Vol. 2, No. 2, October 2023, pp. 171-177
p-ISSN: 2963-8577
e-ISSN: 2964-3511
DOI: 10.57102/jescee.v2i2.72

JESCEE
Journal of Emerging Supply Chain, Clean Energy, and Process Engineering

SIMULATION STUDY OF A SINGLE-PHASE INDUCTION MACHINE AS A WATER PUMP SYSTEM UTILIZING PHOTOVOLTAIC

Elfin Faturiansyah[1], Syukriyadin Syukriyadin[1*], Hafid Hafid[1]
[1]Department of Electrical and Computer Engineering, Faculty of Engineering, Universitas Syiah Kuala

Abstract
This paper presents a simulation study of using a single-phase induction machine as a solar PV powered water pump system equipped with Maximum Power Point Tracking (MPPT) on the boost converter. Inverters are used to convert DC voltage stored in batteries to drive single-phase induction machines. The simulation was carried out to analyze the system's performance in generating electrical power from solar panels and using it to operate the water pump. This research also considers variables such as fluctuations in sunlight intensity, as well as the dynamic response of induction machines and MPPT converters. From the simulation test results, it was found that the system as a whole will work well if it uses a radiation input that is more significant than 750 W/m². The load in the form of a single-phase induction motor, which is inductive, influences variations in the output power produced by the solar PV at the boost converter.

Keywords:
Simulation; solar PV; boost converter; inverter; induction machine

Article History:
Received: October 2nd, 2023
Revised: October 12th, 2023
Accepted: October 21st, 2023
Published: October 31st, 2023

Corresponding Author:
Syukriyadin Syukriyadin
Department of Electrical and Computer Engineering, Universitas Syiah Kuala, Indonesia
Email: syukriyadin@usk.ac.id

1. Introduction

Water use is an obligation that must be fulfilled for human life; in daily needs, water is used for drinking, cooking, washing, and sanitation purposes, as well as agricultural needs [1]. To make it easier for people to regulate the amount of water needed, they can use a water pump machine to provide clean water needs. The problems faced by some people in water pumps, especially those in inland areas, are the need for fuel oil (BBM) supply and the distance of the village from the reach of the PLN electricity network.

Solar power generation (PLTS) is an alternative generator that can be used to overcome this problem. PLTS is also one of the renewable energy generators that is widely used in Indonesia, and this is because Indonesia is a tropical country that has relatively high solar radiation, namely 1677 kWh/m² per year. Its use is quite flexible [2].

A solar panel is a *p-n* junction semiconductor that can absorb photons in light to produce electrical power or what can be called the PV effect. The power produced by the panel depends on the radiation value of sunlight, temperature, and the terminal voltage of the solar panel. Several types of materials are used to make solar panels, which provide different characteristics from one another. Various kinds of research have been carried out to implement a mathematical equation for solar panels or PV cells. One of the equivalent circuit models and the mathematical equation model for solar PV can be seen in [3].

Photovoltaics or solar panels are semiconductors that produce output in the form of DC electricity, which is converted from sunlight. The power produced by photovoltaics is greatly influenced by the intensity of solar radiation and the surrounding air temperature, where these two factors are directly proportional to producing the maximum power point [4].

The output produced by photovoltaics is limited by voltage, current, and power. In conditions of stable solar radiation and panel temperature, there is an operating point that can produce voltage and current output with maximum values. In the literature, maximum power point (MPP) conditions are usually called peak power point (PPP) or optimal operating point (OOP).

Using PLTS or Photovoltaic power plant requires the MPPT control method to obtain maximum power output and high efficiency on solar panels. There are two methods or algorithms that are widely used to implement MPPT, namely the Perturb and Observe (P&O) and Incremental Conductance (IC) methods; both methods are more manageable and require lower costs [5].

The P&O method can cause oscillations in the power produced if solar radiation varies, so this method is more suitable for constant solar radiation conditions. Then, to overcome the shortcomings of the P&O method, the Incremental Conductance method can be used because the IC method has a high level of efficiency, as well as good accuracy and power control [6].

The MPPT algorithm is used in DC-DC converters to extract maximum power output from photovoltaics. The converter input is mostly an uncontrolled DC voltage. Switched-mode DC-DC converters are used to change uncontrolled DC input into controlled DC output at the desired voltage level [7]. A boost converter is used because it is able to transfer maximum energy from the PV panel to the load regardless of the varying solar radiation that occurs. The amount of output voltage produced can be regulated by determining the size of the duty cycle (*D*) using a switching component [7][8].

In this research, a single-phase induction machine as a water pump system utilizing a photovoltaic and boost converter controlled by an incremental conductance algorithm and an inverter will be simulated using MATLAB/Simulink.

2. Experimental Section

A. System Modelling

The block diagram shows the system parts used in this research, as shown in Fig. 1.

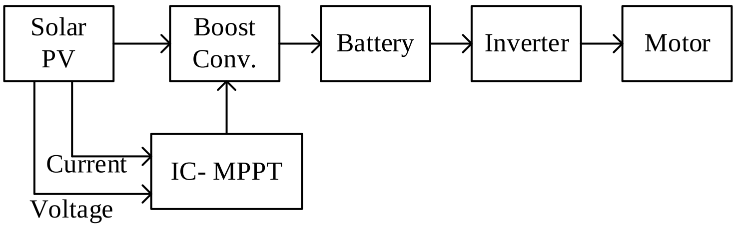

Figure 1. Block Diagram of System Modeling

This research uses Monocrystalline solar panels, the Kyocera KC200GT type, with a capacity of 200 Watts. The solar PV data is shown in Table 1.

Table 1. Specification of Solar PV

Maximum power (Pmax)	200 *W*
Maximum power voltage (Vmp)	26.3 *V*
Maximum power current (Imp)	7.61 *A*
Open circuit voltage (Voc)	32.9 *V*
Shor circuit current (Isc)	8.21 *A*
Series Connected Modules (per String)	12
Strings	2

This research uses induction motor specifications, as shown in Table 2.

Table 2. Specification of Induction Machine

Model	YC90S4
Voltage, Frequency	220V~50Hz
Current	7.7 A
Power	750 Watt
Speed	1500 rpm
Stator impendance	2.02 Ω
Rotor impedance	4.12 Ω
Mutual inductance of the primary winding	0.177 H

B. Simulation Modeling of Solar PV, MPPT with Boost Converter

In this research, it was explained previously that an MPPT system and boost converter will be used, which function to regulate the PV output optimally and according to what is needed. The boost converter will work by following the IC-MPPT algorithm, where the algorithm will provide a reference voltage to the boost converter, which will then be adjusted to the voltage produced by the solar PV so that the output voltage will be maintained at a specific value. The simulation circuit model is shown in Fig .2.

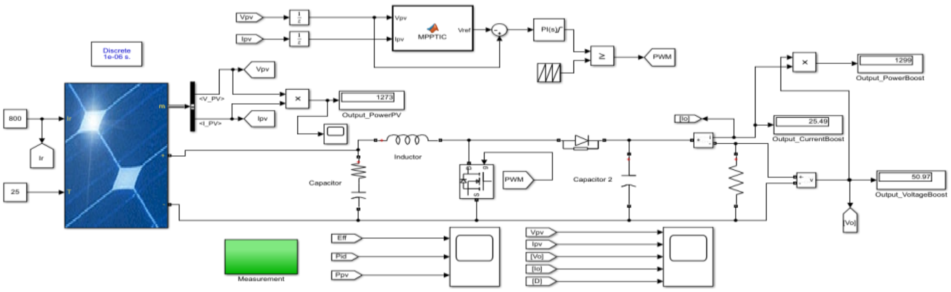

Figure 2. Equivalent Circuit Model of Solar PV, MPPT with Boost Converter

Batteries are used in this research as electrical energy storage, where the stored energy is then fed into the inverter. The inverter used in this research is a single-phase full bridge type with a MOSFET switching component, while the induction motor used is a single-phase induction motor, which functions as the load for the system, as shown in Fig .3.

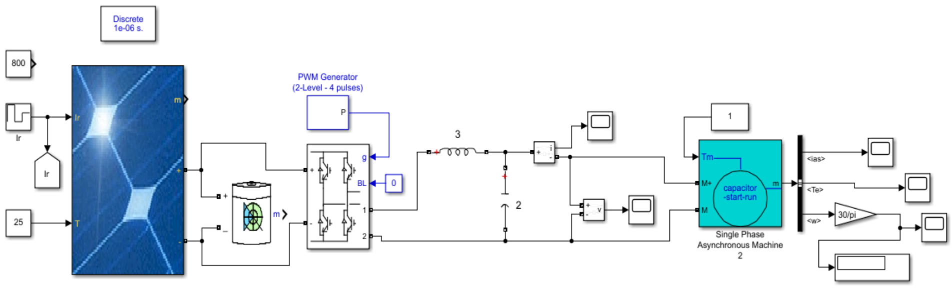

Figure 3. Equivalent Circuit Model of Solar PV, Battery, Inverter and Induction Machine

3. Result and Discussion

The simulation uses a solar radiation value of 800 W/m^2, which is a stable condition because it is considered difficult for solar irradiation to be in STC conditions or a value of 1000 W/m^2. Meanwhile, the temperature has a value of 25°C because this temperature value is still possible to obtain when in the field. Meanwhile, the load used in this simulation circuit is a resistor load with a value of R = 25 Ω, with a time duration of t = 0.75 sec, as shown in Fig .4.

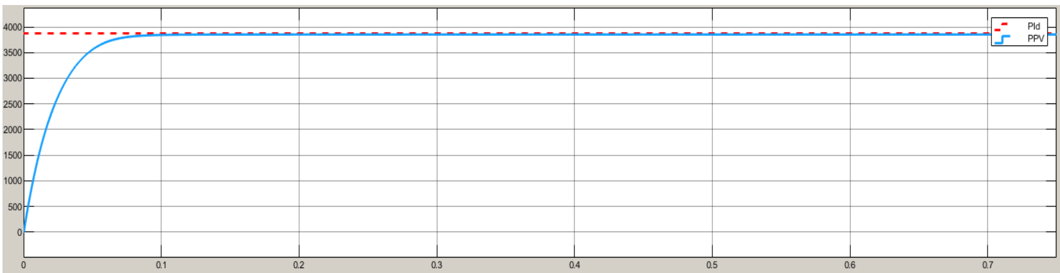

Figure 4. Simulation output power curve under changing environmental conditions

Based on Fig. 4 above, it can be seen that the graph shows the ideal output power Pid as the maximum power that can be produced by the panel (Pmp) according to the datasheet. P_{PV} is as power extracted using a boost converter. The Pid value in Fig. 4 above is 3853 Watts, and this value is obtained through the PV array plot on SIMULINK, which can display the P-V characteristics of the module with an input irradiation value that can be adjusted.

Analytically, the Pid value with irradiation of 800 W/m^2 can be calculated as follows:
Based on the datasheet, it is known as:

V_{oc} = 32.9 V, I_{sc} = 8.21 A, V_{mp} = 26.3 V, I_{mp} = 7.61 A, panel efficiency = 14.19%, and PV STC Area = 1425 mm^2 x 990 mm^2 = 1, 41 m^2.
if P_{id} = P_{mp}, Then P_{id} = Efficiency x Solar Irradiation x PV STC area
Pid = 14.19% x 800 W/m^2 x 1.41 m^2
Pid = 160 W
With a total of 24 modules, then
Pid = 160 W x 24
Pid = 3840 W

The power produced by PV takes time to reach the steady state point (rise time); this happens because the MPPT is tracking the maximum power point, where it will adjust the input voltage provided by the PV with the reference voltage set by the MPPT. The reference voltage Vref on the MPPT is compared with the voltage produced by the PV so that an error value is obtained. The error value will then be entered into the PI controller, which regulates the magnitude of the duty ratio, which will be compared again with the carrier signal so that it can finally be given as input to the IGBT gate driver in the boost converter. This method with a PI controller can provide better tracking results than others because it uses a closed-loop system. From the results obtained, the PI controller has succeeded in providing a duty ratio value that can reduce the rise time required by the circuit for a steady state or that the existing rise time process only takes less than 0.1 sec.

Table 3. Output Power for Changing Irradiation Conditions

Irradiance (W/m^2)	P_{pv} (Watt)	P_{id} (Watt)	Extracted Power (%)
800	3853	3876	99
700	3129	3403	92
600	2333	2923	78

For other irradiance conditions, it is shown in Table 3. Based on Table 3, the higher the simulation input irradiation value given, the greater the output power P_{PV} will be and closer to the maximum power P_{mp} so that the resulting extraction power will be greater. The irradiation value of 800 W/m^2 is the best irradiation value to be used in the next system, and this is because the steady state error difference is slight, making the extraction power used also higher.

To see the response of electromagnetic torque and motor speed when the system is loaded with an induction machine, a simulation test has been carried out, as shown in Fig .5 and Fig. 6, respectively.

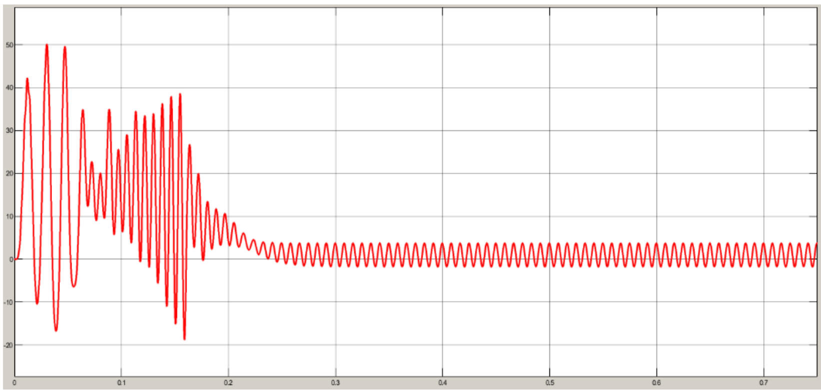

Figure 5. Electromagnetic Torque of Induction Machine

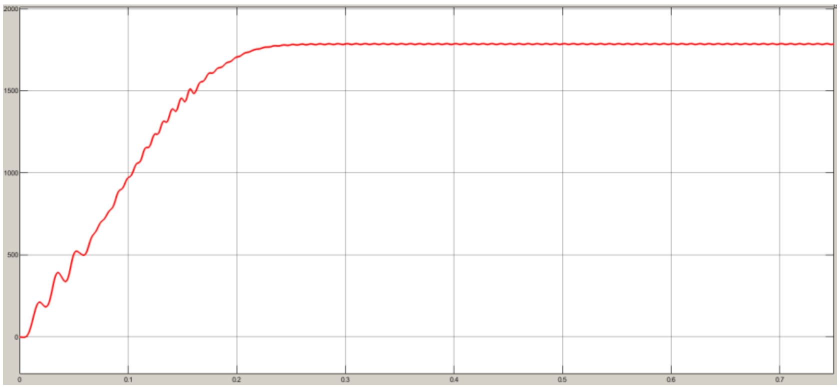

Figure 6. Rotor Speed of Induction Machine

Based on Figure 5, it can be seen that the electromagnetic torque produced by the motor is around 3.7 N.m. Based on Figure 6, the induction machine speed produced by the system is above the synchronous speed of around 1750 rpm; this proves that the induction machine is running at speeds of more than 1500 rpm, so the system has successfully carried the induction machine load.

When the motor is run at irradiance-changing conditions, namely at irradiation conditions of 800 W/m^2 at 0 – 3.5 sec, 600 W/m^2 at 3.51-7 sec, and 700 W/m^2 at 7.1-10.5 sec, the voltage and current responses of induction machine are obtained as shown in Fig .7 and Fig .8, respectively.

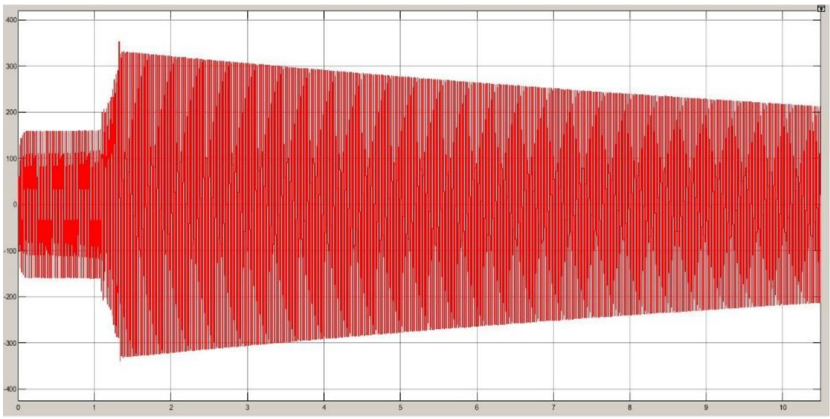

Figure 7. Induction Machine Voltage Response under Variable Irradiance Conditions

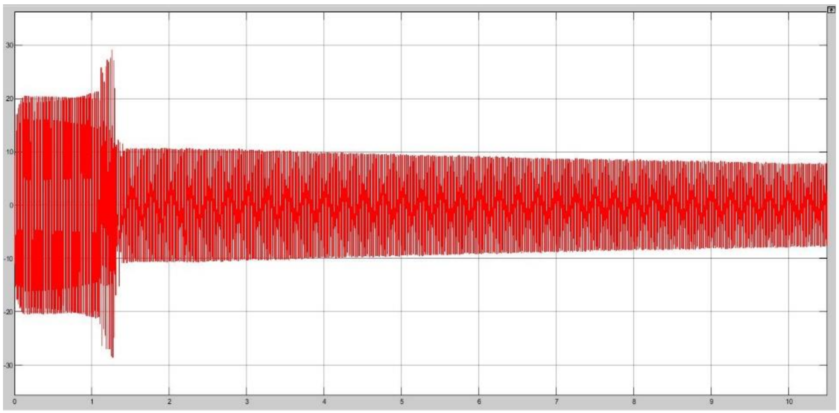

Figure 8. Induction Current Response under Variable Irradiance Conditions

Based on Fig. 7, the voltage produced by the system appears to have decreased quite significantly even though it can produce a maximum voltage at t = 1.25 sec with a value of 320 V; this is due to changes and a decrease in irradiation not being able to provide a stable voltage to the motor load which is an inductive load. Then, the maximum current shown in Fig. 8 above is stable at a value of 10.5 A. The current does not experience significant changes or decreases caused by changes in irradiation, which experience decreases or increases, so the current value will continue to be stable and steady state even though there is a slight decrease.

4. Conclusion

From the simulation results that have been produced, it can be concluded that the system design using the MATLAB/Simulink application has been successfully carried out; this is because the load in the form of a single-phase induction machine has been successfully carried out with a rotor speed of 1750 rpm, which has proven that the system has met load requirements so that the load can produce speeds above the synchronous value.

References

[1] B. Hartono and P. Purwanto, “Perancangan Pompa Air Tenaga Surya Guna Memindahkan Air Bersih Ke Tangki Penampung,” SINTEK J. J. Ilm. Tek. Mesin, vol. 9, no. 1, 2015.
[2] I. D. Sara, “Analisis Potensi Kondisi Suhu dan Radiasi Sinar Matahari di Kota Banda Aceh untuk Pengembangan Pembangkit Listrik Tenaga Surya,” in Seminar Nasional dan Expo Teknik Elektro, 2014, pp. 142–145.
[3] I. Yahyaoui, "Advances in Renewable Energies and Power Technologies: Volume 1: Solar and Wind Energies," Elsevier, 2018.
[4] A. Parastiwi, R. I. Putri, S. Adhisuwignjo, and M. Rifa, "Photovoltaic Terapan: Photovoltaic Terapan," vol. 1. UPT Percetakan dan Penerbitan Polinema, 2018.
[5] M. M. Rana, M. R. Ali, A. K. Ajad, and M. Moznuzzaman, “Analysis of P&O and INC MPPT Techniques for PV Array Using MATLAB,” IOSR J. Electr. Electron. Eng., vol. 11, no. 04, pp. 80–86, 2016.
[6] S. Qin, M. Wang, T. Chen, and X. Yao, “Comparative Analysis of Incremental Conductance and Perturb-and-Observation Methods to Implement MPPT in Photovoltaic System,” in 2011 International Conference on Electrical and Control Engineering, 2011, pp. 5792–5795.
[7] M. K. Kazimierczuk, "Pulse-Width Modulated DC-DC Power Converters," John Wiley & Sons, 2015.
[8] Muhammad Farhan Rozi, Syukiryadin Syukiryadin, Suriadi Suriadi, "Pengaturan Maximum Power Point Tracking (MPPT) Menggunakan Artificial Neural Network (ANN) Berbasis Simulasi," KITEKRO, Vol.5, No.1, 2022.

Biographies of Authors

Elfin Faturiansyah (1998) graduated from Electrical Engineering at Syiah Kuala University in 2023 with a specialization in electrical energy engineering. His research interests are renewable energy, power generation systems, and electric machines.

Syukriyadin (1971) has been working as the academic staff in the Department of Electrical Engineering, University of Syiah Kuala since 1999. His research interests are Renewable Energy Technology, Electric Energy Management, Electric Vehicle Transportation Engineering, Microgrids, Intelligent Electric Power Systems, and Electronic Power Applications in Power Systems.

Hafidh (1972) has been working as the academic staff in the Department of Electrical Engineering, University of Syiah Kuala since 1999. His research interests are focused on power electronics, renewable energy technology and its integration to power grid or isolated grid. His works on renewable energy have been mainly centered in two type of renewable sources; wind and solar. Currently he is preparing some programs related to the integration studies of small scale hybrid renewable power plant and its impact on the distribution networks in a particular area in Aceh, Indonesia.