AC to AC Converter using Sinusoidal Pulse Width Modulation (SPWM) Technique Controlled using Digital Signal Processor (DSP)

Mohd Rizal Bin Mustaffa
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
Email : mrizal2602@gmail.com

Abstract— **This paper presents the DSP design for control implementation of AC to AC converter connected to single phase AC motor. Sinusoidal Pulse Width Modulation (SPWM) technique is used to synthesis the output voltage and efficiencies of the motor by reducing its harmonics. Two insulated gate bipolar transistors (IGBT) are used as the power switching devices. The SPWM and switching circuit are simulated by using MALTAB/SIMULINK tools consists of AC voltage supply, IGBT switches and single phase asynchronous machine. The final output observed by measuring the rotor speed (rad/s) and the electromagnetic torque (Nm). A Digital Signal Processor (DSP) model no. TMS320F2812 was used as the heart of the control electronic implemented to verify operation of the converter. The converter connected to induction motor as the load with C filter with switching frequency of 10 kHz.**

Keywords- sinusoidal pulse-width modulation (SPWM), MATLAB, Harmonic Distortion, insulated gate bipolar transistor (IGBT), real time workshop (RTW), Digital Signal Processor (DSP)

I. INTRODUCTION

AC to AC power converters usually serve the function of changing the frequency and amplitude of the available AC supply voltage to satisfy load requirements. They are used to link AC power systems, to provide variable frequency supplies for AC motor drives and to generate constant frequency power from the output of variable speed AC generators. AC to AC power converters can be classified to three types: those that employ an intermediate DC link (rectifier – inverter arrangements), those that employ an intermediate AC link (high frequency link or base converter arrangements) [1], [2] and those that perform the power converting function in a single stage. The family of direct AC to AC converters are often referred to as frequency changers because of their primary function is usually the conversion of AC power of one frequency to AC power of another frequency.

There is probably a lot of single-phase AC motors in use today. For the household application such as table fan, the capacitor-start induction motor is used. The popularity of these motors is mainly due to their low costs, simple construction, and reliability. The analysis of shaded pole motors has received attention from many researchers during the last 50 years ago. Trickey published the earliest theoretical analysis of the shaded pole induction motor. He had come out with the fundamental circuit analysis and derives the equation for performance calculation. The equations have been used in the determination of the efficiency of the motor, [3], [4].

This paper presents the implementation of the DSP design on controlling the speed of the rotor. The switching technique used is Sinusoidal Pulse Width Modulation technique (SPWM) which is to control the ON and OFF of the IGBTs. SPWM technique is among the most powerful techniques that offer a simple method for controlling of analog systems with the processor's digital output [5]. With the availability of low cost high performance Digital Signal Processor (DSP) chips characterized by the execution of most instructions in one instruction cycle, complicated control algorithm can be executed with fast speed and making very high sampling rate [6]. The technique applied to a proposed converter circuit which connected to the induction motor. The analysis of the induction motor is determined from the rotor speed.

II. SINGLE PHASE INDUCTION MOTOR USING DIRECT AC SUPPLY

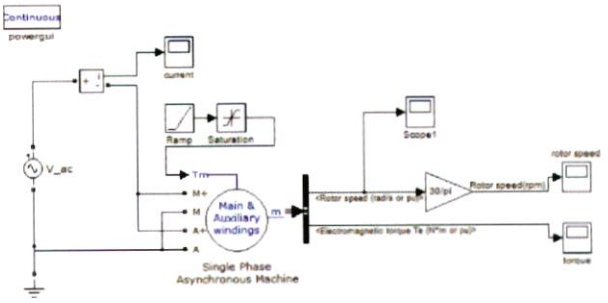


FIGURE 2.1 Direct supply

In this case, the single phase AC motor is connected directly to input supply (AC voltage source). The circuit is shown in Figure 2.1. Figure 2.2 and Figure 2.3 shows the simulation results for the rotor speed (rpm) and electromagnetic torque (Nm) by using frequency of 50 Hz.

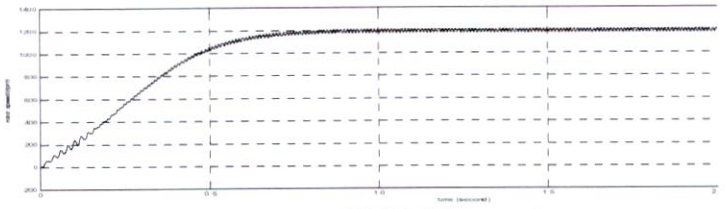


FIGURE 2.2 Rotor speed

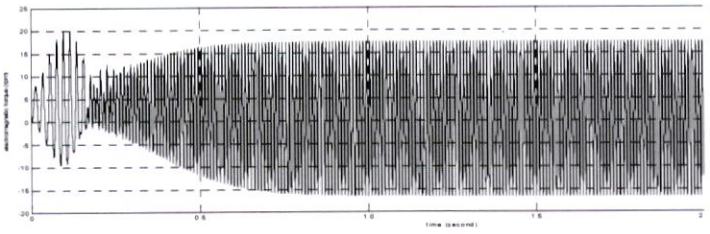


FIGURE 2.3 Electromagnetic torque

III. PROPOSED DESIGN FOR SINGLE PHASE AC TO AC CONVERTER

AC motors are commonly used for the household application. As an example, for table fan, the capacitor-start phase induction motor is used. The popularity of these motors is mainly due to their low costs, simple construction and reliability. For the proposed design, the motor is connected to single phase AC to AC converter which is using two insulated gate bipolar transistor (IGBT). These two IGBT are controlled by using Sinusoidal Pulse Width Modulation (SPWM) technique. Figure 3.1 shows the flow chart for the process in this design.

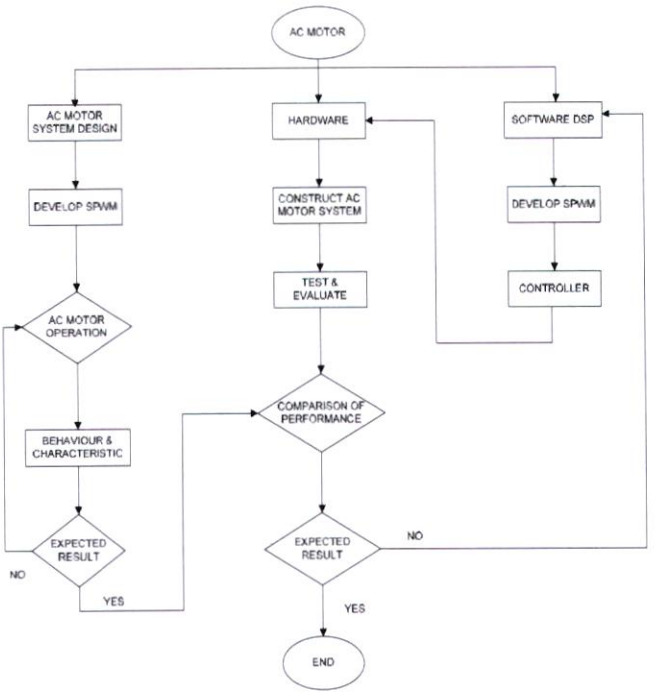


FIGURE 3.1 Flow Chart

Figure 3.1 shows the steps that need to be done to complete this design. Some of the steps are:

I. Developing the Sinusoidal Pulse Width Modulation (SPWM) signal to be injected to the main circuit.
II. Design the full circuit for AC to AC converter.
III. Simulate the designed circuit by using MATLAB SIMULINK and the result observed.
IV. Analysis the output result and THD obtained.

A. Sinusoidal pulse-width modulation (SPWM)

SPWM (Sinusoidal Pulse Width Modulation) waves are commonly used in the control of frequency conversion and test system. With the SPWM technique widely used in the control of frequency conversion and Test System, the shape of the SPWM waveform takes more and more attention. In common, SPWM waves can be adjustable in dead time and frequency of carrier signals and modulation signals. But nowadays in some special test systems, SPWM waves rising/falling time is also an important role which cannot be ignored.[7]. SPWM is a technology of inverter-controlled which uses the desired sine waves as modulation waveform and uses triangle (or saw tooth) waves whose frequency is N times of the modulation waves as the carrier waveform [8]. SPWM control signal is decided by sinusoidal modulation waves and carrier triangular point of intersection. SPWM is a common waveform improvement with good control and regulation performance. Its principle is simple, versatility and

it can eliminate harmonics, regulate and stable the output voltage and so on.

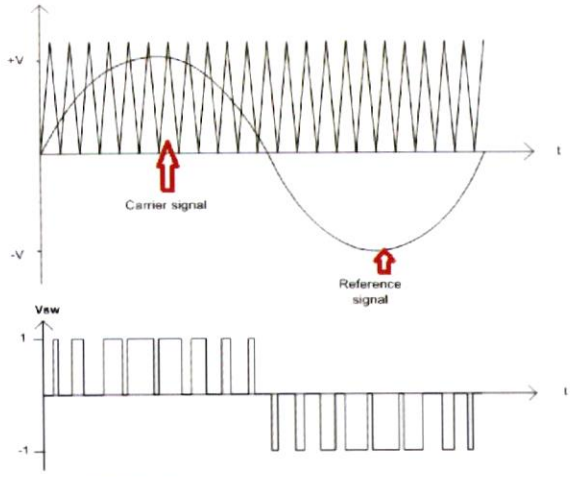


FIGURE 3.2 SPWM Modulation signal

One of the techniques that can be used in order to improve the performance and speed control of AC motor is SPWM current control. This technique can control the current that will be injected to the system. In this project, SPWM current-mode control technique with filter inductor current instantaneously controlled is proposed. The current in the inductor includes both filter capacitor current and load current.[9]

In the designing of SPWM, 2 signals are injected that is sine wave and repeating signal. The SPWM signal has two parts that are positive cycle and negative cycle. The signals are separated into two which is the positive cycle injected into IGBT 1 and the negative cycle injected into IGBT 2.

B. Switching strategies

TABLE I Switching Characteristics

Switch	Positive cycle	Negative cycle
IGBT 1	ON	OFF
IGBT 2	OFF	ON

Table I shows the operation of the converter. During the positive cycle, the switch IGBT 1 will turn ON while switch IGBT 2 will OFF. The current flows from the supply to IGBT1 and the load. During the negative cycle, the switch IGBT 1 will turn OFF and switch IGBT 2 will turn ON. The flow is shown in Figure 3.3 for positive cycle and Figure 3.4 for negative cycle. To turn ON and OFF of the switch, it is depends on the SPWM signal that been injected at the gate of the IGBT.

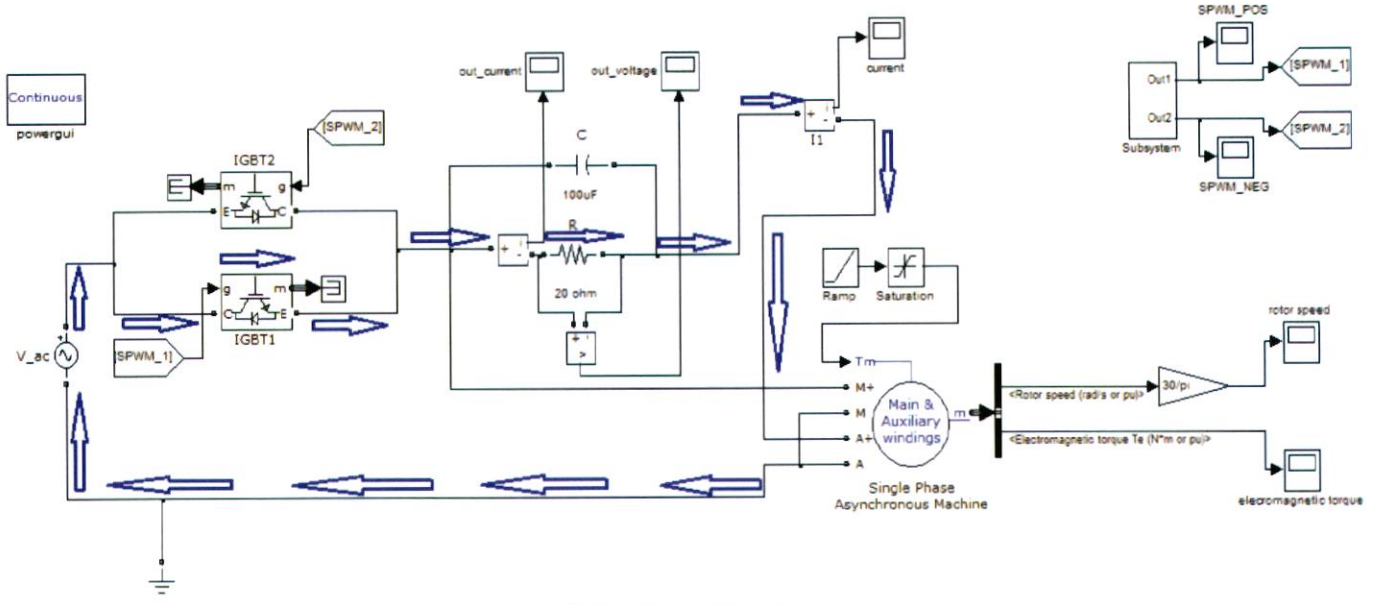


FIGURE 3.3 Positive Cycle

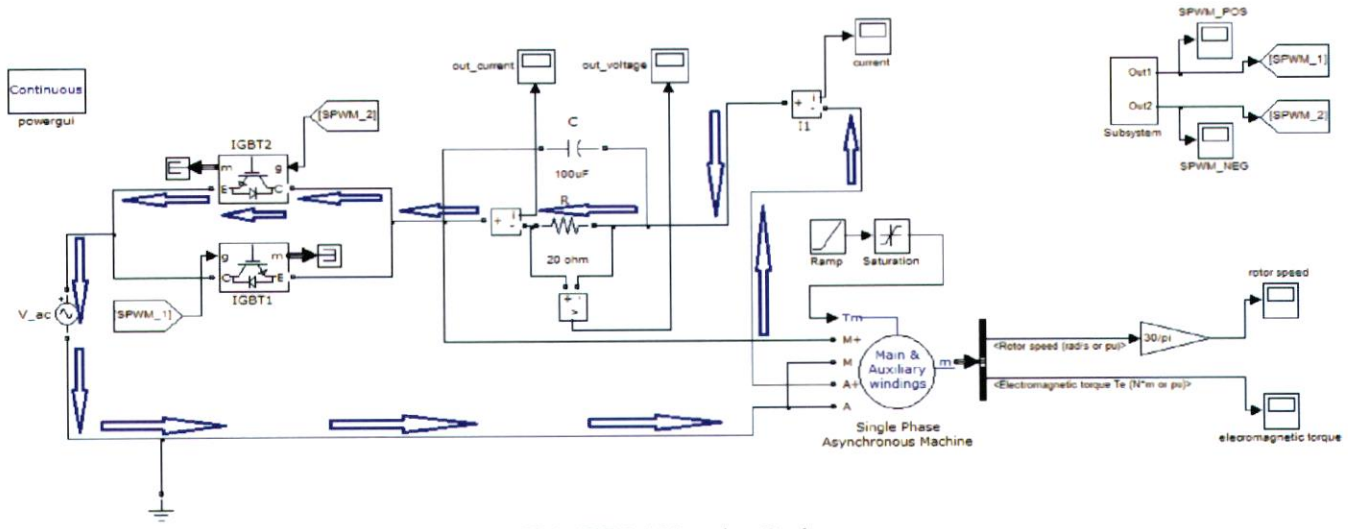


FIGURE 3.4 Negative Cycle

IV. MODELLING AND SIMULATION

AC to AC converter is the main circuit in the supplying input to the AC motor. In this design, there are two IGBTs used as the switch of the converter. The 230 V is injected to the circuit which contains R load, AC motor and C filter.

TABLE II Circuit Parameters

Parameters	Value
Voltage source, V_s	230 V
Switching frequency, f_s	10 kHz
Modulation index, M_a	0.95
Resistor, R1	20 Ω
Capacitor, C1	100 μF

Figure 4.1 shows the circuit for AC to AC converter. The circuit contains AC voltage source, IGBT switches, AC motor and electronic components. Table II shows the parameters that used in the design circuit. The capacitor, C1 is used as the filter in order to get the low total harmonic distortion, THD.

For the second simulation part, the motor load is removed and the V_{AC} is reduced to the 20V and 50V. The result from this part will be compared with the hardware result. Figure 4.2 shows the circuit for the AC to AC converter without the AC motor.

For develop the SPWM signals, the circuit for SPWM modulation have been design. The circuit shown in Figure 4.3 which is contains sine wave, repeating sequence, relational operator and pulse generator. The repeating sequence used to generate arbitrarily shaped periodic signal which is will cooperated with sinusoidal wave that generated by sine wave1 and sine wave2 in the block diagram. Pulse generator is used to generate the square wave pulses at regular intervals which are to determine the shape of the output waveform. The AC motor system designed and the SPWM technique is develops to control the operation of the AC motor. This process has been done by using MATLAB SIMULINK. MATLAB is a high-level language and interactive environment that enable to perform computationally intensive tasks faster than traditionally programming language such as C++. SIMULINK is a software package for modeling, simulating and analyzing dynamical system. It supports linear and non-linear systems, modeled in continuous time, sample time or a hybrid of the two. Once the simulation has been done, the behavior and characteristic of the AC motor are observed. The DSP controller software is used to generate the SPWM. This SPWM will be used as the controller of the IGBT switches, [10]. The purpose of using SPWM is to control the turn ON and turn OFF of the IGBT 1 and IGBT 2. By using logic signal '0' as OFF state and '1' as ON state, it will decide which IGBT will turn ON and OFF.

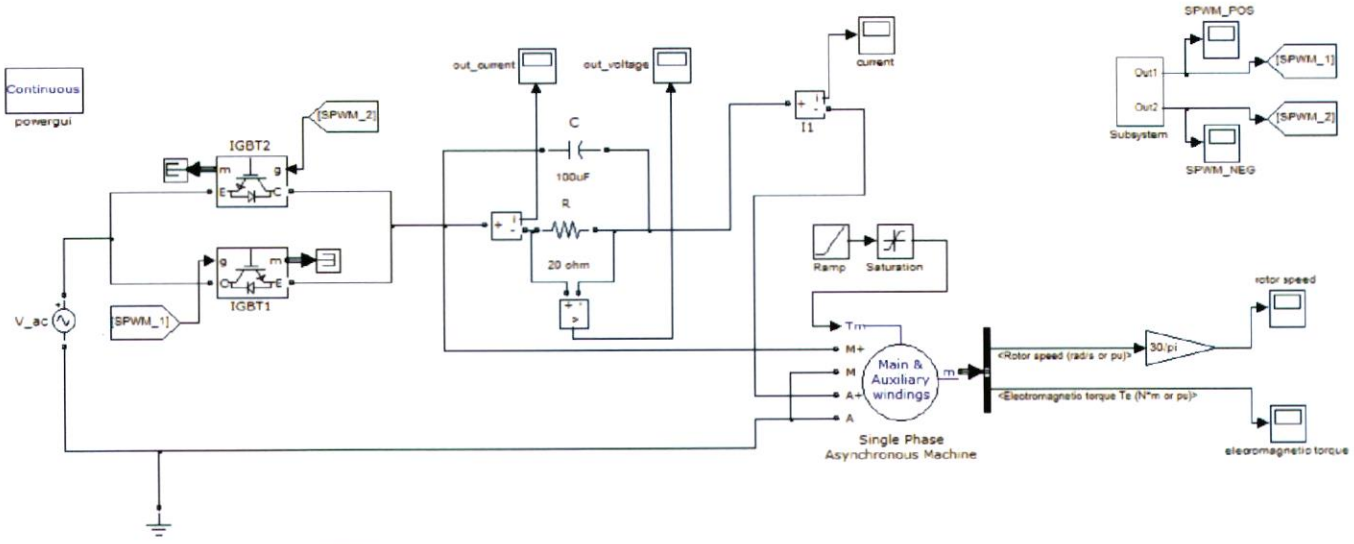


FIGURE 4.1 AC to AC converter circuit with R load and AC motor

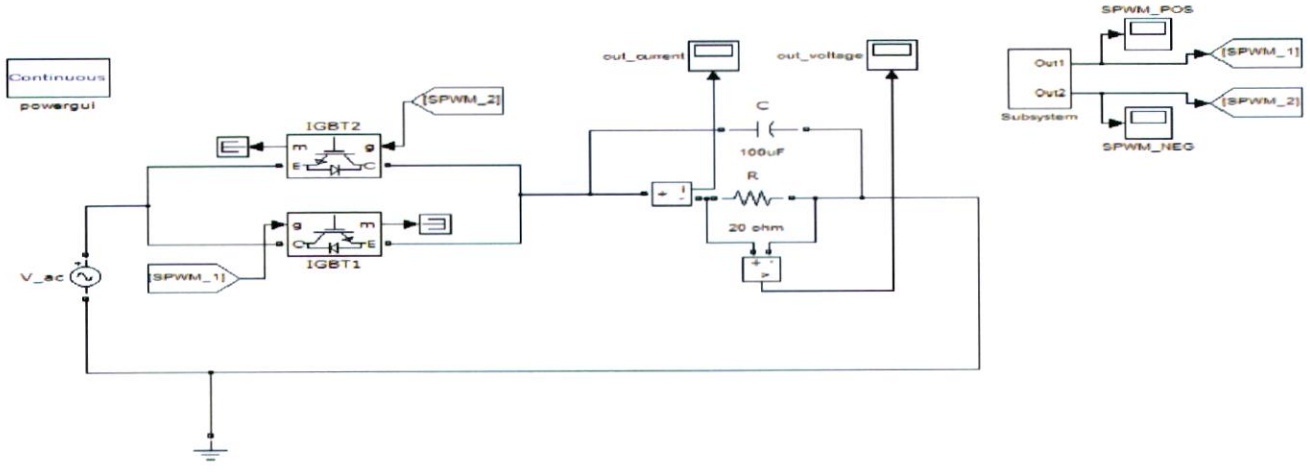


FIGURE 4.2 AC to AC converter circuit with R load

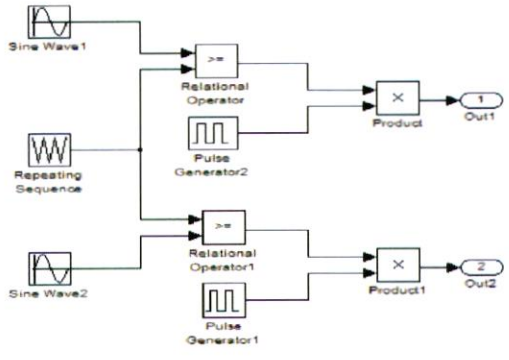


FIGURE 4.3 SPWM modulation circuit

V. HARDWARE IMPLEMENTATION

A. DSP implementation

Texas Instruments TMS320 F2812 DSP is the best suited to this study for DSP based application development and is used to generate PWM signals. The control algorithm is developed in MATLAB/SIMULINK using block diagram, the code is generated with Real Time Workshop (RTW) and compiled, debugged and transferred to DSP board in Code Composer Studio (CCS). eZdsp F2812 DSP board is used for PWM control application [11]. The application of the PWM algorithm requires a time reference, a comparison mechanism

and digital outputs. Event Manager Modules of the DSP have the General Purpose (GP) Timer that can be used as time reference, Full Compare/PWM Units as a comparison mechanism and have dedicated digital PWM outputs.

There are two event manager modules in TMS320 F2812 called EVA and EVB. TMS320 F2812 has six independent pairs of PWM outputs which is three of are controlled by EVA and the other three controlled by EVB. There are two general purpose (GP) timers can work independently from each other. GP timer 1 and 2 are controlled by EVA and GP timer 3 and 4 are controlled by EVB. These timers are used to provide a time base for the operation of compare units and associated PWM circuits to generate the PWM outputs. Figure 5.1 shows the SIMULINK model for PWM controller. The model consists of a sine wave block, a data conversion unit and F2812 eZdsp board. The sine wave block provide a sine reference signal of the same frequency, amplitude and phase as that of the signal of interest [12].

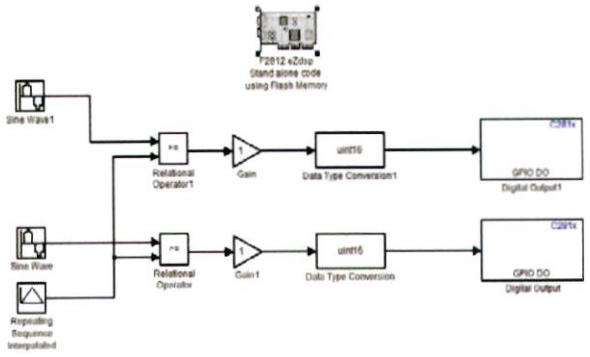


FIGURE 5.1 Simulink Model

1) Code generation process

In this study, the SPWM is developed by using MATLAB/SIMULINK and experiments are performed by using DSP board. The sine wave block provides a sine reference signal of the same frequency, amplitude and phase as that of the signal of interest. The sine wave generates signal in double data type and data type conversion is needed. C28x SPWM generates the SPWM signals by comparing the sine wave with the carrier signal. This block enables us to activate one of the event manager modules EVA or EVB to generate the carrier signal waveforms.

2) Running the software

To run the DSP software, the Real Time Workshop (RTW) will generate the source code of the model. The generated code from RTW should be compiled in Code Composer Studio (CCS) and loaded to DSP by the CCS. When the program is started from CCS, program sets the initial values of DSP board. After initializing the DSP board, initial values of the model are sets. When initialization is finished, program starts to generate the SPWM output signals. Figure 5.2 and Figure 5.3 show the flow for the DSP implementation and the DSP board.

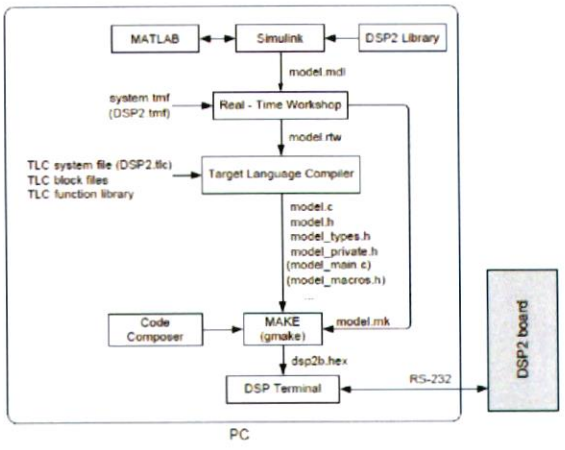


FIGURE 5.2 DSP implementation flow

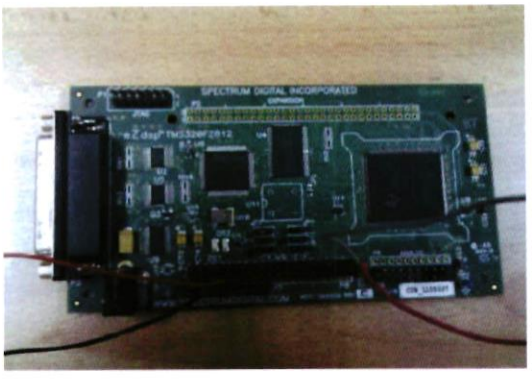


FIGURE 5.3 DSP board

B. *Hardware implementation*

For the hardware part, the load connected is only R load and the filter used is C filter. For the supply voltages, two values of voltage sources injected to the circuit that are 20V and 50V. As the output of the hardware part, the current and the voltage waveforms are observed and then the total harmonic distortions (THD) for both waveforms are measured. The output waveforms recorded from the oscilloscope that has been connected to the isolator.

VI. RESULT AND DISCUSSION

From the simulation part, the signals of SPWM for both positive and negative cycles have been obtained based on the SPWM modulation circuit. The signals obtained then injected to the IGBTs.

A. *Simulation Result*

1. SPWM signal

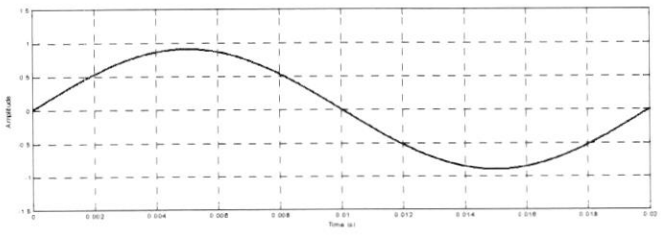


FIGURE 6.1 Positive Sinusoidal Waveform

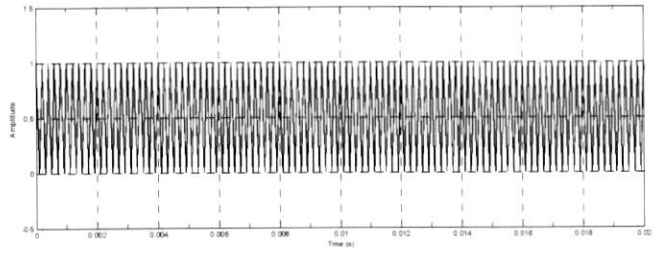


FIGURE 6.2 Repeating Signal

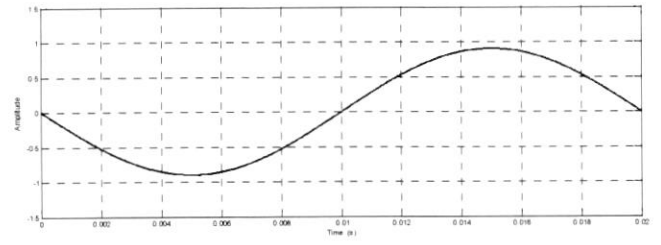


FIGURE 6.3 Negative Sinusoidal Waveform

There are three input signals injected to develop the SPWM signals. The signals are two sinusoidal waveforms that are positive sinusoidal waveform (Figure 6.1) and negative sinusoidal waveform (Figure 6.3) and one repeating signal (Figure 6.2). The repeating signal is determined from the switching frequency used. For this design, the switching signal used is 10 kHz. The positive sinusoidal waveform is needed to get the positive signal of SPWM and the negative sinusoidal waveform to get the negative signal of SPWM.

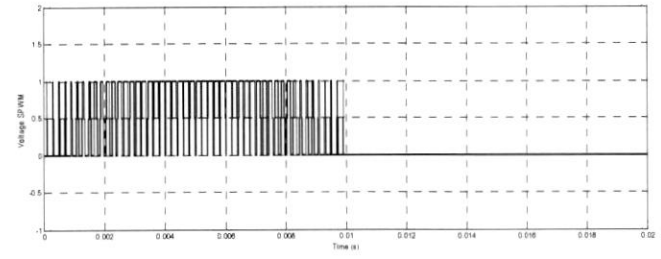


FIGURE 6.4 Positive Cycle SPWM Signal

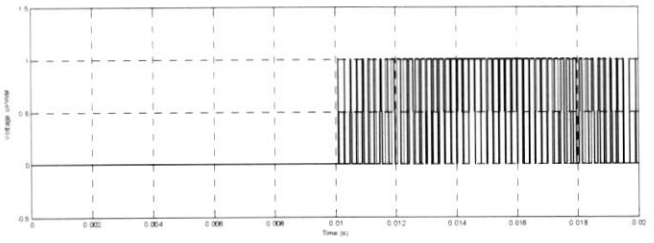


FIGURE 6.5 Negative Cycle SPWM Signal

From the combination of sinusoidal waveforms and the repeating signal, the positive sinusoidal waveform will form positive SPWM signal which is shown in Figure 6.4 and the negative cycle from combination of negative sinusoidal waveform and repeating signal will form negative SPWM signal which is shown in Figure 6.5. The positive cycle of SPWM used to turn on IGBT 1 while negative cycle used to turn on IGBT 2. For the designing of the SPWM signal, the parameters that have been used are:

I. Switching frequency, f_{sw} = 10 kHz
II. Modulation Index, m_a = 0.95

2. Output waveforms

For the output waveforms, the first simulation used 230 V as the voltage supply with connected to R load and AC motor. The waveform for the output voltage is shown in Figure 6.6 and the waveform for the output current is shown in Figure 6.7. From the AC motor that connected to the circuit, the rotor speed and the electromagnetic torque had been obtained. The rotor speed is shown in Figure 6.8 and the electromagnetic torque is shown in Figure 6.9.

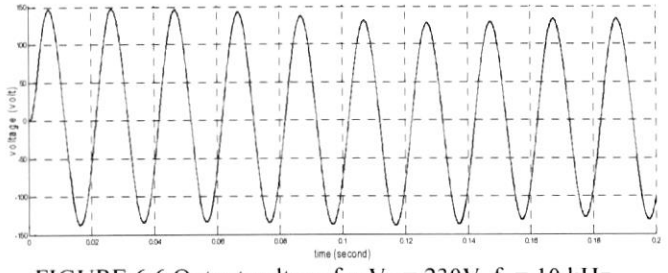


FIGURE 6.6 Output voltage for V_S = 230V, f_s = 10 kHz, m_a= 0.95

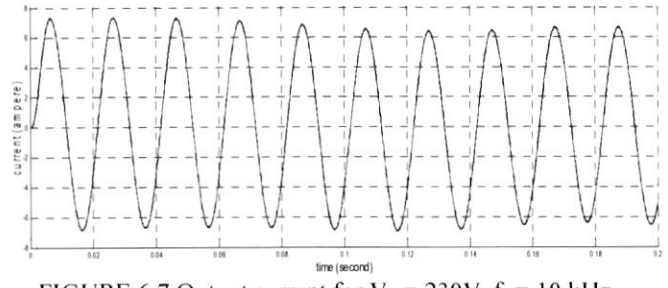


FIGURE 6.7 Output current for V_S = 230V, f_s = 10 kHz, m_a = 0.95

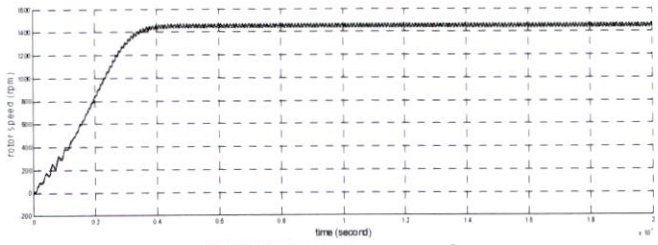


FIGURE 6.8 Rotor peed

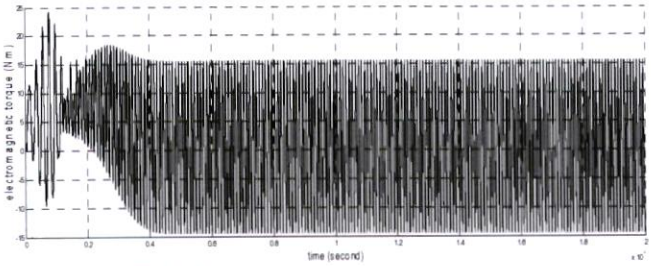


FIGURE 6.9 Electromagnetic torque

From the output voltage and output current, the total harmonic distortion (THD) had been obtained. The measured THD of the output current and output voltage are both 0.93%. The THD for the voltage and current are shown in Figure 6.10 and 6.11 respectively. Since the THD for the current is lower than 10% and output voltage is lower than 5%, it is considered that the losses is very low. Hence it will improve the efficiencies of the operation of the motor.

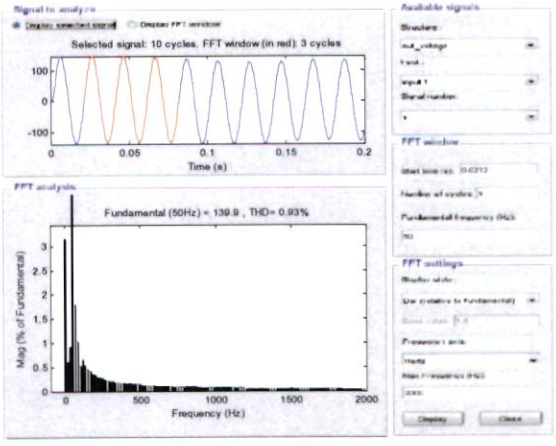


FIGURE 6.10 THD for output voltage

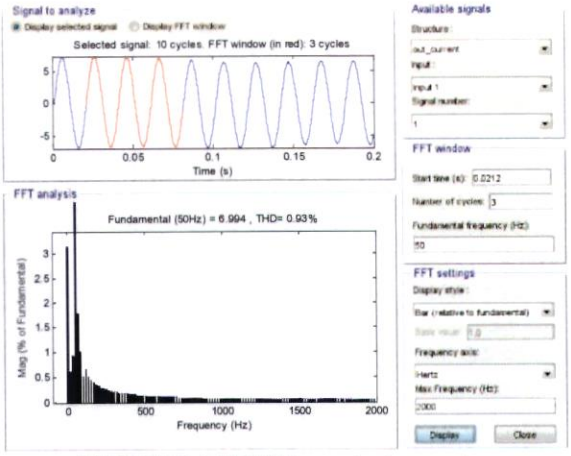


FIGURE 6.11 THD for output current

Figure 6.12 shows the rotor speed of the induction motor for the direct supply circuit and Figure 6.13 shows the rotor speed for the proposed design circuit. The simulation time for both circuits are set to 2. From the waveform observed, it can be seen that for the direct supply circuit, the time taken to reach its steady state is longer than the proposed design circuit. The top speed of the proposed design also is higher than the direct supply design although the input voltage supply and switching frequency for both design are same that is 230 V and 10 kHz.

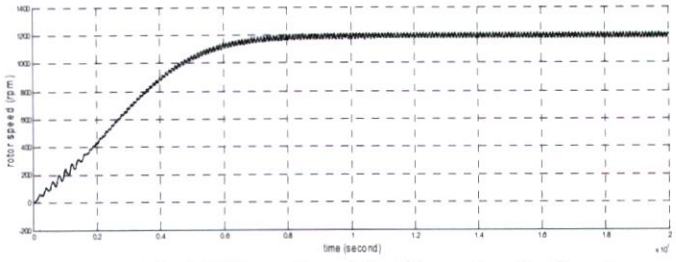


FIGURE 6.12 Rotor Speed for Direct Supply Circuit

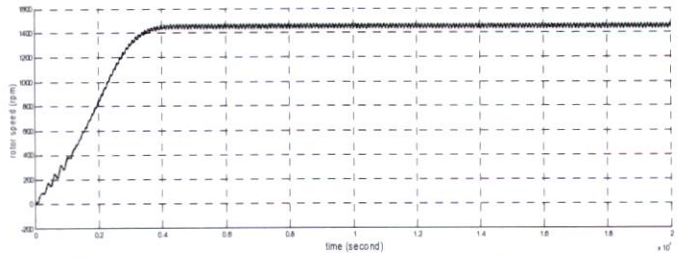


FIGURE 6.13 Rotor Speed for Proposed Design Circuit

For the second simulation, the load connected is only R load without the AC motor. The supply source connected is 20V. Figure 6.14 shows the output voltage waveform and Figure 6.15 shows the output current waveform.

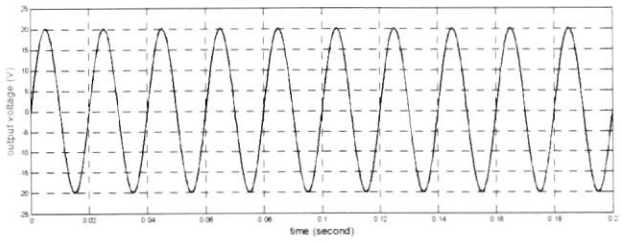


FIGURE 6.14 Output voltage for V_S = 20V, f_s = 10 kHz, m_a = 0.95

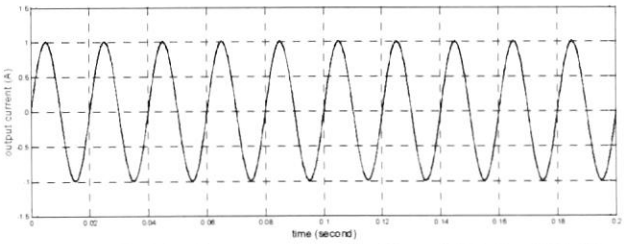


FIGURE 6.15 Output current for V_S = 20V, f_s = 10 kHz, m_a = 0.95

The THD for both of the output voltage and output current are shown in Figure 6.16 and 6.17 respectively.

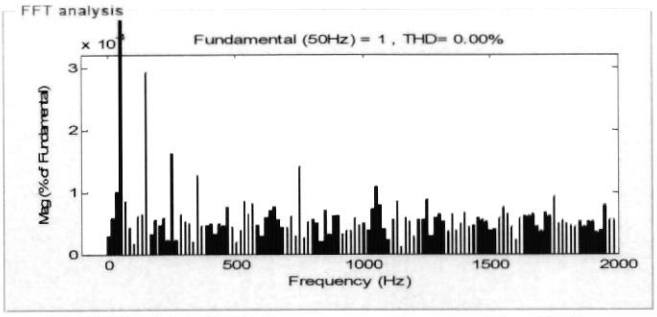


FIGURE 6.16 THD for output voltage for V_S = 20V, f_s = 10 kHz, m_a = 0.95

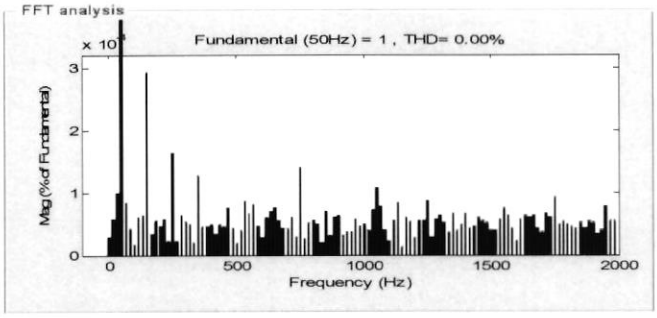


FIGURE 6.17 THD for output current for V_S = 20V f_s = 10 kHz, m_a = 0.95

For the third simulation part, the load connected still the R load without the AC motor but this time, the supply source increased to 50V. Figure 6.18 shows the output voltage waveform and Figure 6.19 shows the output current waveform.

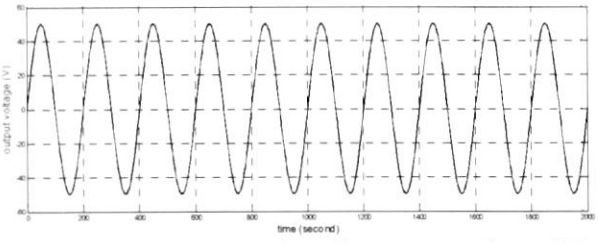


FIGURE 6.18 Output voltage for V_S = 50V, f_s = 10 kHz, m_a = 0.95

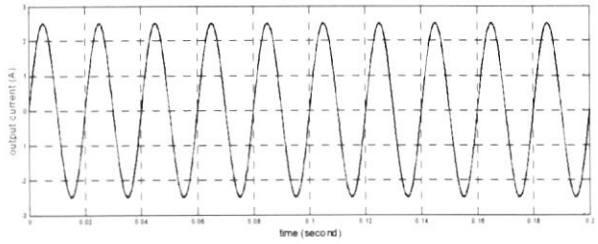


FIGURE 6.19 Output current for V_S = 50V, f_s = 10 kHz, m_a = 0.95

The THD for these output voltage and current waveforms are shown in Figure 6.20 and 6.21 respectively.

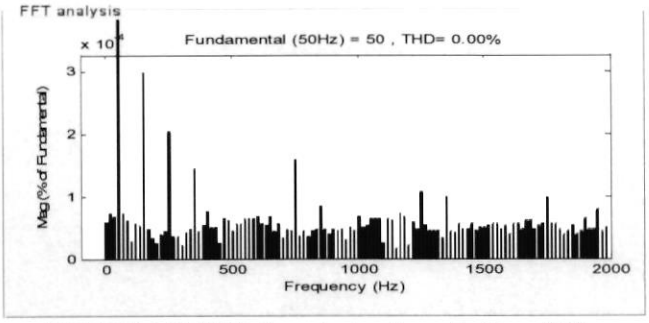


FIGURE 6.20 THD for output voltage for V_S = 50V, f_s = 10 kHz, m_a = 0.95

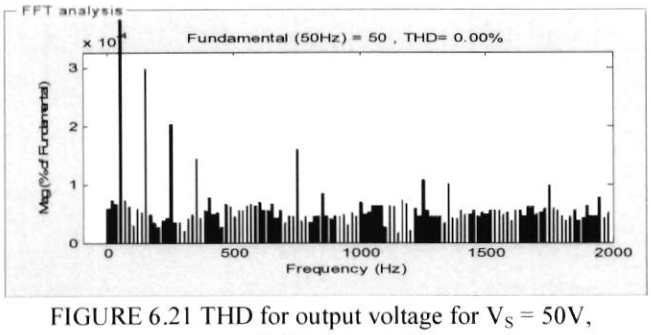


FIGURE 6.21 THD for output voltage for V_S = 50V, f_s = 10 kHz, m_a = 0.95

B. *Experimental result*

The designed AC converter circuit has been tested experimentally and the switching scheme is implemented by using DSP model TMS320F2812. The result that obtained from the DSP controller board is recorded by using digital storage oscilloscope. Figure 6.22 shows the signals that generated by the DSP board. Figure 6.23 shows the shape for one of the SPWM signals generated by the DSP controller board. By using DSP controller, the modulation circuit is used to generate the SPWM signal to be injected into the gate of the IGBTs.

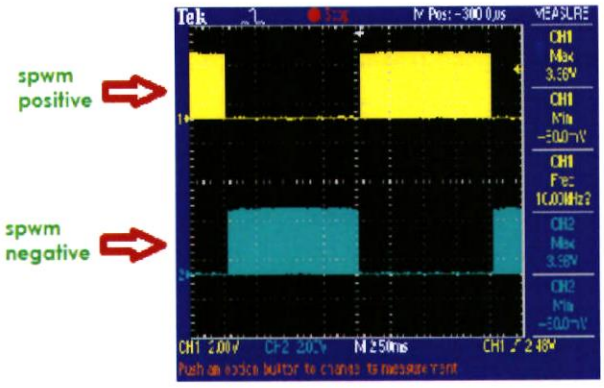


FIGURE 6.22 SPWM signals

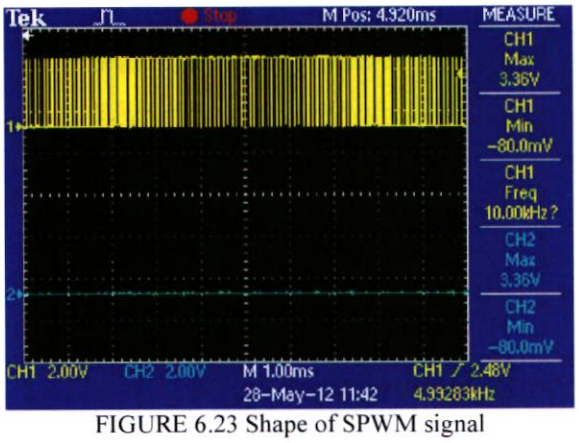


FIGURE 6.23 Shape of SPWM signal

For the hardware part of the AC converter circuit, the load used only the R load without connected to the AC motor. The supply sources used to connect to the AC converter circuit are 20V and 50V. The waveforms for the output voltage and output current have shown in figure 6.24 and 6.25.

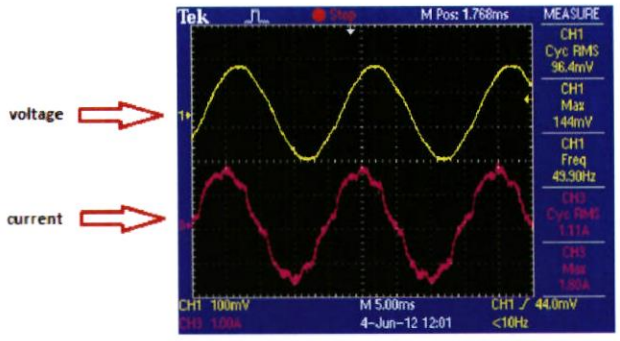


FIGURE 6.24 Output voltage and output current for V_S = 20V, fs = 10 kHz, mi = 0.95

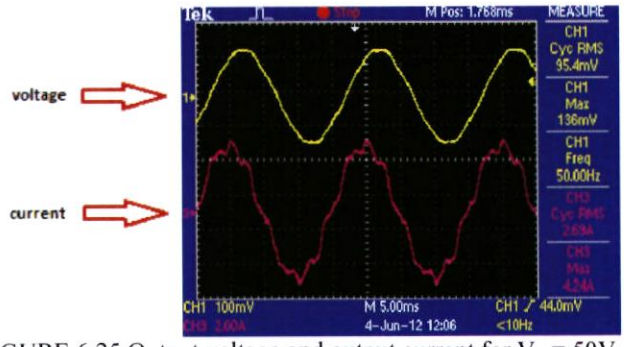


FIGURE 6.25 Output voltage and output current for V_S = 50V fs = 10 kHz, mi = 0.95

Voltage source, V_S	Oscilloscope value	Oscilloscope Division	Isolator Division	Output Voltage
20 V	96.4 mV	100mV/div	20V/div	19.28 V
50 V	95.4 mV	100mV/div	50V/div	47.7 V

For the hardware part, the THD also have been obtained for both output voltage and output current for both V_S = 20V and V_S = 50V. The THD have been shown in Figure 6.26, 6.27, 6.28 and 6.29.

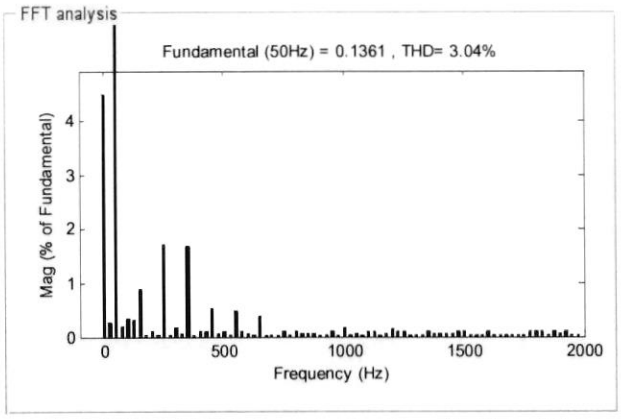


FIGURE 6.26 THD for output voltage for V_S = 20V

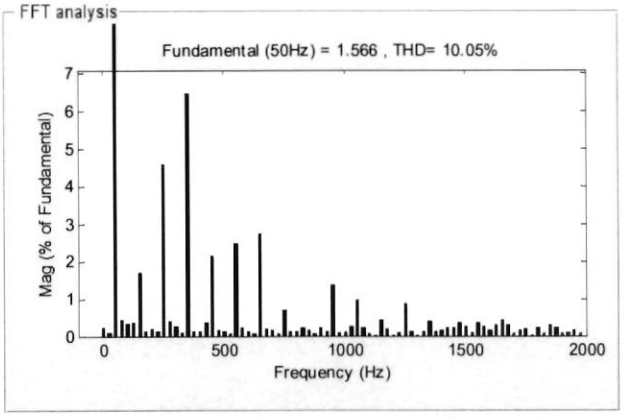


FIGURE 6.27 THD for output current for V_S = 20V

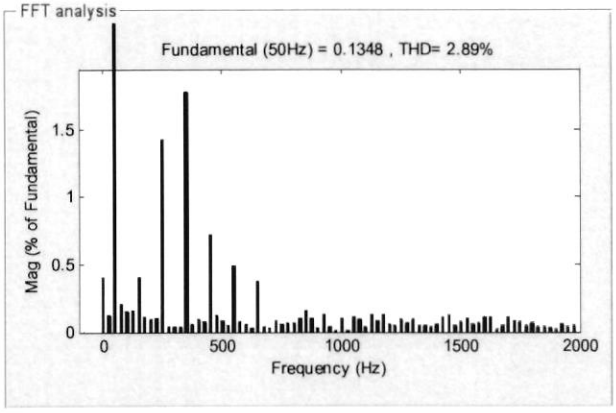


FIGURE 6.28 THD for output voltage for V_S = 50V

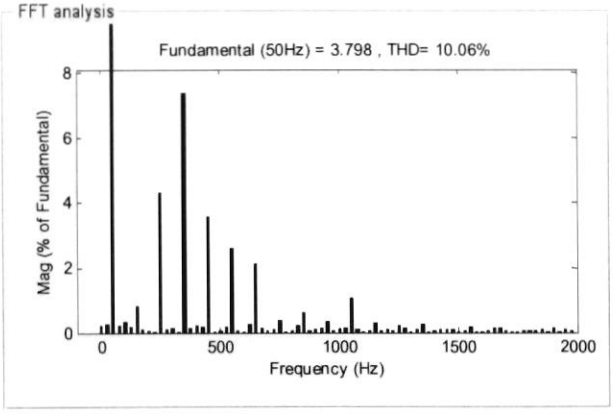


FIGURE 6.29 THD for output current for V_S = 50V

From the hardware implementation, the THD for the output voltage for both 20V and 50V of voltage supplies are 3.04% and 2.89% respectively. The THD is shown in Figure 6.26 and 6.28. From the THD obtained, both of them are lower than 5% and it is considered success while for the output current, the THD is quite high because it exceeds 10%. The THD is 10.05% when connected to 20V and 10.06% when connected to 50V of supply. The low THD is important because it will affect on the efficiencies of the AC motor.

VII. CONCLUSION

The DSP design for control implementation of AC to AC converter connected to single phase AC motor was successfully developed. Two IGBTs were used as the power switches and the output rotor speed was measured and compared with speed from the direct circuit. From the experimental result, the rotor speed from the proposed design circuit was higher than the speed from the direct supply circuit. Besides that the time taken for the rotor to reach its steady state also was faster. In spite of that, the THD for both the output voltage and current were low.As a conclusion, this project was achieved its objective which is to provide higher rotor speed and obtained less than 5% of total harmonic distortion (THD) of output voltage and 10% of the output current. From the simulation results, it can be observed that with the proposed method, the ripple in torque, speed, current and voltage in the solid state drive system can be reduced compared to direct supply method. For the future work, this project can be improved by using filtering technique. The controller technique can be continued further on hardware implementation by connecting the AC converter to the real AC motor. The switching frequency also can be varies to control the speed of the rotor.

VIII. REFERENCES

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