MODELING OF   3/SIMULINK

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ABSTRACT

Solar energy is one of the many forms of renewable energy on earth. By using photovoltaic cell which converts sunlight directly into electricity, this energy can be harnessed. This form of energy has been accepted worldwide as high potential energy alternative energy as current research and markets have shown that solar photovoltaic (PV) is amongst the fastest growing and most promising forms of renewable energy for electricity generation. A photovoltaic array (PVA) simulation model to be used in MATLAB/SIMULINK is developed based on the specification data provided in the manufacturer's data sheets. The model is developed using basic circuit equations of the photovoltaic (PV) solar cells including the effects of solar irradiation and temperature changes. In the present modeling, the focus is only on the cell, module, and array. The model for the proposed range of irradiance and temperature as model inputs, with the corresponding values of voltages, currents, and power as outputs is presented. The objective of this project is to simulate the output current and power characteristics and observe the effects of solar irradiance and temperature changes of the PV system. This project is also to determine and analyze the maximum power point tracker (MPPT) of the PV model. Results from simulation will be compared with points taken directly from the manufacturer's published curves. Overall findings will indicate that the modeling using MATLAB/SIMULINK can be further used for investigation and make improvement in order to identify which best technologies to be implemented.

ABSTRAK

Tenaga solar adalah salah satu daripada bentuk tenaga yang boleh diperbaharui di bumi. Dengan menggunakan sel fotovoltan yang menukarkan cahaya matahari terus kepada tenaga elektrik, tenaga ini seterusnya boleh dimanfaatkan. Bentuk tenaga ini telah diguna pakai dan diterima di seluruh pelosuk dunia sebagai tenaga yang mempunyai keupayaan yang tinggi sebagai tenaga alternatif yang pesat berkembang di pasaran sekarang. Ini telah menunjukkan bahawa tenaga solar adalah tenaga yang paling berpotensi bagi penjanaan kuasa elektrik. Projek ini seterusnya mengunakan kaedah simulasi dalam bentuk MATLAB/SIMULINK. Model ini dibina dengan menggunakan persamaan litar asas solar sel termasuk kesan sinaran solar dan perubahan suhu semasa. Fokus projek ini adalah hanya pada sel dan modul sahaja. Model bagi pelbagai cadangan sinaran dan suhu sebagai input model dengan nilai yang sama voltan, arus elektrik dan kuasa sebagai output. Objektif projek ini adalah mensimulasi keluaran dan ciri-ciri kuasa dan menganalisa kesan sinaran solar dan perubahan suhu sistem ini. Projek ini juga adalah untuk menentukan titik kuasa maksimum oleh sistem fotovoltan. Keputusan dibandingkan dan analisa dibuat. Secara keseluruhan, model yang menggunakan MATLAB/SIMULINK boleh digunakan untuk menganalisa dan penambahbaikan boleh dilaksanakan.

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CHAPTER 1

INTRODUCTION

1.1 Photovoltaic System (PV)

Photovoltaic (PV) systems has become increasingly popular and are ideally suited for distributed systems. Many governments have provided the much needed incentives to promote the utilization of renewable energies, encouraging a more decentralized approach to power delivery systems. Renewable energy resources will be an increasingly important part of power generation in the new millennium. Solar energy possesses characteristics that make it highly attractive as a primary energy source that can be integrated into local and regional power supplies since it represents a sustainable environmentally friendly source of energy that can reduce the occupants' energy bills [1]. Among all renewable energy strategies, photovoltaic systems own several fundamental advantages compare to others. Solar energy has been identified as a static, movement-free and quiet alternative energy which can result to a long term and low maintenance-cost renewable system. Furthermore, due to its infinite and clean energy, there is no controversial issue in term of sustainability and availability of the source.

When it comes to connection strategies, there are two configurations of solar systems applied in any application. The first is a stand-alone system, which is widely used in remote areas, and the second is Grid-Connected system. In electrical power applications, PV energy has its own importance in electrical power applications thus PV systems are ideally suited for distributed resource applications. PV systems produce DC (direct current) electricity when sunlight shines on the PV array, without

any emissions. The DC power is converted to AC (alternating current) power with an inverter and can be used to power local loads or fed back to the utility [2].

PV systems consist of a PV generator (cell, module, array), energy storage devices (such as batteries), AC and DC consumers and elements for power conditioning. The output characteristics of PV module depends on the solar insulation, the cell temperature and output voltage of PV module. It is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications since the PV module has nonlinear characteristics.

As shown in Figure 1 below, a photovoltaic solar cell is essentially a semiconductor which can generate as electric potential when ionized by radiation. In other words, the solar cell can convert the radiant energy of sunlight directly into electricity with high reliability and long life cycle.
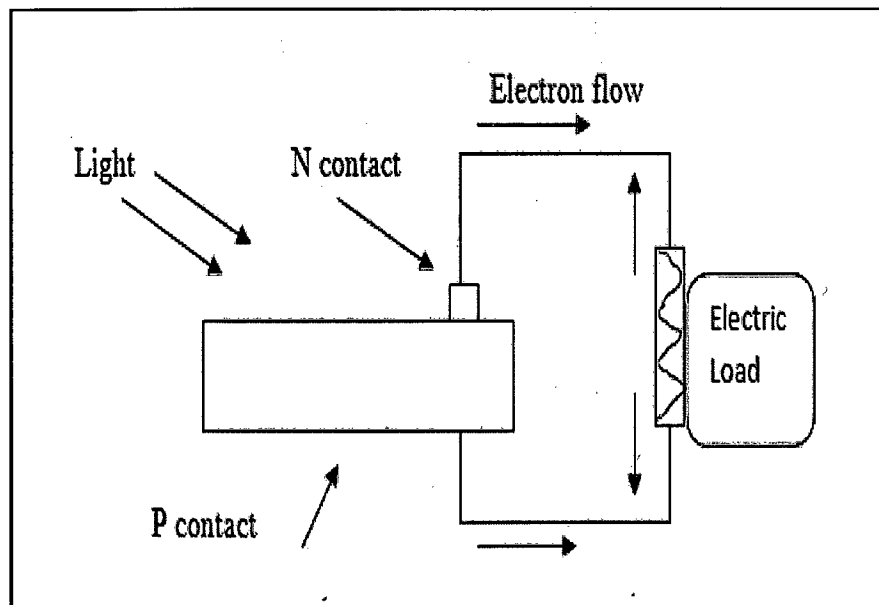
Figure 1.1 PV effect converts the photon energy into voltage across the p-n junction

1.2 Problem Statement

The problem that had faced the modeling of the PV system is usually the complicated in verification the simulation results. This is because the simulation results and waveform that should be produced might not be the same with the manufacturer's curve as different approaches and methods being used. Effects of solar insolation of the PV system is also not clearly justified. The specific problem being analyzed and discussed by simulating the PV system's characteristics. From the simulation results, the effect of solar insolation of PV system also being discussed.

1.3 Objectives

The objectives of this project are:

i) To simulate the output current and power characteristic of PV model.

ii) To determine and analyze the maximum power point tracker (MPPT) of the PV model.

iii) To observe the system response to various weather conditions in terms of change in cell temperature and solar irradiance

1.4 Project Scope

This project only considers modeling of PV system during the normal and sunny day only. So, no consideration will be taken under rainy and cloudy day. In addition, this modeling system only concentrates on software only. MATLAB/SIMULINK is used to models the PV system.

1.5   Outline of Thesis

The thesis begins with the introduction of the PV systems in Chapter 1. The objectives, project scope and the thesis outline are also identified in this chapter.

This is followed by a review of some techniques used for modeling the PV system in Chapter 2. Generally, all presented methods can be divided into three types which are by using Solar Array Simulator (SAS), Microcontroller-Based, Virtual Test Bed (VTB), and Artificial Neural Network (ANN) respectively. This chapter includes all the paper works and related research as well as the studies regards to this project. This literature reviews all important studies which have been done previously by other research work.

Then Chapter 3 will deal with the design of the PV system used for this project. For the purpose of analysis, one complete set of standalone PV system had been constructed using MATLAB/SIMULINK. This chapter will also illustrate the operation and the parameters involved in the photovoltaic stand alone system. The circuit topology that uses a power electronics approach for the photovoltaic stand alone system is described in detail.

Subsequently, Chapter 4 will discuss about the power-current and current-voltage characteristics of the PV system. In this chapter, the maximum power point will also be analyzed and all schemes will be compared to examine their capabilities and effectiveness. The simulation design of the photovoltaic system using MATLAB/SIMULINK will be presented. It also consists of the simulation results and discussion based on the performance of the photovoltaic system waveforms produced.

Finally, Chapter 5 will address conclusions of the project and suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

As mentioned in Chapter 1, numerous methods have been proposed to construct the modeling of PV systems. Therefore, this chapter will review some of the methods being used to model and track the maximum power point of the PV system. Besides that, basic concepts regarding PV will be reviewed as well as the system also shall be discussed. In addition, related works regarding to this research project work will also be conferred in depth. Literature review was ongoing process throughout the whole process of the project. It is very essential to refer to the variety of sources in order to gain more knowledge and skills to complete this project.

2.2 Simplified nonlinear power source for simulating PV panels

In PV systems, power electronic converters play a major role in the efficiency and reliability. The development of power conditioning equipment for operation at the maximum power point and for utility interfacing usually requires Solar Array Simulators (SAS) that are relatively expensive and high cost. A simple nonlinear power source based on a PWM (pulse width modulation) switched resistor that can be used for preliminary evaluations of power conditioning equipment for PV systems. I-V (voltage times current) characteristics similar to those of PV panels and also allows the variation of the solar irradiation level presented in this research. A simple means to implement a non-linear power supply whose output voltage varies

with the output current as in a PV panel been proposed. While, the solar irradiance controlled by varying the current limit of the power source [3]. In the current limiting mode where all possible values of load applied to the proposed solar array simulator, a standard voltage source power supply is used to model the current source due to the photovoltaic conversion one sees in the common current-source and diode model of a PV cell [4].

2.3   MPPT (Maximum Power Point Tracker) / Charging Controller for Standalone PV

There are several control algorithms for standalone PV systems that can track the maximum power point of the solar array while limiting the charging/discharging current and voltage of the battery under different insolation and load conditions. The controller design is verified by numerical simulation in the Virtual Test Bed (VTB) environment for orbital and land-based applications. Simulation results show that the control strategy is robust and demonstrate that the power converter can be appropriately regulated to meet multiple objectives required by standalone PV power systems [5].

In existing MPPT systems, there are two types of configurations which are in series and parallel configurations. In this system, in order to save components and increase system efficiency, the power converter acts not only as a maximum power point tracker but also as a charger to manage the state-of-charge of the battery by regulating the charging current or voltage which means the power converter can also be a multi objective control problem [6], [7]. The constant power load line will move along the I-V curve for the solar array, depending on the load demand plus the solar array voltage output will vary with the load demand.
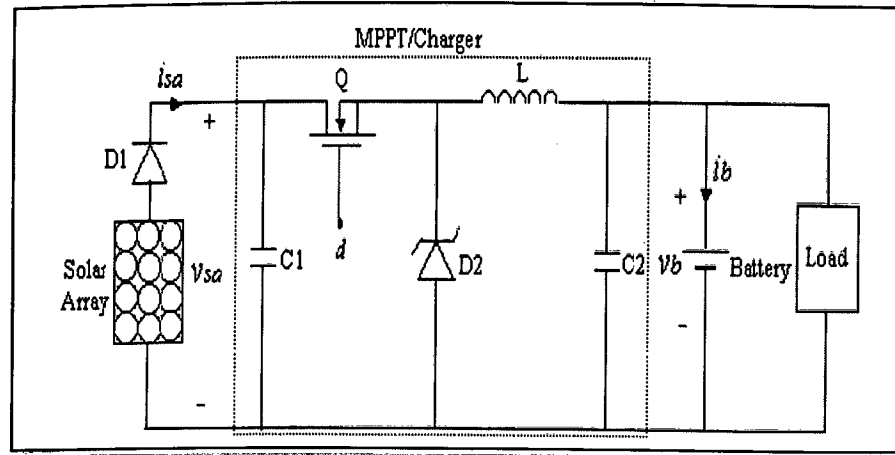
Figure 2.1   MPPT/Charging configuration of a standalone PV power system

In the configuration shown in Figure 2.2, the only control input is the duty cycle of the power converter. By varying the duty cycle, the output current of the solar array and the current of the battery can be regulated. There are three regulation modes which are [7] :

i)   Maximum Power Point Tracking (MPPT mode)

ii)   Battery Current Limit (BCL mode)

iii)   Battery Voltage Limit (BVL mode)

iv)   Disconnecting the Load (DISC)

The control strategy is then coded in the VTB. The MPPT algorithm is to determine the voltage operating point at which the instantaneous conductance is equal to the incremental conductance. The regulation mode select module, MPPT module and the compensation loop module are the main functional blocks in this algorithm [7].

When the increasing insolation makes the capacity of the solar array to exceed the load demand, the extra power automatically flows into the battery and then the battery is charged. Whenever the battery voltage reaches the high limit, the power converter starts to regulate the battery voltage so that it stands at a constant

level and any change in the insolation and load may cause the operating mode to change to another [7]. The change from MPPT discharging mode to MPPT charging mode or vice-versa does not cause any stability problem, since the power converter always tracks the maximum power point of the solar array.

2.4 Standalone PV Charging System

Standalone PV system requires a proper battery charge controller. An efficient battery charge controller using Buck-Boost regulator with MPPT is presented in this research [8]. The voltage command is determined by both the PV panel MPPT control loop and the battery charging loop. The controller is designed so as to balance the power flow from the PV panel to the battery and load such that the PV power is utilized effectively by using MATLAB. In this system, PV module, battery model and the battery charging system is implemented. A single diode model of PV and a simple equivalent circuit model structure for batteries are used to facilitate the model part of the system model [9].

2.5 Artificial Neural Networks (ANN)

Neural network modeling does not require any physical definitions for a photovoltaic array, because they have superior methods' of deriving non-linear models than it was already established as conventional techniques. Back-propagation neural network and radial function neural network employed to simulate and predict the maximum power point of the PV array by using measured environmental data.

In order to maximize the power derived from the solar panel it is very important to operate the panel at its optimal power point and to increase the output efficiency of PV, the PV energy conversion must be operated near maximum power point. Due to the nonlinear nature of PV systems, the current and power of PV arrays

depends on the array terminal voltage. The derived mathematical model may be inaccurate due to lack of this information [10]. In achieving high efficiency in PV power systems, the PV source and load impedance properly matched for any weather conditions, thus obtaining maximum power generated by applying MPPT techniques [11].

The proposed structure combines source modeling and MPPT by providing only one ANN model for load current, maximum current and maximum voltage. The determination of maximum power point is using the load current.

2.5.1 Neural Networks

For solar array modeling and MPPT, a neural network is important because the elements operating in parallel while the function of the network determined by the connections between elements. Neural networks have the potential to provide an improved method of deriving non-linear models, which can be used as conventional techniques thus makes them suitable for modeling system [10].

2.6 Microcontroller-Based, MPPT Control System

A new MPPT system has been developed, consisting of a Buck-type DC/DC converter, which is controlled by a microcontroller-based unit. The main difference between the method used in the proposed MPPT system and other techniques used in the past is that the PV array output power is used to directly control the DC/DC converter, thus reducing the complexity of the system. The resulting system has high-efficiency, lower-cost and can be easily modified to handle more energy sources (e.g, wind-generators) [12].
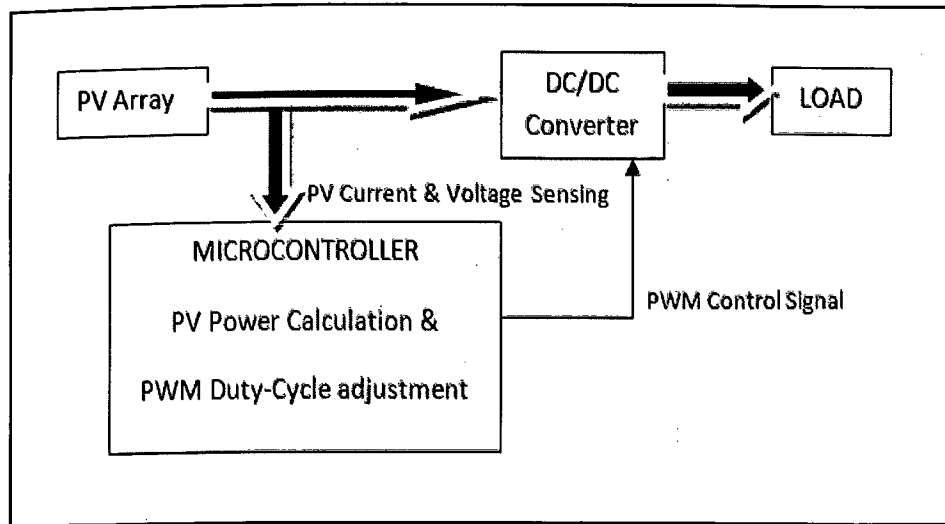
Figure 2.2   Block diagram of the proposed system

In the PV current-controlled MPPT system shown in Figure 2.4, the PV array output current is compared with a reference current calculated using a microcontroller, which compares the PV output power before and after a change in the duty cycle of the DC/DC converter control signal. The PI controller regulates the PV output current to match the reference current.

An output power increase results in both higher output current and higher PWM control signal duty cycle, until the maximum power is transferred to the load. But this method has the disadvantage that it can be used only in applications where the output voltage remains relatively constant. Microcontroller is used to measure the PV array output power and to change the duty cycle of the DC/DC converter control signal. By measuring the array voltage and current, the PV array output power is calculated and compared to the previous PV array output power. The duty cycle is changed accordingly and the process is repeated until the maximum power point has been reached by depending on the result of the comparison [12].

2.7 Single Phase Grid-Connected PV System

A complete computer simulation program of a single phase grid connected PV system using MATLAB/SIMULINK and SimPowerSystem tool in order to monitor and analyze the performance of each unit of the system during a selected day in the year representing a sunny day and another cloudy day using the hourly data of load demand, solar radiation and temperature [13]. The system consists of a PV array subsystem as the primary source of energy, the electric grid as an auxiliary source of energy, the battery bank as a backup source that feeds the electrical load in case of grid failure. This research also focuses on the operational control of the system and the inverter control by using the PI controller to achieve a maximum power point of the PV array. The simulation results of the required system output parameters; PV output power, grid power, load power, battery power, and battery voltage and state of charge also been analyzed and discussed.
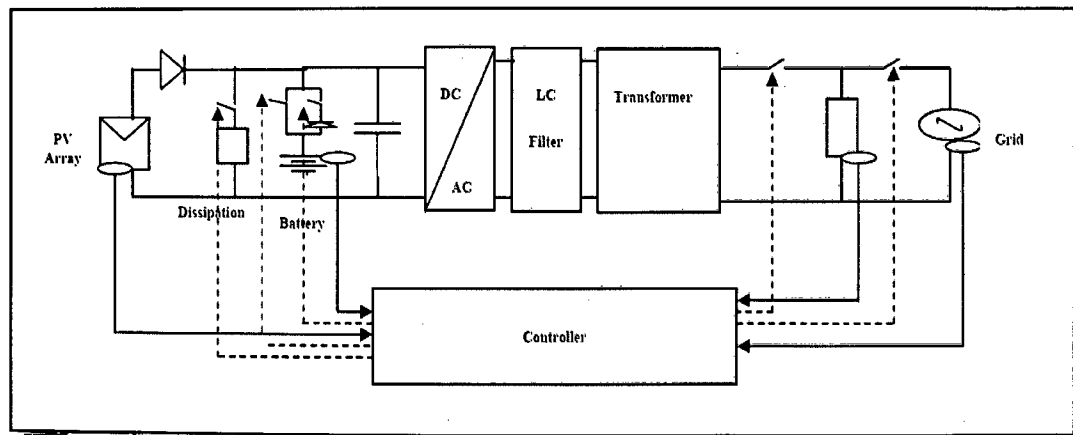

Figure 2.3   Block   diagram   of   single   phase   grid-connected   PV   system

The block diagram of the project shown in Figure 2.5 where the DC link capacitor maintains the solar PV array voltage at a certain level for the voltage source inverter. While the single phase inverter with the output filter converts the DC input voltage into a pure AC sinusoidal wave, then the filter output passes through an isolation step up transformer to setup the filter voltage to 220 Vrms required by the

electric utility grid and load. Function of low pass filter (LPC) second order filter which eliminates all high order harmonics from PWM waveform so that the inverter input is 50Hz, low distortion, pure sinusoidal output voltage wave.

Besides that, the transformer will acts as a step up transformer as it will step up the input voltage to 220 Vrms according to the electric utility load. Meanwhile, controller acts as a control strategy that describes the interactions between its components [13]. By using ON/OFF switch logic controller for the system according to these modes of operation, the control is achieved. This controller is based on sensing of the grid status, PV array output power, load power and state of charge (SOC) of the battery and compare them to each other or to a reference value and then send a control signal to the system switches to open or close according to the mode of operation.

2.8   Maximum Power Point Tracker (MPPT)

MPPT is necessary to draw the maximum amount power of the PV module. The concept of maximum power point tracker (MPPT) is simple that is automatically varied a PV array load condition so it can produce its maximum output power. MPPT is necessary because a PV cell has nonlinear current voltage quality. It also can be defined as a unique point on the curve where array operates with maximum efficiency and produces maximum output power. MPPT is a technique that some applications consist of putting power on the grid, charging batteries, or powering an electric motor benefit from MPPT [10].
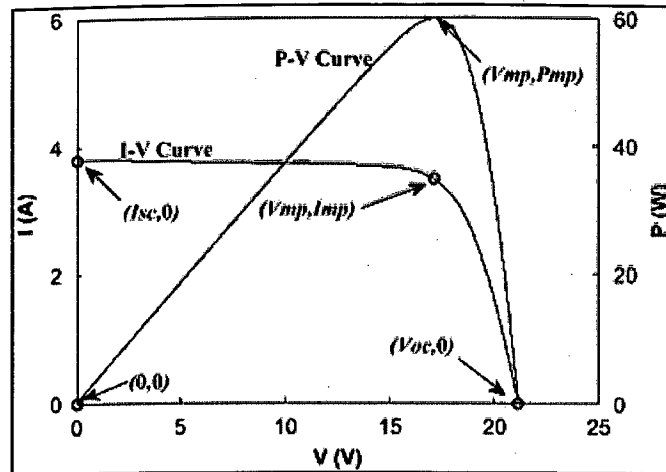
Figure 2.4   I-V and P-V characteristic curve

The power delivered by the PV generator depends on the environmental factors: irradiance, temperature, and shadowing conditions, it is never constant over time. Neither standalone system or connected-grid system, and whatsoever two stages of the PV converter system or single stage PV converter system, it is very important to operate PV energy conversion systems near maximum power point (MPP) to obtain the approximately max power of PV generator. Many maximum power point tracking (MPPT) methods have been developed which are [14] :

i)   Constant Voltage method (CV)

ii)   Perturbation and Observation method (P&O)

iii)   Incremental Conductance method (IncCond) etc.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will explain graphically how the PV systems models by using MATLAB/SIMULINK. In order to complete a project, methodology is one of the most important aspects to be considered to ensure the project runs smoothly and achieves the expected results. A photovoltaic array (PVA) simulation model to be used in MATLAB/SIMULINK is developed based on the specification data provided in the manufacturer's data sheets. The model is developed using basic circuit equations of the PV solar cells. The MATLAB/SIMULINK is used in this paper to establish a model of PV system with MPPT function. The method used here is implemented in MATLAB/SIMULINK programs for simulations and produced its desired voltage, current and power waveforms.

3.2 MATLAB/SIMULINK

SIMULINK is a software package for modeling, simulating and analyzing dynamical systems. It supports linear and nonlinear system, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multi rate have different parts that are sampled or updated at different rates [15].

For modeling, SIMULINK provides a graphical user interface (GUI) for building models as block diagram, using click and drag mouse operations. With this interface you can draw the models just as you would with pencil and paper. SIMULINK includes a comprehensive block library of sinks, sources linear and nonlinear components and connectors [16]. Consequently, during the design process of PV array powered systems; a simulation must be performed for system analysis and parameter settings. Therefore an efficient user friendly simulation model of the PV array is always needed. The PV array model proposed in this paper is a circuitry based model to be used with MATLAB/SIMULINK.

Furthermore, since the MATLAB/SIMULINK contains Power System Toolbox, the software turns into a powerful power systems simulation and analysis tool. Other than that, this software is very helpful because it comes with demos of some power electronics circuit that student can refer to as references for circuit designing and simulation.

For modeling, SIMULINK provides a graphical user interface (GUI) for building models as block diagrams, using click and drag mouse operations. SIMULINK include a comprehensive block diagram of sinks, sources, linear and non linear components, and connectors [10].

3.3   Modeling the Solar Cell

The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction that directly converts light energy into electricity [17]. The principal advantages associated with photovoltaic are that they have no moving part; they don't produce any noise and require little maintenance. The efficiency can drop further due to the solar panel temperature and load conditions. While, under irradiance and temperature conditions with approximate similarity to an array under load, a PV cell's open circuit voltage (Voc) will be varied.

3.3.1 Modeling the PV Module (PV Characteristics)

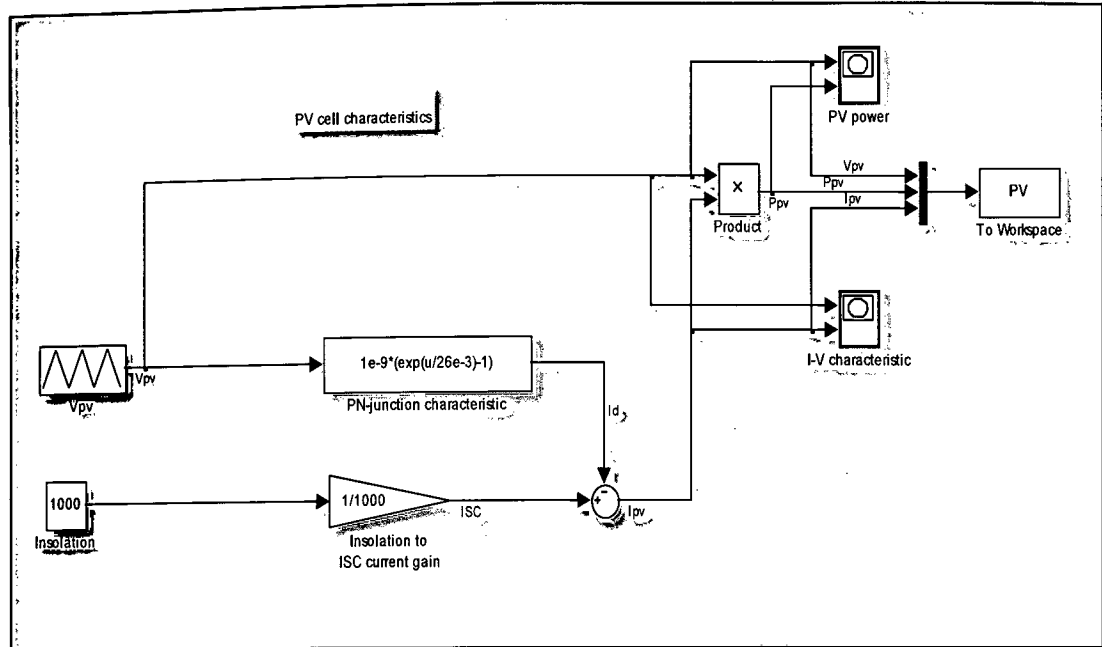i) Non-various insolation levels

Figure 3.1   SIMULINK model of complete PV module's system (Fixed insolation level)

A PV cell is essentially an ideal current source in parallel with an ideal diode. Two key parameters most often used to characterize a PV cell are its short-circuit and its open-circuit voltage. These values are generally provided in the manufacturer's data sheet. The insolation level can be changed to any other suitable values. PV voltage will be the input for the system. While for PN-junction characteristic, the mathematical equation used are 1e-9*(exp(u/26e-3)-1). The PV power and I-V shows the characteristics of the PV system.
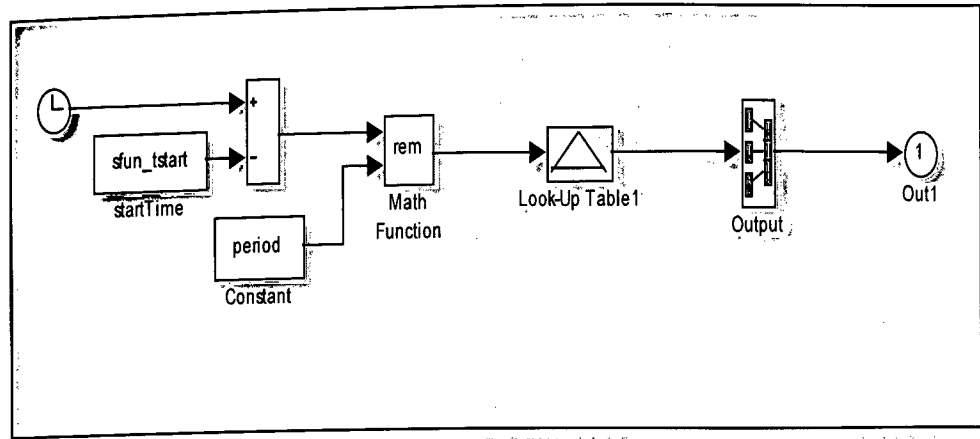
Figure 3.2   Sub-mask for Vpv
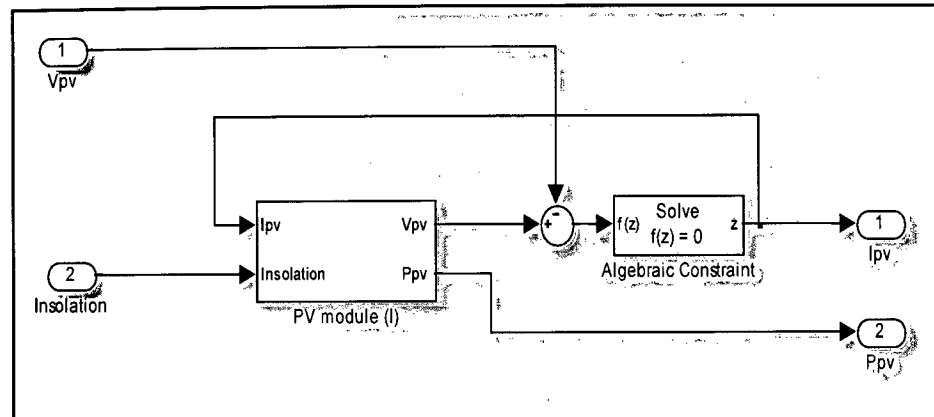
ii)   Various insolation levels

Figure 3.3 SIMULINK model of the solar PV module

PV module model based on module data-sheet parameters. This model has Vpv input, which is suitable for parallel connections of modules. The insolation, G can be varied as 1000 W/m^2, 800 W/m^2 and any other suitable values. There are two limitations of this PV module which are there is no temperature consideration and the module is a static model.