I hereby declare that I have read through this report entitle “Frequency Response Analysis on Solar Cells and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)

Signature	:	....
Supervisor’s Name	:	Mohd Shahril Bin Ahmad Khiar
Date	:	18/6/2014

FREQUENCY RESPONSE ANALYSIS ON SOLAR CELL

AHMAD UZAIR BIN AHMAD SUHAIMI

A report submitted in partial fulfilment of the requirements for the degree of

Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2013

“I declare that this report entitle “Frequency Response Analysis on Solar Cell” 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 : Ahmad Uzair Bin Ahmad Suhaimi

Date : 18/6/2014

ACKNOWLEDGEMENT

Assalamualaikum warahmatullahi taala wabarakatuh,

First and foremost, I would like to thank to Allah the Almighty for giving me the opportunity to complete my Final Year Project. I would like to thank my supervisor, En Mohd. Shahril Bin Ahmad Khiar for his kindness to accept me as one of the students under his supervision. His guidance, encouragement, critics and knowledge have deserved him to receive my biggest appreciation after all this while putting up much effort to see me succeed in completing this project

I would also like to thank my classmates and other Power Engineering lecturers for their support and time in assisting me in completing the project keep and achieve the objectives. Those tips and point of views are valuable enough towards the completion of this project.

Not to forget, my beloved parents, Ahmad Suhaimi bin Zakaria and Sa’adiah Binti Samah for their endless support throughout my studies, for giving me meaningful advices and support me in term of financial support. Being a student handling a project is not easy as people thought. Without parental guidance, support and encouragement, I would not believe that I can have my project completed as it has presented here.

ABSTRACT

Today, from powering a satellite and telescopes in space, to lighting up a solar-powered traffic light on a street; an application of solar energy has rapidly increased and growing over the time. Solar energy is among the renewable energy that important as an alternative to an extinction of fossil fuel generated-electricity like a coal, oil and nuclear energy. It is very significant to comprehend solar cell characteristics in order to study the performance of solar cells. In the real world, manufacturer of solar cell does not include an equivalent circuit model generally or specifically. The circuit is important as it includes the dynamic impedances of solar cells, which are essential in determining the dynamic performance of solar cells. Therefore, with this experiment we can measure and extract the parameter of the circuit using a technique called Frequency Response Analysis (FRA). The main objective for this thesis is to study the function of the FRA device, the Frequency Response Analyzer Bode 100 on a solar cell. Moreover, this thesis will analyze an experimental test for Bode 100 to a solar cell. Then, to study the dynamic impedance of solar cell relationship between different types of solar cells and on different range of DC bias injected to solar cells. The experiment conducted, limit the types of PV modules that tested to two types only, which are 5.5 V 0.85 W poly-crystalline silicon solar cell and 5 V 0.5 W mono-crystalline silicon solar cell. The experiment also uses two amount of different DC bias injected to the solar cell; which are 6 V and 12 V. After design and development of experimental setup takes place, all the data will be capture using software called Bode Analyzer Suite. A frequency injection process runs over the solar cell will produce responses that visualize the pattern of the dynamic impedances. Hence, all the result of the measurement is presented clearly. The result is analyzed through signal processing techniques and comparison techniques. Finally, at the end of this project, dynamic impedances of solar cells have been developed.

ABSTRAK

Hari ini, dari menjanakan satelit dan teleskop di angkasa, hingga menyalakan lampu isyarat solar di jalan; aplikasi tenaga solar telah meningkat dengan pesat dan berkembang dari masa ke masa. Tenaga solar adalah antara tenaga boleh diperbaharui yang penting sebagai alternatif kepada kepupusan bahan api fosil yang menghasilkan elektrik seperti arang batu, minyak dan tenaga nuklear. Adalah sangat penting untuk memahami ciri-ciri sel solar untuk mengkaji prestasi sel solar. Dalam dunia sebenar, pengeluar sel solar tidak menyediakan model litar setara secara am atau secara khusus. Litar ini adalah penting kerana ia termasuk nilai galangan dinamik sel-sel solar, yang penting dalam menentukan prestasi dinamik sel-sel solar. Oleh itu, dengan eksperimen ini kita dapat mengukur dan mengeluarkan parameter litar dengan menggunakan teknik yang dipanggil Analisis Frekuensi Respons (FRA). Objektif utama projek ini adalah untuk mengkaji fungsi alat FRA itu, Frekuensi Response Analyzer Bode 100 pada sel solar. Selain itu , tesis ini akan menganalisis eksperimen untuk Bode 100 dengan sel solar. Kemudian, mengkaji hubungan galangan dinamik sel solar antara jenis sel solar dan pelbagai julat DC bias yang disuntik kepada sel-sel solar. Eksperimen yang dijalankan, menghadkan jenis modul PV yang diuji kepada dua jenis sahaja, iaitu 5.5 V 0.85 W sel solar poli- kristal silikon dan 5 V 0.5 W sel solar mono-kristal silikon. Eksperimen ini turut menggunakan dua jumlah DC berat bias yang berbeza disuntik ke sel solar; 6 V dan 12 V. Selepas reka bentuk dan peekembangan persediaan eksperimen berlaku, semua data akan di tangkap menggunakan perisian yang dipanggil Bode Analyzer Suite. Proses suntikan frekuensi ke dalam sel solar akan menghasilkan tindak balas yang menggambarkan corak galangan dinamik. Oleh itu, semua hasil daripada pengukuran itu dikemukakan dengan jelas. Hasilnya dianalisis melalui teknik pemprosesan signal dan teknik perbandingan. Akhirnya, pada akhir projek ini, galangan dinamik sel-sel solar telah dihasilkan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PV	-	Photovoltaic
FRA	-	Frequency Response Analyzer
ECI	-	Electrochemical Interface
DC	-	Direct current
AC	-	Alternating current
DUT	-	Device under test
M	-	Mega
k	-	Kilo
m	-	Milli
n	-	Nano
Hz	-	Hertz
V	-	Volt
W	-	Watt
R	-	Resistor
L	-	Inductor
C	-	Capacitor
S	-	Siemens
F	-	Farad
H	-	Henry
f	-	Frequency
mono-Si	-	Monocrystalline Silicon
p-Si	-	Poly Silicon

LIST OF SYMBOLS

Ω	-	Ohm
μ	-	Micro
ω	-	Angular frequency

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Today, from powering a satellite and telescopes in space, to lighting up a solar-powered traffic light on a street; an application of solar energy has rapidly increased and growing over the time. Solar energy is among the renewable energy that important as an alternative to an extinction of fossil fuel generated-electricity like a coal, oil and nuclear energy. Moreover, solar energy is a clean form of energy and this will not give any harm to the environment. Solar energy is generated by a solar panel that is made up of solar cells or known as photovoltaic (PV) cells. It produces electricity by converting the solar light energy to electric energy.

It is very significant to comprehend PV cell characteristics in order to study the performance of PV cells. For application, this includes the basics and expansion of modules, effectiveness assessment and different approaches of measurement. The study of characteristic measurement will resolve information that one may diagnose and developing of material attribute in cell manufacture, to determine PV cell grades for cell manufacture, to validate of appropriate models and to calculate of module operation.

In earlier research of solar cell impedances, it is driven by specialized kit, such as a Frequency Response Analyzer (FRA) using an impedance spectroscopy technique and, an Electrochemical Interface (ECI). In addition, the researches focus on solar cell impedances in term of its elemental properties, and deliberated solar cells under dark surroundings with conditions whether it is forward bias or reverse bias.

1.2 Motivation

Analyzing the solar cell to extract the impedances in it may not be easy to be completed. This project may contribute to an adequate learning of extracting fundamental characteristic and measurement from the solar cell to be analyzed. Frequency response analysis, injected certain range of frequency that reacted with the solar cell to give a response of the characteristic of the solar cell. In previous study of this analysis, there are several methods use to analyze the impedances of the solar cell. There are already recognized familiar methods to analyze the impedance on solar cell, such as Frequency Response Analyzer (FRA) using a technique of impedance and Electrochemical Interface (ECI). FRA using a Vector Network Analyzer – Bode 100 is the new and straightforward way for the condition monitoring technique performs over any devices such as transformer, coaxial cable and eddy-current testing.

1.3 Problem Statement

In the real world, manufacturer of solar cell does not include an equivalent circuit model generally or specifically. The circuit is important as it includes the dynamic impedances of solar cells, which are essential in determining the dynamic performance of solar cells. Therefore, with this experiment we can measure the parameter of the circuit using a technique called Frequency Response Analysis (FRA). FRA is commonly used to test the fault of transformer winding [1]. Today, not only restricted for transformer testing; FRA has widened the application to many other electrical devices. Henceforth, the solar cell will be the next Device Under Test (DUT). The study of this thesis can be implemented in designing efficient, reliable, and ensure the stability of the solar driven power system especially solar cell arrays.

1.4 Objectives

i. To study the function of the FRA device with Frequency Response Analyzer Bode 100 on a solar cell.
ii. To analyze an experimental test for FRA Network Analyzer Bode 100 to a solar cell.
iii. To study the dynamic impedance of solar cell relationship between different types of solar cells and on different range of DC bias injected to solar cells.

1.5 Scope of Study

The scope of this project is to carry out an impedance measurement on different types of solar cells as the DUT. This project uses Bode 100 – The Frequency Response Analyzer unit to extract the dynamic impedance of solar cells under test. Wide-range-and-various-level of frequency of 10 Hz to 100 kHz is injected into the PV module to impedance measurement data that will be analyzed through signal processing techniques – comparison and signature technique. The measurement that will be done is in "impedance vs. frequency" and this kind of measurement will be done throughout the procedure. The measured impedance will be in real and imaginary. These experiment will limit the PV modules that will be test by only two type which are 5.5 V 0.85 W poly-crystalline silicon solar cell and 5 V 0.5 W mono-crystalline silicon solar cell. Furthermore, two amount of different DC bias will be injected to the solar cell; which is 6 V and 12 V. Process of study the PV modules characteristic, identify the types of PV module and analyze the PV modules under test will be performed through this project step by step in order to obtain desired objectives.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains the related information in order to increase the significance of studying the project. Frequency Response Analysis (FRA) is studied based on its history of earlier use of the technique. Subsequently, this chapter explain about the principle of frequency response and principles of solar cell. Then, types of solar cell, crystalline silicon solar cells and thin-film solar cells is studied and explained clearly. Lastly, this chapter explain about the understanding of impedance in solar cell.

2.2 Frequency Response Analysis (FRA) and Earlier Researches

FRA is an essential test implement for the measurement of some dynamic systems. Dynamic system is caused by the impedance of the material being tested that is DUT. Impedance generally consists of a resistor (R), inductor (L), and a capacitor (C). The test is established by injecting input of oscillated frequency to a steady process and gives an output of oscillated frequency but mismatched in term of amplitude and phase. Typically use in a power transformer, FRA is specifically used to determine the impedance of the winding over a broad spectrum of frequencies as seen in [1]. The outcome is then set side by side of the reference data set and the variance shall be making used to figure out the category and fault region. Vital broad spectrum of frequencies is injected by either two steps, through inserting a pulse into the transformer winding or by applying a sinusoidal wave to do a frequency sweep. The previous technique is called impulse response method and recently known as the swept frequency method. A graph of the amplitude against frequency is plotted from the result and it is used for comparison for the two sets of measurement. Vital changes like a modulation to the pattern of the curve, the development of new resonant frequencies or the withdrawal of current resonant frequencies and huge deviation of current resonant frequencies. FRA is a convinced and competent medium of finding a deficiency in transformer. The major importance of the method belongs in its capability to find faults but nowadays researchers have found various usage of FRA in other DUT. Among of it are solar cell impedance measurement, small signal transformer analysis, battery impedance measurement, equivalent circuit analysis of quartz crystals and low value impedance measurements. Instead of finding fault in DUT, frequency response analysis is used to find the impedance in solar cell for other means. Impedance in a solar cell is a critical specification to observe as it is symbolic to the aging and consequences of sustaining life period of the solar cell. As stated in [2], variations in this parameter deriving out of guideline shall be applied to evaluate the aging period or fault in the solar cell. Moreover, the study can use to create an adequate, decent, eminent power and small-scale switching power conditioner.

2.3 Principle of Frequency Response

Frequency response is widely recognized to define a specific system in the concept of its dynamic. Meanwhile, frequency response analysis is the method whereby a sine wave is injected to a DUT to measure notches on the frequency response of a transfer function or impedance function [3]. The output – in contrast with the input – as a function of frequency commonly in magnitude and phase measurement. As a matter of fact, frequency response is a fluctuation of the gain and phase with distinct frequency. The fundamental arrangement is presented in Figure 2.1 in which a sine wave *u(t)* is implemented to a system with transfer function *G(s)*.

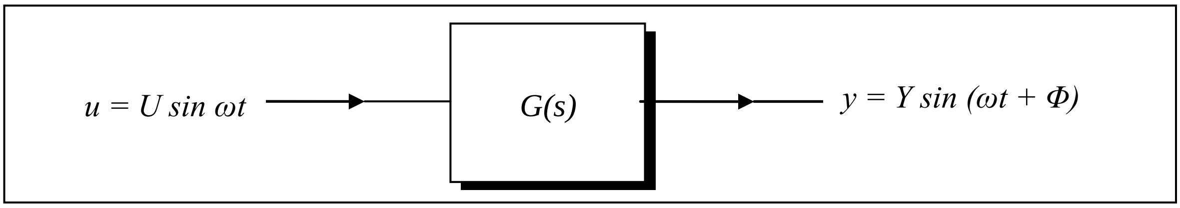

Figure 2.1: Linear Transfer Function with Sine Wave Input [3]

After transients due to earliest circumstances have disintegrated away, the output *y(t)* turn into a sine wave but with a different magnitude *Y* and relative phase Φ. The output *y(t)* are factually related to the transfer function *G(s)* by magnitude and phase, at the frequency (ω rad/s) of the input sinusoid.

$$\frac{Y}{U} = |G(j\omega)| = gain\ at\ \omega \quad (2.1)$$

And

$$\Phi = \angle G(j\omega) = \text{phase at } \omega \quad (2.2)$$

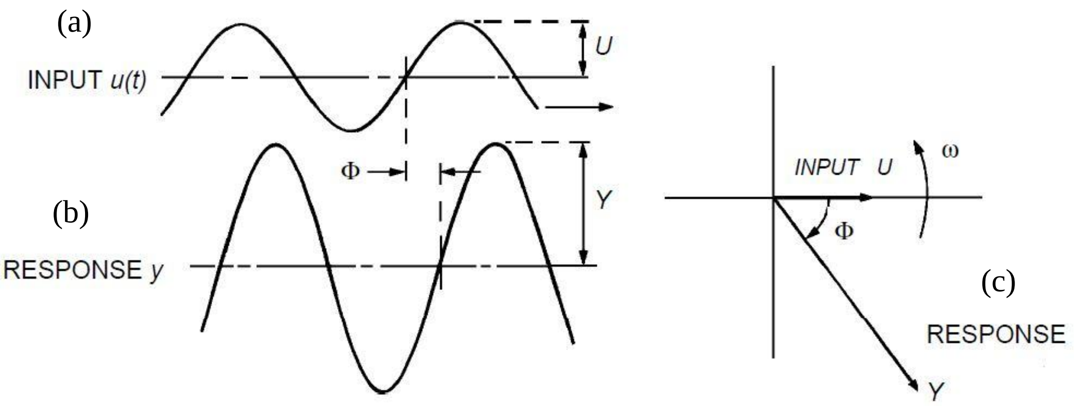

Figure 2.2: (a) Sinewave Input. (B) Steady State Sinewave Response. (C) Corresponding Vector Notation [3]

By nature of the electrical device, in theory they have some resistance, inductance and some capacitance values. Accordingly, the complex RLC circuit is formed without exception in every of them. The label 'theoretical' imply several devices should have very little or no resistance correlated to their inductance and capacitance values over, several devices should have very little or no inductance correlated to their resistance and capacitance and over several devices should have very little or no capacitance correlated to their resistance and inductance but theoretically all of them can be analyzed as an RLC circuit notwithstanding may be R = 0, or L = 0 or C = 0. However, in nearly all cases the resistance, inductance and capacitance of equipment have values (non-zero).

Consequently, the majority of the electrical equipments can be viewed as an RLC circuit thus they give feedback to the frequencies injected and produce a unique indication.

2.4 Principles of Solar Cell

Solar or photovoltaic (PV) cells are comprised of materials that convert sunlight into electricity. PV technologies along with Concentrating Solar Thermal Plant (CSP) are sustainable energy technologies and are clean energy alternatives, as we are aware, most of the energy consumed today is non-renewable. Moreover, the energy is unclean such as the burning of the fossil fuels. PV cells consist of coatings of semiconductors for example, silicon. Energy is generated when photons of light from the sun collides a solar cell and are captivated inside the semiconductor material. This energizes the semiconductor's electrons, result in the electrons to discharge, and produce an electric current [4]. The electricity created is direct current (DC) since the flows of charge is in one direction. One PV cell generates only one or two watts which is not a practical power for most usages. In order to boost power, PV cells are arranged together into what is called a module and packaged into a form which is more usually known as a solar panel. Solar panels that grouped are later called solar arrays [5].

2.4.1 Structure of a Solar Cell

A typical solar cell is a multi-coated unit composed of:

i. Cover glass. A transparent glass or plastic layer that supports exterior safety from the elements.
ii. Anti-reflective Coating. This element is invented to avoid the light that reaches the cell from rebound so that the peak energy is absorbed into the cell.
iii. Front Contact. Conducts the electric current.
iv. N-Type Semiconductor Layer. A thin layer of silicon, mixed with phosphorous using a method called doping to produce a better conductor.
v. P-Type Semiconductor Layer. A thin layer of silicon mixed or doped with boron to produce a better conductor.
vi. Back Contact. Conducts the electric current.

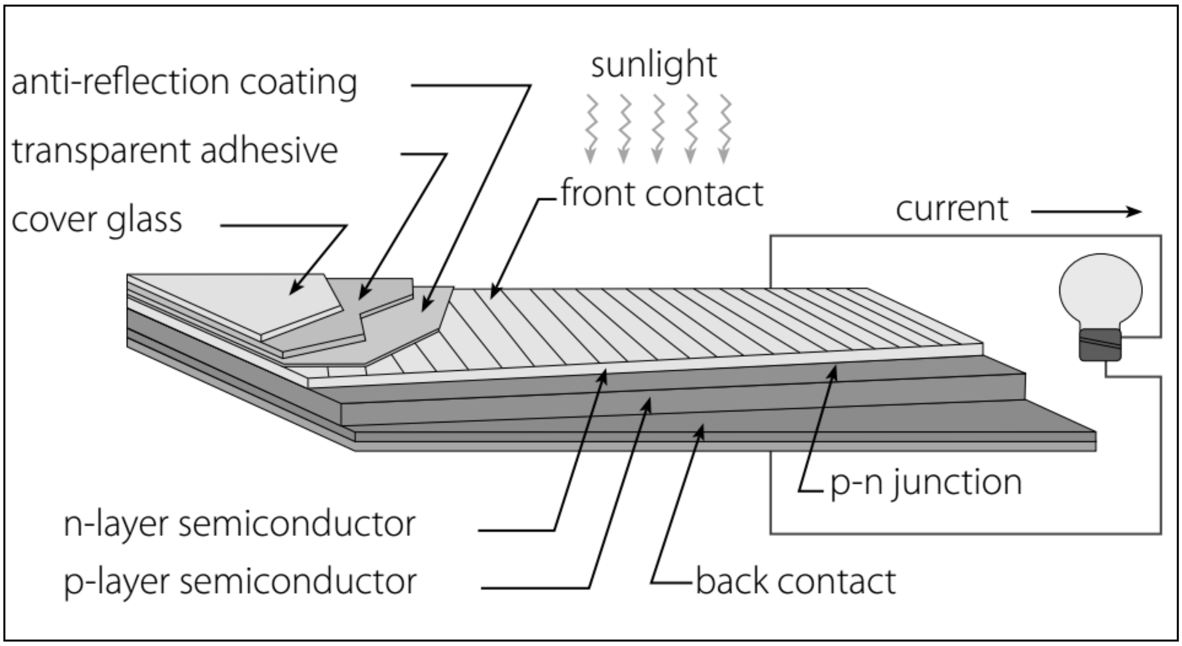

Figure 2.3: Typical Solar Cell Structure [5]

After the layers have been assembled, there is a negative charge in the p-layer and a positive charge in the n-layer region of the junction [4]. This causes lack of balance in the charge of the two layers at the p-n junction. Thus, creates an electric field in the middle of the p-layer and the n-layer. If the PV cell is located in the sun, radiating energy of the sun hits the electrons in the p-n junction and triggers them, hitting them loose of their atoms. These electrons are attracted to the positive charge in the n-layer and are repelled by the negative charge in the p-layer. A wire can be connected from the p-layer to the n-layer to form a circuit. The free electrons are accelerated into the n-layer of the radiant energy, resulting to beat off each other. The wire conducts a path for the electrons to flow away from each other. Current is caused by the movement of electrons and voltage is caused by the electric field of the cell. Hence, power is produced, by the product of current and voltage [4].

2.5 Crystalline Silicon (c-Si)

Nearly 90% of the PV modules manufacturers around the world now are established on some variation of silicon [4]. As mentioned in [4], about 95% of all consignments of U.S. producers in the residential zone were c-Si panels in 2011. The fundamental characteristic is the purity of the silicon [5]. Silicon purity is when the silicon molecules are coordinated to perfection. The perfect the arrangement, the prominent the cell intend to be at converting solar energy (from the sunlight) into electricity (the photoelectric effect). The efficiency of PV cells is associated with purity. Besides efficiency, cost and space-efficiency are reason in choosing the PV cells. Crystalline silicon forms the basis of mono- and polycrystalline silicon solar cells:

2.5.1 Monocrystalline Silicon Solar Cells

Monocrystalline silicon (mono-Si), also known as single-crystalline silicon (single-crystal-Si), are commonly known by an even surface coloring and systematic appearance, shows that it is high-purity silicon as shown in Figure 2.4 [5]. Mono-Si solar cells are made out of silicon mold that is cylindrical in configuration. Four edges of the cylinder-shaped molds are removed out to form silicon substrate, to maximize performance and reduced costs of an individual mono-Si cell, resulting in mono-Si panels their characteristic presence. A good way to separate mono- and polycrystalline solar panels is that polycrystalline solar cells look perfectly rectangular with no rounded edges. The advantages of mono-Si panel are it has the highest efficiency percentages, space-efficient, long life and tend to perform better than similarly rated polycrystalline PV panels at low-light conditions. Mono-Si panel are invented among the topmost quality silicon, hence they have the highest efficiency percentages. It is space-efficient since these PV panels produce the highest power outputs; they also need the smallest amount of space distinguished to any other types. Furthermore, it generates up to four times the amount of electricity as thin-film PV panels. Mono-Si panels also have the longest lifespan. Nearly all PV panel manufacturers put a 25-year warranty on their mono-Si panels. The disadvantages of mono-Si panels are it is the most costly. In addition, if the panel is fractionally closed with shadow, dirt or snow, the whole circuit can malfunction. Besides, the Czochralski process is used to manufacture monocrystalline silicon which results in large cylindrical mold.