figure 3.16: Voltage sensor circuit

D. Water Level sensor

The eTape sensor (see Figure 3.17) is a solid state, continuous (multi-level) fluid level sensor for measuring levels in water, non-corrosive water based liquids and dry fluids (powders).

The eTape sensor's envelope is compressed by hydrostatic pressure of the fluid in which it is immersed resulting in a change in resistance which corresponds to the distance from the top of the sensor to the fluid surface. The sensor provides a resistive output that is inversely proportional to the level of the liquid: the lower the liquid level, the higher the output resistance; the higher the liquid level, the lower the output resistance.

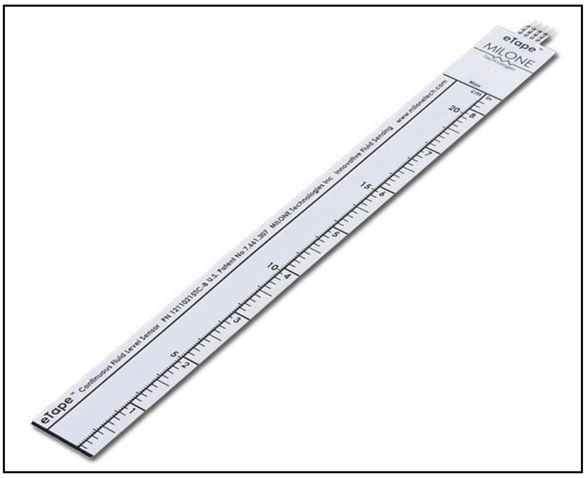


Figure 3.17: eTape MILONE water level sensor

Figure 3.18 is signal conditioning circuit of water level sensor. It use wheatstone bridge model, Rsense is variable resistor which its value equal to water level.

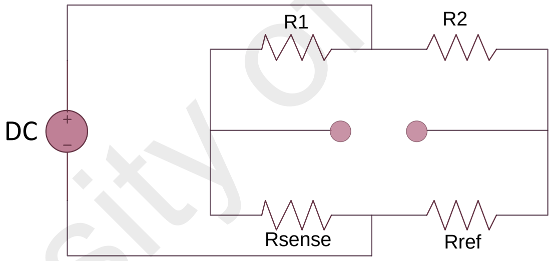


Figure 3.18: SCC of eTape water level sensor

3.1.2.2 Monitoring's Hardware Implementation

(a) *RTU configuration*

Viscon 2 RTU offers the best solution for large applications. The design also offers flexible configuration so that it can be suit to wide range of applications. The Viscon 2 RTU is yet another revolutionary approach in RTU designs for real-time applications. Like its predecessor, Viscon 2 RTU is designed with concept of modularity, robust and fault tolerant. These ensure no miss-operations or failures that will affect the plant. At the same time, the RTU is able to absorb or block any plant failure such as over-voltages or currents from invading the system.

Figure 3.19: Viscon Dua RTU (mix Mode)

In this system, RTU used is 2 pieces mix module mode, where in one RTU module there are 3 different IO card, namely;

- Card 1: Digital Output
- Card 2: Digital Input
- Card 3: Analog Input

Viscon Dua-PDU is a special programming and diagnostic utility that used for RTU configuration and troubleshooting. During the installation, it is used to configure the RTU according to the setup requirement and as a tool for troubleshooting during the RTU operation when the RTU is suspected to perform some miss-operation.

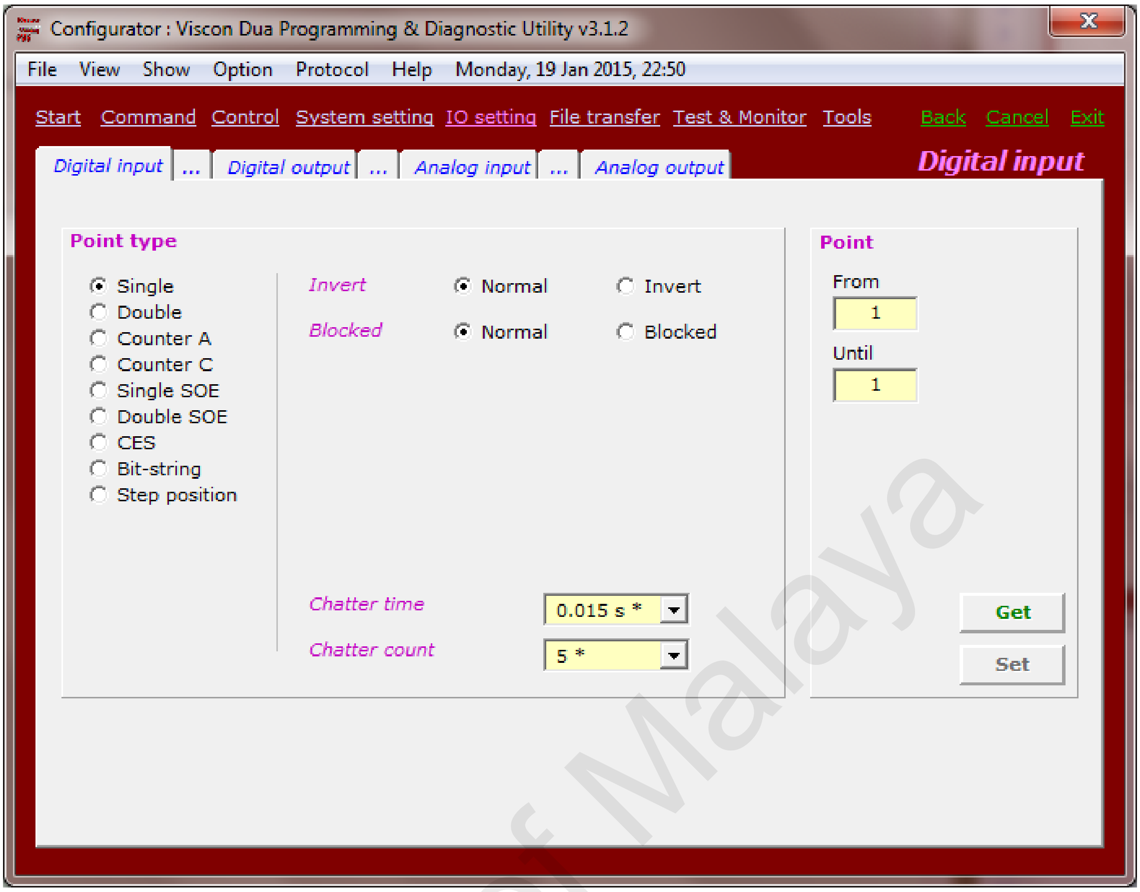


Figure 3.20: Viscon Dua Programming & Diagnostic Utility

A. Sub Master RTU Setting

- System setting

  LA = 1

  CAASDU = 1

- Parameters

  Set RTU 1 as Sub Master.

  Mapping setting:

  ✓ IOA map : Map RTU point, from 1-254

  To IOA point, from 1-254

  ✓ CAASDU Map : Map Slave number, from 1-7

  To CAASDU, from 2-8

B. Slave RTU Setting

- System setting

  LA = 1

  CAASDU = 2

- Parameters

  Set RTU 2 as Slave.

  Mapping setting:

  - ✓ IOA map : Map RTU point, from 1-254
    To IOA point, from 257-510
  - ✓ CAASDU Map : no need to set

3.1.3 Software design and implementation

Software used in this system consists of two parts, the first source code written in C on the software Code Composer Studio (CCS), this software is used to program the DSP, the motor control section is set using this software, while the latter is the source code written in visual Basic 2008, It was part of the visual studio has features that facilitate in making the measurement visual.

Aside from the above software, also create a system for monitoring the use of the PDU. PDU is a software that is used to perform setup of the RTUs, with this software can determine which form of communication will be established between the RTUs and master system, time synchronization between RTU and the master system, and set all the parameters in SCADA communication-based IEC 101.

3.1.3.1 Motor Drive Software

SVPWM and V/f are methods are used drove the motor, both methods are configured in the DSP TMS320F2812.

A. V/f Strategy

V/f method control the induction motor's speed. The control is achieved by adjusting the stator voltage and frequency. Figure 3.21 shows a flowchart of the V/f control algorithm.

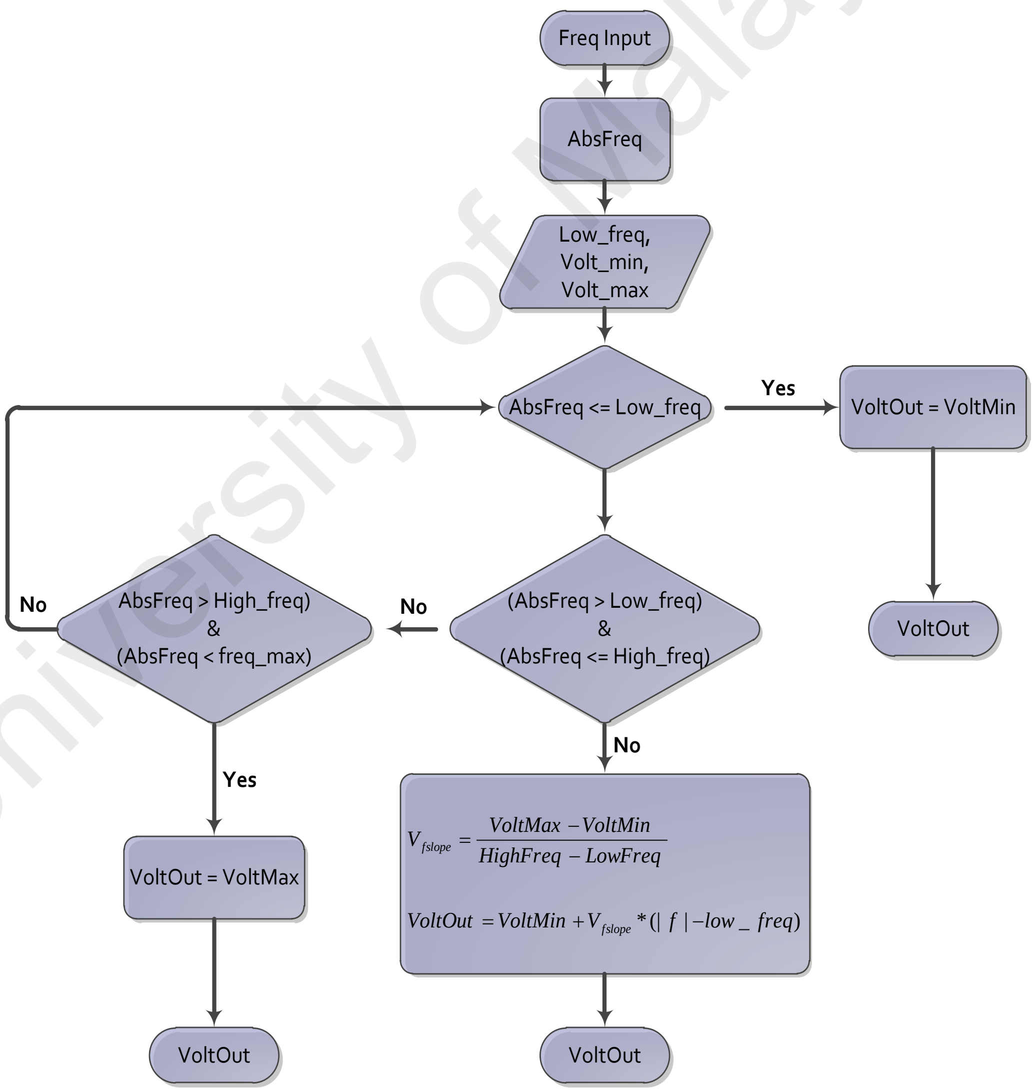


Figure 3.21: Flowchart of the V/f Strategy

B. Space Vector Pulse Width Modulation (SVPWM)

Six PWM channels of the DSP controller implemented the SVPWM algorithm to regulate the motor's phase voltage via control of six switching components of the inverter. Figure 3.22 is the flowchart for SVPWM generation.

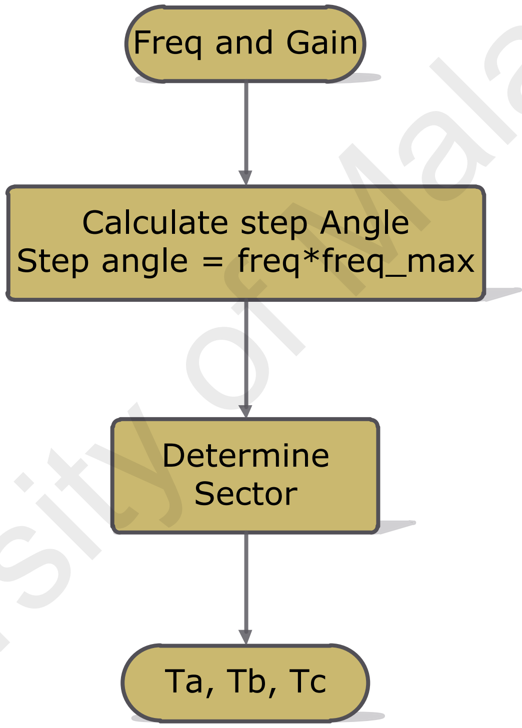


Figure 3.22: Flowchart of the SVPWM

C. PI Controller

The controller is designed to keep the constant output value that is based on set-point value. Its design should have closed-loop control, to minimize error. Constant value of the controller is determinable by trial and error method with Kp = 1.024 and Ki 0.146. Figure 3.23 shows design of the closed-loop control with feedback.

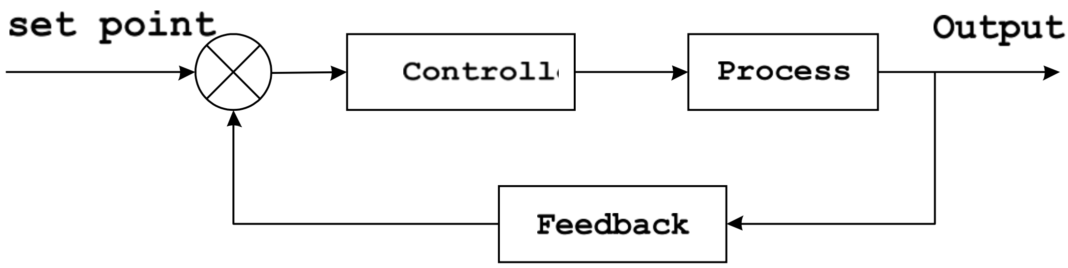


Figure 3.23: Block diagram of process

D. Code Composer Studio

Figure 3.24 is software which is used to write the source code to be uploaded into the DSP TMS320F2812, all the processes, controls and settings are written in C language on CCS. Then, implement the tasks that have been written in the program implemented by DSP.

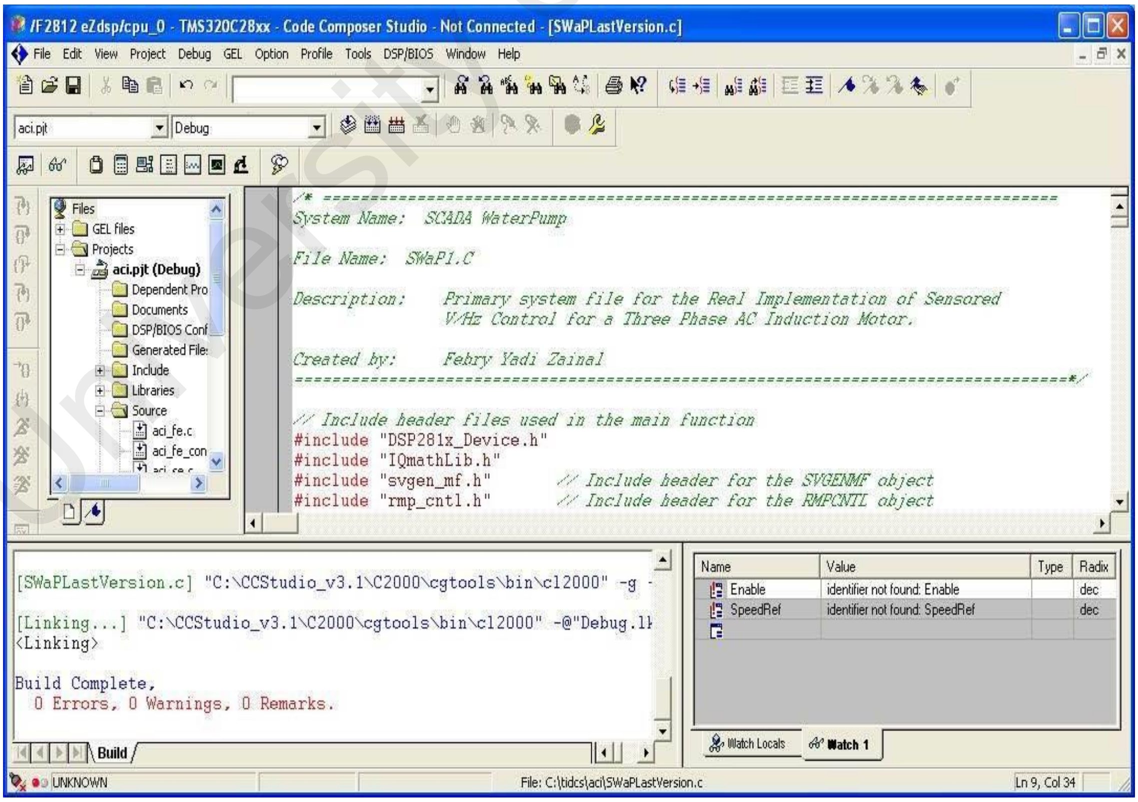


Figure 3.24: Code composer studio

3.1.3.2 Monitoring Software

Visual studio 2008 is powerful programming software for GUI application. It contains helpful ActiveX control tools. Visual basic 2008 is part of Visual Studio programming software.

Visual Basic 2008 used to develop the GUI for Master System of SCADA. It contains graph, meter and other command controls. The master system sent command to DSP through RTUs, the RTUs replies data to master system. The master system processed and displayed the data on the monitor. Hence, the algorithm receives real-time data continuously until the stop instruction is applied by the master system.

The master system has five layers form. That is:

10. GUI-Based Monitoring Display

On this GUI layer contains mimic diagram, control panel, and measurement panel. Mimic diagram is representation of water-pump system plant. This layer is shown in Figure 3.25.

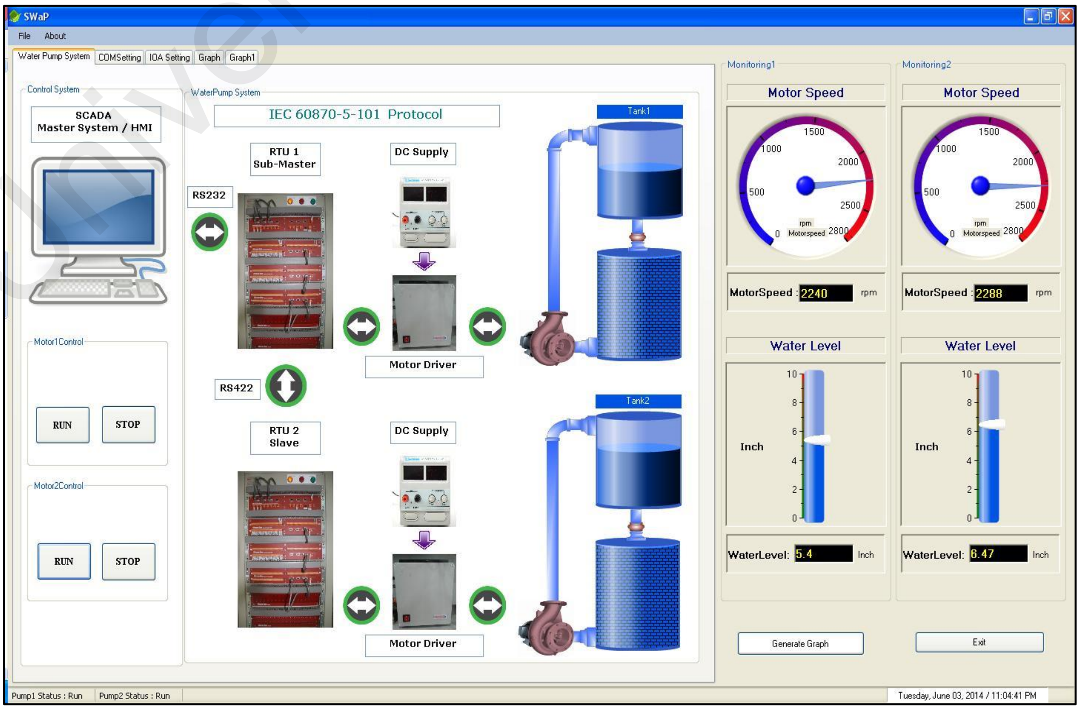


Figure 3.25: GUI-based monitoring display

11. Communication setting and transceiver data view

Before send other command or receives the data, the GUI needs to make connection between master system and RTU. Figure 3.26 shows communication panel and transceiver data monitor.

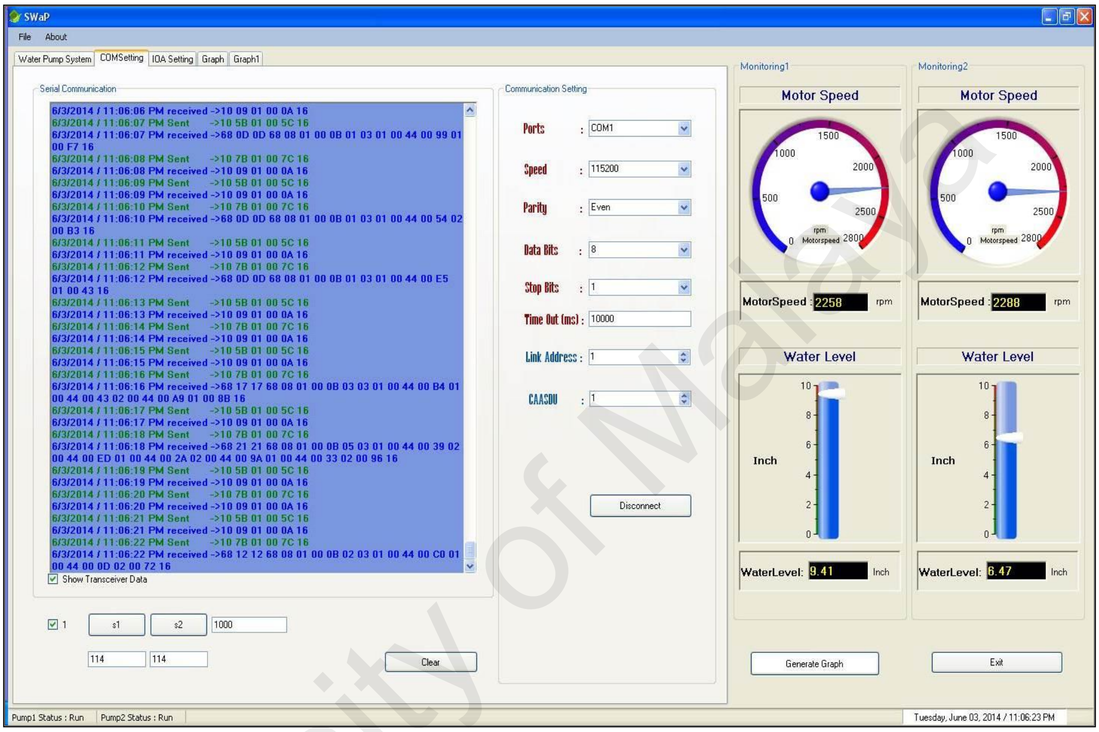


Figure 3.26: Communication setting and transceiver data panel

The following table is communication setting between master system and RTU.

<table>
<tr><td>Comm Port</td><td>COM1</td><td rowspan="6">Serial communication setting</td><td rowspan="8">Master System – RTU Communication setting</td></tr>
<tr><td>Speed</td><td>115200</td></tr>
<tr><td>Parity</td><td>Even</td></tr>
<tr><td>Data bit</td><td>8</td></tr>
<tr><td>Stop bit</td><td>1</td></tr>
<tr><td>Time out</td><td>1000</td></tr>
<tr><td>LA</td><td>1</td><td rowspan="2">RTU Address setting</td></tr>
<tr><td>CAASDU</td><td>1</td></tr>
</table>

Table 3.1 SCADA Communication Setting

12. IOA setting

Every physical input and output port must have address number. Vicon Dua PDU is used to set every port on RTUs as already explained in chapter 4. In order to synchronization between physical port data and display data need to set IOA on master system as show on Figure 3.27

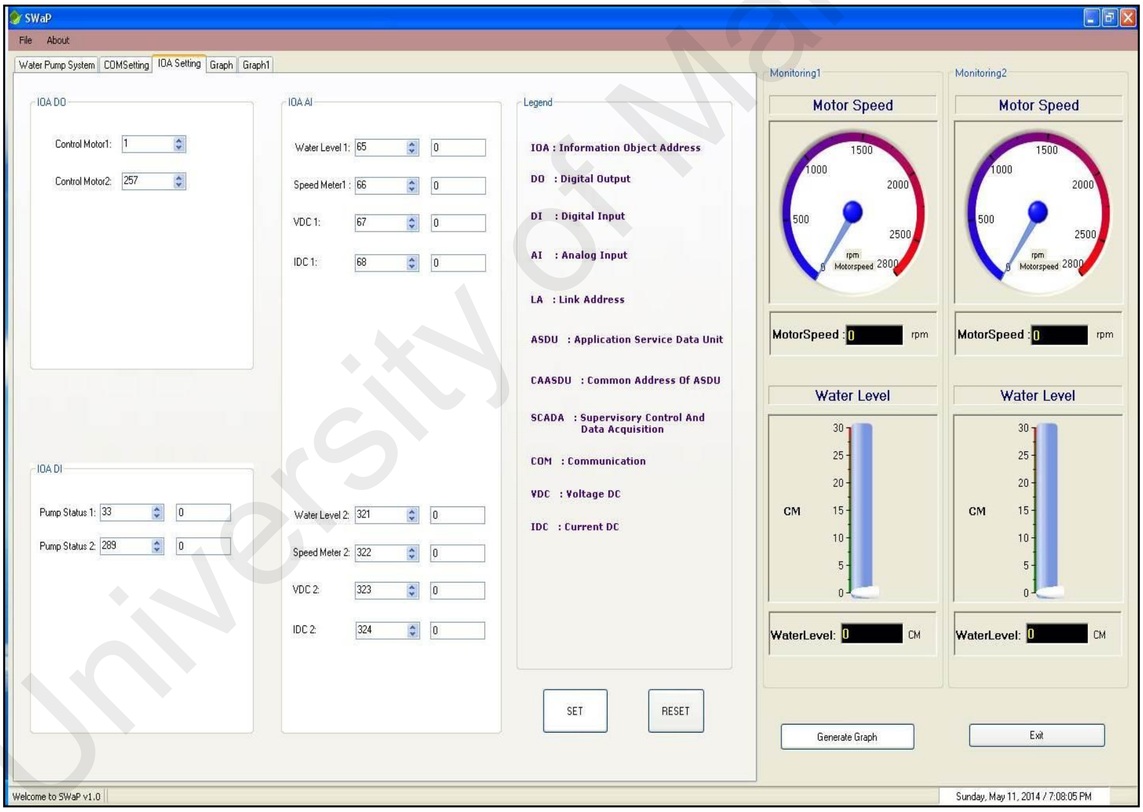


Figure 3.27: IOA Setting

4 & 5. Graph of condition monitoring of water-pump system

Data received from the RTU is shown in graphical form. In addition, data can also be saved in the form of an excel file by right-clicking on the graph and then press the save button. Figure 3.28 shows five graph i.e. voltage input, current input, power input, induction motor's speed and water level. Based on this graphs user can assess the condition of the system and determine the next action.

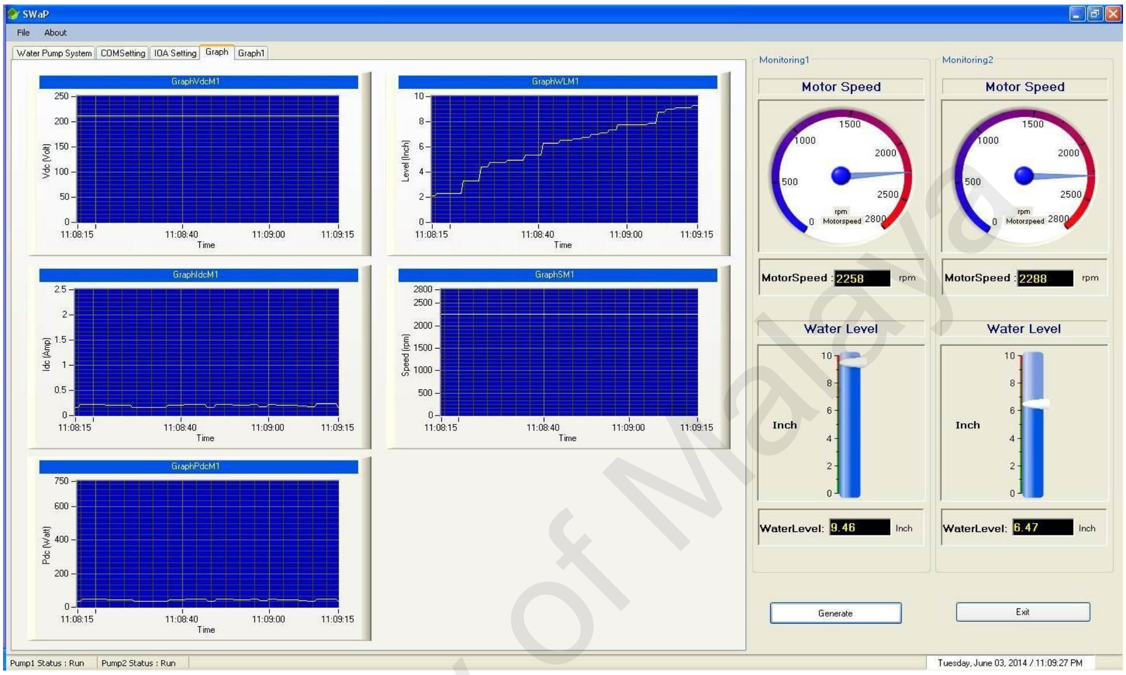


Figure 3.28: Graph Data

CHAPTER 4: EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Introduction

The experimental setup diagram, hardware and software configuration that has been discussed in the previous chapter is integrated and implemented for the water-pump system in real time mode. The system is tested and verified experimentally. This chapter presents the experiment result and its discussion.

The first experiment verified the performance and response of the induction motor and motor driver via real-time data captured by the measurement tools, Overall experiment result is taken with close-loop V/f operating condition. The next experiment verified the performance and response of water-pump system captured by the master system GUI and also by the measurement tools. The results of both measurements were then compared to verify data validity, via errors captured and data lost. The experiment used real water tank and break load to verify data.

4.2 Three-Phase Induction Motor Drive Performance

This session presents the experiment result of 3-phase induction motor drive system. Overall experiment result is taken with close-loop V/f operating condition. The experiment at this stage includes taking graphs SVPWM is the output of the DSP, then the measurement at the inverter output. All these experiments were measured using an oscilloscope.

4.2.1 Three Phase SVPWM Signal Switching

In this experiment, for capturing the waveform a program has been created for SVPWM signal in C language on DSP controller, and the output can be obtained at PWM 7-9 pin. Each pin is applied to three gate drivers in order to increase the signal amplitude. The outputs of gate drivers have to be filtered by using a simple low-pass-filter circuit. The output of low-pass-filter is an analogue signal and it is connected to the Tektronix oscilloscope TDS2024B.

Figure 4.1 shows SVPWM switching signal in yellow graph, and to prove it true or not was used low-pas-filter filter to see the shape of the resulting signal. Signal 2 is graph of SVPWM after filter.

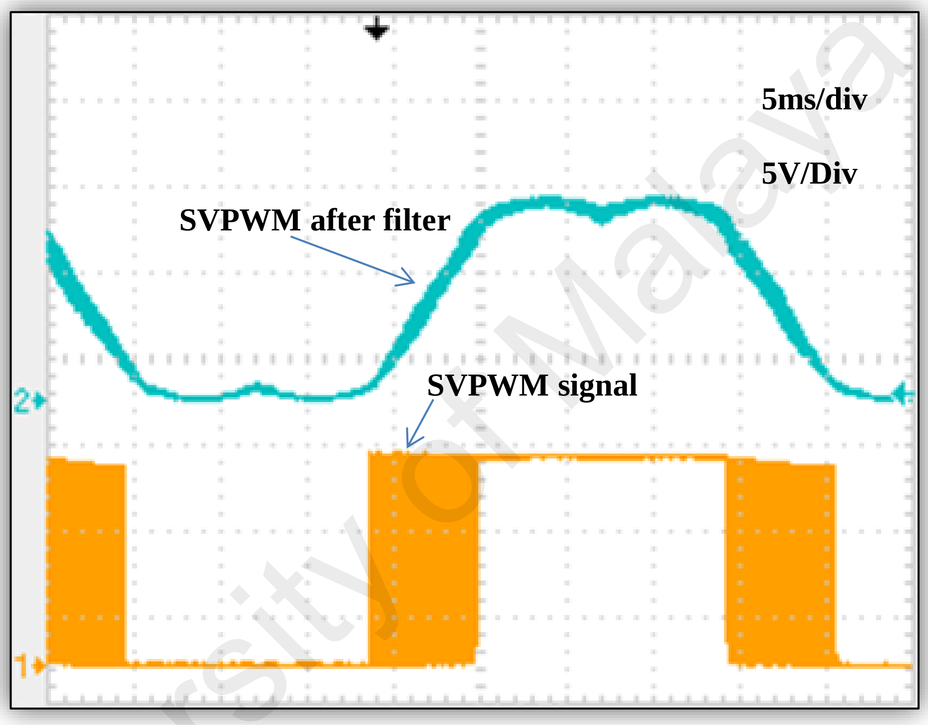


Figure 4.1: SVPWM Signal Switching

Figure 4.1obtained the basic step to drive the AC motor. It looks exactly SVPWM signal generated in accordance with the theory.

In Figure 4.2 shows the SVPWM to drive a 3-phase VSI inverter. Each signal SVPWM the same shape but different in phase angle. After this step, the signal generated from the DSP can already connect to a 3-phase inverter.

4.2.2 Voltage and Current output of 3 Phase VSI

Figure 4.3 shows the line-line voltage of the inverter output at 300 VDC of DC-link voltage in a steady state condition. During system operation, the auto-transformer output voltage is increased gradually up to 300 V of DC-link is obtained across the single-phase rectifier's output terminal. This step is useful to limit the inrush-current during the charging time of capacitor in the start-up period. The line current also shown.

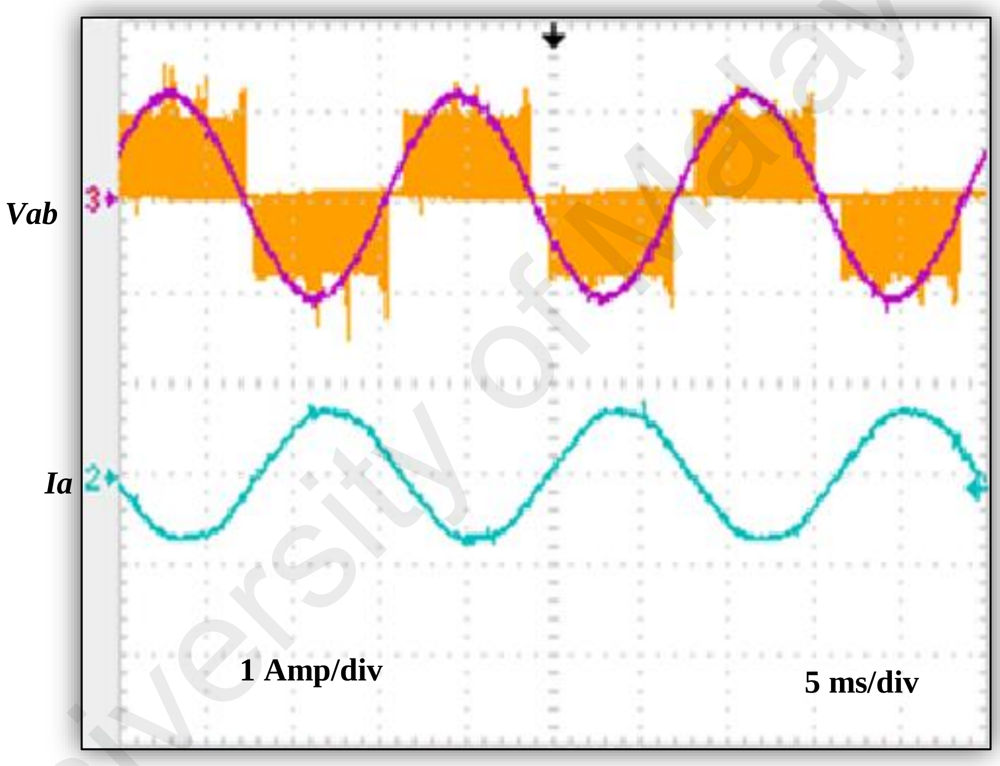


Figure 4.3:Inverter Vout and Ia

Figure 4.4 shows smooth Vac, Ia, Ib, dan Ic, Each current has 120 phase differences.

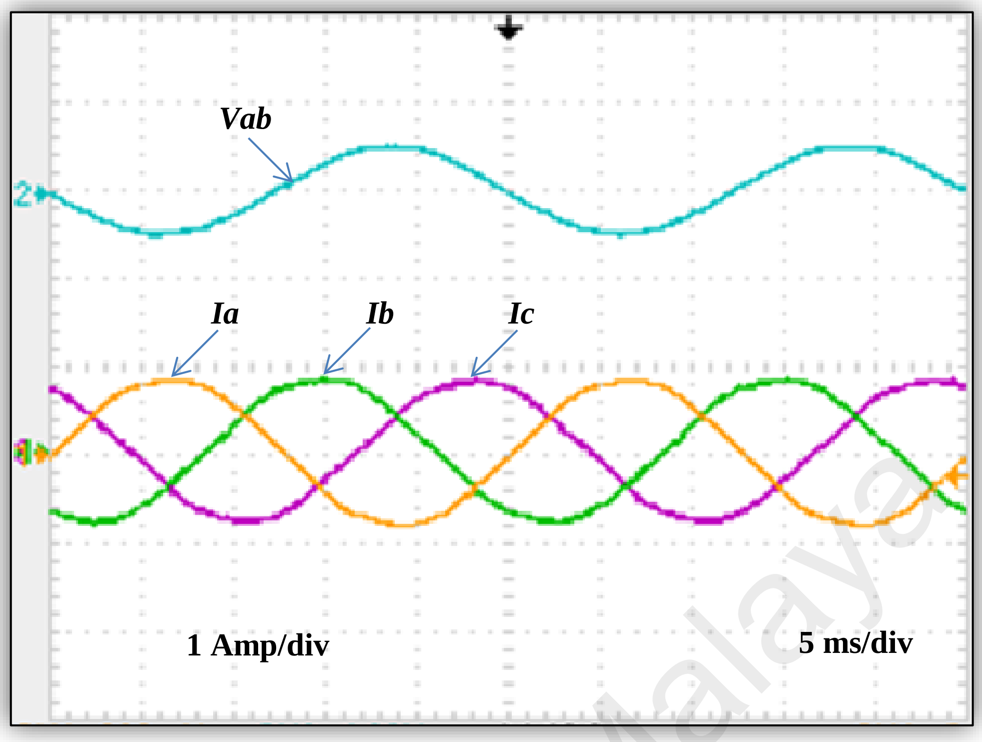


Figure 4.4: Vout and Ia, Ib, Ic

4.3 Speed Step-response

This experiment was conducted for the performance observation of the speed and current motor when the step response of speed reference is applied in the motor drive system. The motor drive system is run at load condition, and the speed reference is changed by keying in the new value of speed reference value in the "watch window" of code composer studio software.

In the Figure 4.5, the motor speed is reduced from 1800 to 700 rpm of speed. During the deceleration, the actual speed decrease gradually with 1100 rpm. The same response is also seen in the phase stator current profile. For acceleration, the motor is accelerated suddenly to standstill, as shown in Figure 4.6

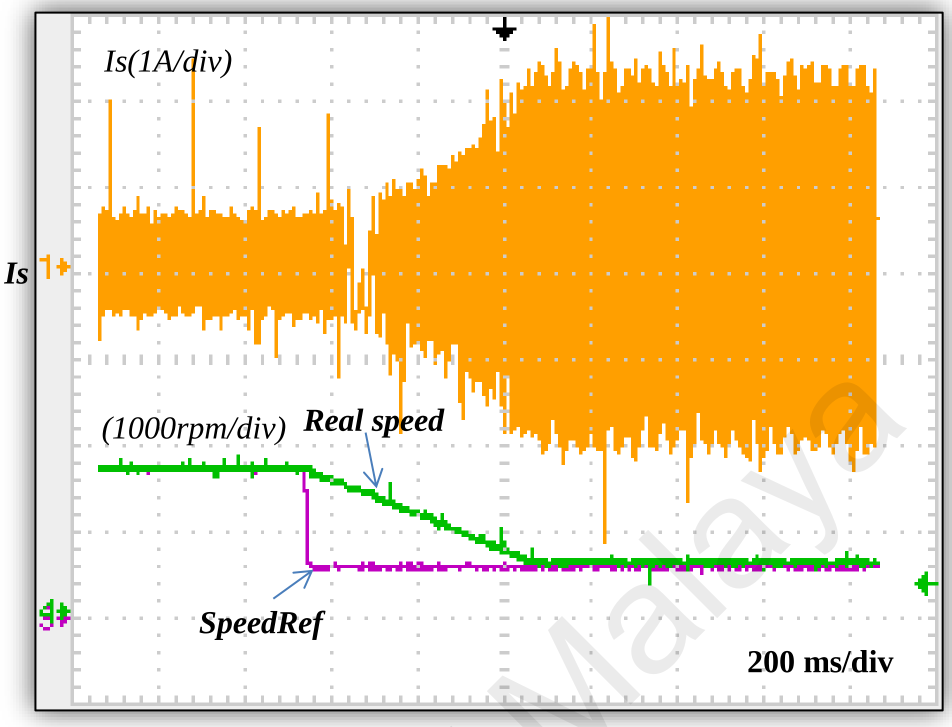


Figure 4.5: Current and Speed Response when SpeedRef decreased

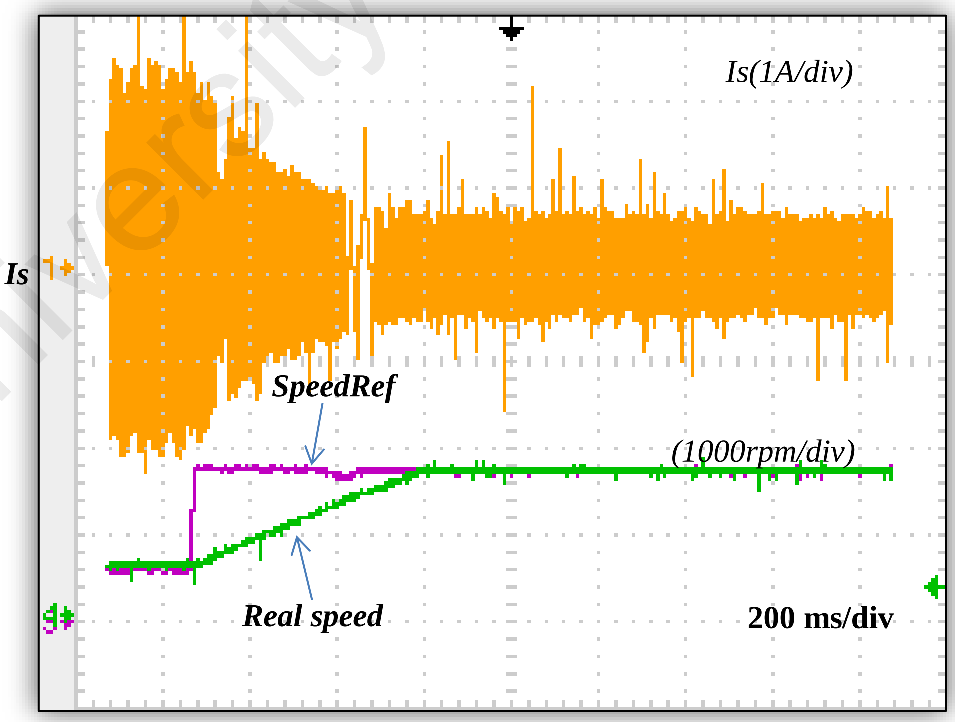


Figure 4.6: Current and Speed Response when Speed increased

In the Figure 4.7 are shows the stator current and the actual speed response when speedref is varied. The motor speed varied from; 1500 rpm to 1000 rpm to 400 rpm to 1500 rpm.

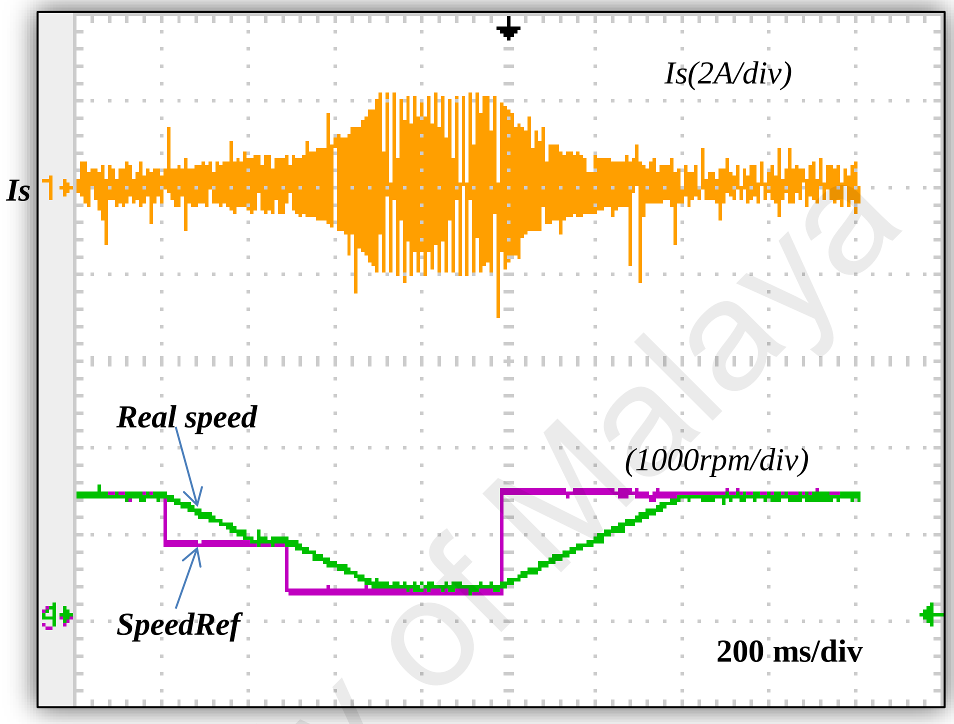


Figure 4.7: Current and Speed Response vs. Various SpeedRef

4.4 Speed and Current response when control via SCADA

Controls implemented by sending the command via GUI, this software send Digital Output control by using IEC 101 frame format. Table 4.1 is the data that is displayed in the transceiver data monitor on the GUI software.

Table 4.1: DO Frame Format of IEC101

no	data	Frame format
1	68	Start (variable)
2	0B	Length
3	0B	Length
4	68	Start
5	08	Control
6	01	LA
7	00	LA
8	2E	Type ID
9	01	VSQ
10	49	COT
11	04	CAASDU
12	00	CAASDU
13	01	IOA
14	00	IOA
15	82	Data
16	08	Checksum
17	16	Stop

This data is flexible; it depends on the settings RTU address, pin IO address, and other settings. In the master system, all of RTU setting must be same.

In the Figure 4.9 and Figure 4.10 are shown current and speed response when GUI send control's command. A data frame containing the DO data is sent to the RTU via serial communication, RTU activate the relay on the DO card then generates a signal. This signal is connected to the motor drive to run the pump as shown in Figure 4.8. The graph below (Figure 4.9), the signal number 2 is the signal generated by the RTU.

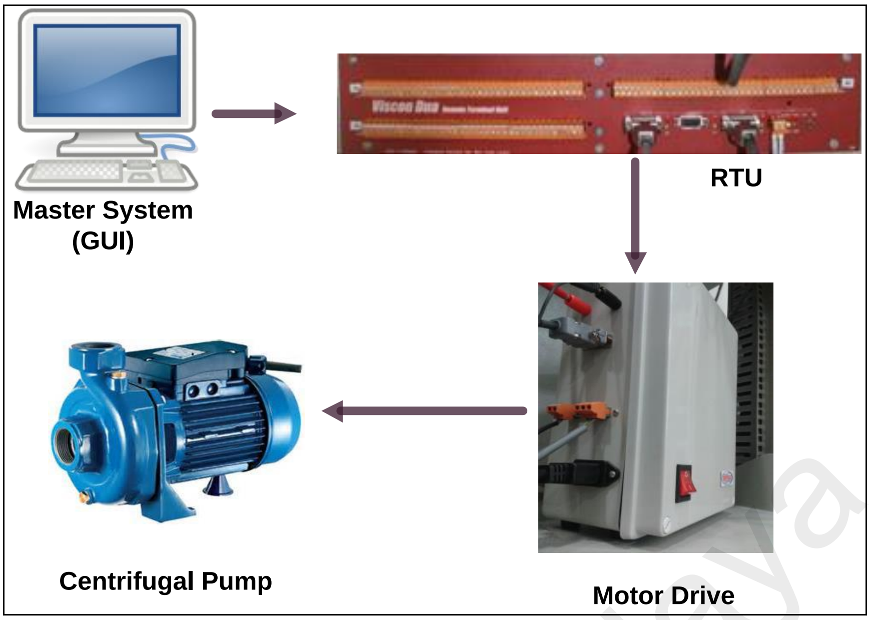


Figure 4.8: Control process

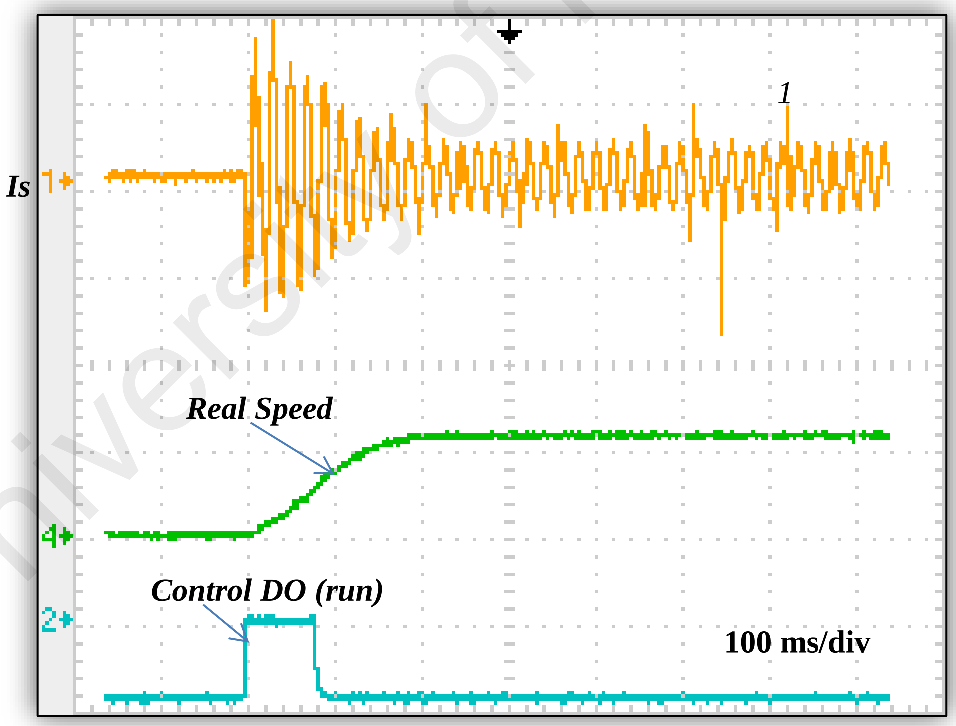


Figure 4.9: Current and Speed Response when Motor's Start

In the Figure 4.9, show the current become high in the beginning of control sent, then slowly down toward stability. Whereas speed response rising smoothly until steady state. Stability at speed obtained from the PI controller.

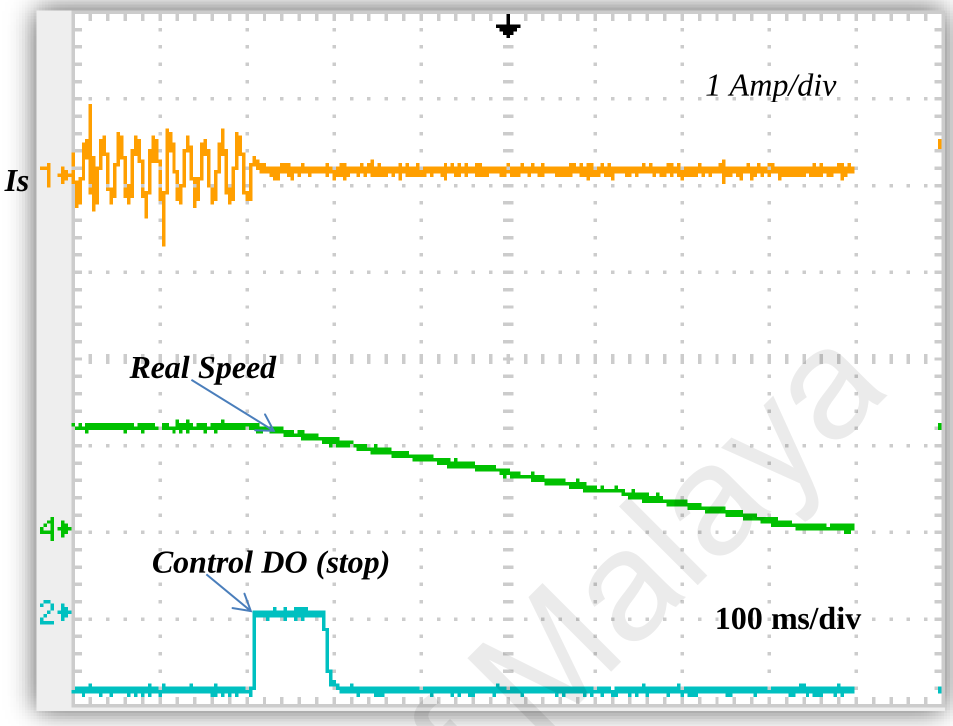


Figure 4.10: Current and Speed Response when Motor's Stop

In the Figure 4.10 show current stator and speed response when the motor stops by giving the control signal to stop via SCADA to the motor driver. The SVPWM signal will stop when DSP received the signal from RTU. The real speed graph the graph does not seem to stop instantaneously due to the experiment there is without load.

4.5 SCADA-based measurement via GUI

The experimental verifies the feasibility of SCADA system in remote monitoring system. The computer as master system was installed with GUI. Figure 4.11 shows the results of graphical interfacing. Graphical data includes; Vdc, Idc, Pin, motor speed, water level. Numerical values of the data were listed on measurement are saved on excel data (see Figure 4.12).

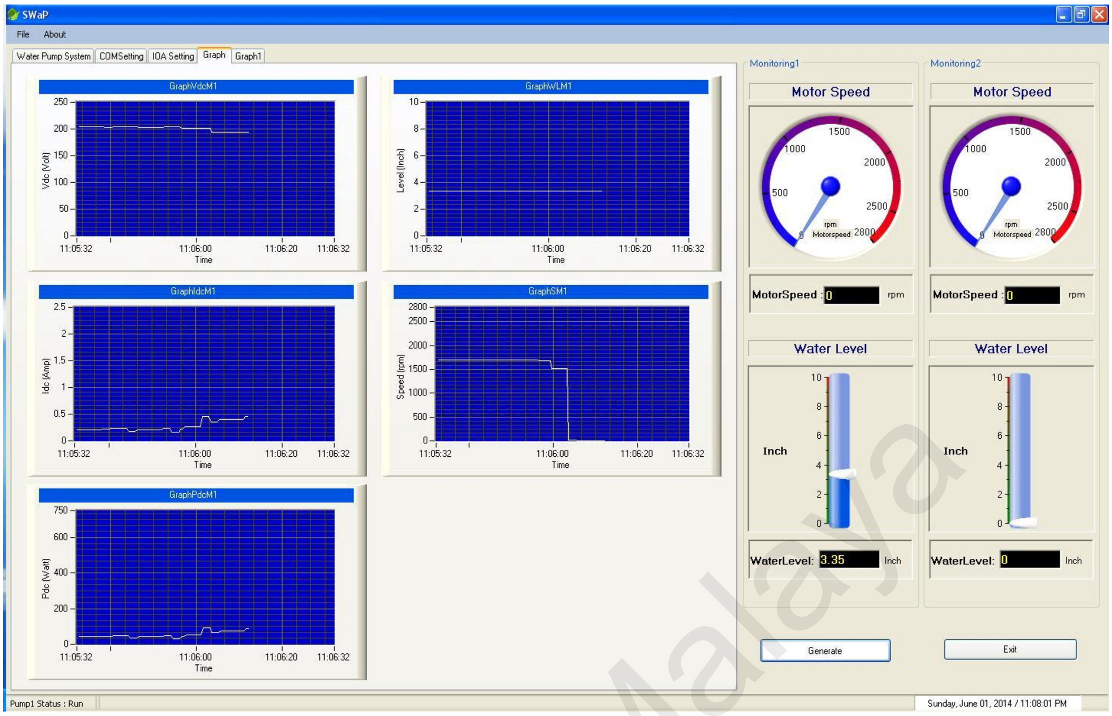
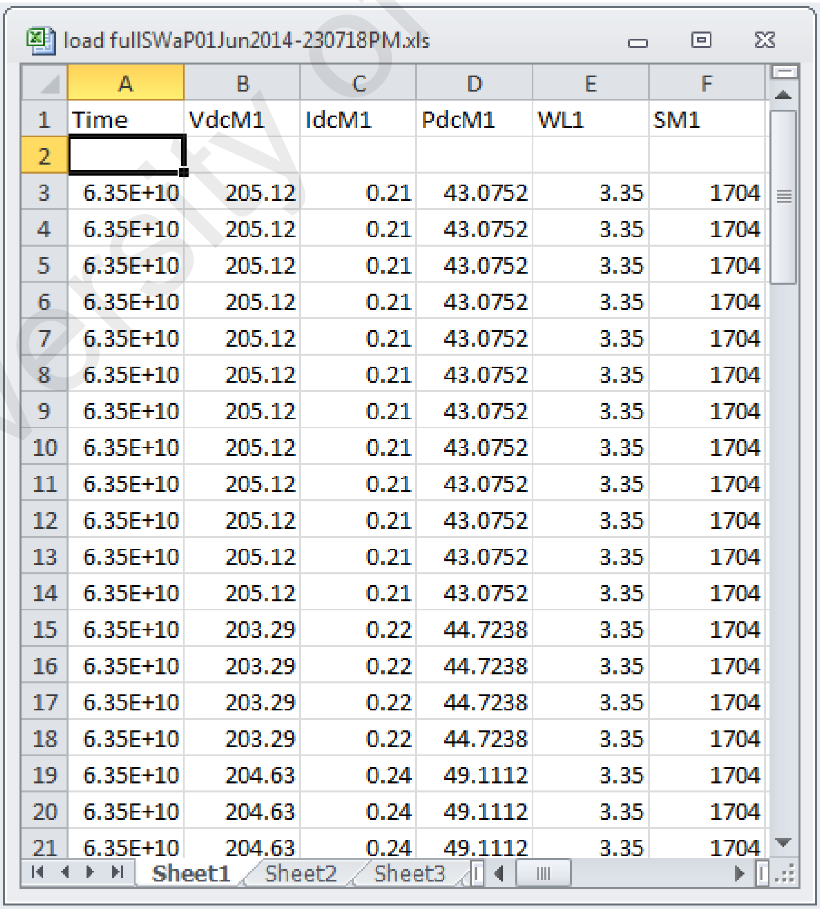


Figure 4.11: Measurement via GUI


load fullSWaP01Jun2014-230718PM.xls

	A	B	C	D	E	F
1	Time	VdcM1	IdcM1	PdcM1	WL1	SM1
2						
3	6.35E+10	205.12	0.21	43.0752	3.35	1704
4	6.35E+10	205.12	0.21	43.0752	3.35	1704
5	6.35E+10	205.12	0.21	43.0752	3.35	1704
6	6.35E+10	205.12	0.21	43.0752	3.35	1704
7	6.35E+10	205.12	0.21	43.0752	3.35	1704
8	6.35E+10	205.12	0.21	43.0752	3.35	1704
9	6.35E+10	205.12	0.21	43.0752	3.35	1704
10	6.35E+10	205.12	0.21	43.0752	3.35	1704
11	6.35E+10	205.12	0.21	43.0752	3.35	1704
12	6.35E+10	205.12	0.21	43.0752	3.35	1704
13	6.35E+10	205.12	0.21	43.0752	3.35	1704
14	6.35E+10	205.12	0.21	43.0752	3.35	1704
15	6.35E+10	203.29	0.22	44.7238	3.35	1704
16	6.35E+10	203.29	0.22	44.7238	3.35	1704
17	6.35E+10	203.29	0.22	44.7238	3.35	1704
18	6.35E+10	203.29	0.22	44.7238	3.35	1704
19	6.35E+10	204.63	0.24	49.1112	3.35	1704
20	6.35E+10	204.63	0.24	49.1112	3.35	1704
21	6.35E+10	204.63	0.24	49.1112	3.35	1704

Sheet1 Sheet2 Sheet3

Figure 4.12: Water-pump system data measurement

The experiment shows the monitoring system display capturing important data from the water-pump system. Data of induction motor and water-level had been monitored in real-time. The experiments verify the feasibility of a SCADA implementation. The results show that SCADA system can be implemented in the monitoring of water-pump system.

Figure 4.13 shows speed and power response when the pump full loads. The motor speed declined to zero. Whereas the power input was increases. This condition could be a signal for fault detection. The motor stops within 1.9 seconds.

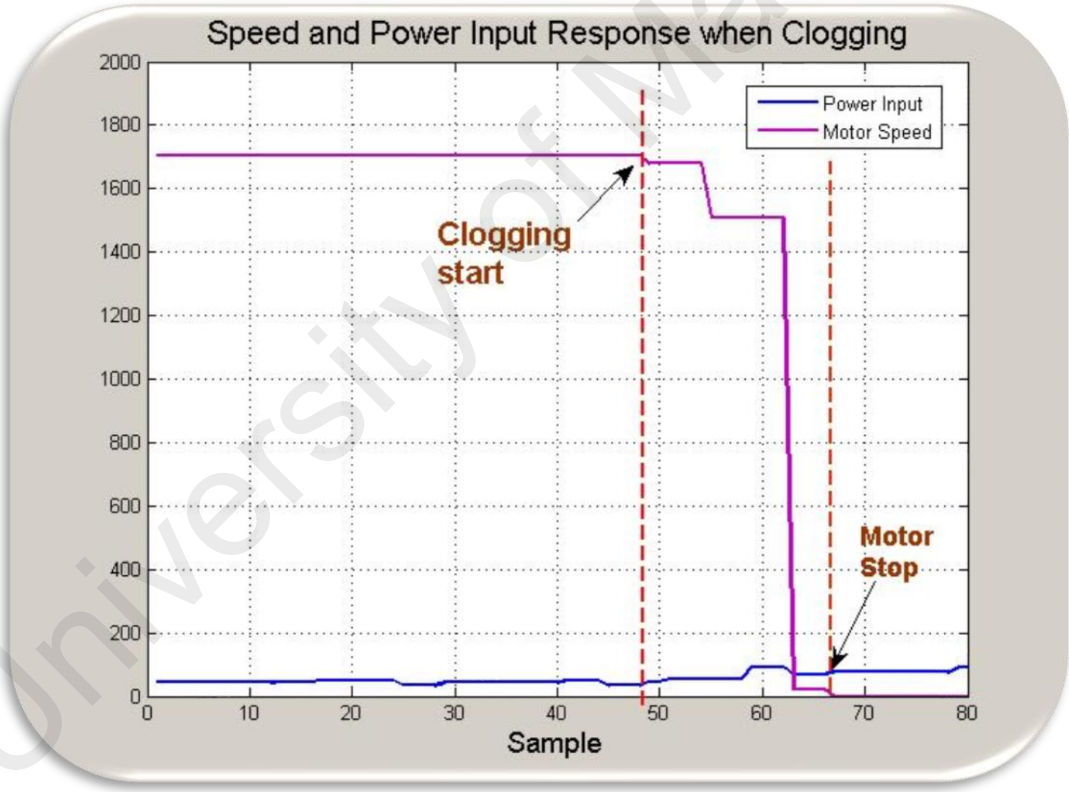


Figure 4.13: Speed and Power Response when Clogging

4.6 Data comparison between measurement tool and SCADA

The experiment is to verify the error occurring during data capture by the SCADA and the measurement tool. The hardware and software of the monitoring system are configured to run simultaneously, the speed captured by oscilloscope in

Figure 4.14 and GUI show in Figure 4.15 . Both of the captured data are re-plotted on one graph to verify the error percentage calculation as shown in Figure 4.16.

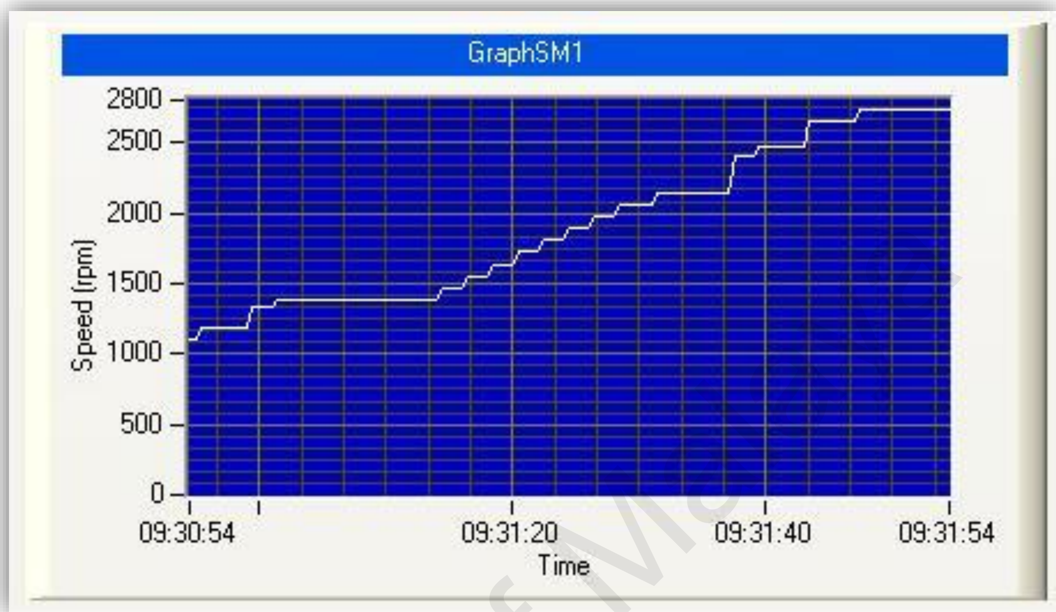


Figure 4.15: Graph of motor's speed via SCADA

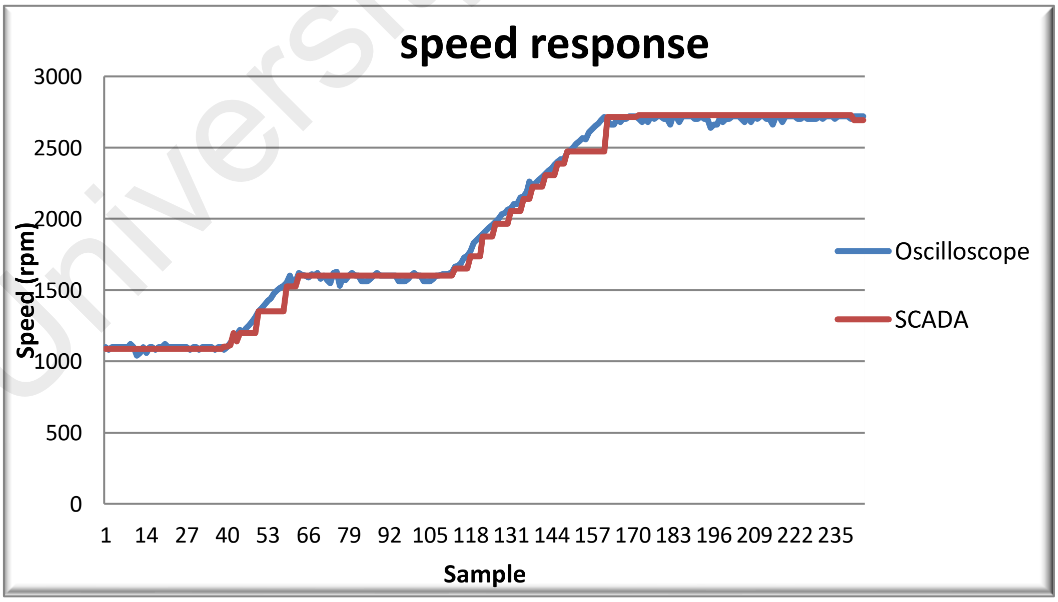


Figure 4.16 speed response

Figure 4.16 shows speed response mode. The speed patterns of oscilloscope and GUI look identical, but ripple and delay appears when the graph of each plotted together. The graph of oscilloscope measurement more ripples than GUI but smalls. The signal of GUI measurement is delayed, because need communication time.

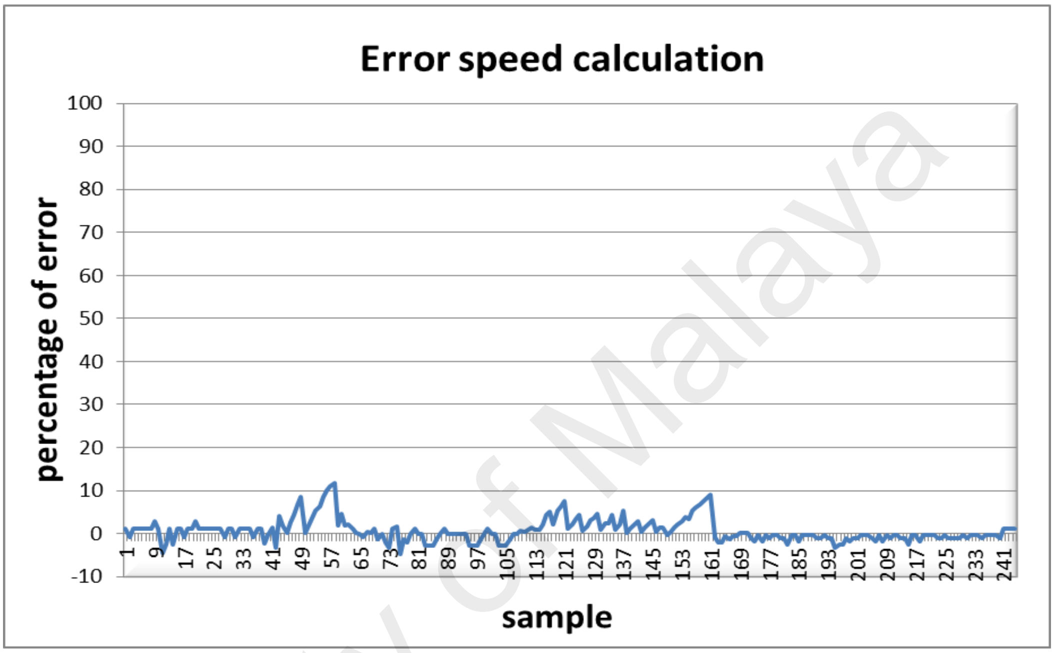


Figure 4.17 Error speed calculation

Figure 5.17 show percentage of speed errors in speed tests for oscilloscope and SCADA. The average of error is calculated by conventional statistical method. The value is 1.81 %. The equation of the average is:

$$M = \left(\frac{1}{n} \sum_{t=1}^{n} \left| \frac{Mo_t - Ms_t}{Mo_t} \right| \right) \times 100\%$$

M = mean absolute percentage error

n = no of sample

Mo = measurement by using oscilloscope

Ms = measurement by using SCADA

CHAPTER 5: CONCLUSION AND FUTURE WORK

5.1 Conclusion

The first objective of the study was to develop hardware and embedded system for 3 phase Induction motor water pump drives. The hardware has been tested and worked properly. PI control and V/Hz strategy run as expected, induction motors can spin well when connected to this hardware.

The second objective of this study was to develop SCADA Master System Application software for Central Supervisory Station via Visual Basic.net based on IEC 60870-5-101 Standard Protocol. The software have been successfully used as a tool to monitor and control the pump that displays animation, graph data and store data in excel file, then allow the user to control the pump from this GUI. The software is special because it has been using international industry standards for the part of its communication protocol (IEC 101), but simplifies the piece of software because it the designed according to the needs of this system only.

The third objective of this study was to validate SCADA implementation in remote control and real-time monitoring of water pump systems based on IEC 60870-5-101 standard protocol. After the system was tested, and compare the data obtained by using the oscilloscope was found the average error is 1.81 %.

Successful experimental results were obtained from the previously described scheme indicating that SCADA System with IEC 60870-5-101 standard protocol can be used in remote and on-line monitoring for water pump system.

5.2 Future Work

The configuration with new multilevel hierarchical has been developed in this work. Separation of controller for motor driver with monitoring system is necessary as described in this study. Future study needs to add Internet of Thing (IoT) and cloud on the hierarchical configurations. Therefore, it is easy to add new plant in the existing system.

The availability of data from the motor drives system and from the plant by using the configuration in this thesis can be used as a reference for analyze big data and adding automation controls such as predictive or fuzzy controls for further study.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

Journal :

1. Journal of Engineering Research, Submitted in 24 April 2017 “Implementation of SCADA system on monitoring and distributed control of water-pumps system”. (ISI Cited Publication-Q4)

Conferences :

1. Power and Energy Conversion Symposium (PECS 2014), Melaka, Malaysia, 12 May 2014, “SCADA-Based Remote and On-line Monitoring of Water-Pump System”.
2. IET International Conference on Clean Energy & Technologies (CEAT 2014), Kuching Serawak, Malaysia, 24^{th}-26^{th} November 2014,“Implementation of IEC 60870-5-101 Protocol on Condition Monitoring of Water Pump”.