DEVELOPMENT OF A DC-AC POWER CONDITIONER FOR WIND GENERATOR BY USING NEURAL NETWORK

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ABSTRACT

This project present of development single phase DC-AC converter for wind generator application. The mathematical model of the wind generator and Artificial Neural Network control for DC-AC converter is derived. The controller is designed to stabilize the output voltage of DC-AC converter. To verify the effectiveness of the proposal controller, both simulation and experimental are developed. The simulation and experimental result show that the amplitude of output voltage of the DC-AC converter can be controlled.

ABSTRAK

Projek ini mempersembahkan fasa tunggal pembangunan penukar DC-AC untuk aplikasi penjana angin. Model matematik penjana angin dan kawalan Artificial Neural Network untuk penukar DC-AC diterbitkan. Pengawal direka bagi memantapkan voltan keluaran penukar DC-AC. Untuk mengesahkan keberkesanan pengawal cadangan, kedua-dua simulasi dan eksperimen telah dibangunkan. Simulasi dan keputusan eksperimen menunjukkan bahawa amplitud voltan keluaran penukar DC-AC boleh dikawal.

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LIST OF ABBREVIATIONS AND ACRONYMS

DC	-	Direct Current
AC	-	Alternate Current
SPWM	-	Sinusoidal Pulse Width Modulation
MATLAB	-	Matrix Laboratory
DSP	-	Digital signal Processes
WECS	-	Wind Energy Conversion Systems
PI	-	Proportional plus Integral
PMSG	-	Permanent Magnet Synchronous Generator
DFIG	-	Doubly Fed Induction Generator
PWM	-	Pulse Width Modulation
SIMULINK	-	Simulation and Link
IGBT	-	Insulated Gate Bipolar Transistor
MOSFET	-	Metal Oxide Semiconductor Field-Effect Transistor
S	-	Switch
VDC	-	Voltage Direct Current
Vr	-	Voltage Reference
Vo	-	Voltage output
Fr	-	Frequency Reference
Vc	-	Voltage Carrier
Fc	-	Frequency Carrier
MF	-	Modulation Frequency
MI	-	Modulation Index
MLP	-	Multilayer Perceptron
BPNN	-	Backpropagation Neural Network

PCB	-	Printed Circuit Board

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter includes some of literature review on wind energy conversion system and wind turbine. Also, focus on main parts of wind turbine system and controller used in this project.

2.2 Wind Power Generate

The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses and schools.

2.3 Literature Review on Wind Energy Conversion System

Wind energy conversion systems (WECS) are the devices which are used to convert the wind energy to electrical energy. There exists a large collection of literature on the modelling of wind energy conversion systems more specifically on the modelling of individual system components of a wind energy conversion system. A wind energy conversion system is mainly comprised of two subsystems, namely a wind turbine part and an electric generator part. Detailed descriptions of these concepts can be found in text books on wind energy (Mukund., 1999) and (Tony Burton, *et al* 2001). A summary of the typical wind turbine models and their control strategies is presented in (Manwell, J.G. McGowan & A.L. Rogers, 2002).

2.4 Literature Review on Wind Turbines

In the literature, most of the models used to represent a wind turbine are based on a non linear relationship between rotor power coefficient and linear tip speed of the rotor blade (Mukund. 1999) and (Slootweg, *et al* 2003).

Muljadi and Butterfield mention the advantages of employing a variable speed wind turbine and present a model of it with pitch control. In this model, during low to medium wind speeds, the generator and the power converter control the wind turbine to maximize the energy capture by maintaining the rotor speed at a predetermined optimum value. For high wind speeds the wind turbine is controlled to maintain the aerodynamic power produced by the wind turbine either by pitch control or by generator load control. However, generator load control in the high wind regions, in some cases suffers from the disadvantage of exceeding the rated current values of the stator windings of the generator. Care should be taken not to exceed the rated values of the current (Eduard Muljadi & C. P. Butterfield, 2001).

References (Anderson & Anjan Bose, 1883) and (Wasynczuk, *et al,* 1981) propose a detailed model of the variable speed pitch controlled wind turbine suitable for studying the transient stability of multi- megawatt sized wind turbines. The simulated model is based on a set of non linear curves depicting the relation between the blade tip speed, rotor power coefficient and pitch angle of the wind turbine. The references also consider a detailed model for the wind input which includes the effects of gust, noise added to the base value of wind input.

(Anderson & Anjan Bose, 1883) uses transfer-functions to represent the dynamics of the electrical generator driven by the wind turbine, while (Wasynczuk, *et al* 1981) usesdq- axis representation for the synchronous machine acting as an electrical generator. A proportional integral (PI) controller is used to implement the pitch angle controller to limit the wind turbine output in the high wind speed regimes. Simulation results obtained for these models indicate a good approximation of the dynamic performance of a large wind turbine generator subjected to turbulent wind conditions.

As an extension to this work done in (Anderson & Anjan Bose, 1883) and (Wasynczuk *et al*, 1981) presented a general model that can be used to represent all types of variable speed wind turbines in power system dynamic simulations. The modelling of the wind turbine given by the authors retains the pitch angle controller, which reduces wind turbine rotor efficiency at high wind speeds, as given in (Anderson & Anjan Bose, 1883) and (Wasynczuk, *et al*, 1981). The wind turbine dynamics are approximated using nonlinear curves, which are numerical approximations, to estimate the value of wind turbine rotor efficiency for given values of rotor tip speed and pitch angle of the blade. The authors offer a comparison between the per-unit power curves of two commercial wind turbines and the one obtained theoretically by using the numerical approximation. The results indicate that a general numerical approximation can be used to simulate different types of wind turbines.

2.5 Literature Review on Generator

The conversion of mechanical power of the wind turbine into the electrical power can be accomplished by an electrical generator which can be a DC machine, a synchronous machine, or an Induction machine.

DC machine was used widely until 1980s, in smaller power installations below 100 kW, because of its extremely easy speed control (Mukund, 1999). The presence of commutators in DC machines has low reliability and high maintenance costs. The second kind of electric generators are synchronous generators, suitable for constant speed systems. Requirement of DC field current and reduced wind energy capture of constant speed systems, compared to variable speed systems, are discouraging factors in their use in wind systems (Mukund, 1999). Another choice for the electric generator in a WECS is a permanent magnet synchronous generator. Reference (Antonios *et al* 2004) presents a model of the variable speed wind turbine connected to a permanent magnet synchronous generator (PMSG). But PMSGs suffer from uncontrollable magnetic field decaying over a period of time, their generated voltage tends to fall steeply with load and is not ideal for isolated operation (Bimal, 2003). Induction generators, on the other hand, have many advantages over conventional synchronous generators due to their ruggedness; no need for DC filed current, low maintenance requirements and low cost (Mukund, 1999).

References (Anca, *et al*, 2004) and (Rajib Datta & Ranganathan, 2002) give a model of the WECS using doubly fed induction generator (DFIG). DFIGs allow one to produce power both from the stator and the rotor of a (wound rotor) induction generator. However increase in the power output comes with increased cost of power electronics, and their control, for the rotor circuit. One advantage of this configuration is its suitability for grid-connected operations where reactive power is supplied by the grid.

2.6 Wind turbine system

The following figure illustrates the most important parts of the wind turbine system. The wind turbine system is divided into two main types:

1 - Mechanical power (Blades and gearbox).

2- Electric power (generators, power converter, transformer and utility).

Figure: 2.1 shows the most important parts wind system Turbine.

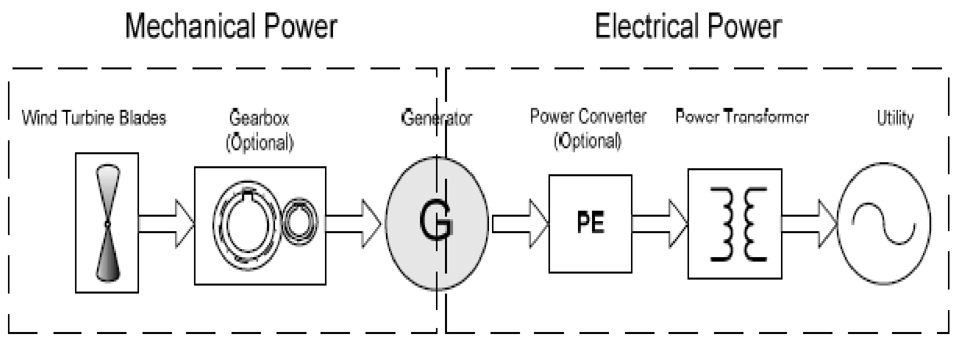

Figure: 2.1 : Wind turbine system.

2.7 DC Generator

An electric generator is a device used to convert mechanical energy into electrical energy. The generator is based on the principle of electromagnetic induction discovered in 1831 by Michael Faraday. Faraday discovered that if an electric conductor, like a copper wire, is moved through a magnetic field, electric current will flow in the conductor. So the mechanical energy of the moving wire is converted into the electric energy of the current that flows in the wire.

By the use of a generator, mechanical energy is then converted into electrical energy fed into a grid. In this stage, a power electronic converter and a transformer with circuit breakers and electricity meters are needed. Wind turbines can be connected to the grid at low, medium, high, and extra high voltage systems since an electricity power system’s transmittable power is usually directly proportional to the voltage level. Turbines these days are mostly using a medium voltage system while large wind farms use high and extra high voltage settings.

2.8 Work of DC Generators

The commutator rotates with the loop of wire just as the slip rings do with the rotor of an AC generator. Each half of the commutator ring is called a commutator segment and is insulated from the other half. Each end of the rotating loop of wire is connected to a commutator segment. Two carbon brushes connected to the outside circuit rest against the rotating commutator. One brush conducts the current out of the generator, and the other brush feeds it in. The commutator is designed so that, no matter how the current in the loop alternates, the commutator segment containing the outward-going current is always against the "out" brush at the proper time. The armature in a large DC generator has many coils of wire and commutator segments. Because of the commutator, engineers have found it necessary to have the armature serve as the rotor (the rotating part of an apparatus) and the field structure as the stator (a stationary portion enclosing rotating parts). The following some advantages of the DC generator:

- Simple structure.
- Can be used for DC appliances.
- No health problems for people near transmission lines.

2.8 Power Electronics

Power electronics is defined as the application of solid state electronics for the conversion and control of electric power. Before discussing the electronic aspects of wind turbines, it is imperative that a discussion on how wind turbines convert mechanical energy to electric energy. Generally, it is composed of three major conversions or transfer. It starts with the rotor converting wind energy into mechanical energy, the generator converts that mechanical energy into electrical power, and then the transformer transfers the electric power to the grid.

2.10 Power electronic devices

Power electronic systems are used by many wind turbines as interfaces. Wind turbines function at variable rotational speed; thus the generator's electric frequency varies and needs to be decoupled from the grid's frequency. This action is possible if a power electronic converter system comes in handy.

The power converter is an interface found between the load/generator and the grid. Depending on the topology and the applications present in the system, power can flow into the direction of both the generator and the grid. In using converters, three important things must be considered: reliability, efficiency, and cost. Figure 2.2 shows a single-input single-output power converter system.

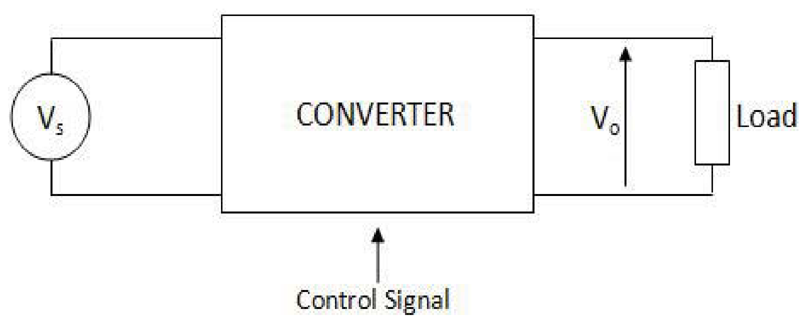

Figure 2.2: A simple power electronic converter system

Converters are made by power electronic devices, and circuits for driving, protection and control. Two different types of converter systems are currently in use: grid commutated and self commutated converters. Grid commutated converters are thyristor converters containing 6 or 12 pulse, or even more, that can produce integer harmonics. This kind of converter does not control the reactive power and consume inductive reactive power.

The other type of converter, self-commutated converter systems, are pulse width modulated (PWM) converters that mainly (IGBTs) or (MOSFETs) Transistors. In contrast to grid-commutated, self-commutated converters control both active and reactive powers. PWM-converters, therefore, have the capacity to provide for the demand on reactive power and a high frequency switching that make them produce high harmonics and interharmonics (Faeka Khater 2002).

2.11 Inverters

Inverters can be found in a variety of forms, including half bridge or full bridge, single phase or three phases. In pulse width modulated (PWM) inverters the input DC voltage is essentially constant in magnitude and the AC output voltage has controlled magnitude and frequency. Therefore the inverter must control the magnitude and the frequency of the output voltage. This is achieved by PWM of the converter switches and hence such converters are called PWM converters.

2.12 Single Phase Full Bridge inverter

A single phase full bridge inverter circuit and its output example are shown in Figure: 2.3. It consists of four switching elements and it is used in higher power ratings application. The four switches are labelled as S1, S2, S3 and S4. The operations of single phase full bridge converter can be divided into two conditions. Normally the switches S1 and S4 are turned on and kept on for one half period and S2 and S3 are turned off. At this condition, the output voltage across the load is equal to Vdc . When S2 and S3 are turned on, the switches S1 and switches S4 are turned off, then at this time the output voltage is equal to −Vdc. The output voltage will change alternately from positive half period and negative half period. In order to prevent short circuit occurred, dead time mechanism has been used in gate driver circuit.

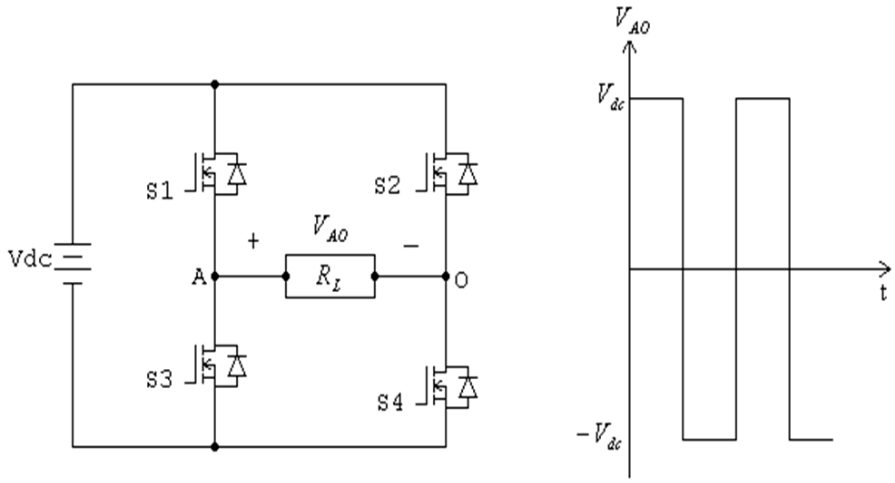

Figure: 2.3: Single phase -Full bridge inverter topology and its output example

The DC to AC converter or inverter takes power from a DC source (voltage or current) and delivers to an AC load. The output variable of the inverter is a low distortion AC voltage or AC current of single-phase or multi-phase. Also, Three-terminal devices such as transistors MOSFET can be used in DC to AC converter (Sanchis 2003).

2.13 MOSFET Transistor

The word MOSFET actually stands for Metal Oxide Semiconductor Field-Effect Transistor. This particular device, which is used to amplify or switch electronic signals, is by far the most common field-effect transistor in both digital and analog circuits . There are two types of MOSFETs which are N-channel type and P channel type. When voltage to the gate is not supplied, the electric current doesn't flow between drain and source. When positive voltage is applied to the gate of the N-channel MOSFET, the electrons of N-channel of source and drain are attracted to the gate and go into the P-channel semiconductor among both .With the move of these electrons, it becomes the condition which spans a bridge for electrons between drain and source. The size of this bridge is controlled by the voltage to apply to the gate. The following Figure 2.4 show symbol of MOSFET transistor.

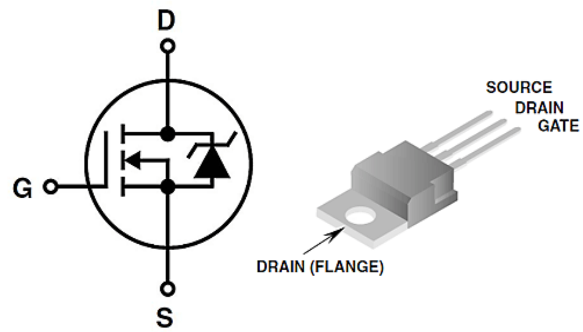

Figure 2.4: symbol of MOSFET Transistor

An MOSFET have many advantage, because of this it can be one choice to make inverter circuit:-

a) Lower Switching Losses.
b) Smaller Component Size.
c) Highly Reliable Components.
d) Faster Switching**.**

2.14 Pulse-Width Modulation (PWM)

Pulse-Width Modulation technique is widely used in variable-speed turbine, especially after the high power rating, fast switching as IGBT or MOSFET come up, which enables a higher switching frequency and thus better performance in dynamic response and reduction in the size, weight and acoustic noise of the system are achievable.

2.15 Sinusoidal Pulse Width Modulation (SPWM)

SPWM is very flexible. The purpose of the SPWM component of the controller is to generate pulses that trigger the transistor switches of the converter. The sinusoidal pulse-width modulated signal is created by comparing a fundamental sine wave (reference signal) with a triangle wave (carrier signal). The variable width pulses from the SPWM drives the gates of the switching switches turn on and off. Figure: 2.5 is describing SPWM with voltage switching.

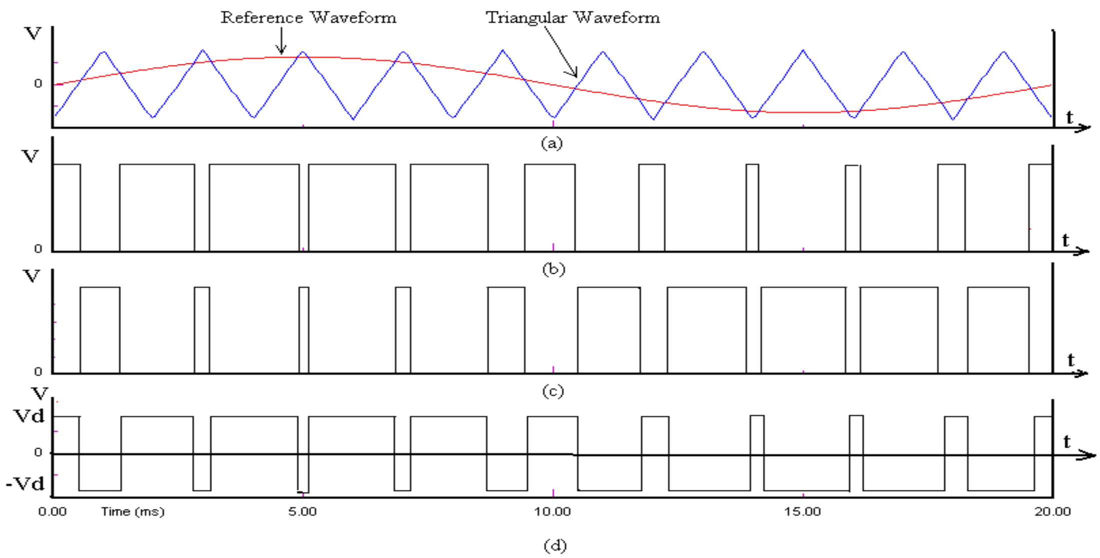

Figure: 2.5: SPWM with voltage switching (a) Comparison between reference waveform and triangular waveform (b) Gating pulses for S1 and S4 (c) Gating pulses for S2 and S3 (d) Output waveform.

However, the reference waveform may come in various shapes to suit the converter topology, such as sine wave and distorted sine wave. A sinusoidal waveform signal is used for (SPWM) in DC to AC inverter where it is used to shape the output AC voltage to be close to a sinewave (L. Hassaine 2001).

The reference signal ***Vr*** is used to modulate the switch duty ratio and has a frequency reference ***Fr***. which is the desired fundamental frequency of the inverter voltage output. Meanwhile the triangular carrier waveform ***Vc*** is at a switching frequency carrier ***Fc*** which establishes the frequency with which the inverters are switched. The frequency modulation ratio ***mf*** is defined as the ratio of the frequencies of the triangular carrier waveform and the reference signals which is written as

$$mf = \frac{f\ carrier}{f\ reference} = \frac{f\ tri}{f\ sin} \tag{2.1}$$

Where:

$f\,carrier$ = $f\,tri$ = Triangular carrier waveform frequency

$f\,reference$ = $f\,sin$ = Fundamental waveform frequency

The amplitude modulation ratio ***mi*** is defined as the ratio of the amplitude of the reference and carrier signals and is given by

$$mi = \frac{V_m\ ,reference}{V_m\ ,carrier} = \frac{V_m\ ,sin}{V_m\ ,carrier} \tag{2.2}$$

Where:

Vm ,*reference* = Vm, sin = Peak amplitude of reference waveform.

Vm, *carrier* = Peak amplitude of triangular carrier waveform

2.16 Generation of ON-OFF SPWM switching signal

Its primary function is to make the attenuated output Vo compared with Vref for obtaining the error signal. In order words, the error signal will be proportional to the difference between Vo and Vref. And then, this error signal is sent through a control system to obtain a control signal +Vcon and –Vcon (Ying Tzou 2004). Therefore Next, figure 2.6 show single phase full bridge inverter circuit with four MOSFET's SA1, SA2, SB1, SB2 and SPWM block can be generated as Fig. 2.7 by combining ±Vcon and triangular Vtri The detailed operation of the SPWM control is as follows :

When +Vcon>Vtri, S1 is ON and S3 is OFF.
When +Vcon<Vtri, S1 is OFF and S3 is ON.
When -Vcon>Vtri, S2 is ON and S4 is OFF.
When -Vcon<Vtri, S2 is OFF and S4 is ON.

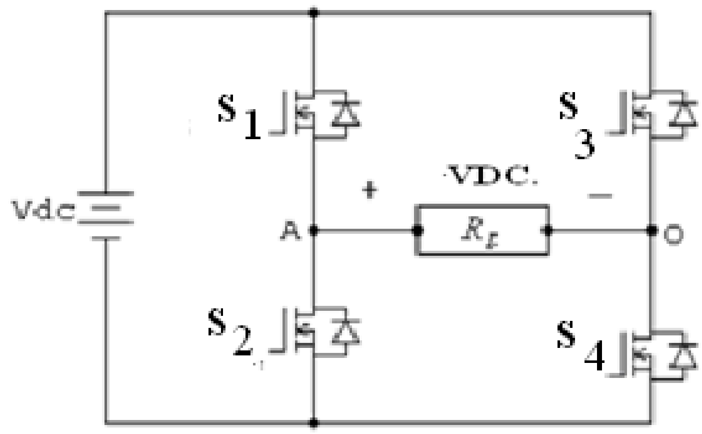

Figure 2.6: Single Phase Full bridge inverter circuit

Based on the above operation, there are 4 kinds of combinations for output Vo as:
(1)S1, S4 is ON: Vo = +VDC.
(2)S2, S3 is ON: Vo = -VDC.
(3)S1, S2 is ON: Vo = 0.
(4)S3, S4 is ON: Vo = 0.

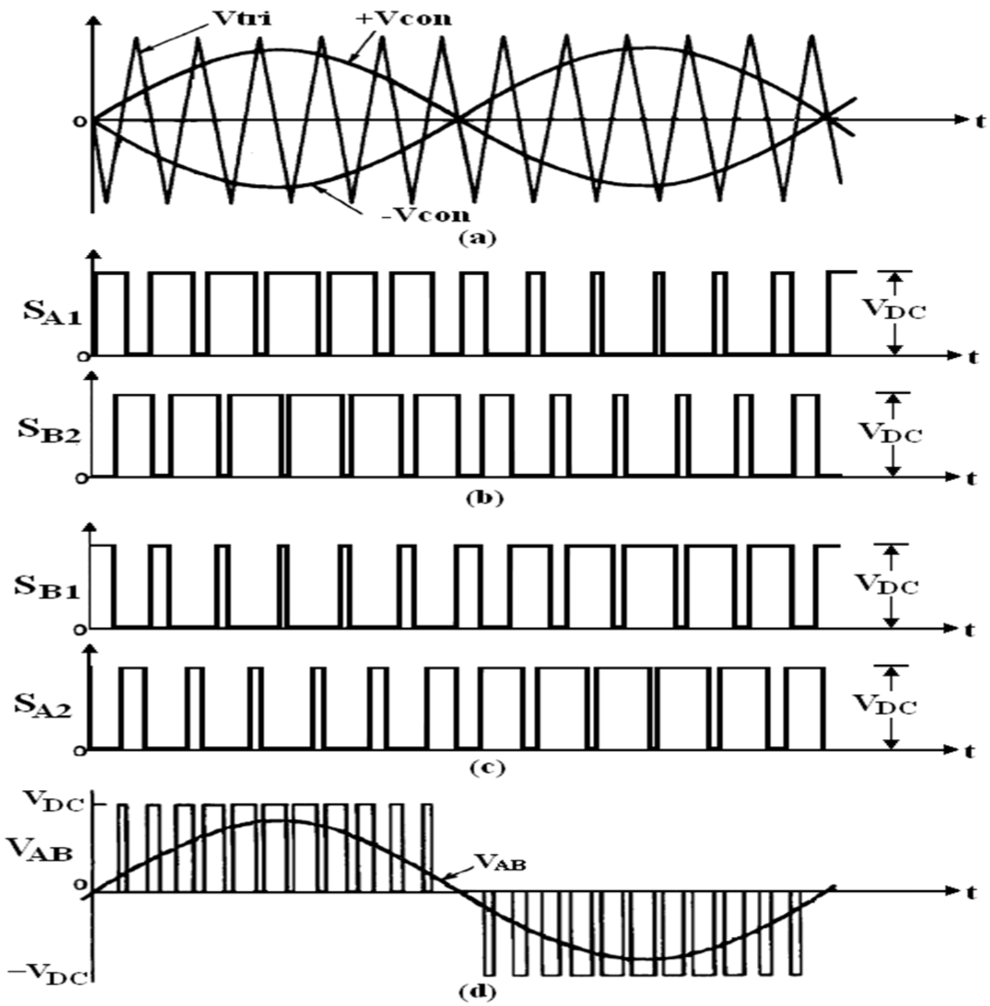

Fig. 2.7: Generation of ON-OFF SPWM switching signal

2.17 Neural Network technique

A neural network is a powerful data modelling tool that is able to capture and represent complex input/output relationships. The motivation for the development of neural network technology stemmed from the desire to develop an artificial system that could perform "intelligent" tasks similar to those performed by the human brain.

The true power and advantage of neural networks lies in their ability to represent both linear and non-linear relationships and in their ability to learn these relationships directly from the data being modeled. Traditional linear models are simply inadequate when it comes to modeling data that contains non-linear characteristic (Martin 2006).

The most common neural network model is the multilayer perceptron (MLP). This type of neural network is known as a supervised network because it requires a desired output in order to learn. The goal of this type of network is to create a model that correctly maps the input to the output using historical data so that the model can then be used to produce the output when the desired output is unknown. A graphical representation of an MLP is shown in figure: 2.8 below.

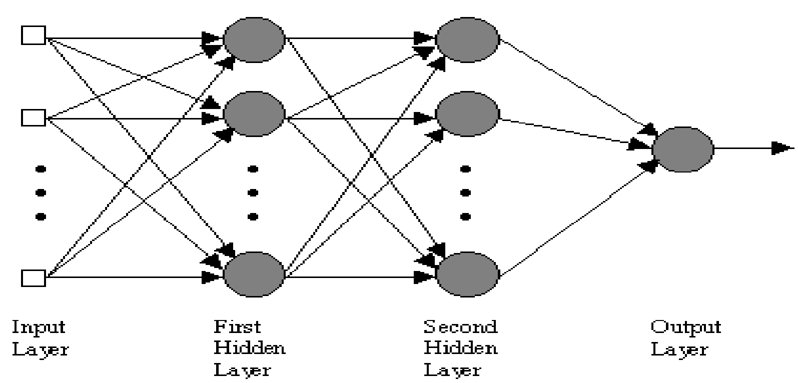

Figure: 2.8: Block diagram of a two hidden layer Multiplayer perceptron (MLP).

The inputs are fed into the input layer and get multiplied by interconnection weights as they are passed from the input layer to the first hidden layer. Within the first hidden layer, they get summed then processed by a nonlinear function. As the processed data leaves the first hidden layer, again it gets multiplied by interconnection weights, then summed and processed by the second hidden layer. Finally the data is multiplied by interconnection weights then processed one last time within the output layer to produce the neural network output (Sebastian Seung 2006).

2.18 C++ Language Programming for DSP

C ++ is a general-purpose computer programming language developed in 1972 by Dennis Ritchie at the Bell Telephone Laboratories for use with the Unix operating system. Although C++ was designed for implementing system software, it is also widely used for developing portable application software.

The C programming language has become the language of choice for many engineering applications, especially digital signal processing(DSP). The C++ language is extremely portable, compact, and lends itself well to structured programming techniques. It has been ported to virtually every major programming platform and is the predominant system programming language for the major operating systems used today .

2.19 eZdsp™ F2808 board

The eZdsp™ F2808 is a stand-alone card--allowing evaluators to examine the TMS320F2808 digital signal processor (DSP) to determine if it meets their application requirements. Furthermore, the module is an excellent platform to develop and run software for the TMS320F2808 processor.

The eZdsp™ F2808 is shipped with a TMS320F2808 DSP. The eZdsp™ F2808 allows full speed verification of F2808 code. Expansion connectors are provided for any necessary evaluation circuitry not provided on the as shipped configuration.

To simplify code development and shorten debugging time, a C2000 Tools Code Composer driver is provided. In addition, an onboard JTAG connector provides interface to emulators, operating with other debuggers to provide assembly language and ‘C’ high level language debug (Texas Instruments 2007). A photograph of the eZdsp™ F2808 board is shown in Figure: 2.9.

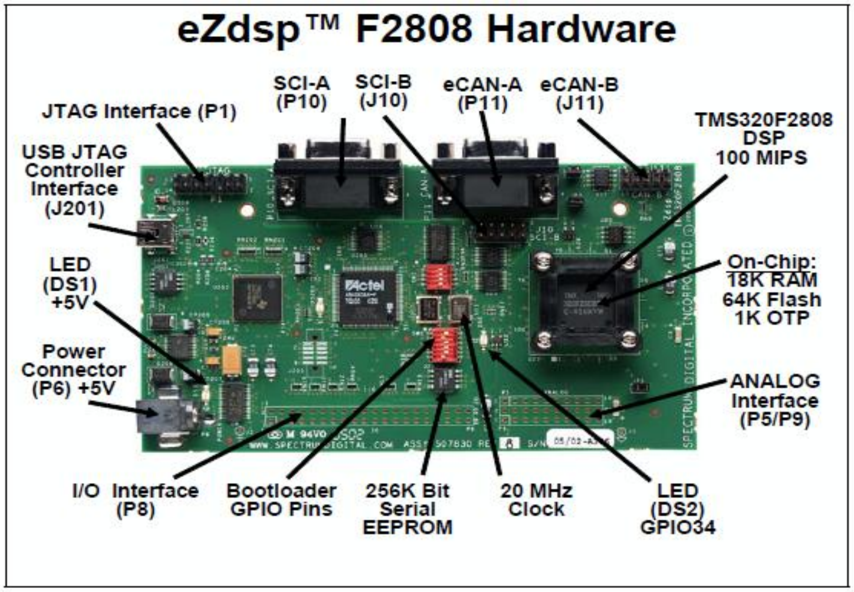

Figure: 2.9: eZdsp™ F2808 board

2.19.1 Key Features of the eZdsp™ F2808

The eZdspTM F2808 has the following features:

- TMS320F2808 Digital Signal Processor
- 100 MIPS operating speed
- 18K words on-chip zero wait state SARAM
- 64K words on-chip Flash memory
- 256K bits serial I2C EEPROM memory
- 20 MHz. clock
- Expansion Connectors (analog, I/O)
- Onboard IEEE 1149.1 JTAG Controller
- 5-volt only operation with supplied AC adapter
- TI F28xx Code Composer Studio tools driver
- On board USB JTAG emulation connector
- 2 SCI UART channels
- 2 eCAN channels.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss about the method that is being used to develop the project including the tools, equipments, procedures and processes involved in the hardware and software development and implementation of the project. The mythology process utilizes both software simulation and hardware construction. It is virtual to simulate the system by using software to get the theoretical result before hardware designation can be made. The selection of component for the hardware is also important in order to reduce cost, increase the system efficiency and increase reliability of the circuit.

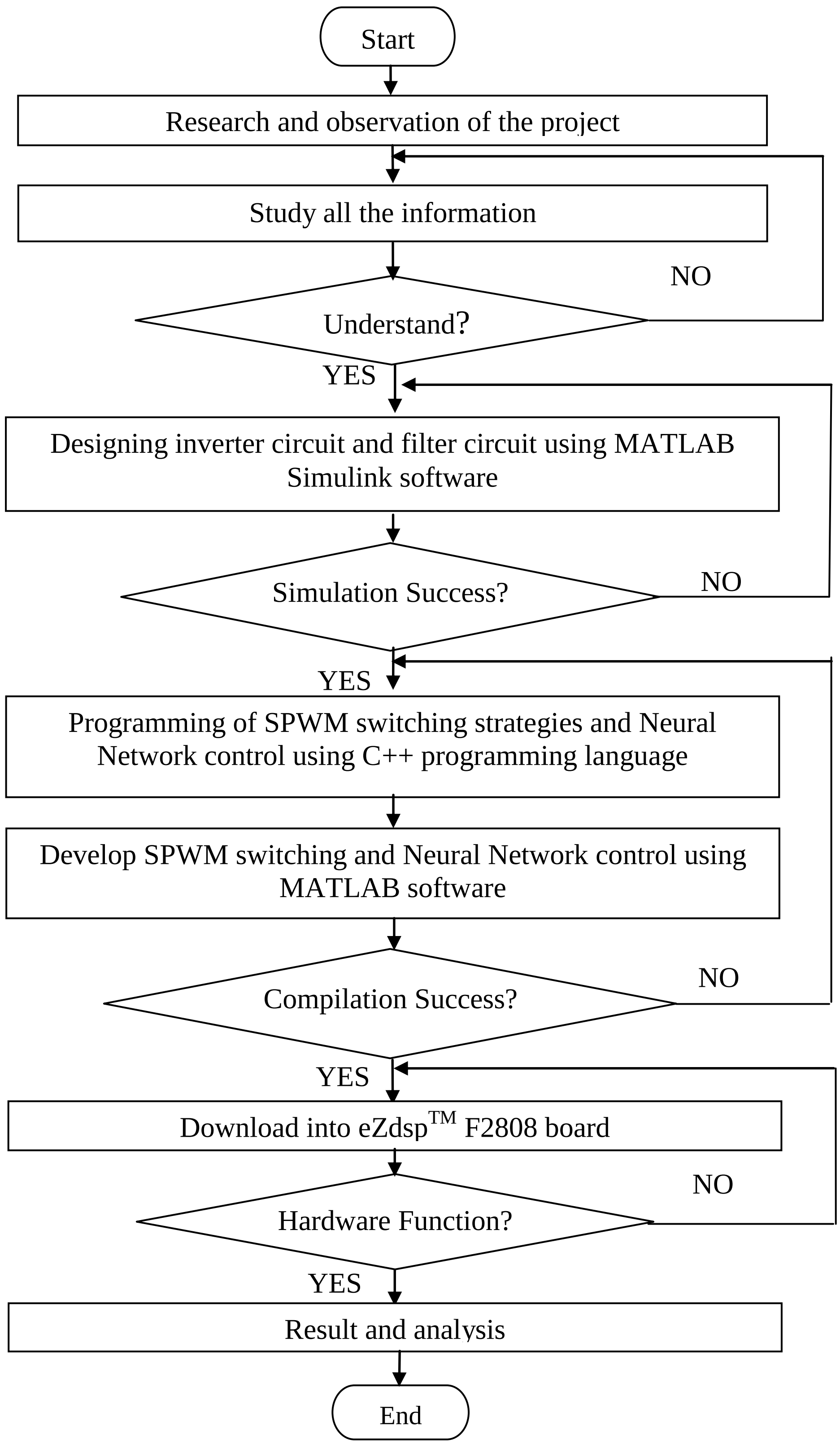

Figure 3.1: Flowchart of project

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