Design of Photovoltaic and Wind Power Hybrid System for DC Air Conditioning Application

by

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LIST OF ABBREVIATIONS

A	-	Ampere
AM	-	air mass
DC	-	direct current
DOY	-	day of year
CERE	-	Centre of Excellent for Renewable Energy
HAWT	-	horizontal-axis wind turbine
kWh	-	kilowatts hour
m	-	Meter
m^2	-	meter square
min	-	minute
MJ	-	mega joule
mm	-	millimeter
m/s	-	meter per second
MET	-	Meteorological Department of Malaysia
Ni-Cd	-	nickel cadmium
PV	-	photovoltaic
s	-	Second
VAWT	-	vertical-axis wind turbine
v	-	Voltage
W	-	Watt

Rekacipta Sistem Hibrid Photovoltaic dan Turbin Angin untuk Aplikasi Penghawa Dingin Arus Terus

ABSTRAK

Pencapaian prestasi yang optimum daripada system hybrid ini, selain mendapatkan sistem rekabentuk yang cekap, banyak kajian mengenai keadaan cuaca perlu dilaksanakan kerana kedua-dua sumber rekabentuk system hybrid ini mampu untuk bekerja dengan lebih cekap dengan bantuan cuaca yang bersesuaian. Sistem hybrid ini mampu untuk membantu system menjadi lebih stabil dan dipercayai dalam menjanakuasa untuk mengecas bateri yang bertindak sebagai penyimpan tenaga untuk memberikan kuasa kepada beban. Dalam projek ini, beban oleh 12 V 630 W DC penghawa dingin telah menjalani kaji selidik dan di analisa dalam beberapa bahagian seperti keluaran array PV dan turbin angin, prestasi cuaca dan beban, dan pemodelan computer menggunakan perisian HOMER. Untuk sistem yang normal, tenaga daripada kedua-dua radiasi solar dan angin akan diuruskan menggunakan alat kawalan secara berasingan. Projek ini, menggunakan Smart Relay SR3 B261JD untuk menguruskan sumber-sumber daripada radiasi solar dan angin. Alat ini berfungsi sebagai alat kawalan untuk memilih voltan yang lebih tinggi yang dihasilkan oleh PV atau angin. Sumber kuasa yang dipilih kemudiannya akan mengecas 7 unit battery YOKOHAMA 100 Ah 12 V yang berjumlah 700 Ah menggunakan pengecas bateri Phocos CX-40. Parameter yang diperhatikan dan dipantau adalah voltan, arus dan kuasa daripada array PV, turbin angin dan beban penghawa dingin DC. Kajian ini membuktikan bahawa tenaga PV adalah lebih stabil berbanding dengan tenaga angin dan sistem hibrid dapat mengecas bateri untuk menyokong beban selama 7 jam sehari. Ini adalah salah satu pendekatan dalam sistem hibrid solar angin dimana akan mewujudkan platform bagi penyelidik di masa hadapan.

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ABSTRACT

The achievement of optimum performance for the hybrid system, besides having the efficient design of the system, a lot of study on the behaviour of the weather needs to be made because both of the resources hybrid system design can work better with the help of the appropriate weather. The hybrid system managed to help the system to be more stable and reliable in generating the power to charge the battery bank that acts as the energy storage to provide the power to the load. In this particular project, the load of 12 V 630 W DC air-condition have been investigated and analysed in several parts such as PV array and wind turbine output, weather and load performances and modelling using HOMER software. For the normal system, the energy from both solar radiation and wind are managed by the PV and wind using device controller separately. This particular project, Smart Relay SR3 B261JD is used to manage the voltage from PV module and wind turbine. The device operates as a controller to choose the greater voltage that produced from either PV module or wind turbine. The selected power source is used to charge 7 units of YOKOHAMA 100 Ah 12 V battery bank that total up to 700 Ah using the Phocos CX-40 battery charger. The parameters investigated and analysed are voltage, current and power of the PV array, wind turbine and the DC air-condition load. This study finds that the PV energy is more reliable compared to wind energy and the hybrid system could charge the batteries to support the load for 7 hours daily. This new approach to solar wind hybrid system will create a platform for future researchers to explore.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Solar power is the conversion of sunlight into electricity. Solar power can directly use photovoltaic (PV), or indirectly use concentrating solar power (CSP). CSP normally focuses on the sun's energy to boil water which is then used to provide power. This technology is implemented in Stirling engine dishes which are using a stirling cycle engine to power a generator. PV is initially used to power the small and medium-sized applications. The application is applied in calculator powered by a single solar cell to off-grid homes powered by PV.

Although the installation cost of solar power has been decreasing gradually thanks to the improved learning curve, nevertheless it still remains as a significant problem. Developing countries had already started to build solar power plants to replace other sources of energy generation. Since solar power is intermittent, it must be combined either with storage or other energy sources to provide continuous power. As for small distributed producer-consumers, net metering makes this transparent to the consumer. A combined power plant has been demonstrated, using 100% renewable energy. One fundamental difference between renewable energy and non-renewable energy is that non-renewable resources can be purchased as they are consumed, whereas with renewable resources, you pay up front for the next twenty years or so for energy (Patel, 2006).

A wind turbine is a rotating machine which converts the kinetic energy from wind energy into mechanical energy. Wind power is the conversion of wind energy into electricity through wind turbines. Large-scale wind farms are typically connected to the local electric power transmission network while smaller turbines are used to provide electricity to isolated locations. Utility companies increasingly produced by small domestic turbines. The wind and solar energy are favoured power source by environmentalists as an alternative source compared to fossil fuels. These sources are plentiful, renewable, widely distributed, clean, and does not produce greenhouse gas emissions. However, the construction of wind farms is not universally welcomed due to their visual impact and other effects on the environment.

Electricity companies harness wind energy with wind turbines. When the wind flows past the turbine's rotor blades, the blades turn and convert the wind energy into kinetic energy. This energy spins a rotor inside a generator, where the kinetic energy is converted into electrical energy. Once the wind energy is converted into electricity, the electricity flows through cables in the turbine, then went down through the turbine tower to connect with the output from other wind turbines in the wind farm, before entering the local electricity networks. The greater the wind speed, the more electrical energy generated. If there are more than one wind turbines working to generate electricity, this is called a wind farm. All the wind turbines in a wind farm work independently. The output of each turbine is combined before it enters a local electricity network or the National Grid.

According to many renewable energy experts, a small "hybrid" electric system that combines the wind and solar (PV) technologies offers several advantages over either single system. In Malaysia, wind speeds are low in the monsoon when the sun shines brightest and longest. The wind is strong in the dry monsoon when less sunlight is available. This is because the peak operating times for the wind and solar systems occur at different times of the day and year; hybrid systems are more likely to produce power. Many hybrid systems are stand-alone systems, which operate "off-grid" or not connected to an electricity distribution system. For the times when neither the wind nor the solar systems are producing, most hybrid systems provide power through batteries.

Wind speeds are often low in periods when the sun resources are at their best. On the other hand, the wind is often stronger in seasons when there are fewer sun resources. With that said, solar-wind hybrid solutions can be one of the alternative to be considered. Even during the same day, in many regions worldwide or in some periods of the year, there are different and opposite wind and solar resource patterns. The hybrid wind-solar electric system demands a higher initial investment than single larger systems.

1.2 Problem Statement

The introduction and demand for the green technology mainly due to the continuous instability of fossil fuel prices, the amount of oil and natural gas reserves is getting lesser and the serious environmental degradation. The wind and solar energy are the two most popular renewable energies that can be harvest due to the constant existence of both the energy throughout the whole year in Malaysia. Solar energy can be produced when there is sunlight, while wind energy is produced when there is wind. The stand-alone system of both energies is not stable when there is no sun at night and when there is no wind during the day. In other words, both stand-alone systems do not present the desirable efficiency in generating energy. Thus, the idea of the combination of the wind and solar energy can help to ensure the system is more stable to produce electricity.

1.3 Aims and Objectives

The main goal of this research is to study and design a hybrid system of the solar and wind power generation as a renewable energy. It will focus on the hybrid system which functions to choose the highest energy generation as load supply. There is a system design for each solar and wind power generation. The hybrid system is a combination of both power generation and the system will manage to select the best and most efficient power generation at the current time.

1. To analyse the potential of solar radiation and wind speed for PV and the wind powered hybrid system and running the 12 V 630 W DC air conditioner.
2. To design an optimum sizing of PV and wind power hybrid system for DC air conditioning application.
3. To evaluate the performance of designed PV and wind power hybrid system.

1.4 Scope of the Project

The research is mainly about the solar and wind power generation. The combination between both of the main power is called hybrid system. Both of the power generations produce direct current (DC) output. The Smart Relay used to manage both power generations before storing process to the battery bank. This Smart Relay contains a programme that created and designed to suit the needs of this hybrid system. The device uses the ZelioSoft Programming software to ensure that the programme is perfect before downloading it to the device. The programme controls the input of the power generation by comparing the input power of each power generation. The programme chooses the greater power generation and passes it to the other section of the system. When there are winds and solar power at certain high values at the same time, the programme will combine it to produce extra power generation.

1.5 Outline of the Project

Chapter one introduces the solar, wind and hybrid system and the characteristics, aims and objectives, problem statements, scope and project overview.

Chapter two discusses the literature review of the wind energy system. It gives the research a foundation of what fellow researchers have done on this topic to get a better and clearer understanding. The information and research milestone for the solar energy system also discussed for this particular energy system. The combination of the wind and photovoltaic energy system manage to produce a more reliable and quality power generation.

Chapter three elaborates on the methodology of the research. This chapter will describe in detail of all the methods and procedures used to finalize the results.

Chapter four explains the results and data that we produce from the output of the solar, wind and hybrid system.

Chapter five concludes the research in a whole and suggests ideas and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Photovoltaic

PV technology and applications are characterized by their modularity and can be implemented on virtually any scale and size. The overall efficiency of systems available on the market varies between 6% and 15%, depending on the type of cell technology and application. The expected life span of PV systems is between 20 and 30 years. The solar modules are the most durable part of the system, with failure rates of only one in 10,000 per year. Individual PV cells are interconnected and encapsulated between a transparent front, usually glass, and a backing material to form a solar PV module. PV modules for energy applications are normally rated between 50and 200 W. The PV module is the principal building block of a PV system and any number of panels can be interconnected in series or in parallel to provide the desired electrical output (Anon, 1890). Table 2.1 shows the example of PV applications according to size.

2.1.1 P-N Junction

P-N junction diodes form the basis not only of solar cells, but many other electronic devices such as LEDs, lasers, photodiodes and bipolar junction transistors (BJTs). A P-N junction aggregates the recombination, generation, diffusion and drift effects described in the previous pages into a single device.

Table 2.1: Examples of PV Applications According to Size

Size class	Applications
up to 10 W	Pocket calculators, radios, remote wireless sensors, small chargers, electric fences
10 W-100 W	Small illumination systems, call boxes, traffic signals, parking meters, navigation lights, small communication systems, weather stations, solar home systems, medical refrigeration, cathodic protection, small stand-alone systems for isolated dwellings
0.1 kW-1 kW	Medium-sized pumping systems and irrigation systems, desalination plants, propulsion of smaller recreation boats, stand-alone systems for isolated buildings, small rooftop systems, small hybrid systems
1 kW-10 kW	Medium-sized, grid-connected building and infrastructure-integrated systems; large stand-alone systems for isolated buildings; medium-sized hybrid systems
10 kW-100 kW	Large grid-connected systems either building and infrastructure integrated or ground-based
0.1 MW to 1 MW and above	Very large grid-connected systems - either building-integrated or ground-based

P-N junctions are formed by joining N-type and P-type semiconductor materials, as shown below. Since the N-type region has a high electron concentration and the P-type has a high hole concentration, electrons diffuse from the N-type side to the P-type side. Similarly, holes flow by diffusion from the P-type side to the N-type side. If the electrons and holes were not charged, this diffusion process would continue until the concentration of electrons and holes on the two sides are the same, as what happens if two gases come into contact with each other.

However, in a P-N junction, when the electrons and holes move to the other side of the junction, they leave behind exposed charges on doping atom sites, which are fixed in the crystal lattice and are unable to move. On the N-type side, positive ion cores are exposed. On the P-type side, negative ion cores are exposed. An electric field E forms between the positive ions cores in the N-type material and negative ion cores in the P-type material. This region is called the "depletion region" since the electric field quickly sweeps free carriers out, hence the region is depleted of free carriers. A built-in potential V due to E is formed at the junction (Brush, 2007).

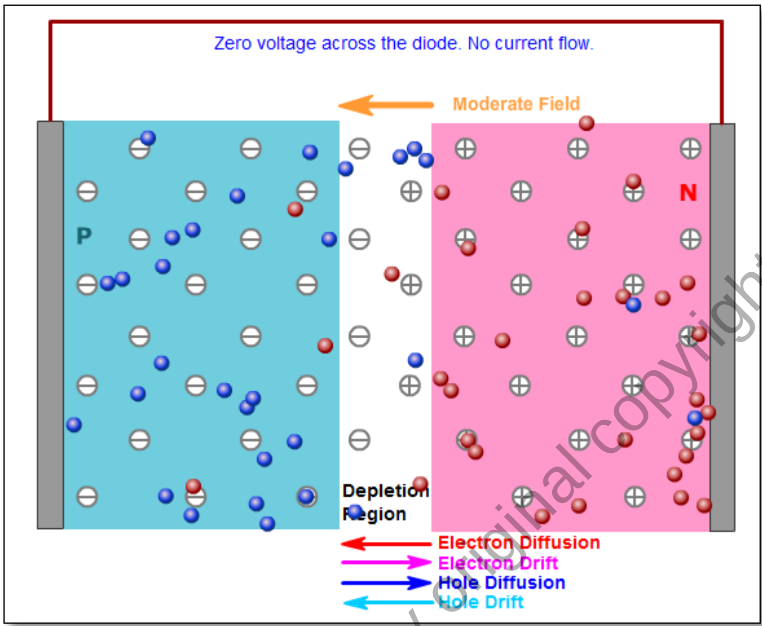

Figure 2.1: P-N behaviour

2.1.2 PV Cell

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both current and voltage to generate electric power. Firstly, this process requires a material in which the absorption of light raises an electron to a higher energy state. Secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor materials in the form of the P-N junction (Brush, 2007).

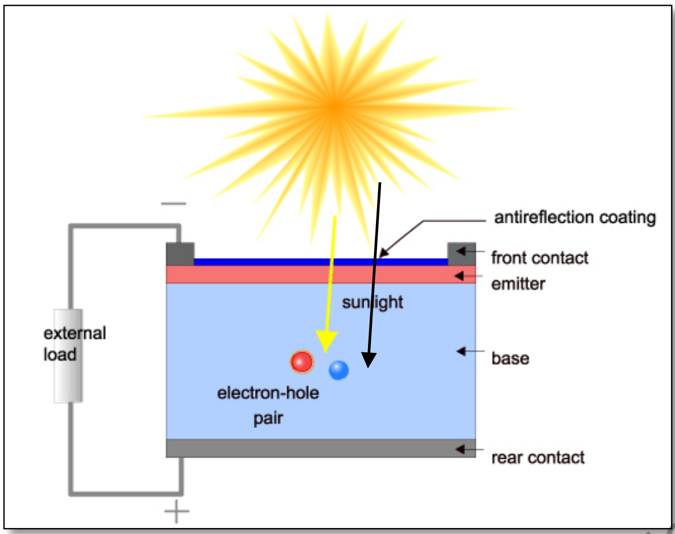

Figure 2.2: Cross section of a solar cell.

2.1.3 Module and Array

The solar cell described in the preceding subsection is the basic building block of the PV power system. Typically, it is a few square inches in size and produces about 4W of power each. To obtain high power, numerous such cells are connected in series and parallel circuits on a panel area of several feet. The solar array or panel is defined as a group of several modules electrically connected in a series-parallel combination to generate the required current and voltage (Patel 2006).

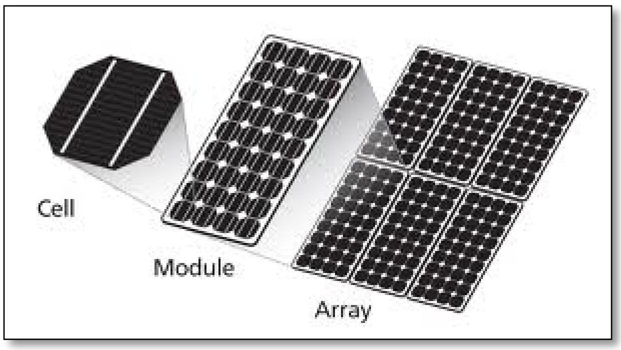

Figure 2.3: The photovoltaic hierarchy.

2.1.4 Light Generated Current

The generation of current in a solar cell, known as the "light-generated current", involves two key processes. The first process is the absorption of incident photons to create electron-hole pairs. Electron-hole pairs will be generated in the solar cell provided that the incident photon has energy greater than that of the band gap. However, electrons (in the P-type material), and holes (in the N-type material) are meta-stable and will only exist, on average, for a length of time equal to the minority carrier lifetime before they re-combine. If the carrier re-combines, then the light-generated electron-hole pair is lost and no current or power can be generated. The second process is the collection of these carriers by the P-N junction, prevents this recombination by using a P-N junction to spatially separate the electron and the hole. The carriers are separated by the action of the electric field existing at the P-N junction. If the light-generated minority carrier reaches the P-N junction, it is swept across the junction by the electric field at the junction, where it is now a majority carrier. If the emitter and base of the solar cell are connected together, the light-generated carriers flow through the external circuit. The ideal flow at the short-circuit is shown in Figure 2.4 (Patel 2006).

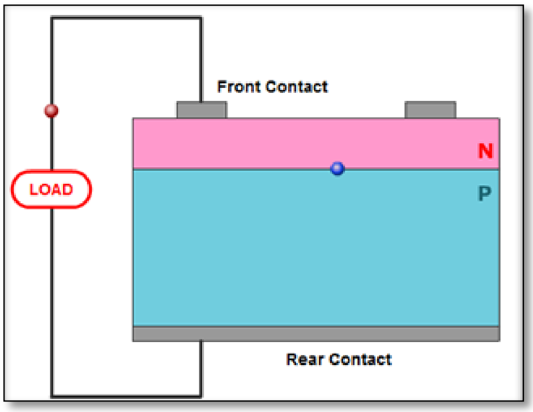

Figure 2.4: The ideal short circuit flow of electrons and holes at a P-N junction

2.1.5 The PV Effect

The collection of light-generated carriers does not give rise by itself to power generation. In order to generate power, the voltage must be generated as well as the current. Voltage is generated in a solar cell by a process known as the "PV effect". The collection of light-generated carriers by the P-N junction causes a movement of electrons to the N-type side and holes to the P-type side of the junction. Under the short circuit conditions, there are no build-up of charge, as the carriers exit the device as light-generated current.

However, if the light-generated carriers are prevented from leaving the solar cell, then the collection of light-generated carriers causes an increase in the number of electrons on the N-type side of the P-N junction and a similar increase in holes in the P-type material. This separation of charge creates an electric field at the junction which is in opposition to that already existing at the junction, thereby reducing the net electric field. Since the electric field represents a barrier to the flow of the forward bias diffusion current, the reduction of the electric field increases the diffusion current. A new equilibrium is reached in which a voltage exists across the P-N junction. The current from the solar cell is the difference between I_L and the forward bias current. Under open-circuit conditions, the forward bias of the junction increases to a point where the light-generated current is exactly balanced by the forward bias diffusion current, and the net current is zero. The voltage required to cause these two currents to balance is called the "open-circuit voltage". The following Figure 2.5 shows the carrier flows at short-circuit condition (Patel 2006).

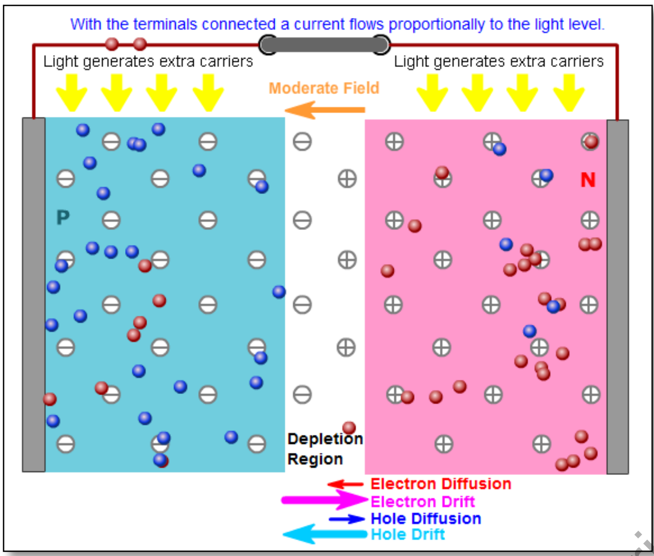

Figure 2.5: Carrier lows in a solar cell under equilibrium.

2.1.6 Current-Voltage Curve

The IV curve of a solar cell is the superposition of the IV curve of the solar cell diode in the dark with the light-generated current. The light has the effect of shifting the IV curve down into the fourth quadrant where power can be extracted from the diode. Illuminating a cell is adds to the normal "dark" currents in the diode so that the diode law becomes:

$$I = I_o\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] - I_L \tag{2.1}$$

I_L = Light generated current (A)

Io = Saturation current (A)

q = Electron charge (1.602 x 10^{-19}C)

V = Voltage

k = Boltzmann constant (1.38 x 10^{-23} J/K)

T = Absolute temperature (K)