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REAL-TIME REMOTE POWER MONITORING OF SINGLE-PHASE SOLAR PV INVERTER

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Bachelor of Engineering (Hons)

Electrical and Electronics Engineering

2019

UNIVERSITI MALAYSIA SARAWAK

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REAL-TIME REMOTE POWER MONITORING OF SINGLE-PHASE SOLAR PV INVERTER

FAM JYE YUN

A dissertation submitted in partial fulfillment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Electrical and Electronic Engineering)

Faculty of Engineering
Universiti Malaysia Sarawak

2019

ACKNOWLEDGEMENT

In this project, I have received the kind support and help of many people. I would like to give a sincere thanks to all of them.

First, I would like to give a thousand thanks to my respected supervisor, Ir. Hazrul Bin Mohamed Basri for his guidance and supervision. I really appreciate him because he provided me the necessary information regarding the solar energy. He answered my questions and taught me. When I faced any problems, he always helped me and guided me to solve the problems.

Next, I want to thank my examiners, Professor Dr. Musse Mohamud Ahmed and Dr Yonis. M.Yonis Buswig who attended my presentation and marked my report. They gave me comments during the presentation and corrected my mistake.

Besides, I would like to thank my parents, Fam Siew Fong and Ting Hung who worried about me. Their encouragement and financial support helped me a lot to complete the project.

I also want to thank my classmates who helped me. I would like to thank my classmate, Teh Xuan Yuan because he is generous for me to use his car to carry the equipment of the project.

ABSTRACT

This thesis focuses on the real-time remote monitoring of single-phase solar PV inverter. The PV module converts sunlight into electricity by producing a direct current (DC) electrical power. The solar charge controller regulates the voltage and current from PV module and store it into the battery. The inverter converts the DC electricity into AC for normal home appliances. The PV system produces DC power which fluctuates with the intensity of sunlight which may not stable. It is necessary to monitor the power produced by the solar PV in real time in order to create an efficient performance for the solar power system. The aim of this project is to set up a data acquisition system to monitor the power output of solar PV system. The data acquisition system includes DAQ device, voltage and current sensors. To monitor the solar PV system, LabVIEW software had been used to get the real-time voltage and current signals from the solar PV system. The voltage and current sensors are set up to the PV input, battery and load output. The LabVIEW is programmed to show the waveform and the value of voltage, current, power and THD for the load. So, it is able to monitor the power generated by the PV module, the power absorbed or supply by the battery and the power consumption of the load. Also, the LabVIEW is programmed to control the switch inside the solar PV system by using the relays. Lastly, it is able to access the LabVIEW by using another computer through web-based interface. So, the solar PV system can be monitored or controlled remotely from long distance as long as there is Internet services. Therefore, it is not necessary to be physically at the solar PV system to monitor the power.

ABSTRAK

Tesis ini memberi tumpuan kepada pemantauan jarak jauh untuk penyongsang fasa tunggal solar PV pada waktu sebenar. Modul PV menukar cahaya matahari ke elektrik dengan menghasilkan kuasa elektrik DC. Pengawal caj solar mengawal selia voltan dan arus dari modul PV dan simpan kuasa elektrik dalam bateri. Penyongsang menukar elektrik DC ke AC untuk diguna peralatan rumah. Sistem PV menghasilkan kuasa elektrik DC ialah tidak stabil kerana turun naik dengan mengikuti cahaya matahari. Sistem solar PV perlu dipantau pada waktu sebenar untuk meningkatkan prestasi yang cekap. Tujuan projek ini ialah menyediakan sistem perolehan data untuk memantau kuasa sistem solar PV. Sistem perolehan data termasuk DAQ, sensor voltan dan arus. Untuk memantau sistem solar PV, LabVIEW telah digunakan untuk mendapat isyarat voltan dan arus pada waktu sebenar. Sensor voltan dan arus telah disediakan di input PV, bateri dan output beban. LabVIEW telah diprogramkan untuk menunjuk bentuk gelombang dan nilai voltan, arus, kuasa dan THD beban. Jadi, DAQ ini boleh memantau kuasa dari modul PV, kuasa diterima atau diberi oleh bateri dan kuasa bekalan beban. LabVIEW juga diprogramkan untuk mangawal sius dalam sistem solar PV dengan menggunakan geganti. Akhirnya, komputer lain boleh akses program LabVIEW yang sedang memantau sistem solar PV melalui berasaskan web. Sistem solar PV dapat dipantau dan dikawal jarak jauh selagi ada perkhidmatan internet. Oleh itu, tidak semestinya ada orang dekat sistem solar PV untuk pemantauan.

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LIST OF SYMBOLS

a	-	Ideality Factor
a_{ref}	-	Reference Ideality Factor
AM	-	Air Mass
D	-	Diode
e	-	Exponential
E	-	Energy
F_P	-	Power Factor
G	-	Solar Irradiance
I	-	Current
I_d	-	Diode Current
I_o	-	Reverse Saturation Current
I_{oref}	-	Reference Reverse Saturation Current
I_{max}	-	Maximum Current
I_{ph}	-	Photon Current
I_{phref}	-	Reference Photon Current
I_{sc}	-	Short Circuit Current
K	-	Boltzmann's Constant
n	-	Diode Ideality Factor
P	-	Power
P_{max}	-	Maximum Power
Q	-	Reactive Power
q	-	Electron Charge
R_s	-	Series Resistance
R_{sh}	-	Shunt Resistance
R_{shref}	-	Reference Shunt Resistance
R_{sref}	-	Reference Series Resistance
S	-	Apparent Power
T	-	Cell Temperature
T	-	Time
V	-	Voltage

V_d	-	Diode Voltage
V_{oc}	-	Open Circuit Voltage
V_{max}	-	Maximum Voltage
Ω	-	Ohm
θ	-	Phase Shift

LIST OF ABBREVIATIONS

AC	-	Alternative Current
AI	-	Analog Input
AO	-	Analog Output
CFL	-	Compact Fluorescent Light
D	-	Diode
DAQ	-	Data Acquisition System
DC	-	Direct Current
DIO	-	Digital Input / Output
DSP	-	Digital Signal Processor
FF	-	Fill Factor
FGPA	-	Field Programmable Gate Arrays
GND	-	Ground
GW	-	Gigawatt
I	-	Current
IoT	-	Internet of Things
IRENA	-	International Renewable Energy Agency
I/O	-	Input / Output
L	-	Load
LCD	-	Liquid Crystal Display
NI	-	National Instrument
P	-	Power
PV	-	Photovoltaic
STC	-	Standard Test Condition
THD	-	Total Harmonic Distortion
USB	-	Universal Serial Bus
V	-	Voltage
VAC	-	Volt in AC
VDC	-	Volt in DC
VI	-	Virtual Instrument
W	-	Watt

CHAPTER 1

INTRODUCTION

1.1 Background

The first observation of photovoltaic effect was in 1839 by Edmond Becquerel, a French physicist [1]. He found that the continuous current produced by immersing two different brass plates in a liquid when illuminated with sunlight [2]. In the 1870s, the PV effect was first discovered by Willoughby Smith, W. G. Adams, and R. E. Day in selenium [1], [2]. After few years, selenium photovoltaic cells built were able to exhibited 1% to 2% efficiency in converting light to electricity [1]. An American named C. E. Fritts found that when the selenium array is exposed to sunlight, it produces a current that is continuous, constant, and of considerable force [2].

A major step forward in solar-cell technology when the Czochralski method was developed for producing highly pure crystalline silicon [1]. In 1954, Bell Labs had resulted in a silicon single-crystal solar cell with 6% efficiency and then researchers brought the silicon solar cell efficiency up to 15% [2]. After 1973, the flat-plate silicon module was having a major improvements in cell and module fabrication. Production module efficiencies have improved to as high as 19% today [2].

Silicon-based cells are still dominating the solar cell electricity market today, but several there are newer cell types have added diversity in potential applications. These newer cell types include hydrogenated amorphous silicon and cadmium Telluride cells, as well as concentrator cells with efficiencies as high as 41% [2].

1.2 Current Analysis on Renewable Energy

The electrical power generation is categorized into renewable and non-renewable energy. Non-renewable energy is mostly using the fossil fuels as the source. When they are burnt to generate electricity, they release multiple harmful gases such as carbon dioxide and sulfur oxides and further causing global warming and acid rain [3]. Renewable energy has the unlimited sources such as water, wind, tidal, biomass, geothermal and solar energy. Renewable energy is normally pollution free. In Malaysia, 82.1% of the energy sources comes from fossil fuels [4]. To avoid environmental detriment, renewable energy resources should improve to increase the generation capacity.

Solar energy is one of the renewable energy that do not emit greenhouse gases after installation. Solar photovoltaic (PV) systems convert the sunlight to electrical energy. It is available at all place as long as it is access to the Sun. Solar energy systems can be installed in a house used. Installing a PV system create own electricity supply that can drop the electricity bills. If the energy generated by the PV system is more than the house used, the surplus will be exported back to the grid.

From 2016 to 2017, the global renewable generation capacity increased by 167 GW and reached 2,179 GW worldwide [5]. According to data released by the International Renewable Energy Agency (IRENA), renewable generation have been increased by an average 8.3% for 7 years. Solar photovoltaic grew by a whopping 32% in 2017, with the cost of electricity from solar PV decreasing by 73%. Solar power technology is now well within the cost range of power generated by fossil fuels [5].

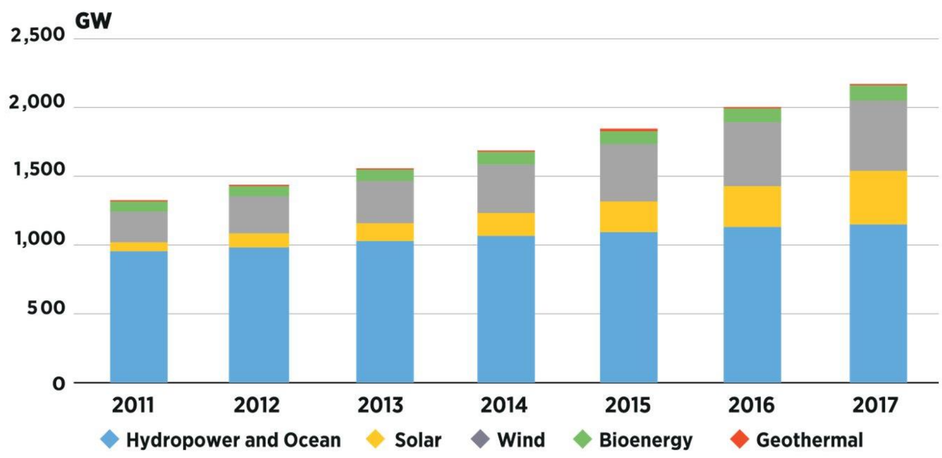

Figure 1.1: Total Renewable Power Generation Capacity [5]

1.3 Fundamental of Solar Energy

Solar energy is known as photovoltaic energy which converts sunlight into electricity [6]. If the sunlight intensity is high, there are more electricity produced by the PV system. During day time, PV system produces electrical energy depending on the sunlight. Even it is a cloudy day, it also produces a small amount of power. If the sunlight is strong enough, it is able to power up some of the load and charge the battery. At night, PV system does not produce any energy. So, solar energy is usually stored in a battery during day time and used in night time.

The photovoltaic effect occurred between two different materials when the common junction is illuminated by photon irradiation [7]. The photovoltaic cell is composed of n-type and p-type semiconductor material. When the electromagnetic radiation of the Sun shines on a photovoltaic cell, the photon is absorbed by the semiconductor material. This phenomena increases the energy of the valence band electrons in n-type material and makes it jump into the conduction band. Then, the electrons flow from n-type material to p-type material. The flow of electron produces a constant direct current which generating electrical power.

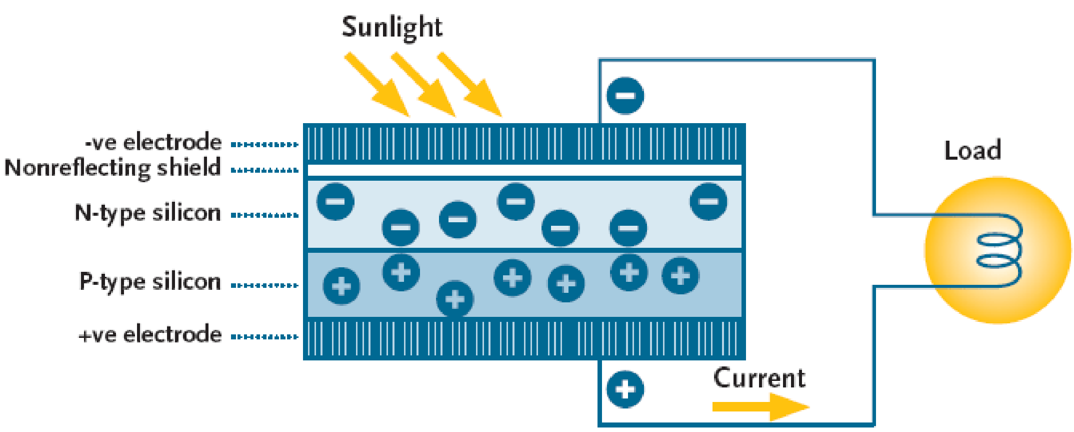

Figure 1.2: Photovoltaic Scale Scheme [8]

A PV module is similar as a current source. The current produced by the solar module is proportional to the solar irradiation intensity falling on it [9]. The equivalent circuit of the PV panel is a current source connected parallel with a diode, D and a resister, R_{sh} and connected in series with another resistor, R_s [10].

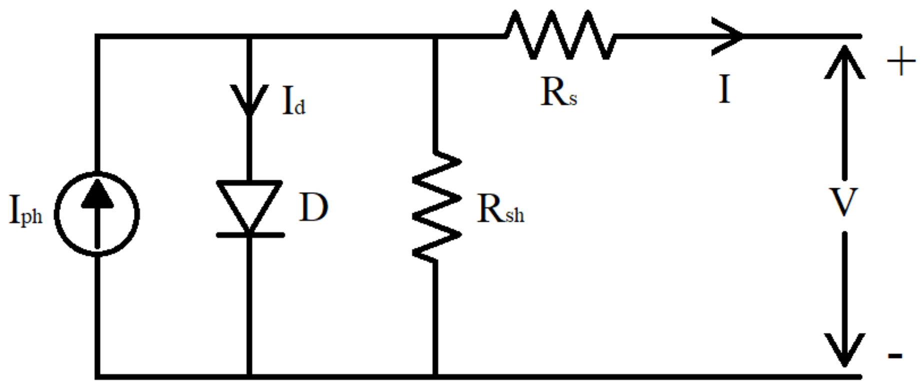

Figure 1.3: PV Module Equivalent Circuit

If the PV module is ideal, there is no power loss at R_s is 0 and R_{sh} is infinity. In real case, there are losses in the module due to the series resistor, R_s and shunt resistor, R_{sh} [9]. The equation of current generated by the PV module is given as

$$I = I_{ph} - I_o\left(e^{\frac{q(V+IR_s)}{nKT}} - 1\right) - \frac{V + IR_s}{R_{sh}} \qquad 1.1$$

The PV module mathematical and circuit model will be discussed in Chapter 2.

PV system includes the PV panels, charge controller, battery and inverter. PV panels absorb the sunlight and convert it into electricity by producing a direct current (DC) electrical power. The PV panels are connected to the charge controller to control the battery charging. The charge controller can keep the battery from overcharging by cutting the current flow to the battery when the battery is fully charged. If a battery is overcharged, it may get hot and being damaged. The controller also keeps the battery from discharging too much. The battery may lose some of the capacity to be recharged.

The charge controller is then connected to the DC loads. Another connection point from the charge controller is connected battery and parallel to the inverter. The battery will be charged when it receives the DC power. The battery will be discharged when the PV panels do not generate enough power to the load. The inverter converts the DC electricity into AC to power up the AC loads.

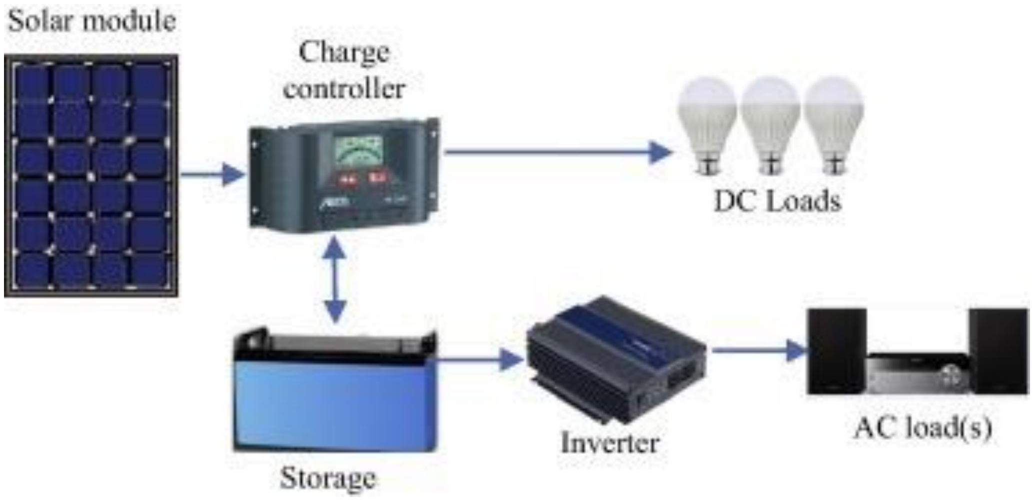

Figure 1.4: PV System [11]

1.4 Problem Statement

The PV system produces DC power which fluctuates with the intensity of sunlight. So, the solar energy may not stable as the system is dependent on the weather. In order to create an efficient performance solar power system, it is necessary to monitor the power produced by the solar PV in real time. Monitoring the solar system is not easy. This project is designing a software to monitor the solar PV system. By using LabVIEW software, the solar system can be monitored from the source to the load at the same time. So, this project can solve problem of monitoring solar system.

Sometimes, there are faults and distortion in the solar system. These faults and distortion may affect the power distributed to the load. If the fault or distortion is very high, it may damage the components or the load. This project monitors the solar system in real time so any problem occurs can be discovered. Besides, this LabVIEW software can display the total harmonic distortion (THD).

It is impossible to monitor the solar PV system on the spot for the whole day. Hence, this project also creates a web-based interface server so that the monitoring system can be done by using another computer remotely. The remote monitoring will be performed by using web-based interface and can be controlled remotely through an Internet service. This remote monitoring system enables the user to control the system anytime.

1.5 Project Objective

This project is to develop a PV system and get the data from solar energy. The voltage and current of the PV system can be collected by using the Data Acquisition System (DAQ) of LabVIEW. In addition, to attain this project, it is mandatory to describe the objective:

1. To set up the data acquisition system including current and voltage sensors at the solar PV
2. To design web-service algorithm using LabVIEW
3. To design ergonomic and user-friendly for energy managers

1.6 Scope of Project

This research involves the study the off-grid PV system. The on-grid PV system is not included. This project is focused on the voltage and current produced by the PV module and the load. In this project, the PV system includes a PV module, charge controller, 12V rechargeable battery, inverter, DC and AC output. The solar system is a lab scale prototype. The PV module used is only 50W and the inverter can only convert 300W of power. The main software used is LabVIEW. The data will be collected by using a LabVIEW DAQ program. The DAQ device will be connected to the laptop to show the data and graph.

1.7 Project Outlines

This thesis is divided into five chapters and each chapter focus on different aspect.

Chapter 1 introduces the history of the solar energy and the theory of PV system. Besides, the problem statement and the objective are described in this chapter as well.

Chapter 2 analyzes the other research related to the simulation of solar energy or PV system. This chapter also compares the research done by other people and try the improvement in self-project.

Chapter 3 explains the method to carry out the project. Both software and hardware used will be discussed in this chapter. For hardware, all the components and the connection of the PV system will be explained. For software, the program will be explained step by step.

Chapter 4 shows the outcome of the experimental result. The simulation of the PV system will be discussed in this chapter as well.

Chapter 5 concludes the whole research. This chapter may also give suggestion for future improvement.

1.8 Summary

In conclusion, solar energy is a renewable energy come from Sun. PV systems can convert the sunlight into the electricity. It is important to develop the solar energy technology instead of non-renewable energy.