“ I hereby declare that I have read through this report entitle “Design And Modelling A Single-Phase Grid-Connected Photovoltaic At Low Voltage Network And Its Performance Using PSCAD Software” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power) with Honours”

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DESIGN AND MODELLING A SINGLE-PHASE GRID-CONNECTED PHOTOVOLTAIC AT LOW VOLTAGE NETWORK AND ITS PERFORMANCE USING PSCAD SOFTWARE

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power) with Honours

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I declare that this report entitle “Design And Modelling A Single-Phase Grid-Connected Photovoltaic at Low Voltage Network and Its Performance Using PSCAD Software” 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.

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DEDICATION

This work is dedicated to my supervisor, Dr. Mohd Hendra Bin Hairi. Without those support, it would have been possible to do this project successfully. Not forgetting to my parents for their supporting as it also helps me no matter in what sense.

Next, I want to extend my appreciation to my supervisor Dr. Mohd Hendra Bin Hairi because he had given me guidance to finish this project as there are some problems in implementing this project.

Furthermore, thanks to all who are willing to give their hands to help me. Not forgetting to my beloved friends who give a hand for this project, without anyone, I cannot complete this project successfully. Finally, thanks to everyone.

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ABSTRACT

The interest for distributed generation (DG) and its integration into the utility grid has gradually increased since the demand of electricity increases from time to time. Due to the economic and environmental issue, the interest to use renewable energy sources (RES) for DG system become more popular. Solar (PV) generation was chosen for this project since Malaysia receive direct sunlight approximately 10 hours during a day. However, there are some issues occur when DG system was connected with the grid such as synchronization issue, overvoltage and undervoltage issue, and stability issue. The aim for this project is to examine the impacts on grid and load side based on power injected from single-phase grid-connected photovoltaic system. In order to complete the modelled circuit, block diagram is used to show the flow of this project. The circuit was modelled using PSCAD software and the performance of the single-phase grid-connected PV system will be analysed based on a few case studies which are import and export power at point of common coupling (PCC), effect of excessive power to support load without grid connection, effect of power injected from PV model against voltage impact with grid connection, fault analysis at load, and analyse fault current contribution from PV model and from grid using Microgrid model. From all case studies, it can be conclude that the PV model able to export active and reactive power to grid and load when load demand is less than the power generated by PV model while grid will support the insufficient power needed by load if load demand greater than power generated by PV model. Besides that, power received by load will affect the voltage across the load. PV model should able to generate sufficient output power to prevent undervoltage and overvoltage problem which can cause damage to equipment. Voltage profile can be improved by connecting the PV model at the furthest load in Microgrid model as furthest load have the highest voltage drop. Lastly, different types of fault could give different amount of fault current in the system. Fault current contribution is higher when the location of fault near the power source. As conclusion, the single-phase grid-connected photovoltaic that have been modelled able to be used to produce results for the case studies.

ABSTRAK

Penggunaan sistem penjanaan kuasa teragih (KT) yang disambung ke grid pengagihan semakin meningkat dengan berlakunya peningkatan kehendak elektrik dari semasa ke semasa. Projek ini memilih kaedah penjanaan tenaga menggunakan tenaga solar fotovolta kerana Malaysia menerima cahaya Matahari sekurang-kurangnya 10 jam dalam sehari. Walaubagaimanapun, terdapat beberapa isu yang timbul semasa penyambungan sumber penjanaan kuasa dengan grid. Antara isu-isu yang boleh berlaku adalah seperti ketidakserasian antara sistem fotovolta dan grid, masalah lebihan dan kekurangan voltan pada beban, dan juga masalah kestabilan sistem apabila berlakunya gangguan. Tujuan utama projek ini adalah untuk mengenalpasti kesan penghantaran kuasa yang dihasilkan daripada model sistem penjanaan kuasa satu fasa menggunakan tenaga solar fotovolta terhadap beban dan sistem grid. Gambarajah blok dibuat bagi mengenalpasti dan memahami perjalanan sistem tersebut dengan lebih mudah. Perisian PSCAD digunakan untuk membuat model sistem ini dan keupayaan sistem akan dianalisis berdasarkan kesan terhadap import dan eksport kuasa pada titik sambungan (TS) grid, sistem fotovolta dan beban, kesan kuasa berlebihan pada beban tanpa bergantung pada grid dan kesan menghantar kuasa daripada model yang telah direkabentuk terhadap voltan di beban dengan penyambungan grid, menganalisis kesalahan arus elektrik pada beban, dan menganalisis sumbangan arus kesan dari gangguan pada model fotovolta dan sistem grid menggunakan model Microgrid. Berdasarkan kajian kes yang dijalankan, model fotovolta mampu mengeksport kuasa yang dihasilkan kepada grid dan juga beban. Selain itu, model fotovolta haruslah menghasilkan jumlah kuasa yang sama dengan beban untuk mengelak masalah lebihan atau kekurangan voltan pada beban. Profil voltan dalam model Microgrid boleh diperbaiki dengan menyambungkan model fotovolta pada beban paling jauh kerana ia mempunyai jumlah kejatuhan voltan yang paling tinggi. Akhir sekali, sumbangan arus gangguan akan menjadi lebih tinggi apabila gangguan yang berlaku berdekatan dengan

sumber kuasa. Kesimpulannya, sistem fotovolta satu fasa yang dimodel mampu menghasilkan keputusan bagi kesemua kajian kes yang dijalankan.

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CHAPTER 1

INTRODUCTION

1.1 Background

An electrical power system is a network of electrical components that generate electrical power from any source such as coal, water, gas, nuclear energy and oil. The generated power was then transmitted and distributed to users. Basically, there are three main parts in electrical power system which includes generation, transmission, and distribution. Low-voltage distribution network is at the end of the electricity network, directly connected to the users [1].

Nowadays, the interest for distribution generation and its integration into the utility grid has gradually increased along with time and never stopped growing. This is due to energy crisis, economic, and environmental issues. Engineer decided to use renewable energy sources to generate power especially at the distribution power systems [2].

In general, distributed generation (DG) refers to small-scale (typically 1 kW to 50 MW) electric power generators that produce electricity at a site close to users or that are tied to an electric distribution system. It is active power generating unit that is connected at distribution level. DG system can reduce losses in distribution network. Besides that, it also can increase the power reliability as backup or standby power to the customers, easy for maintenance because of its simple construction and able to improve the efficiency of providing electrical power to customers [3].

There are several technologies that are used as distributed generation such as wind turbines, fuel cells, photovoltaic (PV) system, micro turbines, and combustion gas turbines. Most of developed countries try to set targets to increase penetration of renewable energy (RE) in energy production intended for environmental reasons and diversification of energy sources [4].

Solar energy is one of renewable energy that is popular in generating electrical power. There are two different ways in using solar energy to generate electrical power which are using photovoltaic (PV) plants and Concentrating Solar Thermal Plant (CSP). According to a fact, Malaysia receives direct sunlight approximately 10 hours during a day. This shows that Malaysia is suitable for solar energy generation system which can give a great impact as backup power generation to users [5]. Photovoltaic (PV) system can give a lot of benefits as it can reduce greenhouse effect, can be installed anywhere, require low maintenance, clean energy sources and long lasting RE technology. However, the cost of installation for PV panel is expensive.

Grid-connected PV systems are designed to operate in parallel with an interconnection to the grid network. The main component in grid-connected PV systems is inverter. Inverter is used to convert the direct current (DC) produced by the PV panel into alternating current (AC) consistent with the voltage and power quality requirements of the grid. When the electrical load are greater than the PV system output, the balanced power required by the loads was received from grid. However, the PV generation need to have synchronization to inject the power to the grid. In order to synchronize the PV system with grid, the voltage, frequency, phase sequence, and phase angle generated from PV system should match with grid [6].

1.2 Problem Statement

Nowadays, the use of renewable energy technology has become more popular. This is due to the energy crisis, economic issues, environmental issues, and the increased of load demand. As PV generation system was connected with grid, various issues might appear which includes synchronization issue, overvoltage and undervoltage issue, and stability issue. In term of synchronization issue, it can be occur when magnitude of voltage, phase angle and frequency from PV model are not same with grid network. This could damage the equipment at the load side. Overvoltage issue can occur when the generated power from PV model is higher than load demand which cause voltage at load higher than 5% tolerance limit of its nominal value while undervoltage occur when power supply from grid is not sufficient to support the load especially the one that connected the furthest from grid source. Due to this, voltage collapse and blackout could happen in the residential area. Occurrence of fault in as system could affect the stability of the system. There are several types of fault that can occur in a system which are single line-to-ground (SLG) fault, double line-to-ground (DLG) fault, and three-phase to ground fault. Due to fault, equipment could be damage if there is no protection in the system. In order to know the possible consequences from these problem towards single-phase grid-connected photovoltaic system, the objectives for this project was developed to make sure the users get the efficient voltage profile to perform their daily routine activity.

1.3 Objectives

i. To design and model single-phase grid-connected photovoltaic system and Microgrid model using PSCAD software.
ii. To examine the impacts on grid and load side based on power injected from model single-phase grid-connected photovoltaic system using PSCAD software.
iii. To analyse the performance of single-phase grid-connected photovoltaic system based on case studies which includes:
    - Import and export of active and reactive power at point of common coupling (PCC).
    - Effect of excessive power injection from PV model without connected to grid.
    - Voltage impact across Microgrid model and voltage drop at the load side.
    - Stability – system will be analyse using single line-to-ground (SLG) fault, double line-to-ground (DLG) fault, and three-phase to ground fault.

1.4 Scope of Project

This project focus on:

- Designing and modelling single-phase grid-connected photovoltaic at low voltage network to reduce losses near at the load side using PSCAD software.
- The effect of injected power at point common of coupling (PCC).
- Fault is used to analyse the fault occurs at load side, and fault contribution from PV model and from grid.

CHAPTER 2

LITERATURE REVIEW

2.1 Single-Phase Grid Connected Photovoltaic System

Nowadays, renewable energy is popular in generating electricity power due to the increase of energy demand. Photovoltaic (PV) solar energy is one of renewable energy resource that have been popular around the world including Malaysia. According to the environment fact, Malaysia receive direct sunlight for almost 10 hours per day with $800\ W/m^2$. It can received up to maximum value which is $1000\ W/m^2$ solar irradiation for 6 hours during peak time [5].

Single-phase grid-connected PV system is one of distributed generation (DG). This means that the connection of the system is near to the load which is consider as residential consumer. Photovoltaic (PV) system has been frequently used in generating electricity because it is safe, environmentally friendly, easy to install and available almost anywhere. PV generation system can be divided into two types which are stand-alone and grid-connected. For stand-alone system, it is used to provide power directly to loads that are not connected to grid such as supplying the load demand in a house. This type of system require battery as storage. Grid-connected PV system does not have battery as storage and it is used to provide energy for local loads and for the exchange power with utility grid [7].

Benefits of single-phase grid-connected photovoltaic network is it can improves the voltage profile, reduce the losses in distribution network and also helps the grid to support loads [9]. In order to have synchronization with load, the frequency, output voltage, and phase angle of inverter must be same with grid. The output of inverter can be controlled using Pulse Width Modulation (PWM) by comparing the modulating signal and carrier signal. There are a few important components in designing a single-phase grid-connected PV system as shown in Figure 2-1.The solar panel will absorbs solar energy and convert it into DC source. The DC source is then converted into AC form by using single-phase inverter. The output of inverter is then filtered and flow to step up transformer to setup the filtered output voltage to $240V_{rms}$ which is suitable for utility grid and loads.

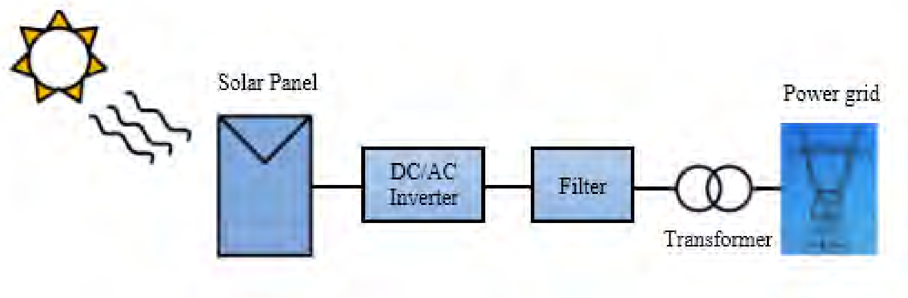

Figure 2-1: The basic of single-phase grid-connected PV system.

Single-phase grid-connected PV system is the decentralized or on-site electric energy system which is installed at distribution network. Since the PV system is connected with grid network, there are various issues that may occur such as stability, synchronization, harmonic, and overvoltage or undervoltage [10].

2.2 The Components of Single-Phase PV System

2.2.1 Solar Panel

The important component to generate electricity from solar energy is solar panel. Solar panel is used to convert the sunlight to the direct current (DC). In other word, this process is also known as "photovoltaic" which getting from the Greek word [11]. Solar panel has many photovoltaic cells which are function as collecting agent. The cells will absorb the sunlight and carry the converting process of electricity. Solar cells are made from semiconductor material such as silicon. It consists of n-type region and p-type region. When sunlight (made of photons) hits this material, knocking loose the free electron on the n-type region, and it will move to fill the holes at p-type region. This will cause the electron flow from n-type to p-type region to create electricity. Figure 2-2 shows the structure of solar cell [12].

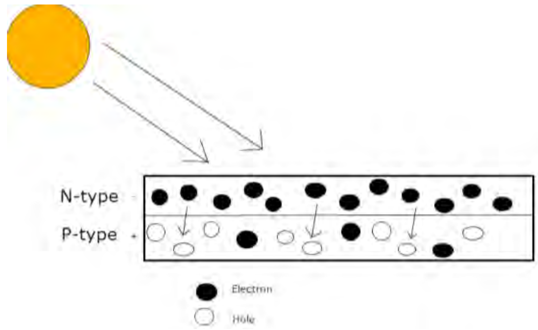

Figure 2-2: Structure of solar cell.

Another important aspect in solar panel performance is the effect of temperature. When the solar panel receive higher temperature, it will produce higher current. The output voltage of the module is inversely proportional to the temperature. Figure 2-3 shows the effect of temperature on the I-V characteristics in term of solar irradiance condition [13].

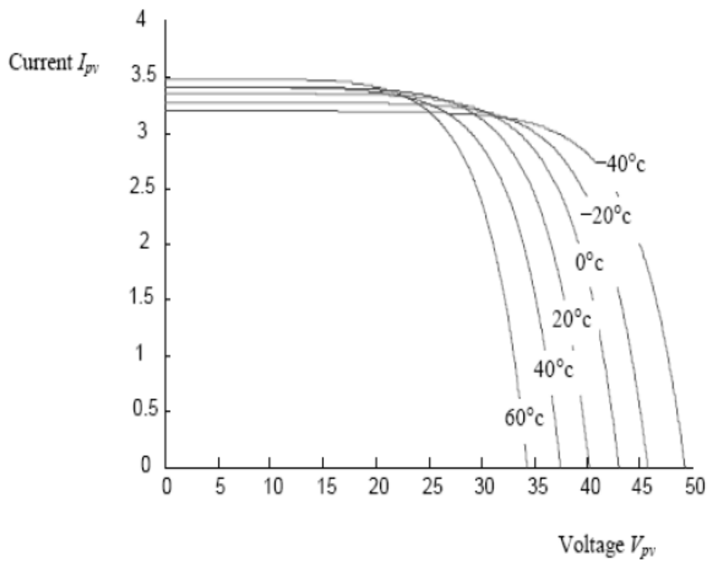

Figure 2-3: The effect of temperature on the I-V characteristics.

2.2.2 DC to AC Inverter

Inverter is use in several applications such as for adjustable speed drives, uninterruptible power supplies (UPS) and use at grid connected systems. The main function of the inverter is to produce an AC output waveform from a DC power supply. The magnitude, frequency, and phase should be controllable for sinusoidal AC outputs. There are two types of inverter which are voltage-source inverters (VSI) and current-source inverters (CSI). VSI is independently controlled AC output voltage waveform, while CSI is independently controlled AC output current waveform [14]. Figure 2-4 shows the single-phase full-bridge inverter circuit using IGBT.

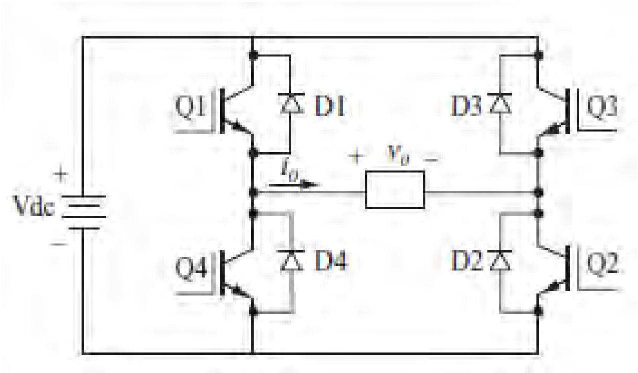

Figure 2-4: Single-phase full-bridge inverter.

The inverter can produce two types of waveform which are modified sine wave and purely sine wave. Modified sine wave is almost similar with square wave. This waveform is easy to produce because it depends on the switching scheme. This type of inverter is cheaper than pure sine wave inverter but unfortunately, it does not work properly for some devices. For pure sine wave inverters, it produces a sine wave output identical to the power from an electrical outlet. This type of inverter is expensive than modified sine wave inverter. Figure 2-5 below shows how the modified sine wave tries to emulate with sine wave itself [15].

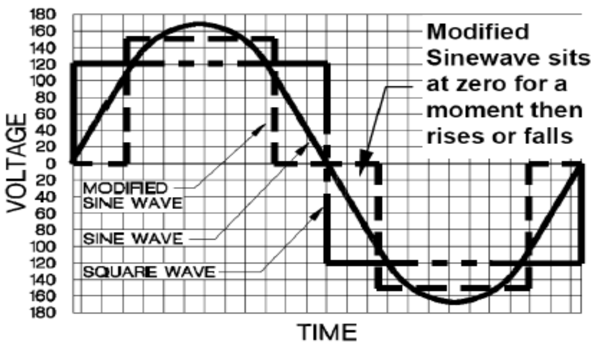

Figure 2-5: Square, modified, and pure sine wave.

Since this project need the conversion of DC source to AC source at the generating site before synchronize with grid, the power switches used for inverter must be choose properly. The Insulated Gate Bipolar Transistor (IGBT) was chosen because it has more advantages compared to Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET) and Bipolar Junction Transistor (BJT). Basically, IGBT is the simplified of two-transistor circuit model which are MOSFET and BJT. IGBT has high input impedance of MOSFET along with high current gain and small on-state conduction voltage of BJT [16]. Figure 2-6 shows the symbol of IGBT.

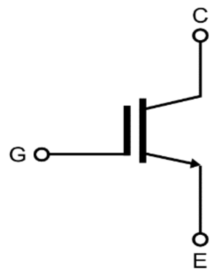

Figure 2-6: Symbol of IGBT.

IGBT was chosen as switching mechanism because it can operate at high switching frequency, high switching voltage, and high switching current. Normally, it can operates up to 30 kHz of switching frequency, 3.5 kV and 2 kA for maximum voltage and current rating as shown in Table 2-1. IGBT can control the power flow in the switch using gate voltage. IGBT is widely used in distribution system for 3kW and higher [16]. Table 2-1 shows the comparison characteristics between IGBT, BJT, and MOSFET.

Table 2-1: Comparison characteristics of BJT, MOSFET, and IGBT.

Switch Type	BJT	MOSFET	IGBT
Base/Gate Control Variable	Current	Voltage	Voltage
Switching Frequency	Medium (10 kHz)	Very High (up to 1 MHz)	High (up to 30 kHz)
On-State Voltage Drop	Low	High	Medium
Max. Voltage Rating	1.5 kV	1 kV	3.5 kV
Max. Current Rating	1 kA	150 A	2 kA

2.2.3 Pulse Width Modulation (PWM)

Pulse-width modulation (PWM) is one of alternative technique to reduce the total harmonic distortion (THD) of load current. The amplitude of the output voltage can be