MODELING AND SIMULATION OF INVERTER-CONTROLLED HYBRID PHOTOVOLTAIC-WIND CONNECTED TO THE GRID GENERATION SYSTEM

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My dedication goes to:

For my beloved Mother and Father

Whose hearts are always with me and their prayers light on my daily live.

Thanks for everything, I cannot thank enough for your patience and unlimited support on my side.

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ABSTRACT

The rapid growth demand for energy and the depletion of fossil fuels leads researchers to develop alternative and sustainable energies sources like wind and solar renewable sources which is becoming the largest potential in renewable energies. The aim of this project is to design 10kW hybrid PV-Wind hybrid connected to the grid generation system, this system is regulated by the common DC link in order to contribute some power to the grid. The project consists of Permanent Magnet Synchronous (PMSG) as a wind generator, solar connected in series and parallel modules, DC-DC Boost converter equipped with MPPT, this, Maximum power point tracker (MPPT) control is essential to extract the maximum power of the output of photovoltaic power generation system and wind turbine at its maximum power point. Perturbation & observation (P&O) strategy is utilized and modelled in MATLAB/Simulink. This strategy is modest in operation and hardware requirement is minimal, a Phase Locked Loop (PLL) is used for control of multifunctional VSC. The voltage source converter (VSC) controller uses the load and source forward terms for fast dynamic response by regulating and giving required power to the grid. The simulation studies are performed on MATLAB/Simulink. The alternating power from the sources is connected voltage source inverter which regulates the injected DC voltages before sending to the grid. This inverter transfers the energy drawn from the wind turbine and PV array to the grid by keeping common DC voltage in constant value. The simulation results demonstrates the control performance and dynamic behaviour of the hybrid PV-wind connected to the grid generation system by using MATLAB/Simulink.

ABSTRAK

Keperluan tenaga yang meningkat secara mendadak dan bahan api fosil yang semakin berkurangan mendorong penyelidik untuk mencari sumber tenaga alternatif seperti tenaga solar dan angin. Tenaga ini berupaya menjadi tenaga yang boleh diperbaharui. Tujuan projek ini adalah untuk mereka bentuk hibrid 10kW hibrid PV-Angin yang disambungkan ke sistem penjana grid. Sistem ini dikawal oleh pautan voltan arus terus untuk menyumbang tenaga ke dalam grid. Projek ini menggunakan magnet kekal segerak (PMSG) sebagai penjana angin, panel solar yang disambungkan secara siri dan selari, penukar DC-DC Rangsangan dan grid suai muka songsang. Strategi kawalan kuasa digunakan untuk menghasilkan kuasa maksimum. Kawalan penjejak titik kuasa maksimum (MPPT) adalah penting supaya keluaran bagi system penjana kuasa fotovoltaik dan turbine angin adalah maksimum. Kaedah gangguan dan pemerhatian (P&O) digunakan dan disimulasikan dalam MATLAB/Simulink. Kaedah P&O beroperasi dengan mudah dan keperluan perkakasan adalah rendah. Gelung Terkunci Fasa (PLL) digunakan untuk mengawal VSC yang mempunyai pelbagai fungsi. Pengawal penukar sumber voltan (VSC) menggunakan beban dan sumber ke hadapan untuk tindak balas dinamik yang cepat dengan mengawal selia dan memberi kuasa yang diperlukan kepada grid. Kajian simulasi dilaksanakan dalam MATLAB/Simulink. Kuasa ulang alik dari sumber disambungkan kepada sumber voltan songsang untuk mengawal selia voltan terus yang dimasukkan sebelum dihantar ke dalam grid. Suai muka sumber voltan songsang dengan grid memindahkan tenaga dari turbin angin dan susunan PV ke dalam grid dengan mengekalkan nilai voltan terus. Hasil daripada simulasi menunjukkan prestasi kawalan dan sifat dinamik hibrid PV-Angin yang disambungkan ke system penjana grid dengan menggunakan MATLAB/Simulink.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Due to the critical condition of fossil fuels which include oil, gas and natural gases, the development of renewable energy sources is continuously improving. This is the reason why renewable energy sources have become more paramount these days. Few other reasons include advantages like abundant availability in nature, eco-friendly and recyclable [3, 4]. Many renewable energy sources like solar, wind, hydro and tidal are there, among these renewable sources solar and wind energy are the world's fastest growing energy resources with no emission of pollutants, energy conversion is done through wind and photovoltaic cells.

The term hybrid is referred as the combination of two or more renewable sources to cover up optimally in required demand of power. The merging of PV-wind generates combination of power for complementation of each other by considering availability of sources. The individual harnessing of wind and solar sources have uncertain characteristics. For instance, in the day time solar energy is shining, hence because of the sun density and unforeseeable shading by the trees, or weather changes, the solar radiation intensity also changes. For this cause solar energy can be undependable [5]. In the meantime wind can be formed by uneven heating of the atmosphere and this varies by weather condition. Because of this concept, wind can be unreliable too.

As the individual renewable energy utilization becomes unreliable so it is imperative to implement hybrid generation system which is more efficient than individual generation. [6]. In this project, modelling of inverter-controlled hybrid PV-wind generation system connected to a grid is proposed and simulated. Figure 1.1 shows proposed complete system block diagram.

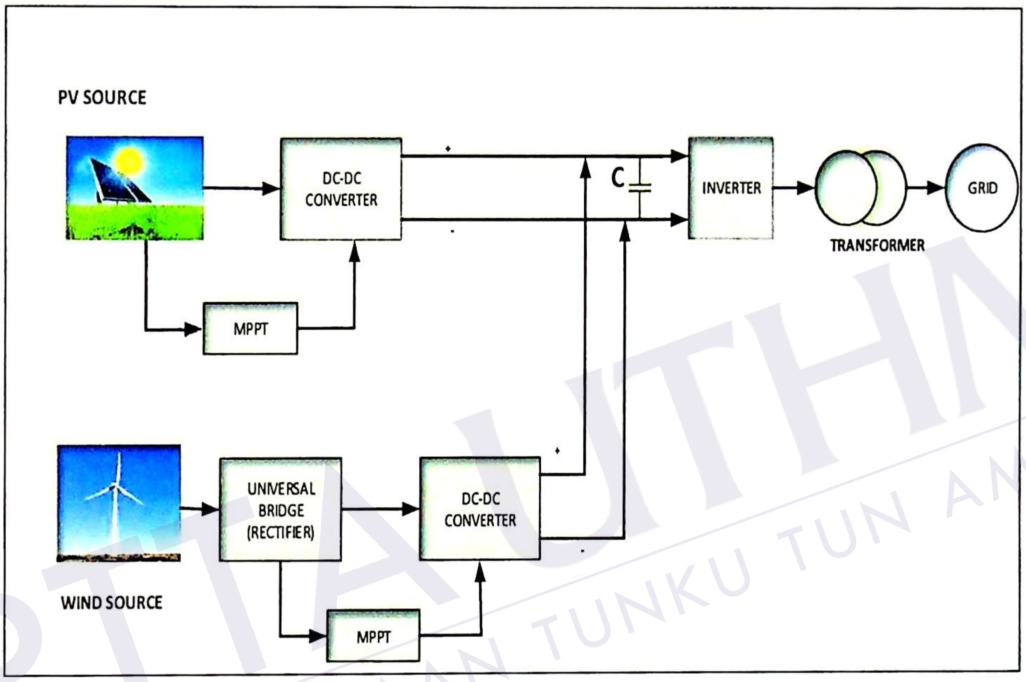

Figure 1.1: Grid-connected Hybrid PV-wind block diagram

The suggested hybrid system contains two separate sources which is PV and wind source, in the proposed system, contains wind turbine and PV as sources, the wind turbine has PMSG which is built-in generator to produce AC power from moving rotor of the wind. In the other side, there is PV sources which produces DC voltage which is then boosted to the desired voltage by the DC-DC boost converter. This two sources shares common DC link voltage which is injected to the inverter this inverter harnesses DC power from the PV array and the wind turbine which maintains the voltage and frequency of the grid [7].

1.2 Problem Statement

Wind and solar energy are reliable energy sources. However, the renewable energy generation has drawbacks that the change of the output characteristic becomes intense because the output greatly depends on climatic conditions, including solar irradiance, wind speed, temperature, and etc.

Thus, in order to conquer this obstacle is better to hybrid the system, however to combine renewable energy systems is also big challenge because of the different characteristics of the different sources and it is response of fluctuating load, the main confrontation of the hybrid is synchronization of the system from the source to the load, so it is required to keep constant DC output voltage for both sources whether the both sources is balanced or not.

Many researchers studied and published papers related to the hybrid system. mostly they used stand-alone systems which is always have constant load, however when connected to grid suffers a lot of synchronization problems specially in the DC side, the researchers mostly implemented balanced system which gives almost constant DC output voltage by using battery bank to compensate the DC voltage required by the inverter, thus this is not suitable for the unbalanced sources and also not cost-effective as they need to have always battery bank.

Thus, in this project is proposed "modelling of inverter-controlled hybrid PV-wind connected to a grid generation system". in this work focuses on controlling DC link voltage which is to be injected to inverter, the proposed inverter control compares the voltages comes from the two sources and referenced voltage before processing to the grid, if the referenced voltage is higher than the input voltages from the sources, boost converter having maximum point tracker (MPPT) is equipped in order to boost inputs voltages to referenced voltage by varying the duty-cycle. The proposed control criteria operates well and keeps unity power factor ,but mostly suffers to high power PV-wind sources, as the inverter losses synchronization and could not afford to keep unity power factor and compensate the DC voltage from the sources.

1.3 Objectives

Objective of this project is as follows:

(i) To model hybrid photovoltaic-wind connected to the grid generation system having DC boost converter equipped with MPPT controller

(ii) To examine dynamic performance of the MPPT for implementation of the hybrid system.

(iii) To control and keep constant in common DC-link voltage for the hybrid system connected to the grid.

1.4 Scope of the project

The project scope is as follows

(i) The system is based on grid connected hybrid PV-wind generation system for remote areas power supply.

(ii) Modelling solar and wind combination equipping with boost converter is used by simulating MATLAB \Simulink.

(iii) Sun Power SPR-305E-WHT-D solar type is validated for solar modelling, and permanent magnet asynchronous generator (PMSG) wind type also used for wind turbine modelling.

(iv) Perturb and Observe (P&O) maximum power point tracker (MPPT) strategy is used for the DC boost converter.

(v) 3-Φ voltage source inverter (VSI) is implemented as the control criteria for DC –link voltage.

1.5 Research Motivation

Nowadays renewable energy sectors are getting more attention towards developed countries due to affordability and cheaper. For instance, according to the [8], the investment in renewable energy was higher in the world's poorest countries than the richest ones for the first time last year, to a major new report. A total of about £196.5 was spent renewable power and fuels globally in what was a record year for investment in the sector.

1.6 Thesis outline

This report contains five chapters. Chapter 1 explains introduction of the project. It also determines the background of the project. This also summarizes and reviews all the main structure of the project. It includes problem statement, objectives of the project, motivations and its scope.

Chapter 2 basically reviews and discusses previous research and finding for this area and how it relates to this work. This also determines some refinement from previous work to merge the goal of the project.

In chapter 3 discussed methodology of the project, the design and methods used are explained in this chapter as well as developing the hybrid controlled system in MATLAB\Simulink.

Chapter 4 states in detail all the results approved in the system by showing and proving the functioning of all the components of the system and lastly gives the discussion of the all results in the project.

Lastly, chapter 5 concludes and summarizes the project by pointing out some of the future work expansion and recommendation for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Background of the Project

Solar power is energy from the sun that is converted into thermal or electrical energy. Solar energy is the cleanest and most abundant renewable energy source available, Modern technology can harness this energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use.

The sun radiates 174 trillion kWh of energy to the earth per hour, In other words, the earth receives 1.74 x 10 17 watts of power from the sun [9].The estimated distance from the sun is 150,000,000 km while the sun is stationed and spins around by the earth in an elliptic orbit, the light having the travelling speed of 300,000 km/sec to overcome the aforesaid distance, it consumed approximately 8.5 minutes [10].Wind turbine theory has progressed rapidly in recent years and it was at the hub of high tech industry. This is becoming more powerful, with the latest turbine models having larger blade sizes which can generate more wind which in return produce more electricity [11]. Solar-wind hybrid generation system is the combination of power generating by solar photovoltaic modules and wind turbines. Using this system, power generation by the turbines when there is enough wind the wind and generation from the PV module when there is sunlight radiation is available can be achieved. Both systems can generate power when both sources are available [12].

2.2 Modeling of Photovoltaic (PV) Module

The modeling of the photovoltaic modules can be designed by connecting series and parallel combination in photovoltaic cells to acquire high power.

2.2.1 Modeling PV cell

The photovoltaic cells is made of combination photonic current from the cell with diode for directing the generated current from the cell. Figure 2.1 shows basic circuit of ideal PV cell.

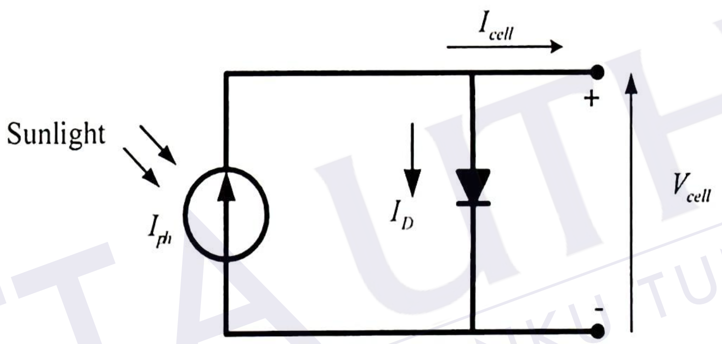

Figure 2.1: Ideal Single Diode Circuit

The general Equation from the characteristics of semiconductors that describes the I-V characteristic of ideal PV cell is [13].

$$I_{pv} = I_{ph} - \underbrace{I_{o,cell}\left[\exp\left(\frac{qV}{akT}\right)-1\right]}_{I_d} \tag{2.1}$$

Where I_{pv} is the light photons current, I_D is the diode equation, $I_{o,cell}$ is the reverse leakage current of the diode, and q is the electron charge.

As shown in Figure 2.2, the I-V curve comes in Equation (2.1). The net cell current I contains of the light-generated current I_{pv} and the diode current I_D.

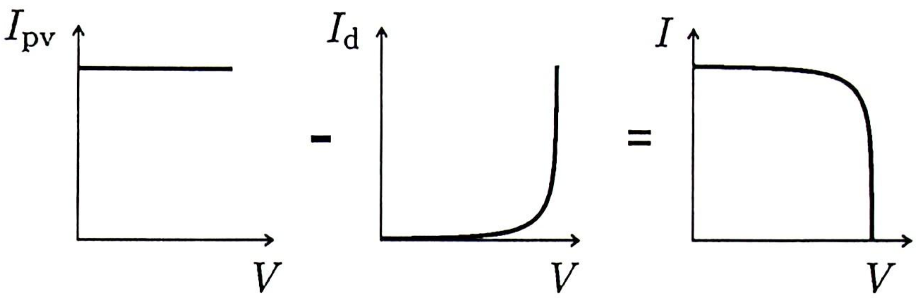

Figure 2.2: Characteristic I-V curve of the PV cell

2.3 Photovoltaic Modeling

In general, the Equation (2.1) of the basic photovoltaic cell does not determine the I-V characteristic of a modern PV array. Modern arrays are made of string connected PV modules, and analyzing of the characteristics of PV arrays need to implement PV module. The implementation of the PV module is created from the equivalent circuit of PV module as shown in Figure 2.3, this circuit based on single diode PV module.

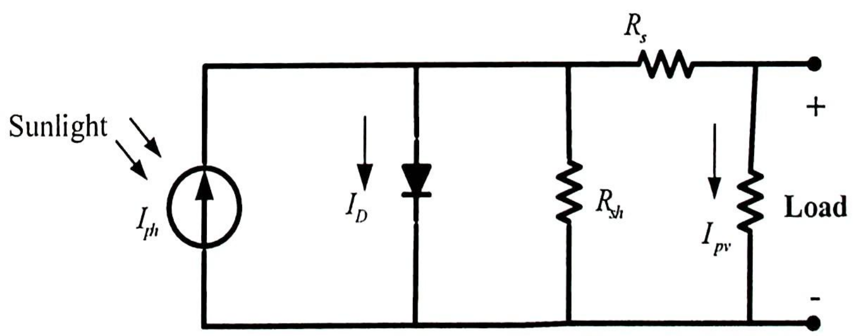

Figure 2.3: Photovoltaic Module Circuit

From the Figure 2.3 in photovoltaic module circuit can be simplified by using Kirchhoff's Current Law (KCL), diode characteristic, and Kirchhoff's Voltage Law is formed [14]:

$$I_{ph} - I_D - \frac{V_D}{D} - I_{pv} = 0 \tag{2.2}$$

In KCL for the diode characteristic

$$I_D = I_O\left(e^{\frac{V_D}{V_T}} - 1\right) \tag{2.3}$$

For KVL:

$$V_{pv,cell} = V_D - R_s I_{pv}$$

(2.4)

In Equation (2.3), diode characteristic is shown by diode current I_D ,while in KVL shows the Equation (2.4) for $V_{pv,cell}$ .The general observation characteristic in PV array current can be [15]:

$$I_{pv} = I_{ph} - I_o\left[\exp\left(\frac{V + R_s I_{pv}}{V_t a}\right) 1 - \right] - \frac{V + R_s I_{pv}}{R_p} \tag{2.5}$$

Where I_{pv} is the photovoltaic (PV) current and I_o is the saturation current, while $V_{t=N_s} kT / q$ is the thermal voltage of the array with N_s cells connected in series module. When the cells connected in series, it increases the generated output voltages, while the cells connected in parallel increases the generated current. If the array contains number of parallel connections of the cells and saturation currents may be expressed as $I_{pv} = I_{pv,cell} N_p$, $I_o = I_{o,cell} N_P$.

The relationship between R_s and R_p, can be found [16]:

$$R_p = \frac{V_{mp(V_{mp}+I_m R_s)}}{\left[V_{mp}\left\{I_{pv} - Id\right\} - P_{\max,E}\right]} \tag{2.6}$$

The initial conditions for both R_s and R_p, can be expressed

$$R_S = 0 \quad ; \quad R_{po} = \frac{V_{mp}}{I_{sc} - I_{mp}} - \frac{V_{oc} - I_{mp}}{I_{mp}} \tag{2.7}$$

In Equation (2.7) determines that for any given value of R_s there is identical of R_p that gives the I-V curve.

2.4 Photovoltaic Array Characteristics

The photovoltaic I-V and P-V characteristic is not constant and changes with irradiation and temperature. At the maximum power point (MPP), the modules gives the most power available under conditions of irradiance and temperature. Figure 2.4 shows I-*V* curve of PV module with labelling maximum power point (MPP).

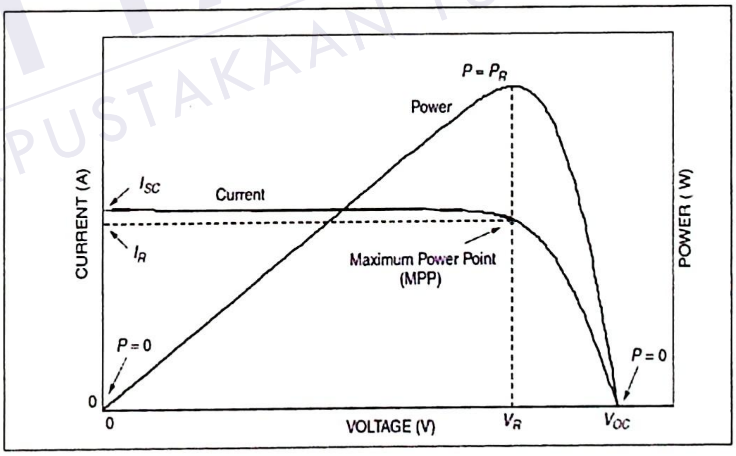

Figure 2.4: Sample I-V Curve [17]

2.5 Effect of Irradiance and Temperature

When the irradiance of the solar panels decreases, the power generated will be very small in a cloudy sky, and it will not effect to the efficiency of solar panels, but it will minimize production of current because of low current. In Figure 2.5 shows variation of different irradiation on PV module which produces different maximum output power.

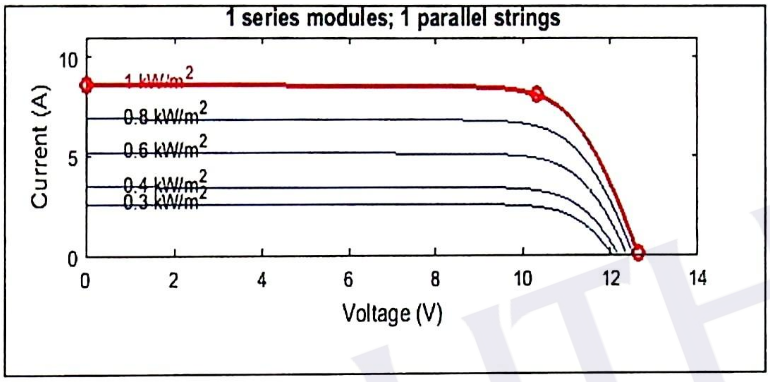

Figure 2.5: Different Irradiation Curves in PV Modules

In other hand when the surrounding temperature of the PV module increases, the current produced remains practically unchanged, whereas the voltage decreases which causes reduction in the performances of the PV panels in terms of produced power. It is always good to keep under control the service temperature trying to give solar modules enough ventilation to minimize temperature variation on them. Figure 2.6 shows the effect of variation surrounding temperature in some type of PV modules.

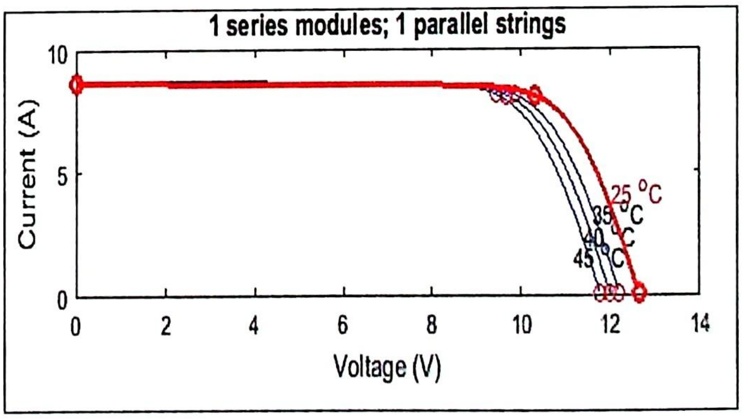

Figure 2.6: Different Temperature I-V Curves in PV modules

Furthermore, there is another condition with may experience the use solar panels which can affect the performance of modules and is called shading condition. When analyzing this condition can be seen multiple peaks on I-V and P-V curves which produces different curves in compared to normal condition. In Figure 2.7 shows I-V and P-V curves under partial condition, the curve determines the optimum output power on the curve which represents as global maximum power point, while other power represents as local maximum point.

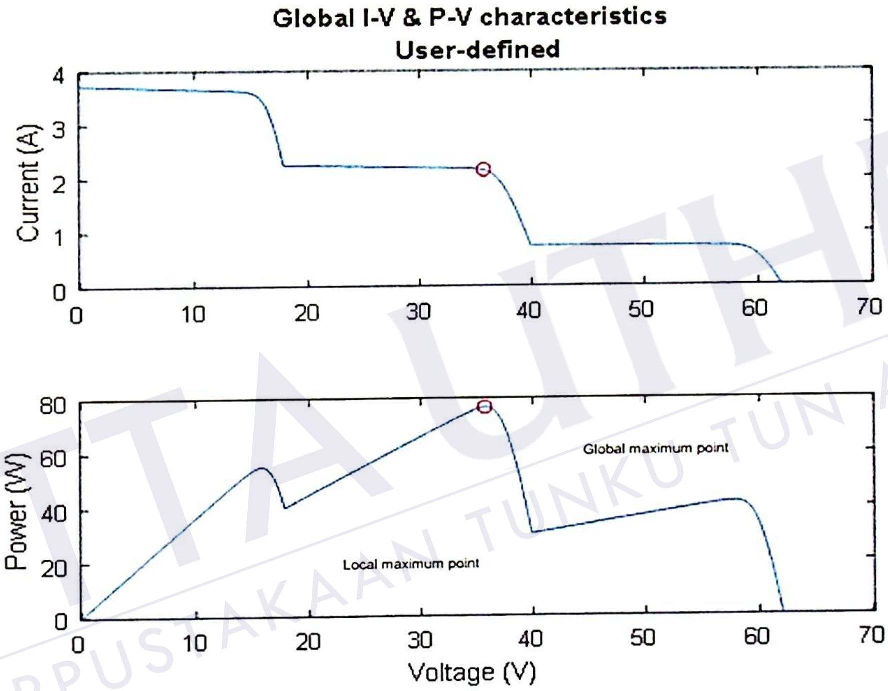

Figure 2.7: Partial Shading Effect

2.6 DC-DC Boost Converter

Boost converter is DC-DC power converter whose function is transform the input DC voltage to the desired and higher. It is function is like a transformer circuit , unlike transformer changes AC source while the DC-DC converter deals with DC sources , the input voltages is stepped up by switching and controlling duty cycle.

The main working principle of boost converter is that the inductor in the input circuit resists sudden variations in input current. When switch is OFF the inductor stores energy in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. The large time constant compared to switching period ensures a constant output voltage. In Figure 2.8 determines the circuit operation of DC-DC boost converter.

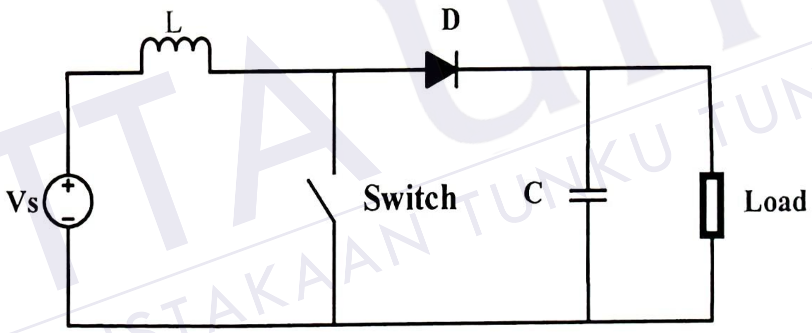

Figure 2.8: Boost Converter Circuit [2]

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