IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Fuzzy Logic Controlled Solar Module for Driving Three- Phase Induction Motor

Fuzzy Logic Controlled Solar Module for Driving Three-Phase Induction Motor

Nurul Afiqah Zainal[1], **Chan Sooi Tat**[2] **and Ajisman**[3]
Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

nafiqahz90@gmail.com[1], cst1990@live.com[2], ajisman@ump.edu.my[3]

Abstract. Renewable energy produced by solar module gives advantages for generated three-phase induction motor in remote area. But, solar module's output is uncertain and complex. Fuzzy logic controller is one of controllers that can handle non-linear system and maximum power of solar module. Fuzzy logic controller used for Maximum Power Point Tracking (MPPT) technique to control Pulse-Width Modulation (PWM) for switching power electronics circuit. DC-DC boost converter used to boost up photovoltaic voltage to desired output and supply voltage source inverter which controlled by three-phase PWM generated by microcontroller. IGBT switched Voltage source inverter (VSI) produced alternating current (AC) voltage from direct current (DC) source to control speed of three-phase induction motor from boost converter output. Results showed that, the output power of solar module is optimized and controlled by using fuzzy logic controller. Besides that, the three-phase induction motor can be drive and control using VSI switching by the PWM signal generated by the fuzzy logic controller. This concluded that the non-linear system can be controlled and used in driving three-phase induction motor.

1. Introduction

Nowadays, non-renewable resources have heavily damage to the environment and became less available in recently year. The alternative renewable energies such as solar energy can be used with renewable solar technologies to replace some of them for lower environment impact especially in remote area. However, the power outputs from solar modules are unstable with low efficiency due to non-linearity of solar radiation. Hence, to have optimum and stable power of solar module, fuzzy logic controller of Maximum Power Point Tracking (MPPT) is added as to improve the performances of the system [1].

AC power systems are clearly dominated over DC system and induction motors are greatly used in many applications. The speed of induction motor can be controlled by variable frequency using power electronic circuits and microcontrollers [2]. Power electronics devices such as Insulated-Gate Bipolar Transistor (IGBT) and microcontrollers are implemented as to make the electric drive system become low cost in terms of construction and also maintenance.

The designed system proposed is to maximize the photovoltaic voltage from solar module and the supply from voltage source inverter to control the speed of three-phase induction motor. This study

[1] Email: nafiqahz90@gmail.com

also designed the fuzzy logic algorithm and generates three phase PWM using microcontrollers. Figure 1 shows the block diagram of designed system for this project.

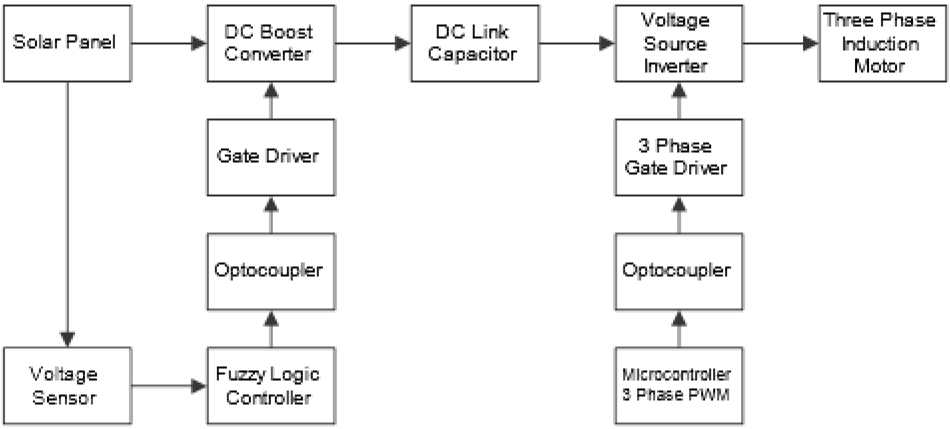


Figure 1. Block Diagram of designed system.

2. Fuzzy Logic Controller

The specifications of solar panel need to be considered as to maximize the power of solar module. These specifications are used as the inputs variables of fuzzy logic algorithm. Malaysia Solar Resources (MSR) 245W solar panel as shown in figure 2 is chosen with maximum voltage of 29.702V and maximum current of 8.107A.

Figure 2. MSR 245W solar module.

Most common method for fuzzy inference technique is Mamdani method which are performed in this four steps: fuzzification, inference mechanism, aggregation and defuzzification. The inference mechanism of Mamdani method used fuzzy rules for linguistic variables [3]. The linguistic variables are classified as Negative Big (NB), Negative Small (NS), Zero Less (ZL), Zero (ZE), Positive Small (PS) and Positive Big (PB) in every fuzzy set that are created. As for the inputs, Voltage Error (V_{error}) and Voltage Change of Error (V_{COE}) are placed as to control the output variable of Duty ratio (D).

Maximum power voltage of solar module is used as reference voltage to be compared with the input of photovoltaic voltage in V_{error} calculation. As for V_{COE}, it used to measure the changes of voltage in current time. The formulae for V_{error} and V_{COE} are as in Equation (1) – (2) respectively.

$$V_{error}, E(k) = \frac{V_{ref} - V_{in}}{V_{ref}} \quad (1)$$

$$V_{COE} = E(k) - E(k-1) \quad (2)$$

Where V_{ref} and V_{in} are the reference voltage and input voltage of solar module respectively. E(k) and E(k-1) are the values of the error at the instant (k) and (k-1).

Fuzzy rules are defined as conditional statement of variables. It is written in fuzzy rule base which have V_{error} and V_{COE}. Fuzzy rules created for fuzzy sets as to do an evaluation of possible outputs of input variables. This is based on fuzzy rule base and aggregate of the rule outputs for defuzzfication (Table 1).

Table 1. Fuzzy rules base

		V_{COE}				
		NB	NS	ZE	PS	PB
	NB	NB	NB	NB	NS	NS
	NS	NB	NS	NS	NS	ZE
V_{error}	ZL	NS	ZL	ZL	ZL	ZE
	ZE	PS	ZE	ZE	ZE	ZE
	PS	PS	PS	PS	ZE	ZE
	PB	PB	PB	PS	PS	PS

The defuzzifed output is the duty ratio between value of 30 and 100 which represented the duty cycle. The duty cycle output from fuzzy logic algorithm will trigger MOSFET gate of DC-DC boost converter as to maximize the photovoltaic voltage. The desired voltage is higher than photovoltaic voltage and the fuzzy logic will set duty cycle as ZE to get the desired output. If the V_{in} is lower than V_{ref} thus V_{error} will be positive and V_{COE} will calculate the previous input voltage either it is raised or lower before come out with duty ratio value. Figure 3 shows the membership function of inputs, V_{error} and V_{COE} whereas the output is Duty ratio.

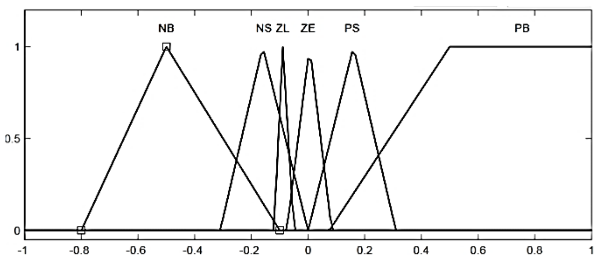


Figure 3(a). Error (V_{error}).

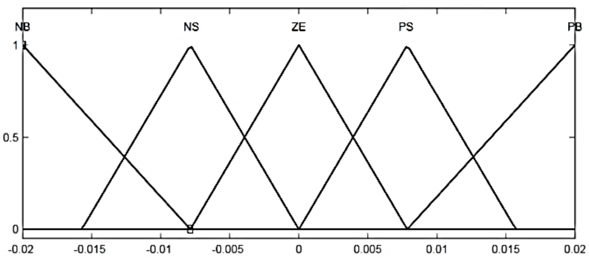


Figure 3(b). Change of Error (V_{COE}).

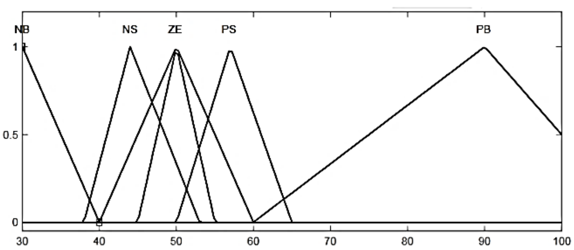


Figure 3(c). Duty ratio (D).

The Fuzzy Logic Controller (FLC) generated duty cycle in Pulse Width Modulation (PWM) mode by using microcontroller. The fuzzy inference algorithm is implemented into microcontroller and PWM signal is generated as to maximize the output voltage.

3. DC-DC Boost Converter

Voltage divider act as a sensor to measure the photovoltaic voltage input from the solar panel. This voltage divider used resistors with value of 51 kΩ and 7.5 kΩ to sense maximum 38V of photovoltaic voltage and converted it into 5V for the microcontroller. This is due to the microcontroller only able to receive up to 5V for the voltage input. Equation 3 below shows the formulae used for the voltage divider.

$$V_{out} = \frac{R2}{R1+R2} V_{in} \tag{3}$$

Where V_{in} and V_{out} is the input and output voltage of the voltage divider respectively, while R1 and R2 are the value of resistors.

Duty cycle generated by FLC is used to boost up photovoltaic voltage into desired output which is 60 V. DC-DC boost converter is designed as to get higher DC voltage to run a load. The FLC is used to switch on MOSFET device for boost operation by maximized the photovoltaic voltage constantly. Equation 4 below indicates the equation used to determine the output voltage from the boost converter.

$$D = 1 - {V_s}/{V_o} \tag{4}$$

Where V_S is the input voltage from solar panel, V_O is the output voltage from the boost converter and the D is the MOSFET duty ratio.

The component selection for DC-DC boost converter are considered to be important for designed the DC-DC boost converter [4]. The DC-DC boost converter is affected by inductor, capacitor, frequency and load. Inductor current ripple and frequency are the important specifications that need to be considered in selecting suitable inductor.

Besides that, selecting suitable capacitor need to be considered in DC-DC boost converter. The ESR of the capacitor output produced some ripple with current ripple affect the minimum requirement for output capacitance.

Optocoupler act as isolation circuit between fuzzy logic controller and gate driver from high current rating. Optocoupler circuit is connected to IR2112 gate driver as it will result in smooth PWM output signal and increase in voltage from 5V to 12V for switching the MOSFET.

4. Voltage Source Inverter

The voltage source inverter is supplied by DC-DC boost converter output in order to drive three-phase induction motor. The three-phase induction motor used AC voltage which converted from DC voltage supplied by the solar panel by voltage source inverter. The three-phase PWM algorithm used same clock frequency to generate out duty cycle. PWM module in microcontroller created sine function and produced sine PWM waveform for each phase as it is one of the popular technique namely as PWM technique by microcontroller [5].

Microcontroller PIC18F4431 used C language in order to generate sine function PWM. Six PWM signals are generated by the microcontroller are high side and low side PWM signal. Besides that, switches are added into voltage source inverter system as to change the frequency of the PWM outputs.

Insulated gate bipolar transistor (IGBT) module SKM200GB123D used as inverters for this circuit. It consisted of six IGBT inside the module which connected to IR2130 H-bridge driver. The driver consisted of high side bootstrap circuits with fast rectifier that switched the IGBT to turn on and off for voltage source inverter.

The outputs of IGBT module are connected to three-phase induction motor in wye-connection. The direction of rotation for induction motor can be changed by changing connection. The controlled speed of three-phase of induction motor can be adjusted by pressing buttons to change the duty cycle.

IOP Conf. Series: Materials Science and Engineering **114** (2016) 012138 doi:10.1088/1757-899X/114/1/012138

5. Result and Discussion

Figure 4 below shows the PWM signal that are generated by FLC. The duty ratio indicates as 50% with maximum voltage, V_{max} is 5.36V.

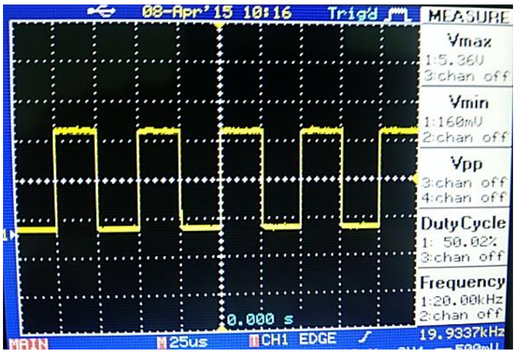


Figure 4. PWM outputs from fuzzy logic controller.

The PWM signal from FLC has triggered the MOSFET in DC-DC boost converter to boost up the solar module voltage from 29.702 V to 58.4 V. The output voltage then is smoothed by using DC bus capacitor as to get fine signal. The DC output voltage result with fewer ripples as shown in figure 5 shows that the maximum output voltage could be supplied to the voltage source inverter.

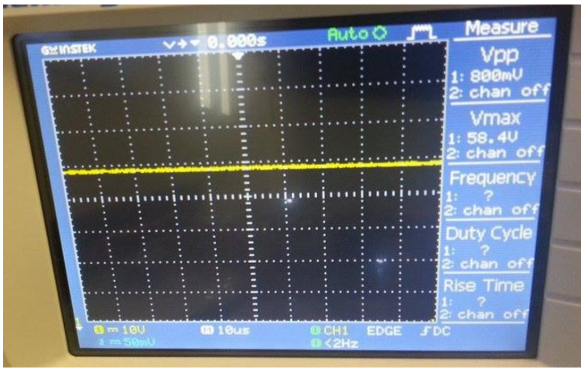


Figure 5. Voltage output from DC-DC boost converter.

Figure 6 shows the complete circuit of fuzzy logic controller and DC-DC boost converter that are used in this project.

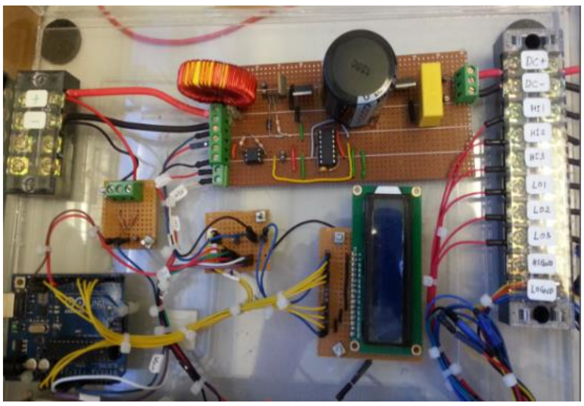
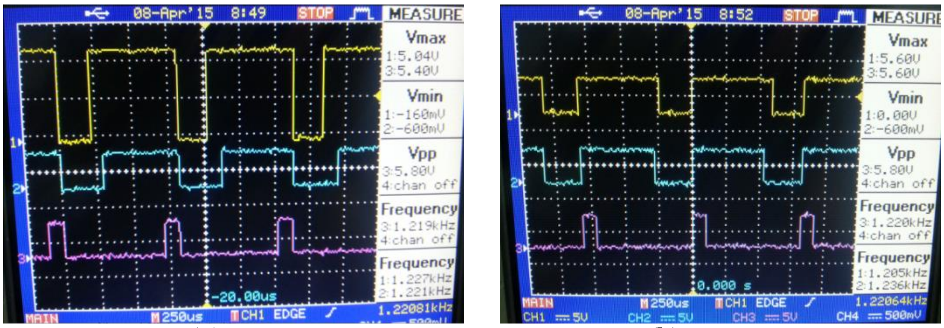


Figure 6. FLC and DC-DC boost converter complete circuit.

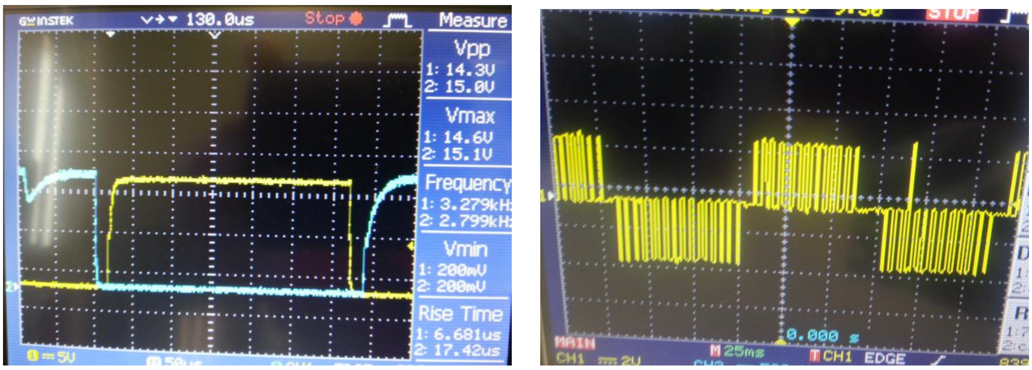
The microcontroller PIC18F4431 generated three-phase PWM signals which can be varied by using switch in order to change the frequency. The outputs from the microcontroller have been captured by oscilloscope. Figure 7 shows the high side PWM (a) and low side PWM (b) signal that are generated.



(a) (b)

Figure 7. Three-phase PWM in high side (a), low side (b)

The 15V of PWM signal to be switched on and off IGBT switched the voltage source inverter which converted DC to AC voltage in order to drive three-phase induction motor. The dead time of PWM signal is 6.681µs which is higher than the IGBT modules minimum requirement. Thus, it could turn on and off the IGBT. The three-phase PWM signals from the IGBT and the outputs from three-phase induction motor have been captured as shown in figure 8 (a) and (b).



(a) (b)

Figure 8. IGBT PWM in dead time (a) and AC voltage line-to-line (b)

By varying the frequency of three-phase PWM signal has control the speed of three-phase induction motor. This can be done by switching the switch from the microcontroller. The designed circuit has maximized the output voltage from solar module and supplied to the voltage source inverter. The speed of three-phase induction motor can reached up to 305.4 rpm by one 245 W solar module. The designed circuit for voltage source inverter and controlled speed of three-phase induction motor are shown in figure 9 and 10 respectively.

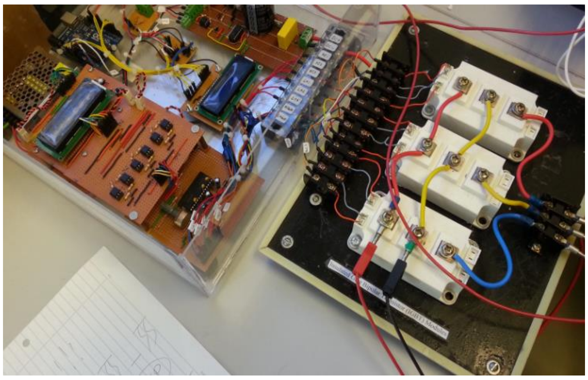


Figure 9. Circuit of voltage source inverter.

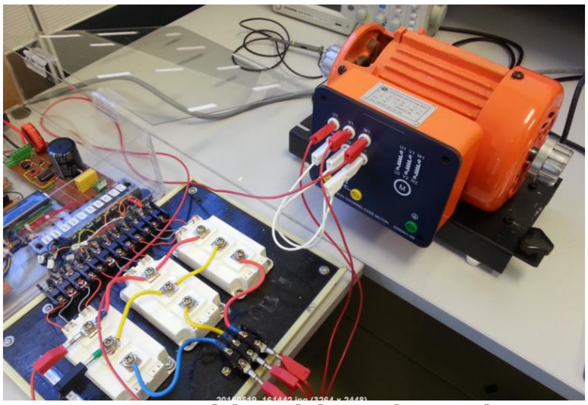


Figure 10. IGBT module and three-phase induction motor.

6. Conclusion

The designed circuit demonstrated the fuzzy logic algorithm implemented into microcontroller as controller by applying MPPT method in order to maximize output voltage and boost up by using DC-DC boost converter. DC-DC boost converter is designed for fuzzy logic controller as to increase the efficiency of solar module. It also designed to drive voltage source inverter for controlling the speed of three-phase induction motor. Remote areas with low supply of energy are suitable to use this system as it based on solar energy. This system proves that, by using solar module, driving three-phase induction motor is possible and also can be used in other applications.

References

[1] M.S. Ait Chikh, C. Larbes, G.F. Tchoketch Kebir and A.Zerguerras (2007). Maximum power point tracking using a fuzzy logic control scheme. Revue des Energies Renouvelables Vol. 10, no.3, pp 387-395

[2] Pedro Nuno da Costa Neves and Joao L. Afonso (2006). Development of a Variable Frequency Power Electronics Inverter to Control the Speed of a Three-Phase Induction Motor. 3rd International Conference on Hands-on Science, Science Education and Sustainable Development, Braga, Portugal.

[3] Negnevitsky, M. (2011). *Artificial Intelligence: A Guide to Intelligent Systems*. (3rd ed). England: Pearson Education Limited 2002.

[4] Hasaneen, B.M, Mohammed, A.A.E (2008), "Design and simulation of DC/DC boost converter", IEEE, Power System Conference, 2008. MEPCON 2008. 12th International Middle-East, pp. 335-340

[5] Sunil Panda, Anupan Mishra, B.Srinvas (2009), "Control of Voltage Source Inverters using PWM/SVPWM for Adjustable Speed Drive Applications, BTech thesis 2009