FUZZY LOGIC CONTROLLED SOLAR MODULE FOR DRIVING THREE-PHASE INDUCTION MOTOR

CHAN SOOI TAT

Thesis submitted in partial fulfilment of
the requirements for the award of the
Bachelor of Engineering (Hons) Mechatronics Engineering

Faculty of Manufacturing Engineering
UNIVERSITY MALAYSIA PAHANG

JUNE 2015

ABSTRACT

Renewable Energy such as solar modules to generate electricity are getting serious in modern life due to high consumption of electricity generation for applications such as three-phase induction motor. The three-phase induction motor been used widely for industrial applications and the speed to be controlled by variable frequency using power electronics. Solar modules used to generate electricity to supply the three phase induction motor but photovoltaic output is uncertain and complexity. The Fuzzy Logic controller is one of controllers that can handle non-linear system and maximum power of solar module. Fuzzy logic controller to be used for Maximum Power Point Tracking (MPPT) in the non-linear system with fuzzy rules to control Pulse-Width Modulation (PWM) for switching Metal Oxide Semiconductor Fast Emitted Transistor (MOSFET). DC boost converter used to boost up photovoltaic voltage to desired output for supply voltage source inverter which controlled by three-phase PWM generated by microcontroller. IGBT switched Voltage source inverter produced alternating current (AC) voltage from direct current (DC) source to control speed of three-phase induction motor from boost converter output.

ABSTRAK

Tenaga boleh diperbaharui seperti modul solar untuk menjana tenaga elektrik yang semakin serius dalam kehidupan manusia kerana penggunaan yang tinggi penjanaan elektrik untuk aplikasi seperti tiga fasa motor induksi. Motor aruhan tiga fasa telah digunakan secara meluas untuk aplikasi industri dan kelajuan boleh dikawal dengan frekuensi pembolehubah menggunakan elektronik kuasa. Modul solar boleh digunakan untuk menjana elektrik untuk membekalkan motor aruhan tiga fasa tetapi output solar adalah tidak menentu dan kerumitan. Pengawal Logik Fuzzy adalah salah satu pengawal yang boleh mengendalikan sistem bukan linear dan kuasa maksimum modul solar. Pengawal logik kabur boleh dihasilkan maksimum Kuasa Cahaya Perikutan (MPPT) dalam sistem bukan stabil dengan set kabur untuk mengawal Pulse-Lebar Moduklutor (PWM) untuk Transiktor besi perudaran cepat semikonductor (MOSFET). DC penukar rangsangan boleh menaikkan voltan solar kepada output yang dikehendaki untuk voltan bekalan sumber inverter yang dikawal oleh HPWMs dihasilkan oleh pengawal mikro. Voltan sumber inverter boleh menghasilkan voltan seli semasa memandu kelajuan dikawal tiga fasa motor aruhan daripada output rangsangan penukar.

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LIST OF SYMBOLS

D	Duty Cycle
Verror	Input Variables
Vcoe	Input Variables
V_{gs}	Gate Voltage
V_{mpp}	Maximum power voltage
V_{oc}	Open circuit voltage
I_{mpp}	Maximum power current
Isc	Short circuit current
P_{max}	Maximum power
V_{th}	Threshold voltage
V_{in}	Voltage input from boost converter
V_{out}	Output voltage from boost converter
I_{pv}	Photovoltaic current
I_{ph}	Photovoltaic current
V_{pv}	Photovoltaic voltage
HIN	High input to gate driver
HO	High side PWM output
LIN	Low side PWM input
LO	Low side PWM output
f_s	Frequency
P_d	Diode power
Ton	Turn on time
Toff	Turn off time

Δi_L	Current ripple
L_{min}	Minimum inductor
C_{min}	Minimum capacitor
V_{ab}	Voltage from line a-line b
V_{LL}	Line-to-line voltage

LIST OF ABBREVIATIONS

AC	Alternative current
DC	Direct current
FIS	Fuzzy Inference system
FLC	Fuzzy Logic Controller
IDE	Integrated development environment
Verror	Input variable of Fuzzy Logic
Vcoe	Input variable of Fuzzy Logic
LCD	Liquid-crystal display
LED	Light-emitting diode
MOSFET	Metal-oxide-semicondcutor field-effect transistor
BJT	Bipolar Junction Transistor
MPPT	Maximum power point tracking
PV	Photovoltaic
PWM	Pulse-width modulation
IGBT	Insulated-Gate Bipolar Transistor
PID	Proportional, integral and derivative
PIC	Peripheral Interface Controller
COG	Center of Gravity

CHAPTER 1

INTRODUCTION

This chapter will make brief discussion about background, problem statement, objective and scope of the project.

1.1 BACKGROUND

In 1889, Nicole Tesla invented the AC phase induction motors while DC motors were also used in that time. DC motor and AC motor have the same function of converting electrical energy into mechanical energy but different power, construction and control methods. Today, AC power systems are clearly dominated over DC systems and induction motors are greatly increase used in many applications. Besides that, the reason of DC brushed motors are replaced by AC brushless motors due to free maintenance, cheap costs and no commutation. The speed of induction motor can be controlled by variable frequency using power electronic circuits and microcontrollers. Power electronic devices like controlling such as Insulated-Gate Bipolar Transistor (IGBT) and microcontrollers can also make the electric drive system become cheaper compared to DC motor.

The three-phase induction motor construction is smaller size compared to one-phase induction motor with same power capacity. Single-phase induction motor cannot do self-starting because of single-phase only produce single-phase field. The single-phase induction motor cannot do self-starting because of single-phase motor produces single magnetic field only. However, three-phase induction motor is the self-starting motor. Three-phase induction motor usually uses for higher torque and higher power rating compares to single-phase induction motor. The efficiency of three-phase induction motor is higher than single-phase induction motor.

Nowadays, electric power plants have been using non-renewable resource such as fossil fuel, coal and natural gas to generate huge power electricity for industries and homes. Those resources have heavily damage to environment and it became less available in recently year. The alternative energy such as solar energy can be used with renewable solar technologies to replace some of them for cheaper energy and lower environment impact. Besides that, factories in remote area which are off-grid electricity generation from power plants are hard to obtain electricity for driving the factory. Utility industries will not build distribution line for only few industries in remote areas due to uneconomical outcomes. Industries use solar module to produce direct current by convert solar energy into electrical energy as power supply to drive loads. The cheaper energy will give benefits to industries in remote area in term of economical saving and convenience.

The solar modules made from wafer-based crystalline silicon cells arrange in arrays were exposured to sun irradiation and convert solar energy into electrical energy due to photovoltaic effect. It has a sheet of glass cover the semiconductors and protect them from any conditions. DC output power is converted by DC-DC converter to get the desired output. Outputs from solar modules are unstable conditions and low efficiency due to different range of sun radiation. The optimization of solar module can be improved by using fuzzy logic controller of Maximum Power Point Tracking (MPPT).

Fuzzy logic controller is a control system that using digital or discrete value in the system that act like human brain. The input of non-linear systems which are uncertain and confusing information can be presented indirect way using fuzzy set. Despites PID controller is much better performance either linear system or non-linear system when transfer function is known, PID controller is not so robust with non-linear system that is uncertainty. Within this situation, the fuzzy logic controller can handle the non-linear system by decreasing the possible uncertain effects. Fuzzy logic controller can produced Maximum Power Point Tracking (MPPT) in the non-linear system with fuzzy set to control Pulse-Width Modulation (PWM) for Metal Oxide Semiconductor Fast Emitted Transistor (MOSFET) or Insulated Gate Bipolar Transistor (IGBT).

1.2 PROBLEM STATEMENT

The output power of solar module is unstable and low efficiency due to sun radiation and low efficiency rate of solar cells. Fuzzy logic controller optimizes power output power of the solar module. The efficiency of three-phase induction motor is low without control method and using Volt/Hz control to increase the efficiency of three-phase induction motor.

1.3 OBJECTIVES

The objectives of this project are:

1. To optimize the output power of solar module by fuzzy logic controller using microcontroller.

2. To control there-phase induction motor using voltage source inverter switching by microcontroller generated PWM signal.

1.4 SCOPES OF PROJECT

- Fuzzy Logic Controller programmed with Arduino microcontroller using C language.
- Using DC-DC boost converter to convert low DC input voltage to higher output DC voltage.
- Optocoupler of 4N25 will be used to prevent changing voltages and isolate control circuit to power systems circuit.
- Software of Picbasic Pro compiler will be used to generate programming code and ProKit2 will be used to transfer the coding from MicroCode Studio into the microcontroller to produce PWM signal.

- Voltage source inverter used IGBT modules for generating AC output from DC input. The AC output then will be used to drive the three phase induction motor.
- Three-phase squirrel cage induction motor will be selected as the type of induction motor in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 SOLAR MODULES

Solar module or Photovoltaic module is allowing light to pass while protecting the semiconductor wafer by a sheet of transparent glass on the sun-facing side (Wikipedian, 2010). Example, the MYS-48P has tempered 3.2mm/4 mm solar gas. One of the solar modules is silicon crystalline based solar cell is popular in the market because the silicon crystalline based solar modules are low manufacturing cost and non –toxic materials used in the final product. There are four types of silicon crystalline solar cells which are single crystal, mulitcrystalline, ribbon, and silicon thin film (Y.S. Tsuo, T.H Wang, T.F Ciszek, 1999).

Several types of solar modules efficiencies are measured under room temperature, 25 ℃ with spectrum 1000W/m^2 which is silicon crystalline solar module, polycrystalline solar module, thin-film polycrystalline solar module and amorphous silicon solar module. The efficiency of silicon crystalline solar cell is 22.9% ± 0.6 and silicon multicystalline solar module efficiency is 17.3% ± 0.5. The efficiency of amorphous silicon solar module is 13.8% ± 0.5 and thin-film polycrystalline solar module efficiency is 8.2% ± 0.2 (Martin A. Green, Keith Emery, Yoshihiro Hishikawa and Wihelm Warta, 2010).

The one diode model equivalent circuit of solar module is shown as figure 2.1. The simplest form of equation for solar module is about output current, where the Iph is photocurrent and Id is diode current that is shown as below. When there is parasitic effect of solar module, it will reduce the efficiency of solar module and equation 2.3 is shown about effect parasitic on output current (Smitha Krishnamurthy, 2006).

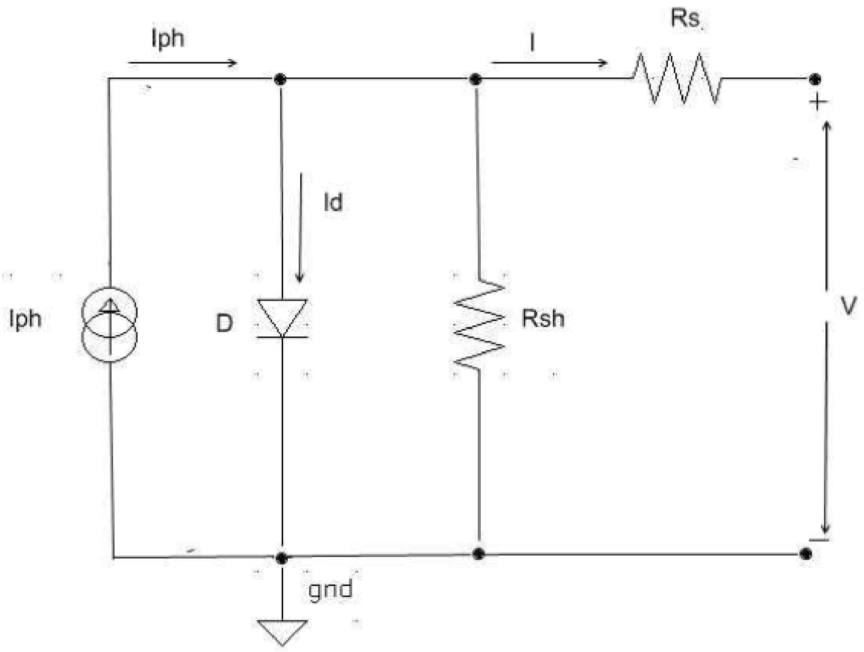

Figure 2.1: Equivalent Circuit of Solar Module

Source: Smitha Krishnamurthy, 2006

$$I = Iph - Id \quad (2.1)$$

$$I = Iph - Is\left\{\exp\left(\frac{q\,Vd}{n\,K\,T}\right) - 1\right\} \quad (2.2)$$

$$I = Iph - Is\left\{exp\left(\frac{q\,[V + I\,Rs]}{n\,K\,T}\right) - 1\right\} - \left(\frac{V + I\,Rs}{Rsh}\right) \quad (2.3)$$

For this project, the MYS-60M/B3/CL-245 mono-cyrstalline photovoltaic module is chosen and distinguished by 245 watt of solar cells with efficiency up to 15.35% high output per square meter of module area. Vmpp and Impp can reach up to 29.702 V and 8.107 A. It also has 25 years long life span of power output and noise free (Malaysian Solar Resources, 2012).

2.1.1 SOLAR CELL BYPASS DIODES

Bypass diodes in solar cells has purposed of protect against high spot damage when it is used in different weather condition. The diode voltage drop is because of internal resistance in operation and power loss. For solar module bypass diode must always higher breakdown voltage than the open circuit voltage (Voc). The damage on bypass diode will occurs when the output voltage is higher than breakdown voltage from power dissipation. The equation 2.4 is shown as below as power dissipation which consists of breakdown voltage and current at breakdown operation.

$$P_d = V_{BR} \times I_{BR} \tag{2.4}$$

The monocrystalline silicon solar module commonly will used schottky rectifiers as bypass diodes. Schottky rectifiers has characteristic of low forward voltage, better efficiency and current density but consider reverse leakage current will increase when exposure to the sun which may be damage to the diode. The reverse leakage current is related to the reverse biased voltage (Vishay Document Number 89398, 2011).

2.2 MAXIMUM POWER POINT TRACKING (MPPT)

The photovoltaic module operation can be defined by getting 2 types of characteristic of a PV module which are current-voltage characteristic and power-voltage characteristic. We need to overcome the unstable of solar module, we can use MPPT controller which consists of DC-DC converter to control operating voltage (M.S Ait Cheikh, C.Labers, G.F Tchnoketch Kebir and A.Zerguerras, 2007).

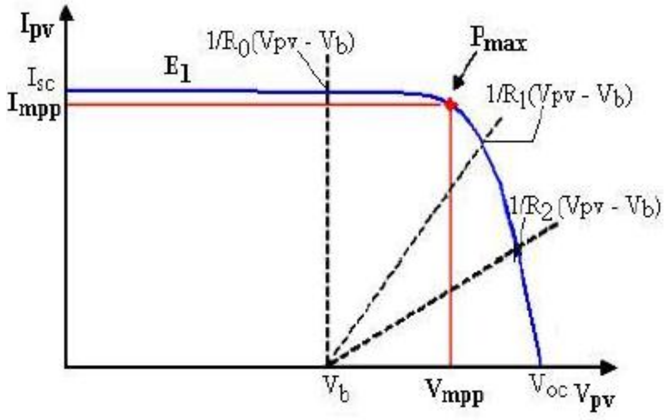

Figure 2.2: Current-voltage Characteristic PV Module

Source: M.S Ait Cheikh, C.Labers, G.F Tchnoketch Kebir and A.Zerguerras, 2007

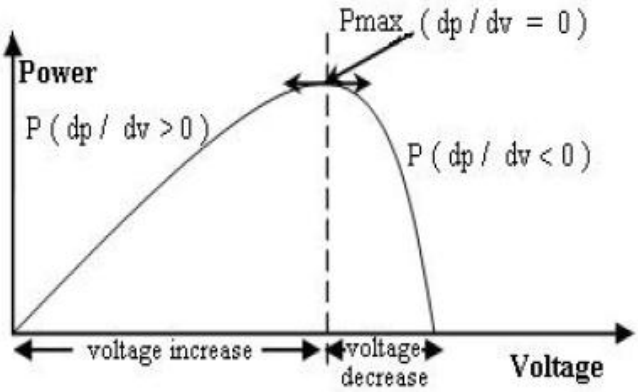

Figure 2.3: Power-Voltage Characteristic PV Module

Source: M.S Ait Cheikh, C.Labers, G.F Tchnoketch Kebir and A.Zerguerras, 2007

2.3 DC BOOST CONVERTER

A boost converter usually is used for modifying levels of voltage. Boost converters have a MOSFET that receives control signal from controller and then the same of a switch, it become on or off. The boost converters can be used in solar module act like switching modules between solar module and the load by letting MPPT control.

Figure 2.4 indicates boost converter with a PWM comparator (A.Gheibi, S.M.A Mohammadi and M.M Farsangi, 2014).

The PWM module can able to control between command voltage with control signal after compare with saw tooth output signal to make PWM control signal as gate signal for power device such as MOSFET transistor. The boost converter can alter input resistance larger than Rmpp and due to the fact the photovoltaic resistance is higher than Rmpp resistance in high radiations (1000 W/m^2), and considering that during day time tracking photovoltaic resistance is usually higher than Rmpp resistance, therefore the boost converter is used more often for tracking purposes. (A.Gheibi, S.M.A Mohammadi and M.M Farsangi, 2014).

$$I_L = I_o\left[\frac{1}{1-d} - \frac{R_L}{2Lf}d(1-d)\right] \tag{2.5}$$

Where,

I_L = Minimum inductor current

I_o = Output current

R_L = Resistance of load

f = Switching frequency

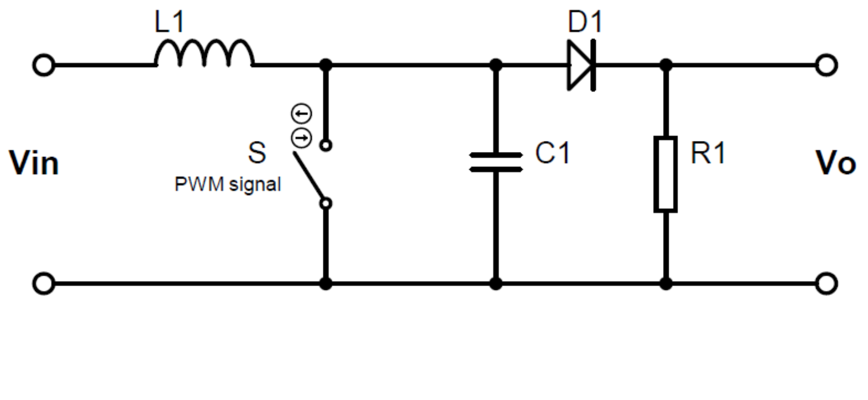

Figure 2.4: DC-DC Boost Converter

Inductor current must be zero when steady-state operation, which the formula can give in conducting ratio of Vo and Vi:

$$\frac{V_o}{V_{in}} = \frac{1}{1-d} \qquad (2.6)$$

Where d is a duty cycle (Dylan Dah-Chuan Lu, David Ki-Wai Cheng and Yin-Shu Lee, 2003).

2.4 FUZZY LOGIC CONTROLLER

Fuzzy logic is been built when 1965 by Lotfi A. Zadeh which defines it is control logic which using fuzzy concept to represent common sense and decision selective than the binary logic system. It can able to provide an effective way of get suitable results from complex data which different in real world. The fuzzy logic controller (FLC) is defined as linguistic control rules using human language which is related by fuzzy rules as inference and implications. A fuzzy logic controller is popular for complexity analysis by some methods or when input variables of information are uncertainly or inexactly (Chuen Chien Lee, 1990).

Compare to Boolean logic which is 2 simple value set, fuzzy logic is not crisp number but multi-valued logic. By using different types of methods, it had deals with degrees of truth and degrees of membership. The degree must take in range of 0 to 1. Fuzzy logic uses the real number of logical values between 0 (completely false) and 1 (completely true).

It means that element that belong to fuzzy set have certain degree of membership. So, the matter to deal in fuzzy logic can be nearly true or nearly false to any degree from range of crisp number (Micheal Negnevitsky, 2011).

The range of linguistic variables can be set as the fuzzy set theory. A linguistic variable is represent as fuzzy variables when fuzzy inference. As figure 3, the linguistic values of height are short, average and tall which can apply to practical. The height is the universe of discourse that acts like natural language. The height range of fuzzy logic control can be seen in figure 2.5 below. The hedge is acts as break down continuums into fuzzy intervals.

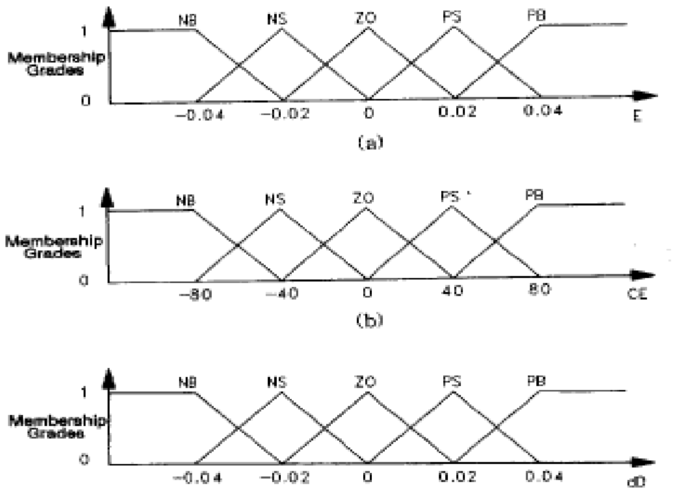

Figure 2.5: The Linguistic Variable Range of Height

Source: C.Y Won, D.H Kim, S.C Kim, W.S Kim, H.S Kim,2008

Fuzzy rule acts like human knowledge to analysis of complex system which was published by Lotfi Zadeh in 1973. Fuzzy set can determine the linguistic values by universe of discourses. Fuzzy rules can be defined as a conditional statement in the form as shown as below (Micheal Negnevitsky, 2011).

IF X is A
THEN Y is B

Where,

X and Y = linguistic variables

A and B = linguistic values

Fuzzy inference can be described as process of letting input variables using theory of fuzzy set to get suitable output. This is shown as figure 2.6 as below. One of