Evolution in Electrical and Electronic Engineering Vol. 3 No. 2 (2022) 650-660
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Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Simulation of On Grid PV System for Residential

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DOI: https://doi.org/10.30880/eeee.2022.03.02.077
Received 03 August 2022; Accepted 19 September 2022; Available online 30 October 2022

Abstract: Nowadays, the demand for electrical energy is growing every day, yet conventional energy sources are dwindling. Alternative energy resources must be used to bridge the gap between rising demand and supply in order to close the gap. A source of renewable energy appears to be a promising option. Because of its natural availability, clean, environmentally beneficial, and an endless supply of energy, solar energy is the greatest option. By using MATLAB/Simulink software, this research presents a design and simulation of a home on-grid solar system. The system comprises of a solar array that transforms light radiation into electrical power, a boost DC-DC converter that boosts the photovoltaics' voltage, and an on-grid photovoltaic inverter that converts DC electricity to single-phase AC power. The maximum power point tracking (MPPT) control was developed to track the solar array's maximum power output. This project uses MATLAB/Simulink to simulate the output power when using an MPPT controller and without an MPPT controller by using a residential load. As a consequence, the suggested system has the potential to lower household power expenses.

Keywords: Solar Energy, Home On-Grid Solar System, MPPT, MATLA/Simulink

1. Introduction

Nowadays, solar power is one of the best renewable energy choices recommended by people to consume electricity. The function of solar power is it can convert sunlight into electricity by the conversion of energy. Solar power can be divided into three categories which are either directly, indirectly, or, a combination of both of them.

Solar power is famous around the world because it can be found anywhere. Thus, nowadays, it also can be found in rural and residential areas. It got a lot of attention from people because solar energy can be used in all kinds of applications. It got a lot of attention from people because solar energy can be used in all kinds of applications.

For this project, we will be more focused on on-grid photovoltaic systems. Solar systems that are connected to the grid, or on-grid, are by far the most prevalent and frequently utilized by households and businesses. These systems do not require batteries and are powered by solar inverters or micro-

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inverters. They are also connected to the power grid. Any excess solar power that you generate is exported to the electricity grid and you usually get paid a feed-in-tariff (FiT) or credits for the energy you export [1]. For the electrical grid, other grid users (neighbors) might benefit from the electricity generated by our solar system and transmitted to the grid. Furthermore, we will start importing or using power from the grid if our solar system is not operational or if we are using more electricity than our system produces.

Due to variations in irradiance and temperature, the voltage-power characteristic of a photovoltaic (PV) array is nonlinear and time-changing. In PV power systems, the job of maximum power point (MPP) tracking (MPPT) is to continually adjust the power system to extract the most power possible from the PV array. Grid-connected photovoltaic inverters have grown in popularity recently since they do not require battery backups. In solar systems, a number of maximum power tracking (MPPT) techniques have been introduced. In many solar power applications, perturbation and observation (P&O), which periodically changes the PV array output voltage, is used to shift the operating point toward the maximum power point. The implementation of this function is also quite straightforward.

2. Materials and Methods

The methodologies utilized in this study will be the main topic of this session. Also covered in more detail in this part are the system design, project planning, project flowchart, and software utilized. A workflow planning flowchart, which is to build and model an on-grid solar PV system design circuit employing a PV array, a boost DC-DC converter, an inverter converter, a single-phase DC-AC full-bridge converter, an MPPT controller, and a linked load. The on-grid PV circuit is being researched to establish each component function and parameter that is appropriate for this project. The on-grid PV circuit was then developed and modeled using MATLAB/Simulink software.

The on-grid PV system is made up of a series of six PV arrays, a boost DC-DC converter, an MPPT controller, an inverter controller, a single-phase DC-AC full-bridge rectifier, and loads. This section also describes in detail the model formulation and procedure that was utilized to apply in the systems.

2.1 Photovoltaic Array

The type of photovoltaic array chosen for the system is LG Electronics Inc. LG400N2W-A5. In the circuit, there are 6 photovoltaic arrays and each of them consists of 1 series module and 1 parallel string. Figure 1 shows the PV strings section. It has 2 input which is solar irradiation and temperature. The PV strings section implements a home installation of six PV array blocks in series that can produce 2400W of power at a solar irradiance of 1000 W/m2. In the advanced tab of the PV blocks, the robust discrete model method is selected and a fixed operating temperature is set to 25°C.

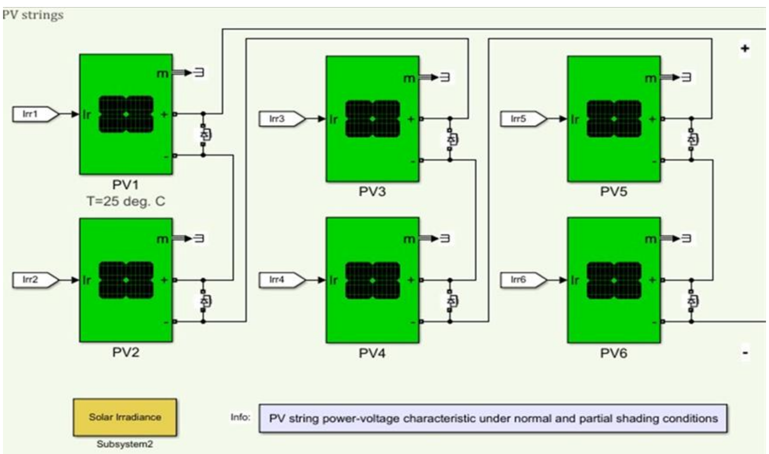

Figure 1: The PV string section in the system.

The power produced by the PV strings is fed to the house and utility grid using a two-stage converter which is a boost DC-DC converter and a single-phase DC-AC full bridge converter.

2.2 Boost DC-DC Converter

Based on the modeling simulation, the photovoltaic array is connected to boost the DC-DC converter. Through a DC connection, the boost converter's outputs are linked to an individual single-phase DC-AC full-bridge converter. The boost DC-DC converter is PWM controlled with a switching frequency of 20 kHz. Using the Switching Function method with PWM pulse averaging, it allows a simulation sample time of 5 microseconds and good accuracy on harmonics generated. Furthermore, the boost converter, on the other hand, is regulated by a separate Maximum Power Point Tracker (MPPT). The Maximum Power Point Tracking (MPPT) controller is based on the Perturb and Observe approach and supports scanning. In order to extract maximum power, the MPPT system automatically adjusts the duty cycle of the boost converter. Furthermore, this DC-DC converter boosts the inverter input voltage while isolating the low and high-voltage circuits. Then, numerous control objectives may be tracked simultaneously with the PV system functioning between the photovoltaic array and the inverter linked to the electric grid. Figure 2 shows the modeling of the boost DC-DC converter in the system.

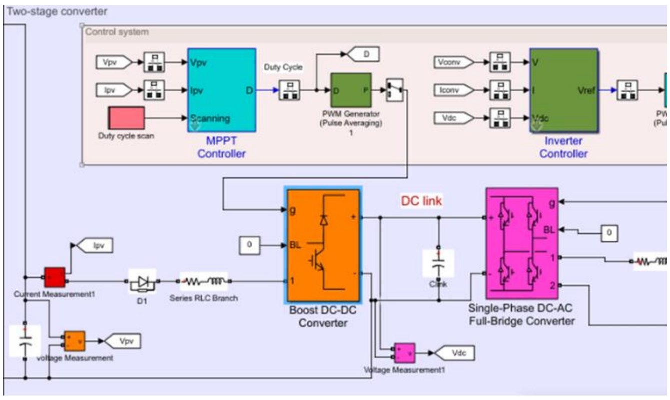

Figure 2: Modeling of the boost DC-DC converter in the system.

2.3 Maximum Power Point Tracking (MPPT)

The Maximum Power Point Tracking (MPPT) controller is based on the Perturb and Observe technique with scanning capability. The MPPT system automatically varies the duty cycle of the boost converter to generate the required voltage across the PV string in order to extract maximum power. Meanwhile, under the partial shading condition, a duty cycle is initiated to find the global maximum power point (GMPP) among various local maximum power points (LMPP).

2.4 Perturb and Observe (P&O)

The perturb and observe MPPT principle is to perturb a low-amplitude voltage and study the effect on the power produced [1]. Under variable radiation and temperature circumstances, the photovoltaic array provides maximum power [2].

If a positive increase in voltage V_{pv} results in an increase in power P_{pv}, the operating point is to the left of the MPP point. If the power drops, it indicates that the operating point is to the right of the MPP. When the voltage drops, the same logic may be applied. It is simple to discover the operating point relative to the MPP and converge it to the maximum power through an order of suitable control based on these numerous analyses on the effects of a change in voltage on power. In summary, if the power increases after a voltage perturbation, the direction of the perturbation is maintained. Otherwise, the process is reversed to resume convergence toward the new MPP [1].

2.5 Inverter for On-Grid Photovoltaic System

For the inverter controller, the inverter function as to control and maintain the DC link voltage at 400V while keeping a unity power factor. The controller uses a voltage regulator outer loop and a fast inner loop current regulator to generate the appropriate reference voltage (V_{ref}) for the PWM generator controlling the full bridge converter [3].

Furthermore, in the event of a utility blackout, solar panels in a grid-connected PV system will continue to provide electricity as long as the sun is shining. The supply line becomes an "island" of electricity surrounded by a "sea" of unpowered lines in this situation. As a result, automated anti-islanding circuitry is often required in solar inverters that are meant to deliver electricity to the grid. The generator disconnects from the grid and compels the distributed generator to power the local circuit in purposeful islanding. This is frequently used as a backup power system for buildings that sell their electricity to the grid [3].

2.6 Load and Utility Grid

The electricity generated by the system is sent into the grid and utilized to power various gadgets. The installation of the same is equally simple and straightforward [4]. The grid is modeled using a typical pole-mounted transformer and an ideal AC source of 14.4 kVrms. Pole-mounted transformers are power distribution transformers that are placed horizontally to overhead wires on a power pole (wood or concrete). Pole-mounted transformers are commonly used to convert distribution voltage to a 120/240 Volt power supply for residences. After that, the transformer 240 Volt secondary winding is center-tapped and the central neutral wire is grounded and for the inverter, the 2500W residential load, as well as the neighbors' load, are connected to the 240V secondary winding. Figure 3 shows the setup for residential load and utility grid in the photovoltaic system.

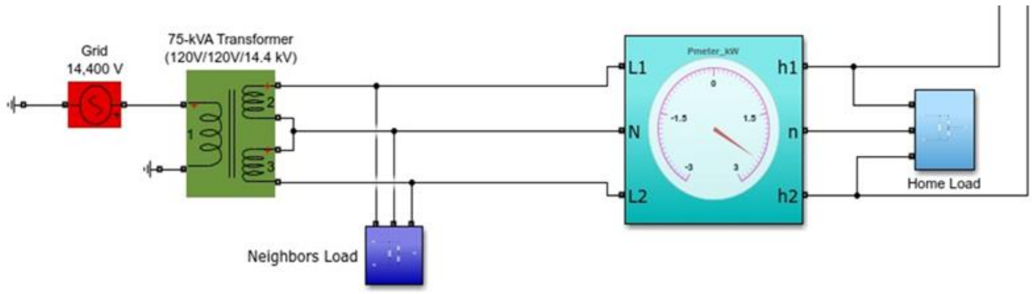

Figure 3: Setup for residential load and utility grid in the photovoltaic system.

3. Results and Discussion

This chapter covered the project's outcome. The simulation of an on-grid photovoltaic system using MATLAB/Simulink software was analyzed and explained. This case study also consists of the performance of the system with an MPPT controller and without an MPPT controller.

3.1 Design Results

3.1.1 Design of PV Array for On-Grid Photovoltaic System

For validation and testing of the maximum power point tracking (MPPT) method, the model is evaluated under standard temperature conditions (STC) with radiation of 1000 W/m2 and a temperature of 25°C. Table 1 shows the parameter used for the 6 PV arrays provide by its data sheets.

Table 1: The parameter of the PV array

Parameter	Data
Rated power, (P_{max})	400.316W
Current at maximum power point (MPP), (I_{mpp})	9.86A
Voltage at maximum power point (MPP), (V_{mpp})	40.6V
Short-circuit current, (I_{sc})	10.47A
Open-circuit voltage, (V_{oc})	49.3V

3.1.2 PV Array Characteristics

The maximum power point is the only location on a PV module where its characteristics are defined. The voltage varies significantly throughout the zone, while the current fluctuates far less. The PV module performs the function of a current source in this region. Figure 4 shows the characteristics of the PV module that is functioning at a local maximum power point and at the global maximum power point.

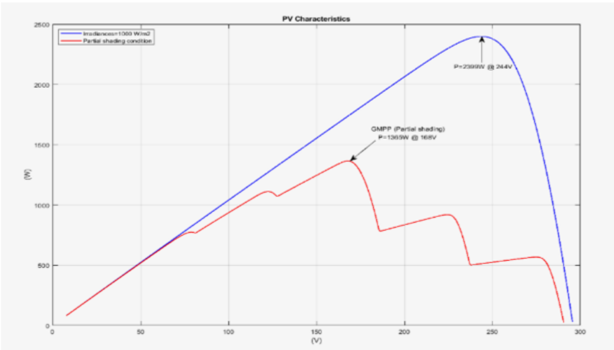

Figure 4: The PV characteristics.

3.1.3 Design of Boost DC-DC Converter.

A boost converter (step-up converter) is a DC-to-DC power converter that increases the voltage from its input (supply) to its output while decreasing the current (load). In the circuit, the type of boost DC-DC converter used is the type of the switching function. This type is chosen to offer an effective way to increase the voltage of a given DC voltage source to a specific amount.

3.1.4 Design of Inverter Controller.

A Grid-Connected Photovoltaic System (GCPS) uses inverters to connect to the electrical grid. At the connecting point, this integration causes certain problems. As a result, grid-tied inverter control is essential for providing the power system with high-quality electricity. The inverter controller used in the circuit is the control system for a 2.5kW grid-connected inverter. The setting value for the inverter controller used in the circuit. After stimulating the circuit, the generated input which is the AC voltage (Vrms) is at 240V meanwhile the DC voltage (V) value is 400V. Furthermore, the power used to control the system is 2500 VA and the frequency is at 60 Hz.

3.1.5 Design of Single-Phase DC-AC Full Bridge Controller.

One of the popular designs that offer isolation in addition to stepping up or down the input voltage is a full bridge converter. Reversing polarity and delivering several output voltages at once are two possible additional functionalities. The setting single-phase DC-AC full bridge converter is used in the circuit. The converter is modeled by a switching function. It is controlled by firing pulses which is produced from the PWM generator (0/1 signal) or firing pulses averaged over a specified period (PWM averaging: signals between 0 and 1).

3.1.6 Design of MPPT Controller and Duty Cycle Scan.

The technique chosen in this circuit to produce maximum power output from the PV array is by Perturb & Observe method. According to the Perturb & Observe method, when the PV panel's operational voltage is changed by a little amount, if the resulting change in power P is positive, we are moving in the direction of MPP and we continue perturbing in that direction. If P is negative, we are moving in the opposite direction as the MPP and need to adjust the provided perturbation sign.

Furthermore, the MPPT controller is also linked with the duty cycle. MPPT controller generates a duty cycle in order to create switching signals for the converter. The switching signal allows the boost converter to operate the solar PV system at the optimum voltage and current so that maximum power extraction is possible.

3.2 Overview Circuit.

Figure 5 and 6 shows the circuit of the on-grid PV solar system by using the MATLAB/Simulink software of this project. The component used in the simulation is the PV array with a solar irradiance of 1000 W/m2 and a fixed operating temperature set to 25°C. The PV array is connected to the boost DC-DC converter to enhance the PV array's output voltage. To get the maximum power output from the PV array, the MPPT controller is connected through the circuit.

3.2.1 Model Implementation of Photovoltaic System with MPPT controller

Figure 5 presented the on-grid photovoltaic system simulation model with an MPPT controller. The tuned output from the MPPT controller subsystem is fed to the inverter subsystem.

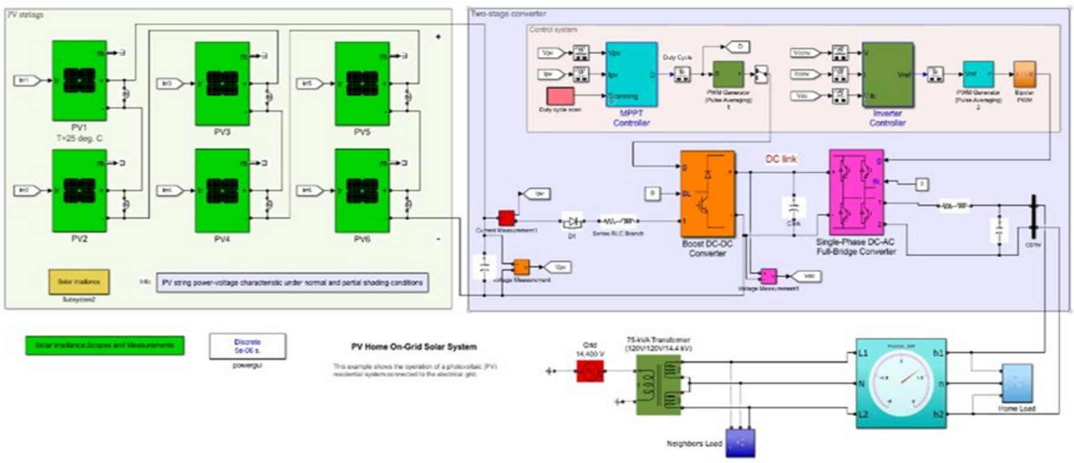

Figure 5: On-grid photovoltaic system with MPPT controller.

3.2.2 Model Implementation of Photovoltaic System without MPPT controller.

Figure 6 shows the on-grid photovoltaic system without using an MPPT controller. In this procedure, the maximum power point is not reached, and the PV array's power is lost numerous times. To give gate pulses to the inverter switches, the PWM technique is used.

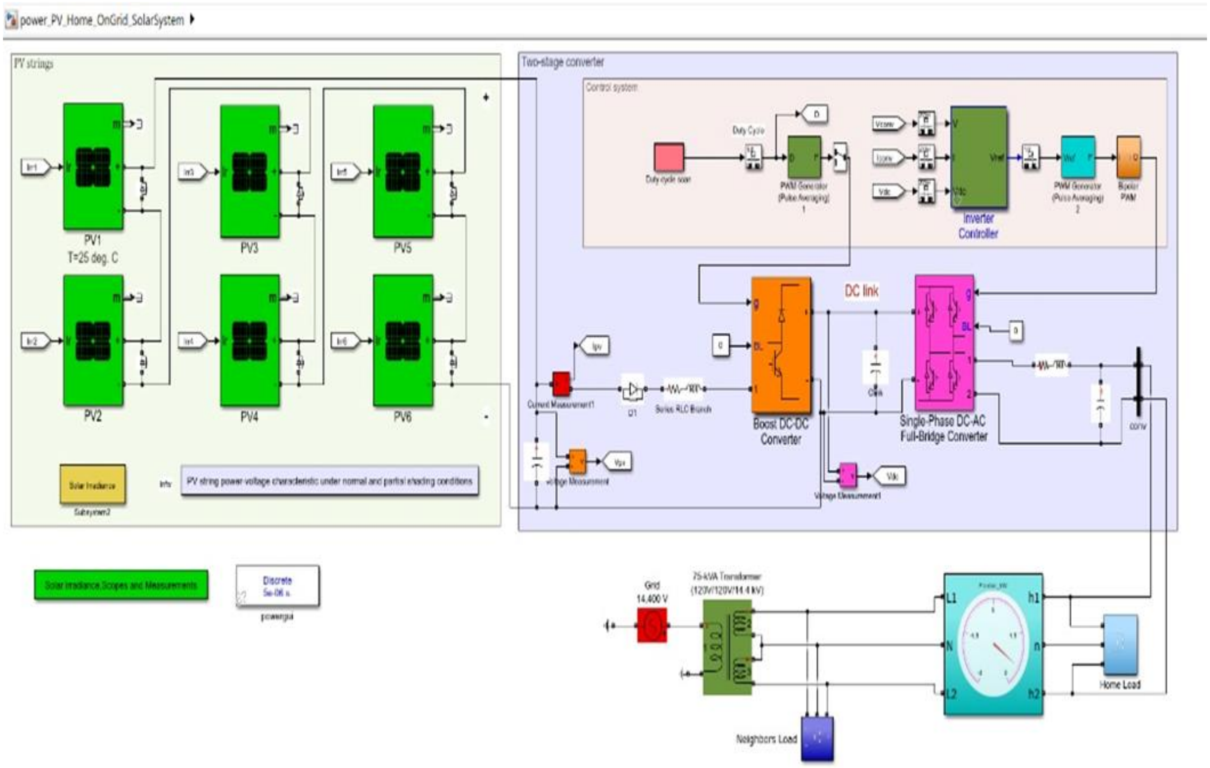

Figure 6: On-grid photovoltaic system without using MPPT controller.

3.10 Simulated Output Waveforms of The Implemented Design Model with MPPT controller.

Figure 7 until Figure 10 show the result of graphs and waveforms after running the simulation of the on-grid photovoltaic system when using the MPPT controller.

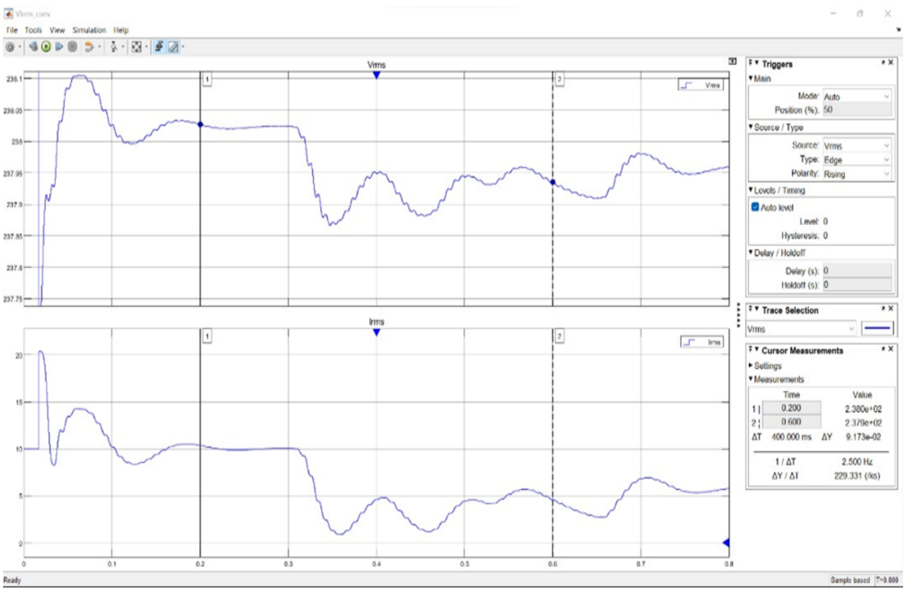

Figure 7: Graph of V_{rms} and I_{rms} of the converter with sample time is 0.8s.

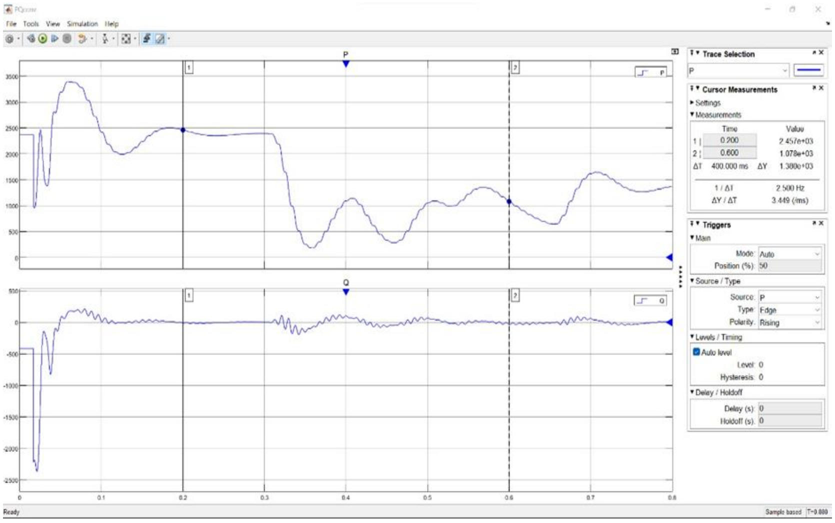

Figure 8: Graph waveform of active and reactive power of a voltage-current pair at fundamental frequency 60 Hz.

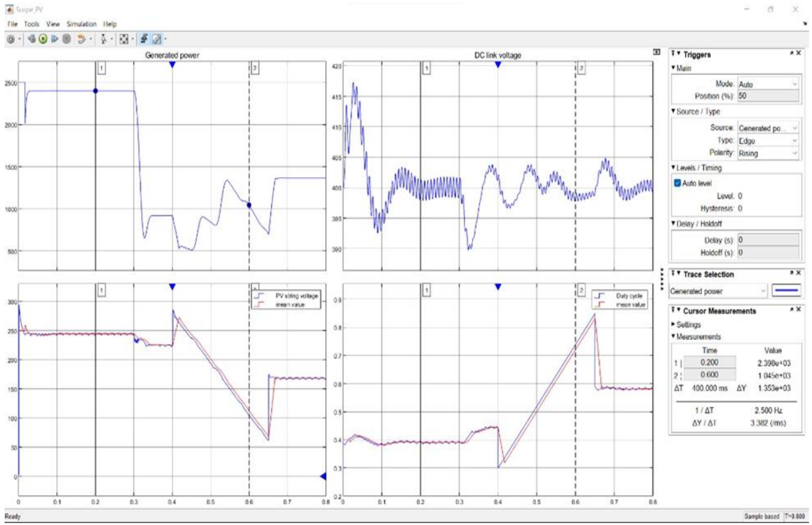

Figure 9: Graph of generated power, DC link voltage, PV string voltage with the mean value and duty cycle with the mean value.

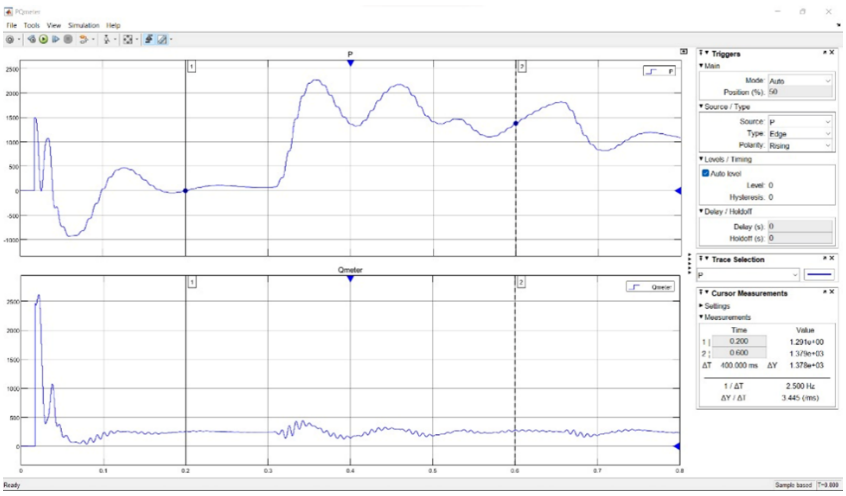

Figure 10: Graph of active and reactive power for a load of the on-grid photovoltaic system when using MPPT controller.

From all of the graph, we can conclude that stable condition is attained at 0.25s with a solar irradiation of 1000 W/m2 on all PV modules. Due to the single-phase power produced from the PV string, the solar system generates 2400 Watts and the DC connection is kept at 400 volts with a minor 120-Hz ripple. According to the utility meter, the system uses almost no power from the grid to provide the total load of the home.

Furthermore, a partial shade situation is established at 0.3s by lowering the irradiance on certain PV modules. The MPPT controller has set the boost duty cycle to 0.44 when steady-state is attained at 0.35s, resulting in a PV string voltage of 225 V. This voltage extracts 920 W from the PV string. The PV curve characteristic shows that the system is functioning at a local maximum power point but not at the global maximum power point.

After that, the MPPT controller does a duty cycle scan of 0.25 seconds at 0.4s to determine the GMPP point. Moreover, the MPPT controller has set the boost duty cycle to 0.58 at 0.7s, resulting in a PV string voltage of 168 V. This voltage extracts 1364 W from the PV string, which is the GMPP value. According to the utility meter, it currently needs roughly 1100 W (2500 W residential load - 1364 W provided by PV) from the grid to supply the home's total load.

3.11 Simulated Output Waveforms of The Implemented Design Model Without MPPT Controller.

Figure 11 until Figure 14 show the result of graphs and waveforms after running the simulation of the on-grid photovoltaic system when the system does not use an MPPT controller.

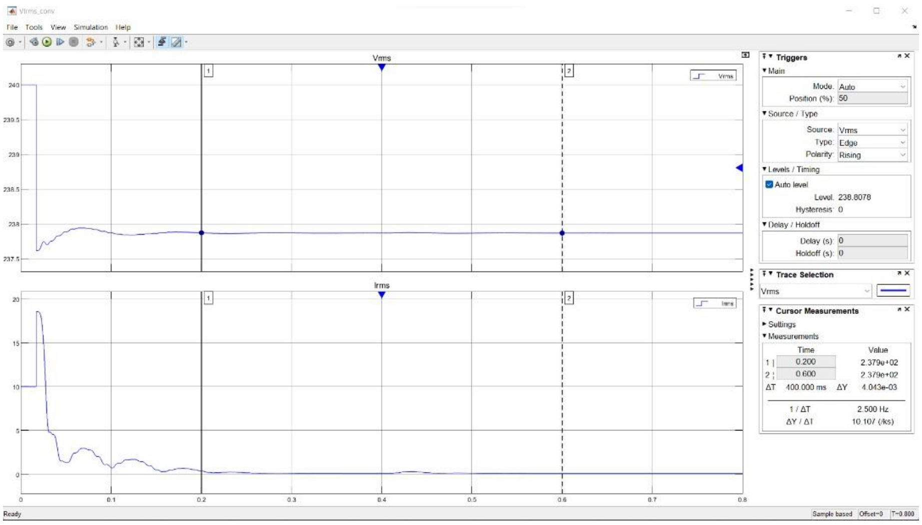

Figure 11: Graph of V_{rms} and I_{rms} of the converter with sample time is 0.8s for without using MPPT controller.

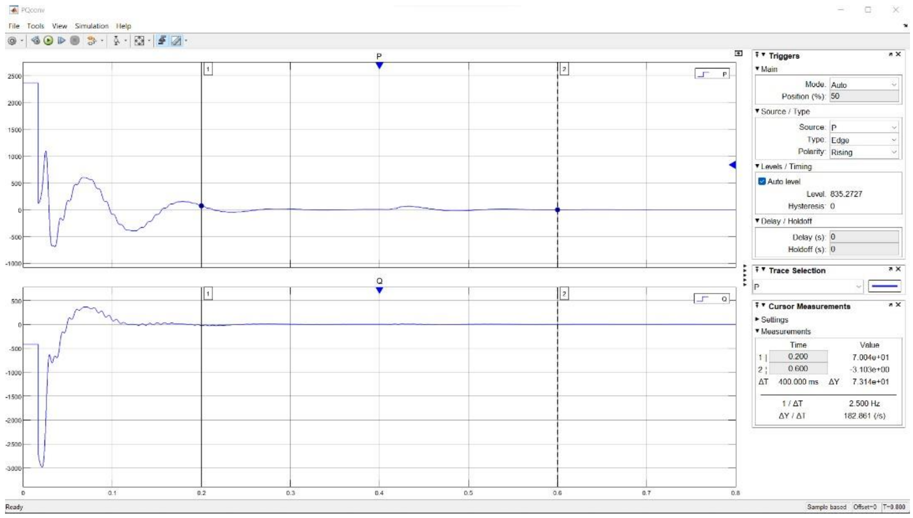

Figure 12: Graph waveform of active and reactive power of a voltage-current pair at fundamental frequency 60 Hz for without using MPPT controller.

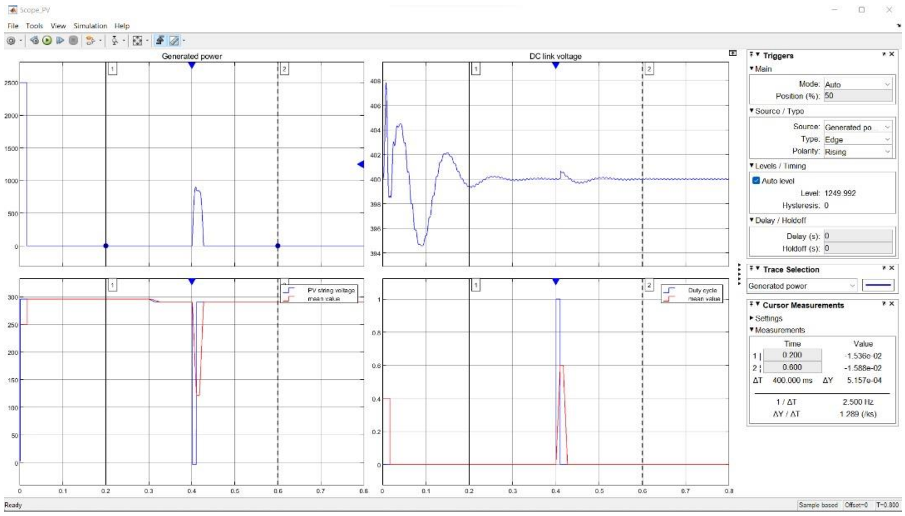

Figure 13: Graph of Generated power, DC link voltage, PV string voltage with the mean value and duty cycle with the mean value without using MPPT controller.

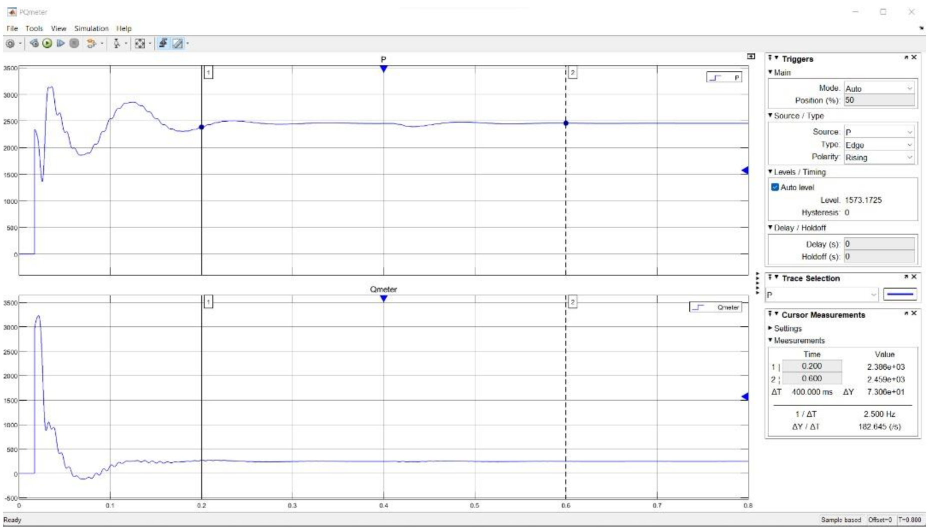

Figure 14: Graph of active and reactive power for a load of the on-grid photovoltaic system without using an MPPT controller.

From all of the graphs, we can conclude that at 0.25s, the waveform in the graph is not in stable condition compared to the graph in figure 15 which when the system uses MPPT controller but the solar irradiation use to the system still 1000 W/m2 on all PV modules. Due to the single-phase power produced from the PV string, but in conditions without using an MPPT controller, the solar system generates 0 Watts and the DC connection is at a low rate which is at 0.2 volts. According to the utility meter, the system uses around 2400 kW from the grid to provide the total load of the home.

Furthermore, at 0.4s, the PV string voltage is drop at 0 V for a second and remained constant at 300V at 0.5s. The MPPT controller has set the boost duty cycle to 1 when the peak voltage of the PV string drop to 0, resulting in a PV string voltage of 0 V. This voltage extracts 920W from the PV string only for a little moment and remained 0W afterward. The PV curve characteristic shows that the system is not functioning at a local maximum power point.

After that, the MPPT controller does a duty cycle scan of 0.25 seconds at 0.4s to determine the GMPP point. Moreover, the MPPT controller does not produce a boost duty cycle anymore because the PV string does not produce voltage anymore. Automatically, there are no voltage extracts from the PV string.

4. Conclusion

In a conclusion, the objective of this project is to develop and simulate a home on-grid solar system by using the photovoltaic array, boost DC-DC converter, MPPT controller, inverter controller, single phase DC-AC full-bridge converter, residential loads, and utility grid all included in these systems. This objective has been successfully achieved. The simulation of the circuit is stimulated by using MATLAB/Simulink software. From the simulation, the power output from the photovoltaic arrays has been delivered to the loads. Next, the simulation It has been used to demonstrate the simulation performance of on-grid photovoltaic systems with and without MPPT controllers using MATLAB/ Simulink software. The result of waveforms after the circuit is stimulated with MPPT and without the MPPT controller in the circuit. This objective also has been achieved because the result it shows the critical differences between both circuits. The waveform obtained for each circuit has a different outcome because of the different value output power achieved.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, for its support.

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