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A Study of MPPT Charge Controller Roles in Photovoltaic Energy Management

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Abstract: Nowadays, the world's demand the energy is increasing. So, we need a good energy management system to use the available energy. An energy management system consists of maximum power point tracking (MPPT) charge controller, battery management, and the power conversion stage to control and reduce energy consumption. Solar energy is used solar radiation and is converted into electrical energy. In photovoltaic (PV) system consists of a PV module, charge controller, battery storage, and load. Arduino NANO is used in this project because it's low cost and has an efficient microcontroller in the MPPT charge controller to prevent the battery from overcharging and display the maximum power point (MPP). Perturb and Observe (P&O) and Incremental Conductance (InC) algorithm is used in the MPPT charge controller to transfer maximum power from the PV module which is executed using a microcontroller. The voltage, current, and power from the MPPT charge controller, are shown on a liquid crystal display (LCD). The benefit of this project is to achieve high efficiency and low cost of photovoltaic modules for the design of photovoltaic systems with a simple MPPT.

Keywords: Energy management, PV module, MPPT charge controller, P&O algorithm

1. Introduction

Petroleum and natural gas are widely believed to be destroyed or better known as fossil energy sources. Next generation energy supply options are from sustainable and renewable energy sources. Solar energy, for example, is of great importance since it is the most plentiful and reliable source [1]. Photovoltaic (PV) devices may easily create clean energy [2]. PV systems, on the other hand, still have low efficiency and high prices. As a result, much research has been conducted in order to get better productivity and accomplishment of photovoltaic converters and lower their manufacturing costs [3]. Furthermore, the PV panel's nonlinear behaviour and great sensitivity to external climatic conditions and load characteristics make maximising PV energy the most difficult task. Operate the PV panel at its MPP to overcome the issue that is the one solution proposed in the literature [4].

One important necessity in life is electricity. There's a lot of electrical equipment we use every day. In this developed world, to carry out any daily activities we will depend on the energy source. It is too much to state about the importance and usefulness of electric power. Meanwhile, there are three main types of power plants in Malaysia, namely hydro power station, thermal power station and gas power station [5]. Hydro power stations use the kinetic energy of water to rotate a turbine which in turn drives a generator to produce electricity. Next, the thermal power station uses fuels such as coal and gas to heat the water in the boiler [6]. To rotate the turbine fan, the boiler must emit high -pressure steam. Steam energy will be converted to mechanical energy. Mechanical energy is from the result of the rotation of the turbine and the generator will convert from mechanical energy to electrical energy. The last is a gas power station that uses high pressure gas to drive turbines [7]. Combustion boilers through the placement of air can produce high pressure gas. Steam energy will be converted from thermal energy to electrical energy.

Nowadays, many users wonder why cannot get possible maximum power from solar photovoltaic module and the energy consumption cost is rising. It is due to the lack of devices on the PV panel installation. The user must get to reduce this risk by reducing demand for energy and by controlling it. Next, there are not many research papers about

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the MPPT charge controller roles in photovoltaic energy management. The voltage generated by the solar array is not stable due to fluctuating solar irradiation caused by clouds. Next, MATLAB cannot create software development simulations until the PCB is ready. It will slow down system testing and waste time if the system fails. Lastly, the existing MPPT algorithms suffer from the drawback of being slow tracking, due to which the utilization efficiency is reduced.

Based on the research context and the above problem statements, the aims of this analysis are to investigate the MPPT charge controller roles in solar energy management in PV systems. Next, to design and simulate the PV energy management system in PROTEUS and lastly, to elucidate the accuracy between Perturb and Observe (P&O) and Incremental Conductance (InC) MPPT Algorithm.

2. Literature Review

An energy management system is abbreviated as EMS. The aim of an EMS is to maximize the amount of energy available. As a result, self-consumption can be improved while energy prices are lowered [8]. These programmes educate consumers of their energy usage practices and assist them in adopting energy-saving habits. Consumers can get actionable information and control functionality with the latest generation of EM systems, which use sophisticated analytics and connectivity technology to ensure ease of use, availability, reliability, and privacy.

Next, energy management system also is a system that makes a perfect use of energy. It analyses and processes energy data so that expert energy management employees may have a real-time understanding of the system's status and ensure that it is operating at peak efficiency through acceptable adjustments [9]. **Error! Reference source not found.** shows the overview in the system consists of PV module, MPPT charge controller, battery storage and display value to monitor energy measurement data from the field. It has the potential to save operational expenses while also increasing productivity. In MPPT charge controller consists of few components which are current sensor, voltage sensor, converter, led as indicator and microcontroller to process all the calculation.

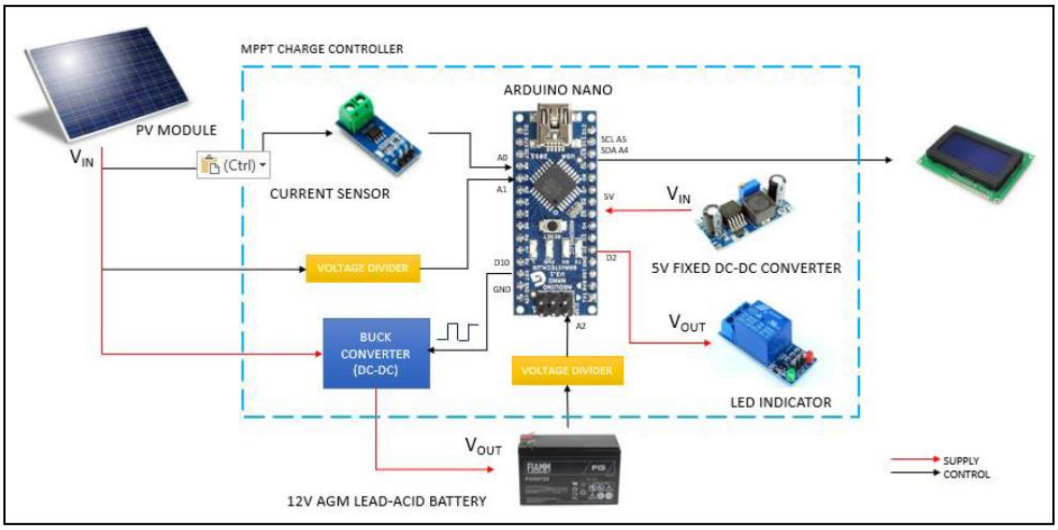

Fig. 1- Overview of energy management system

A photovoltaic cell (PV cell) or solar cell gathers light from the sun and generates electricity. Photo means light and voltaic means electricity. The sun emits energy in the form of wave. Photons touch the surface of solar cells when the sun is shining. Wafers made of semiconductive materials, usually silicon are the active part of the solar cell [10]. Semiconductors are a form of material that normally does not conduct electricity well, but under certain circumstances, they can be made to do so.

3. Simulation Model of PV Module

The appropriate photon energy is received by a photovoltaic (PV) cell when it enters its surface, causing energy-carrying electrons to be produced and circulate in a closed-loop circuit through an external load to deliver it with energy. The PV cell's difficult physics might be stand for the comparable electrical circuit shown in Fig. 2; based on conventional theory, a set of equations has been generated [11-13].

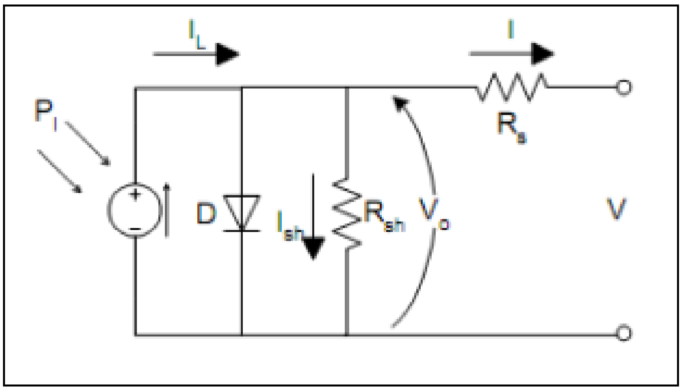

Fig. 2 - PV module electrical circuit equivalent [14]

Equivalent circuit models define a cell's, module's, or array's thorough I-V curve as a repeated function for a specific set of control parameters. The one diode model is a common basic equivalent circuit design. This is an analogous circuit of photovoltaic cell. In several articles, it is also referred to as a “five-parameter model”. It considers various solar cell parameters such as:

- Rs is purpose to consider the voltage drops and internal losses due to the flow of current.
- Rsh takes into account the leakage current to the ground when the diode is in reverse biased.
- However, because this model ignores the diode's reunification impact, it is still not the most accurate model.

As illustrated in the analogous circuit, the solar cell produced the current is equal to the current source minus the current that runs through the diode minus the current that flows through the shunt resistor [11].

$$I=IL+ID+Ish \quad (1)$$

Where there is an output current (I), photogenerated current (IL), diode current (ID) and shunt current (Ish). The voltage across these components controls the current that flows through them:

$$Vj=V+IRs \quad (2)$$

Where the equation 2 is the voltage applied across both the diode and the resistor Rsh (Vj), voltage across the terminals of the outputs (V), output current (I) and series resistance (Rs). According to the Shockley diode equation is:

$$ID=I0\{\exp[qVj/nkT]-1\} \quad (3)$$

The reverse saturation current, diode ideality factor, elementary charge, boltzmann's constant, and absolute temperature are all variables in the Shockley diode equation. The at $25oC, kT/q \approx 0.0257volt$) [15]. Ohm's law governs how much current flows through the shunt resistor. The element identification of a solar cell, by substituting solar cell specification to output current and voltage into the first equation:

$$I=Iph-Io[\exp(V+IRs/nsV)-1]-[(V+IRs)/Rsh] \quad (4)$$

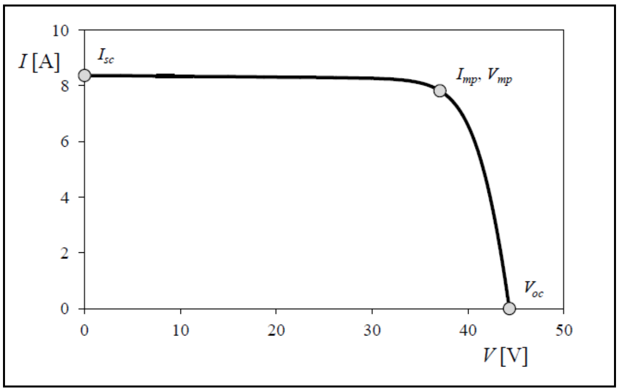

Fig. 3 - Characteristic I-V Curves of a Solar Panel [16]

By having the correct experimental measurements, the current versus voltage of the electrical specification of the PV module, or the array can only be determined [9]. This measure will provide useful information for PV system design, installation, and maintenance. The I-V characteristics experimental measurement is important because it could be regarded as a high standard and accomplishment certificate for each PV module. [17, 18]. The short-circuit current (ISC) and the open-circuit voltage (VOC) are the two key points of the current versus voltage curves' features. The outcome of current and voltage at each point on the current versus voltage curve is represented by the output power for that operating state.

4. Boost Converter Circuit

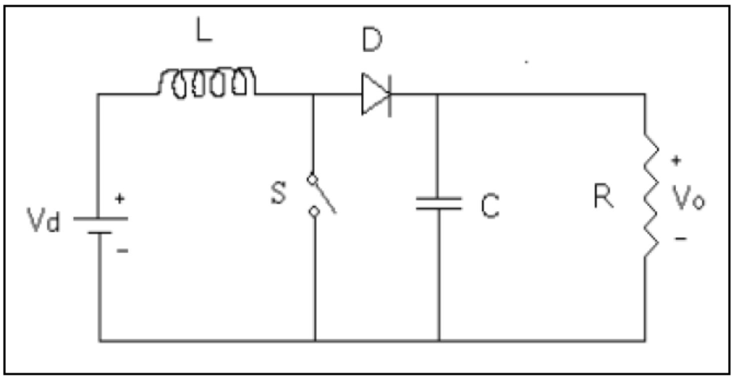

Fig. 4 - Boost converter circuit [19]

Known that the Boost converter is always the output larger than the input or also known as a step-up converter. The schematic diagram of Boost converter at Fig. 4. The solid-state device is operating a switch that is linked across the source and Fig. 4 shows an inductor is connected with the input voltage source. The diode is used as the second switch. In Fig. 4, the two are connected in parallel i.e., the capacitor and the load and the capacitor are connected to the diode. The Boost converter is referred to as a constant current input source because the inductor is connected to the input source causing a constant input current. The load can also be thought of as a constant voltage source.

5. Maximum Power Point Tracking (MPPT) Techniques

In MPPT charge controller has two category which are direct and indirect. Fig. 5 and Fig. 6 shows the direct method in MPPT charge controller. Perturb and observe (P&O) and incremental conductance (InC) algorithm is used to transfer maximum power from the photovoltaic module which is executed using a microcontroller.

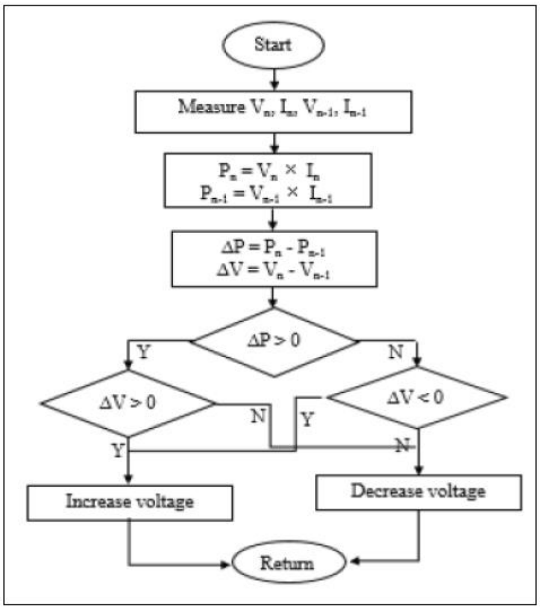

Fig. 5 - Flow chart of conventional P&O algorithm [20]

Implementation to disrupt and observe, a sensor that monitors voltage and current and is installed in solar cells is employed. Voltage and current receive as inputs to the microcontroller. Next, the voltage and current values are then transferred to an Arduino NANO microcontroller, where they are used in the algorithm. As the starting point, the value 0 is chosen for the first iteration. Then there were computations and comparisons to previous power, followed by P&O. The duty cycle is used to made a modification. The iteration starts a new after, measured and compared the new power voltage value. Fig. 5 depicts the algorithm.

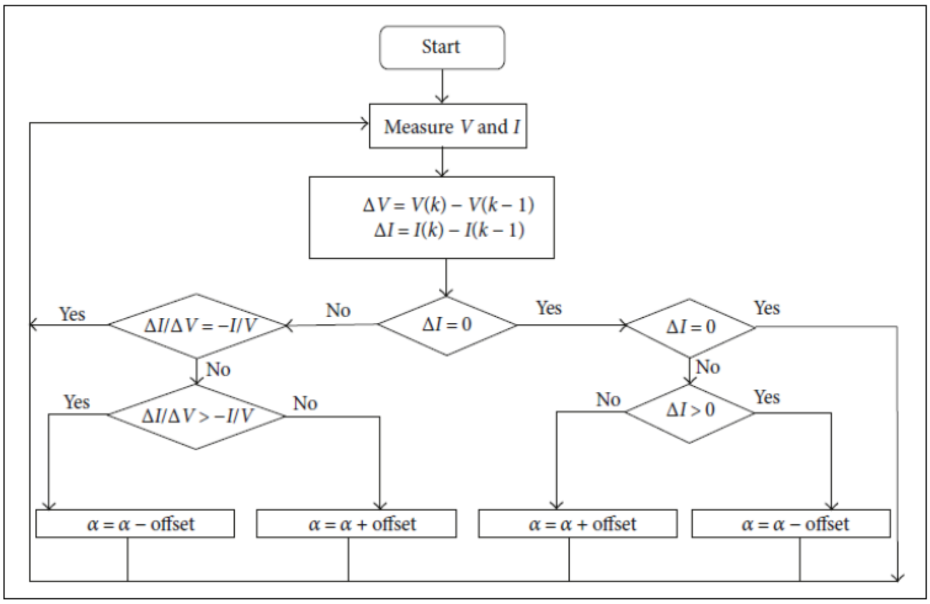

Fig. 6 - Flow chart of conventional InC algorithm [21]

Incremental conductance algorithm flowchart Fig. 6 starts with measure the voltage and current value. Then, find the difference in voltage and current. If the ΔI is bigger than zero, it will check if the $\Delta I/\Delta V = -I/V$ which this at maximum power point (MPP). If the $\Delta I/\Delta V > -I/V$, the voltage panel should be increase by reducing the value of the duty ratio. If the value of voltage near or reach the maximum power point, it will start plot to the graph and measure again.

6. PV Module

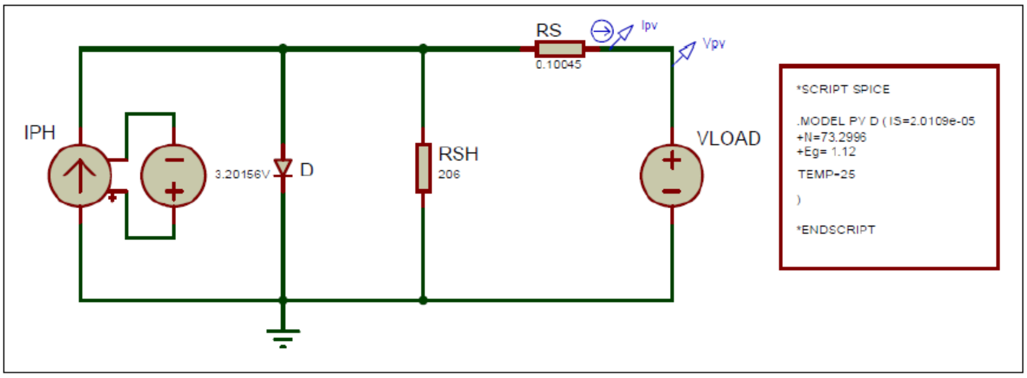

Fig. 7 - PV Module using SPICE in Proteus [11]

A voltage-controlled current source is connected in parallel with diode to simulate shunt and series resistors (whose SPICE code is changed according to the photovoltaic panel's needs), and in Proteus, two resistors are tied in series and parallel. The Proteus model and associated SPICE code are shown in Fig. 7. In addition, below shows the procedure for modelling the PV Panel in Proteus.

1. Model the Current Source.
- To simulate the model under STC, 3.20156V is set to the "DC Voltage Source" block's value, which is the LC50-12M panel under STC photocurrent.
2. Model the Diode.

- A diode with updated Spice code is used in this model, as shown in Fig. 7. Note that N is equal to the ideality factor multiplied by the number of cells, which is 73.2996. It's worth noting that the Spice code is written in Proteus' "Text Script mode."

3. Model the Resistor.

- Table 1 show Rsh and Rs are chosen to model the shunt and series resistance.

4. Model a Variable Load.

- As a variable load, the PV panel model is connected with a "DC Voltage Source" block. Used the "DC SWEEP ANALYSIS" to simulate graph model and its value must match the "Sweep variable" value, as shown in the result. Note that the "Sweep variable" range is 0 V to the open-circuit voltage (22.50V).

$$I=I_{ph}-I_s\{exp[(V+IR_s)/(nN_sV_{th})]-1\}-[(V+IR_s)/R_{sh}] \quad (5)$$

$$V_{th}=k/Tq \quad (6)$$

$$N=n \times Ns \quad (7)$$

PLACE FIGURE 7 HERE

Table 1 shows the PV module parameters which is LC50-12M Mono crystalline. The parameters value for PV module was taken from previous journal [22]. The DC voltage source is used to model the current source and it easy to run the simulation in PROTEUS to get the result. This script spice can be modified. It’s used with a diode to change the values in the script according the Table 1. After that, equation 6 shows the total current for PV module consist of series-connected cells. The first side is the light-generated current, Isc which It's approximately proportional to the amount of incident insolation. The next side is the Shockley’s diode equation. It represents the diode current and the last side is the current in the shunt resistance. Equation 6 is diode thermal voltage that defined in terms of electronic charge, Boltzmann’s constant and temperature in kelvin. From the previous article, it said that the value of thermal voltage in room temperature is 26mV [22].

Table 1 - The LC50-12M PV panel specifications at STC

Parameters	Value
Maximum power point (MPP)	49.88 W
Voltage at MPP (Vmp)	17.20 V
Current at MPP (Imp)	2.90 A
Open-circuit voltage (Voc)	22.50 V
Short-circuit current (Isc)	3.20 A
The number of cells in series (Ns)	36
Light-generated current (Iph)	3.20156 A
Diode saturation current (Is)	2.0109×10−5 A
Ideality factor (n)	2.0361
Shunt Resistance (Rsh)	0.10045 Ω
Series Resistance (Rs)	206 Ω

7. MPPT Charge Controller

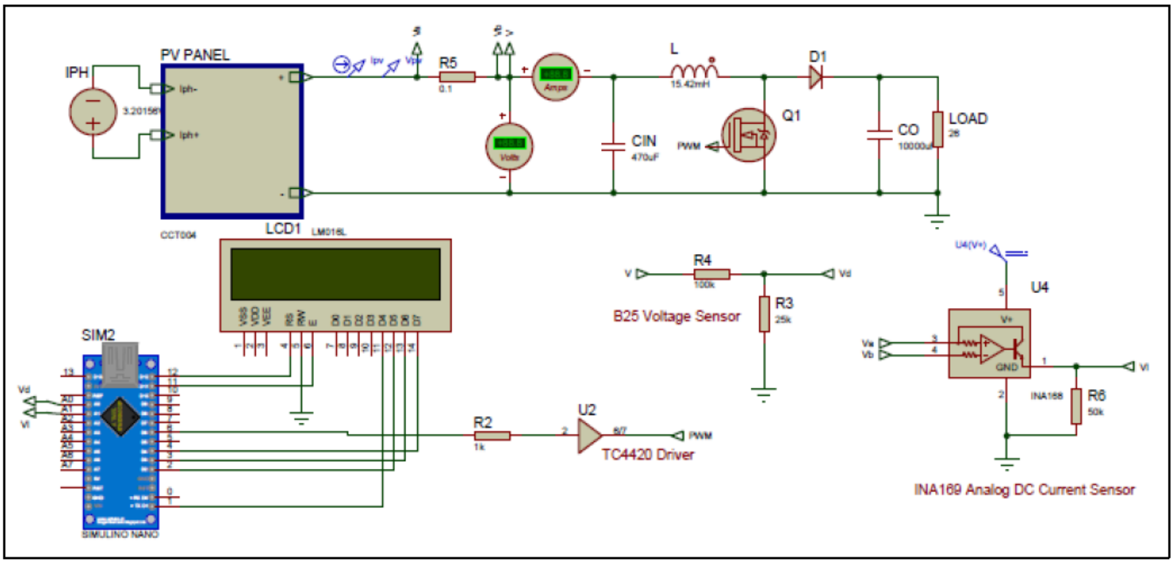

Fig. 8 - Modified MPPT charge controller by using Arduino NANO

The Boost converter is utilised in this study to reduce the mismatch between the panel and the load and run at MPP, as shown in Fig. 8 [23, 24]. The Boost converter operates by the following equations [21]:

$$VO=V/(1-\alpha) \tag{8}$$

$$IO=I(1-\alpha) \tag{9}$$

Then, the optimal inductor value may be calculated using the following formula:

$$L \gg V\alpha/rIFs \tag{10}$$

As a result, the input capacitor may be calculated using equation 11 and 12, with the required V equalling 1% of the input voltage [25]:

$$Cin \geq \alpha/(8xF2xLx0.01) \tag{11}$$

$$Co \geq \alpha/(0.02xFx\mathrm{R}) \tag{12}$$

The MPPT charge controller are constructed in PROTEUS simulation software. The boost converter in charge controller is help to boost the current during times of peak demand. In boost converter has capacitor input, capacitor output, inductance, MOSFET as switch, diode, and load. Capacitor input and output in converter is to controller the voltage ripple which capacitor input to control input part and capacitor output to control output part. To have a good or fast system, inductance value must lower and almost reach to zero. Equation 11 shows went the capacitor input increase; the inductance value is decrease. Then, equation 10 show how to get conductance value. The lower the inductor; the higher the current.

The Va and Vb pin were connected to the DC current sensor and V pin was connected to the voltage sensor. Then, these two sensors have one pin that connected to the microcontroller Vl and Vd. Driver used to control the MOSFET transistor form the microcontroller. Write the P&O and InC algorithm code in the Arduino IDE software to compile the code. Copy the hex.file and paste in the microcontroller program to run the simulation and get the result.

8. PV Module Result

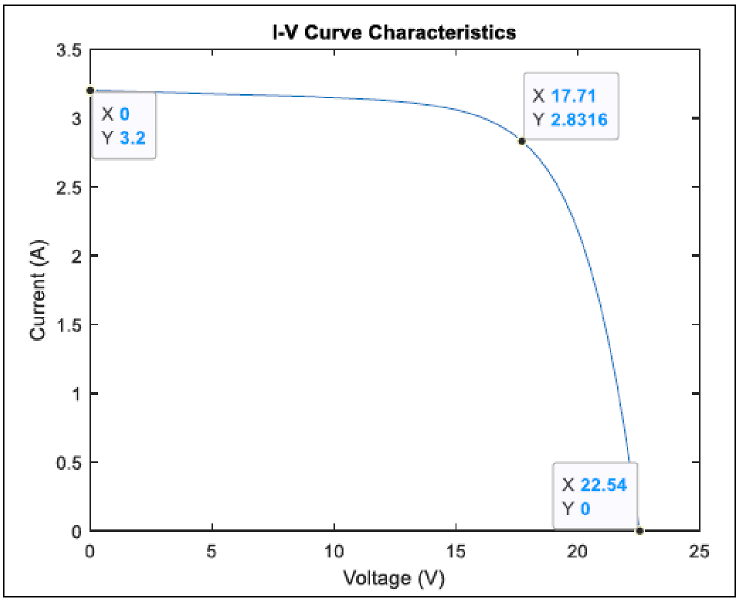

Fig. 9 - Current versus voltage curve characteristics of PV module

Fig. 9 shows the current versus voltage curve characteristics of PV module result from Proteus software. The value for saturated current, Isc and voltage open circuit, Voc can get from the graph. When the Voc is equal to zero, the Isc is 3.2 A and when Isc is equal to zero, the Voc is 22.54 V. From the graph, the Isc at 3.2 A. The Voc start to increase and at the certain point the Isc is start slightly decrease until the Isc reach zero value.

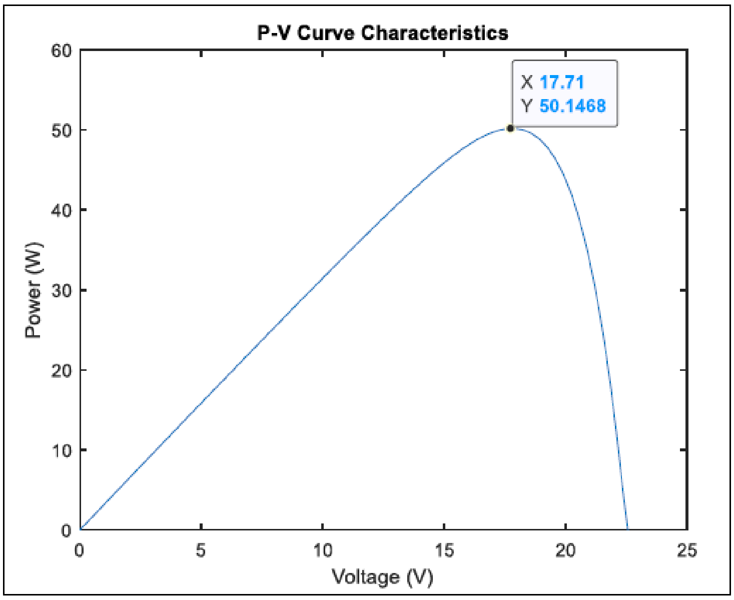

Fig. 10 - Power versus voltage curve characteristics of PV module

Fig. 10 shows the power versus voltage curve characteristics of PV module result from Proteus software. The value for maximum power, Pmp can get from the saturated current, Isc and voltage open circuit, Voc value. The value for maximum power, Pmp is 50.1468 W. From the Pmp value, the value for voltage maximum point, Vmp also can get which is 17.71 V. Value for current maximum point, Imp can get from Fig. 9. Imp is 2.8316 A which Vmp is intersect with the I-V curve.

9. MPPT Charge Controller Result

10. The plot of the maximum power point, *Pmp* is more fluctuated and not smooth in Fig. 11 because there has a ripple. The ripple is quite big from one time to another one time. Sometimes the value is a sudden drop, then stable, and its sudden drop again for example at a range from 0.4 s to 0.6 s. According to Table 2, the power maximum power point, *Pmp* in this graph is 50.1625 W and the minimum value at the sudden drop is 48.48 W. At 0.1085 s, where there is the first response after the first perturb which, the power is 49.87 W.

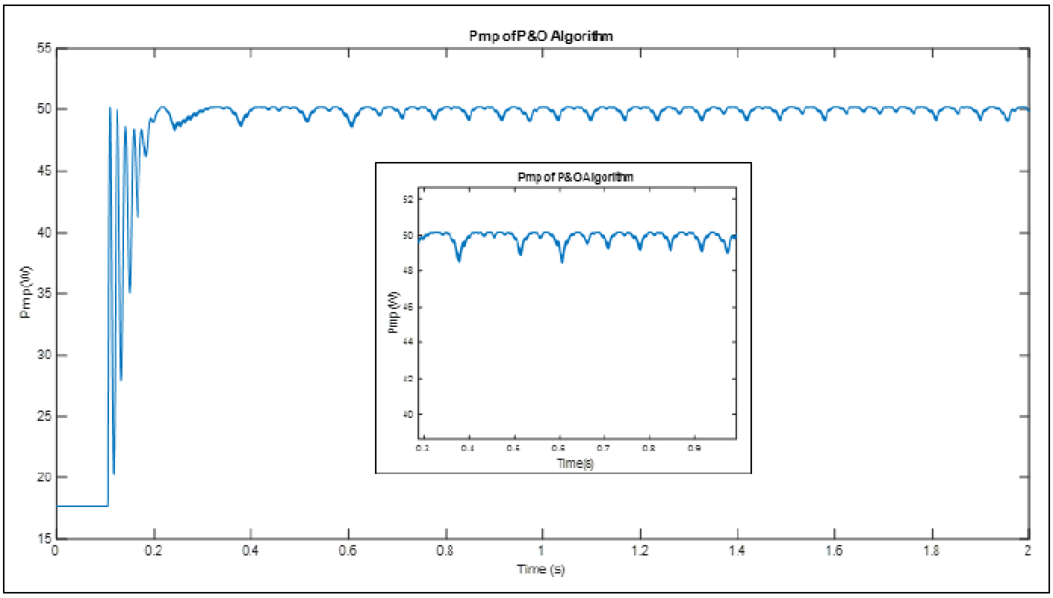

Fig. 11 - Maximum power point using P&O algorithm

The plot of the maximum power point, *Pmp* is more stable and slightly smooth in Fig. 12 because there has less ripple. According Table 2, the maximum power point, *Pmp* in this graph is 50.1648 W and the minimum value is 49.44 W. From the graph, the gap between one time to other is very close and near compare to the perturb and observe algorithm. The maximum power point, *Pmp* at Fig. 11 is like ±2 V compare to the maximum power point, *Pmp* at Fig. 12. The incremental conductance algorithm is faster than perturb and observe algorithm at 0.1064 s, where there is the first perturb which, the power is 49.89 W. The maximum power value at first perturb is closer to the calculation value.

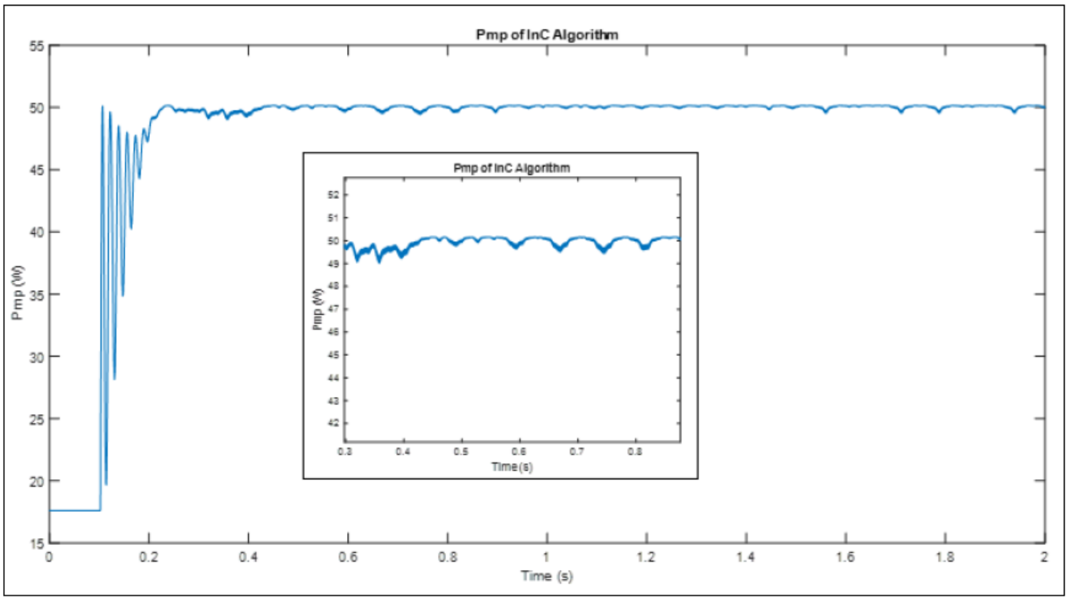

Fig. 12 - Maximum power point using InC algorithm

Table 3 shows the value of power efficiency in MPPT charge controller between perturb and observe and incremental conductance algorithm. Incremental conductance (InC) algorithm is more efficient than perturb and observe (P&O) algorithm.

Table 2 - Power maximum point at algorithm

	P&O Algorithm	InC Algorithm
Power Maximum Point, Pmp	50.1625 W	50.1658 W
Power Minimum Point, $Pmin.p$	48.48 W	49.44 W
First Response at 0.1085 s	49.87 W	-
First Response at 0.1064 s	-	49.89 W

Table 3 - Power efficiency in MPPT charge controller

Time range = 0 – 2 s	P&O Algorithm	InC Algorithm
Total Power (W)	2053168.70	2161287.44
Average Power (W)	49.50	49.63
Efficiency (%)	99.23	99.49

Conclusion

The major purpose of this project is to solve problems that arise in Malaysia that many users wonder why cannot get possible maximum power from solar photovoltaic module and the energy consumption cost is rising. To conclude the project's success, the researcher must return to this project goal as an indicator of the system's success. This project is about the maximum power point tracking (MPPT) charge controller is to detect and deliver the most efficient amount of energy from the solar array to the battery bank electronically. Next objective is to investigate MPPT charge controller roles in solar energy management in PV system and to elucidate the accuracy between perturb and observe (P&O) and incremental conductance (InC) MPPT algorithm. This maximum power point tracking (MPPT) charge controller is to extract the maximum power from the PV module and reduces complexity, optimized self-consumption and reduced cost in energy management system. The simulation boost converter of MPPT charge controller in Proteus help to boost the current during times of peak demand and stable power in energy management system. Moreover, the maximum power point give responds swiftly and accurately to design in the ambient conditions that impact the PV output. The P&O algorithm involves direct measurement of current, voltage or power more accurate and faster response. It increases or decrease in power of voltage array and has 99.23% of efficiency. The drawback is the operating point is never steady at the maximum power point and struggles under rapidly changes of power. Also, InC algorithm measures the incremental change in the conductance with instantaneous conductance and decide the operating point is towards the maximum power point value and it has 99.49% efficiency. It has higher accuracy and higher power value after the first perturb that shown by power versus time curve as compare to P&O algorithm. This paper presents a study of MPPT charge controller roles in photovoltaic energy management. The studied system consists of a photovoltaic as a main renewable energy source. The simulation in this project has been modelled and it has been simulated using PROTEUS software to get current versus voltage and power versus voltage characteristics and P&O algorithm. Finally, the performances of the proposed method are validated by simulations. This system has been shown that using incremental conductance algorithm is more efficient than perturb and observe algorithm. As the closing opinion, this project achieved and obtained all objectives set as benchmark. A quick analysis of simulation to record the maximum power point in MPPT charge controller using perturb and observe and incremental conductance algorithm is shown in diagram. As a result, all of the results were recorded, the outcome was excellent, and everything was completed on time. As a final conclusion, this project met and exceeded all four benchmark objectives. This project is progressing smoothly and according to schedule.

Future recommendation is critical for the next developer to recognise existing project constraints and problems so that a better system can be developed in the future. This project path has the potential to help society and Malaysia as a whole. There some possibilities for improving future performance and adaptability. The first recommendation is to modified perturb and observe or incremental conductance algorithm which it can be more improved the efficiency in MPPT charge controller. Lastly, implemented the MPPT charge controller in a microcontroller hardware device that can monitor in real-time and can compare the maximum power point between simulation and hardware.

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