STAND-ALONE PHOTOVOLTAIC (PV) SYSTEM DESIGN

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A Report is submitted in Partial Fulfillment of Requirements for the Degree of Bachelor of Electrical Engineering (Industry Power)

Faculty of Electrical Engineering

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Mei 2009

“I hereby declared that I have read through this report entitle Stand-Alone Photovoltaic (PV) System Design and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power).”

Signature : ……………………
Supervisor‟s Name : EN ASRI BIN DIN
Date : 13 Mei 2009

“I hereby declared that this report entitle Stand-Alone Photovoltaic (PV) System Design is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………….
Name : GHAFAR BIN JENAL
Date : 13 Mei 2009

Dedicated to my beloved parents …Hj Jenal B. Md Yassin,
and Hjh Jamilah Bte Hj Ngah

Thanks for being supportive, caring and loving…

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ABSTRACT

Renewable energy is also called an alternative energy source which replenishes itself naturally. Renewable energy included five parts, it is biomass, water (hydropower), geothermal, solar and wind. In Malaysia, solar is one of the renewable energy that had been used to generate energy for residential and remote area that far away from electrical grid and it is clean and quiet. This project is to design and develop *"Stand-Alone Photo Voltaic System Design"*. This project focuses more to develop graphic user interface (GUI) and design stand-alone photovoltaic (PV) system. This program provides facilities to users in estimation design their own stand-alone photovoltaic system especially in Malaysia situation. This program is design for agricultural and farms area. Visual Basic (VB) 6 is used to design and develop this program. This research and studies which is includes calculation of power consumption and sizing the PV sub system. The expected results are the PV program more easily, fast and accurate compare to the manual calculation.

ABSTRAK

Tenaga yang diperbaharui juga sering dipanggil sebagai punca tenaga alternatif dimana oleh ditukar dengan sendirinya. Tenaga yang diperbaharui ini mengandungi lima bahagian iaitu biomass, air (mini-hidro), geothermal, solar dan angin. Di Malaysia, tenaga solar merupakan salah satu tenaga yang diperbaharui dan telah digunakan untuk membekalkan tenaga elektrik ke kawasan kediaman dan kawasan yang jauh dari system grid dimana ia selamat dan bersih. Untuk projek ini, memfokuskan kepada membangunan graphical user interface (GUI) iaitu antaramuka pengguna bergrafik dan merekabentuk sistem stand-alone photovoltaic (PV). Perisian ini direka dan dibentuk untuk bertujuan memberi kemudahan kepada pengguna membuat perkiraan didalam memilih sub sistem yang bersesuian untuk situasi di Malaysia. Program ini juga amat bersesuaian untuk sektor pertanian dan peladangan dimana sesetengah kawasan amat jauh dari sistem grid elektrik. Perisian Visual Basic 6 pula digunakan untuk mereka dan membangunkan perisian ini. Kajian dan penelitian termasuk perkiraan penggunaan kuasa beban serta merekabentuk sub sistem PV turut dilakukan. Keputusan yang bakal didapati dari penggunaan perisian ini adalah ia mudah digunakan, pantas, dan jitu jika dibandingkan dengan menggunakan pengiraan manual.

TABLE OF CONTENTS

3 PROJECT METHODOLOGY

4 RESULT AND DISCUSSION

5 RECOMMENDATION AND CONCLUSION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A - Ampere
V - Voltage
W - Watt
Hz - Hertz
Hp - Horse Power
$^{\circ}C$ - Celsius
Ah - Ampere-hour
Ah/day - Ampere-hour per day
Kwh/m^2 - Kilowatt-hour per meter square
W/m^2 - Watt per meter square

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Problem statement

Manual calculation of stand-alone photovoltaic system is the conventional way to sizing the system and a lot calculation required. In this case, longer time needed and the potential to do mistake is high in order to solve the calculation. Moreover, the inaccurate design may contribute to inefficient of spending money, energy and time.

1.2 Project Objective

The main purposes of this project are:

a) Studies and make some research regarding the power consumption that especially used by agricultural and veterinary in remote area.

b) Design the PV stand-alone system including power consumption calculation and sizing the PV sub system.

c) Implement designing of sizing PV sub system into graphical user interface (GUI) using Visual Basic 6.

d) To make this software/program as estimation for design the PV sub system and more easily, fast and accurate compare to the manual calculation.

1.3 Project Scope

In this project, the scope of work is limited to design the stand-alone PV system in software package by using Visual Basic 6 and Microsoft Access. The general factors that influence the subsystem performance are considered in designing process. The design will include several parts which are electrical load estimation, battery sizing, array sizing, controller specification and inverter specification. In addition, to make the stand-alone PV system more practical, the size of back-up generator is also provided in the developed GUI. The Sample data accumulation for load consumption that used by the farmer and breeder will be taken in several places in Melaka state. At the end of this project, GUI software program will be developed to be used as an estimation method to design the stand-alone. Although this GUI software able to provide the convenience way for designing purposes, it is only the estimation method. Therefore, the need of guidance from a specialist designer in this field is required. It is essentially in order to fulfill all factors that need to be considered especially in terms of the system safety, reliability and costing.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Renewable Energy

“Renewable energy is the energy that generated from natural source such as wind, sunlight, tides, rain and geothermal heat which replenishes itself naturally”[4]. Renewable energy technologies include solar power, wind power, mini hydro, biomass and biofuels. Solar energy technologies can provide day lighting and thermal comfort in passive buildings, potable water via distillation and disinfection, hot water, pumping water and drying crop.

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sunlight directly into electricity. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems. There are two type of PV systems almost used, grid connected and off grid (stand-alone) [1].

2.2 Stand-alone Photovoltaic system

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. These types of systems may be powered by a PV array only, or may use wind, an engine-generator as an auxiliary power source in what is called a PV-hybrid system. Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. In many stand-alone PV systems, batteries are used for energy storage. Figure 2.0 shows a block diagram of a typical stand-alone PV and Figure 2.1 shows a block diagram of a PV hybrid [1].

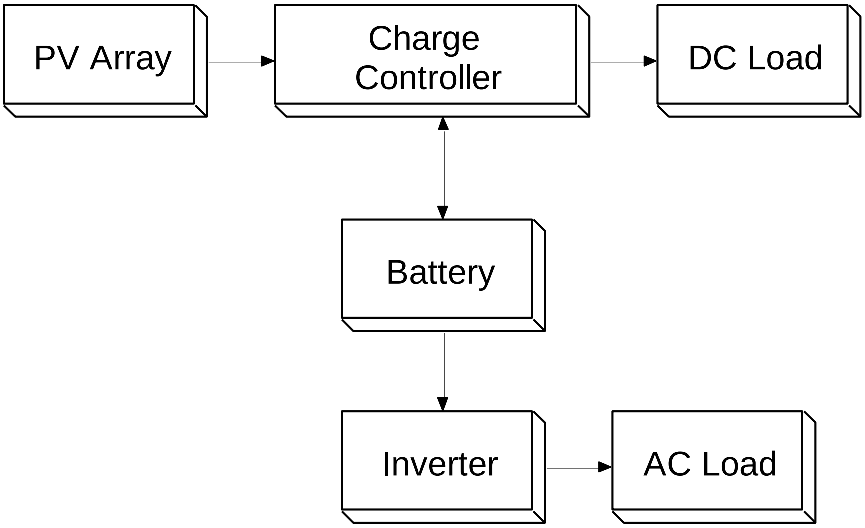

Figure 2.0: Stand-Alone Photovoltaic System Block Diagram

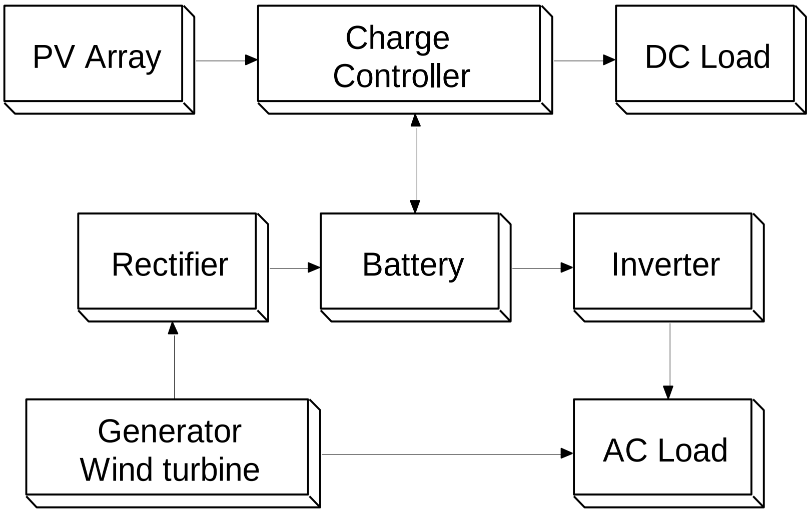

Figure 2.1: Photovoltaic Hybrid System Block Diagram

2.3 Grid connected system

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized [1]. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance.

This allows the AC power produced by the PV system to either supply on-site electrical loads or to back-feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back into the utility grid when the grid is down for service or repair. [1] Figure 2.2 show grid connected system block diagram.

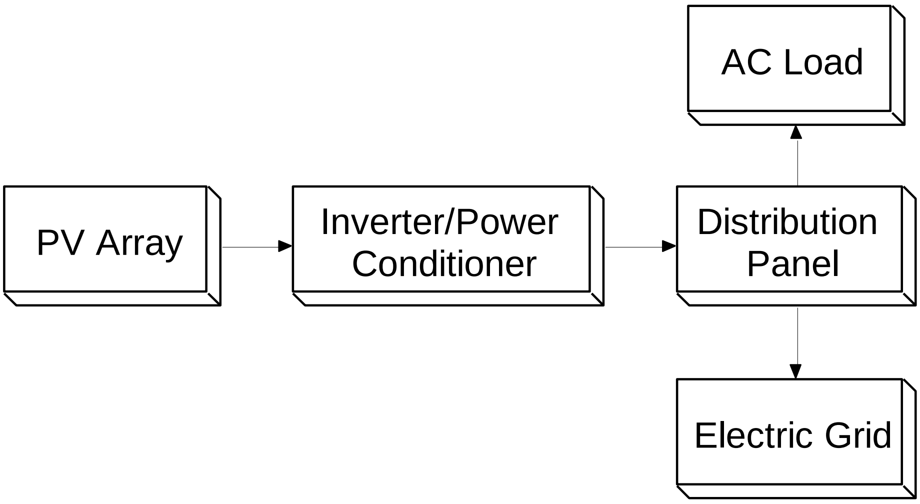

Figure 2.2: Grid Connected System Block Diagram

2.4 Photovoltaic Stand-Alone Sub system

In the Photovoltaic Stand-Alone system there are several components. These components functioning to received, storage, regulated and produced the voltage and current for appliances. The component which is includes:

2.4.1 Module array

In the field of photovoltaic, a photovoltaic module is a packaged interconnected assembly of photovoltaic cells, also known as solar cells. An installation of photovoltaic modules or panels is known as a photovoltaic array or a solar panel. The photovoltaic array is a linked collection of photovoltaic modules, which are in turn made of multiple interconnected solar cells. The cells convert solar energy into direct current electricity via the photovoltaic effect. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can plug into the existing infrastructure to power lights, motors, and other loads. [1]Figure 2.3 show the module array

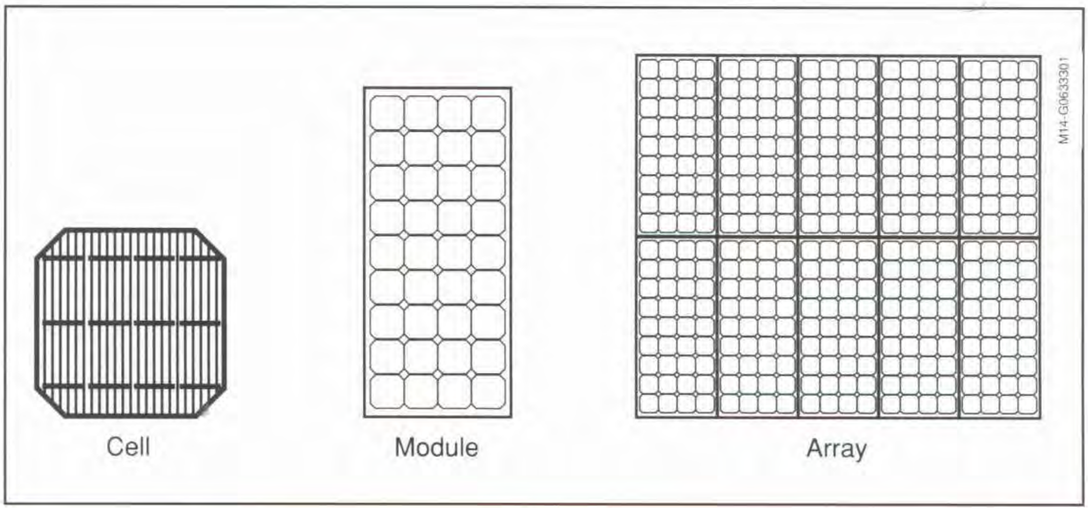

Figure 2.3: Module Array

The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Figure 2.4 show the connection of module array in parallel and series. Solar arrays are typically measured by the electrical power they produce, in watts, kilowatts, or even megawatts. PV modules are rated based on the maximum power produced in Watts when the amount of sunlight is 1,000 Watts/m2. PV systems are rated based on the maximum combined power output of the PV modules and since the amount of sunlight changes, the power output of the system will vary. [5]

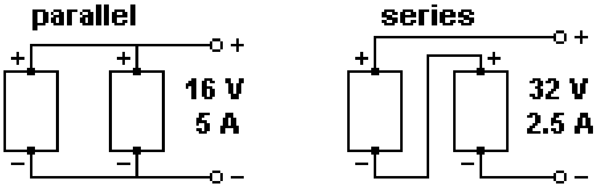

Figure 2.4: Connection Module in Parallel and Series

2.4.2 Charge controller

Charge Controllers or voltage regulators protect batteries from becoming overcharged, which can shorten their lives as well as the lives of some loads powered by them. Electronic circuit in the regulator measures battery voltage, which rises as the battery state of charge increases. At some voltage, which will be different for different types of batteries and at different temperatures, the regulator will stop the charging of the battery.

When the charging stops, the battery voltage begins to fall. At some preset lower voltage, the regulator allows the charging to resume. The basic functions of a controller are quite simple. Charge controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery over discharge, protect from electrical overload, and display battery status and the flow of power [1].

There are two basic types of controllers used for small PV systems. A shunt controller redirects or shunts the charging current away from the battery. These controllers require a large heat sink to dissipate the excess current. Most shunt controllers are designed for smaller systems producing 30 amperes or less, a series controller interrupts the charging current by open-circuiting the PV array. This switching controller is thus limited by the current handling capability of the components used to switch the dc current [1].

2.4.3 Batteries

Batteries are the most common energy storage devices. There are two classifications for batteries: primary and secondary. Primary batteries (e.g., flashlight batteries) are not rechargeable. Secondary batteries (e.g., car batteries) are rechargeable. However, car batteries are unsuitable for PV applications, as they are designed to provide high-current cold cranking amps for a short period of time. Afterwards, the battery is quickly recharged. PV batteries are designed to provide consistent quality energy for a long period of time. When connecting the batteries in Series the voltage will double while maintaining the same capacity rating (amp hours), When connecting in Parallel the capacity (amp hours) of the battery will double while maintaining the voltage of one of the individual batteries [5]. Figure 2.5 shows the connection series and parallel of the batteries.

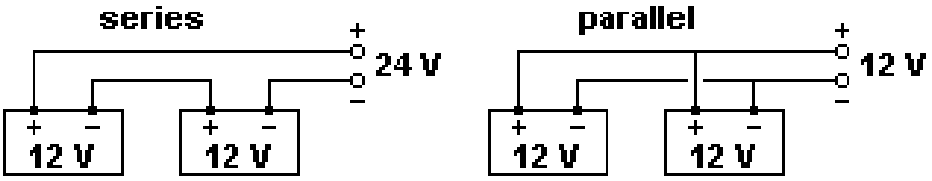

Figure 2.5: Connection Batteries Series and Parallel

2.4.4 Inverter

These devices convert direct-current (dc) electricity to alternating-current electricity (ac). Since PV arrays produce dc electricity, stand-alone PV systems often require an inverter to produce ac electricity for a broad range of loads. The use of large inverters results in approximately 10 percent loss of generated electric energy. However, it is sometimes easier to use such devices rather than to convert all appliances to operate on dc electricity.

Stand-alone inverters typically operate at 12, 24, 48 or 120 volts dc input and creates 120 or 240 volts ac at 50 or 60 hertz. The selection of the inverter input voltage is an important decision because it often dictates the system dc voltage. The shape of the output waveform is an important parameter. Inverters are often categorized according to the type of waveform produced; square wave, modified sine wave, and sine wave. The output waveform depends on the conversion method and the filtering used on the output waveform to eliminate spikes and unwanted frequencies that result when the switching occurs [1].

2.4.5 Conductor (wire)

Proper wire sizing depends on the current to be carried by the wire, but at the low voltages, primary on the length of the wire and the resulting voltage drop. The wiring of PV source circuits and PV output circuits thus must be capable of carrying 156% of short-circuit current of either the source circuit or output circuit whichever applicable. Wire size is given in term of American Wire Gauge (AWG). A larger has a greater amp city and will be designated by a smaller AWG number up to #1 AWG wire. For example, a #14 AWG wire is smaller than a #10 AWG wire [1].

2.5 Sizing the Stand-Alone PV system

Stand-alone photovoltaic power systems are a low-maintenance, versatile solution to the electric power needs of any “off-grid” application. It is important to determine the correct system size, in term of both peak output and overall annual output, in order to ensure acceptable operation at minimum cost. If the system to large, it will more expensive than necessary without increasing performance levels unsubstantially and therefore the system will be less cost-effective than it could be. However, if too small a system is installed, the availability of the system will be low and the customer will be dissatisfied with the equipment. Again, the cost-effectiveness is reduced. Although the same principles are included in the sizing process, the approach differs somewhat for the stand-alone and grid connected [1].

'Sizing' a system means determining how much energy is required and how many solar modules are needed to generate it.
A solar power system must provide enough energy to replace what is being consumed daily by the loads; lights, appliances, equipment, etc. Plus some additional output to compensate for energy used by the system itself. To develop the whole PV stand- alone system there are several procedure design must be taken [2].

2.5.1 Estimating the electrical load

The first step in the design of a PV system is to determine the load size to be powered. If ac loads exist, inverters must be used. When ac loads dominate the system, system voltage should be compatible with the inverter input. Efficiency of ac inverters is increased with higher input voltage. However, as the voltage is increased, larger PV arrays and storage systems are necessary. On the other hand, higher system voltage corresponds to lower system current. High currents require large wire size, fuses, switches, and connectors. Therefore, keeping the current low will enhance cost-effectiveness [2].

For dc loads operating on voltages different from the system operating voltage, dc converters can be used to obtain adequate voltage to power such loads. Alternatively, the batteries can be tapped if the dc loads are small enough. If the batteries are supplying dc loads, battery charges equalizers must be used to overcome the problem of unequal current draw from series-connected batteries, eliminating possible battery failure [2]. Details see Appendix A1

The formula that used to calculate the electrical power load is:

a) AC Power Load (Watt) = Voltage Load (V) x Current Load (I) (2.1)

* For DC power load calculation it is same as AC power load calculation

b) $\text{Total Amp} - \text{Hours load}\left(\frac{\text{AH}}{\text{DAY}}\right) =$

$$= \frac{\frac{\frac{\text{Equation 1 x Daily use}\left(\frac{\text{Hours}}{\text{Day}}\right)\text{x Weekly use}\left(\frac{\text{Days}}{\text{Week}}\right)}{7}}{\text{Power Conversion Efficiency (Decimal)}}}{\text{Nominal System Voltage (V)}} \qquad (2.2)$$

c) $$\text{Peak Current Draw (A)} = \frac{\text{Total DC Load Power (W)} + \text{Total AC Load Power(W)}}{\text{Nominal System Voltage (V)}} \qquad (2.3)$$

d) $$\text{Corrected Amp} - \text{hour load}\left(\frac{\text{Amp}}{\text{Hours}}\right) = \frac{\frac{\text{Equation 2}}{\text{Wire Efficiency Factor (decimal)}}}{\text{Battery Efficiency Factor (decimal)}} \qquad (2.4)$$

Description

i. Power Conversion Efficiency - This factor accounts for power loss in systems using power conditioning components (converters or inverters). If the appliance requires ac power or dc powers at a voltage other system voltage, which should enter the conversion efficiency of the device. If the system does not have the actual efficiency of the converter is being used, the default values will used for initial sizing. Table 2.0 shows the power efficiency conversion factor.

Table 2.0: Power Efficiency Conversion Factor

Power Efficiency Conversion Default	
DC to AC	0.85
DC to DC	0.9

ii. Nominal system voltage (V) - The designer should enter the desired system voltage. The system voltage is normally the voltage required by the largest loads. Common values are 12 or 24 volts dc and 240 volts ac.

iii. Peak Current Draw (A) - To calculate the maximum current required if all the loads are operating simultaneously. This value is used for sizing fuses, wiring, etc.