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DESIGN AND MODELLING A THREE-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

Faculty of Electrical Engineering
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2017

I declare that this report entitle Design and Modelling a Three-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 diploma and is not concurrently submitted in candidature of any other degree.

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To my beloved father, mother, family, lecturer and friends for their loving, understanding, care and support in many aspects.

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ABSTRACT

Solar photovoltaic generation system is one of distributed generation (DG) that can generated electricity power to support load demand. Solar energy is the cleanest, sustainable and environmentally friendly renewable energy. Environment in Malaysia is more suitable for solar generation compared to wind generation since Malaysia receive sunlight for almost 10 hours a day besides wind speed in Malaysia is not enough to generate electricity. Since the output of the PV generation need to connect with grid network, there could a few issues occur. The issues that may occur including synchronization issue, overvoltage and undervoltage issue, and stability issue. The aim for this project is to analyze the impact of power generated by three-phase grid-connected photovoltaic system towards grid and load. Power System Computer Aided Design (PSCAD) software was used to model the three-phase grid-connected PV system. The flow of the three-phase grid-connected PV system was illustrated in block diagram to summarize the actual circuit. The performance of three-phase grid-connected photovoltaic system was analyzed based on several case studies which includes the import and export of active and reactive power at point of common coupling (PCC), impact of excessive power to support load demand without grid connection, effect of generated power from PV model toward voltage impact at distribution network including Microgrid and analysis of abnormal condition at PV model. From the case studies, it can be concluded that voltage across load was affected by the amount of power generated from PV model and capacity of the load. PV model also have a capability to export its generated power to grid and load. Besides that, generated power from PV model must equal with load demand to prevent undervoltage and overvoltage problem which can cause damage to equipment. In Microgrid model, it can be conclude that by connecting the PV model to the furthest load from utility grid can improves its voltage profile. Lastly, different types of fault give different amount of fault current. Three-phase fault will provide the highest fault current in the system and amount of generated power from PV model also can affect the amount of fault current in a system. As conclusion, three-phase grid-connected photovoltaic system that have been modelled able to be used in completing the case studies.

ABSTRAK

Sistem solar fotovolta (PV) merupakan salah satu sistem penjanaan kuasa teragih (KT) yang berupaya menjana kuasa elektrik bagi memenuhi permintaan pengguna. Tenaga solar merupakan satu tenaga yang boleh diperbaharui yang bersih, mampan dan mesra alam. Keadaan negara Malaysia lebih sesuai menggunakan tenaga solar untuk menjana tenaga elektrik berbanding tenaga angin kerana Malaysia menerima cahaya Matahari sekurang-kurang 10 jam dalam sehari. Hasil keluaran sistem penjanaan solar perlu disambungkan ke grid pembahagian dan ini mungkin akan menimbulkan beberapa masalah. Antara masalah yang mungkin timbul adalah masalah 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 dilakukan adalah untuk menganalisis kesan penjanaan kuasa dari sistem solar fotovolta tiga fasa terhadap grid dan juga beban. Perisian PSCAD digunakan untuk membuat model sistem solar fotovolta tiga fasa. Beberapa kajian kes dijalankan untuk menganalisis keupayaan sistem iaitu import dan eksport kuasa di titik sambungan (TS) grid, sistem fotovolta, dan beban, kesan kuasa berlebihan untuk menampung beban tanpa penyambungan grid, kesan jumlah kuasa yang dijana oleh sistem fotovolta terhadap voltan dibeban termasuk dengan menggunakan model Microgrid dan yang terakhir adalah analisis terhadap gangguan yang berlaku pada sistem fotovolta. Berdasarkan kajian kes yang dijalankan, model fotovolta mampu mengeksport kuasa yang dihasilkan kepada grid dan juga beban. Selain itu, jumlah kuasa dari model fotovolta haruslah sama dengan jumlah beban bagi mengelak berlakunya masalah lebihan atau kekurangan voltan. Profil voltan dalam model Microgrid boleh diperbaiki dengan menyambungkan model fotovolta dengan beban yang paling jauh dari grid. Beban yang paling jauh mempunyai kejatuhan voltan yang paling tinggi. Akhir sekali, jenis gangguan yang berbeza menghasilkan jumlah arus gangguang yang berbeza. Gangguan tiga fasa menghasilkan arus yang paling tinggi dan jumlah kuasa dari model fotovolta juga mempengaruhi jumlah arus gangguan. Kesimpulannya, sistem solar fotovolta tiga fasa yang dimodel mampu berfungsi dengan baik untuk melengkapi kajian yang dijalankan.

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CHAPTER 1

INTRODUCTION

1.1 Background

Electrical power network is a system that consist of several electrical component that are able to produce electrical power. There are three major sections in electrical power network which are generation, transmission, distribution and end users. Generation side will generates voltage from generating plant and the voltage is then step up and transmitted to distribution network. At distribution side, the voltage will be stepped down before distribute to end users. End users include large customer (factory), medium customer (business) and small customer (residential) [1].

Distributed Generation (DG) system also known as embedded system and it is a small scale electricity power generation technologies that produce electricity at site close to load or customers. Distributed generation can be a single structure or part of a Microgrid. DG can be classified as Microgrid when a smaller grid tied into the larger electricity delivery system. There are several DG that has been used for generation such as solar photovoltaic system, wind turbines, biomass combustion and combined heat and power (CHP) systems. DG was is one of alternative to produce electricity as it is convenient to avoid transmission and distribution losses. DG also requires lower cost to build the infrastructure as it is in small size. Besides that, DG technologies can produce near-zero or zero pollution [2].

Solar PV system is one of distributed system that was used to generate electricity. Compared to other renewable energy, solar energy is more suitable to be implemented in Malaysia since Malaysia receives direct sunlight approximately 10 hours a day. For solar irradiance between $800\ W/m^2$ and $1000\ W/m^2$, Malaysia receives approximately 6 hours a day. Besides that, solar energy system is more environmentally friendly as it does not produce any pollution during operation and require low maintenance. However, the installation of PV technologies requires higher cost as it is long lasting renewable energy technology [3]. Solar panels which is used to absorb solar energy can be mounted anywhere as long as it facing the sun and the angle of solar panel is important in order to receive 100% sunlight.

Photovoltaic arrays produce electricity once it is exposed to sunlight. Basically, solar energy that is collected by photovoltaic arrays is in DC form and will be converted into AC form using inverter. The electron that are freed by solar energy can be induced to travel through an electrical circuit, powering electrical devices or sending electricity to the grid [4]. Three-phase inverted was required to convert the DC electricity produced onto AC form before connect to grid. Switching mechanism that was use in the inverter is Insulated-Gate Bipolar Transistor (IGBT) because IGBT is a minority-carrier device with high input impedance and high current-carrying capability. Due to its bipolar output characteristics, IGBT also suitable to scale in current handling capability at higher voltage levels [5]. Each phase from solar PV system is 240V with $50H_Z$which will be connected to three-phase grid network.

1.2 Problem Statement

Distributed Generation (DG) system also known as embedded system and it is a small scale electricity power generation technologies that produce electricity at site close to load or customers. Solar PV system is one of distributed generation system that was used to generate electricity. PV generation system can be connected with grid network and this might lead to several issues such as synchronization issue, overvoltage and undervoltage issue, and stability issue. Synchronization issue occur when frequency, magnitude of voltage and phase angle from PV model are not same with grid network. The failure to follow this requirement could damage the equipment connected with the system. Besides that, overvoltage issue occur when voltage across load is higher than 5% allowable tolerance limit. This is due to the power generated by PV model that exceed the load demand. Insufficient power supply from grid can cause undervoltage problem as voltage across load is below 230V. This problem can occur especially at the load that was connected the furthest from grid network. Lastly, stability of the system can be affected by the occurrence of fault in the system. There are several types of fault that can occur in three-phase grid-connected photovoltaic system which are single line-to-ground (SLG) fault, double line-to-ground (DLG) fault and three-phase fault. Equipment can be damage if there is no protection in the system. Objectives for this project was developed in order to know the possible consequences from the following problem towards three-phase grid-connected photovoltaic system. In future development of PV model, suitable protection device can be choose based on the results from this project.

1.3 Objectives

This project should fulfil the following objectives:

- To design and model a three-phase grid-connected photovoltaic system and Microgrid model using PSCAD software.
- To examine the impact of power generated by three-phase grid-connected photovoltaic system towards grid and load using PSCAD software based on case studies which includes:
    i. Import and export of active and reactive power at point common of coupling (PCC).
    ii. Impact of excessive power to support load demand without grid connection.
    iii. Effect of generated power from PV model toward voltage impact at distribution network including Microgrid.
    iv. Stability of system – using single line-to-ground (SLG) fault, double line-to-ground (DLG) fault and three-phase fault.

1.4 Scope of Project

The scope of project are:

i. Designing and modelling of three-phase grid-connected photovoltaic system at low voltage network to reduce losses at load side using PSCAD software.
ii. The effect of injected power at point of common coupling (PCC).
iii. Abnormal condition occur at the photovoltaic model only.

CHAPTER 2

LITERATURE REVIEW

2.1 Three-Phase Grid-Connected Photovoltaic System

Solar energy is the cleanest, sustainable and environmentally friendly renewable energy. In generating electricity using solar energy, there are two different ways which is using solar collector and using photovoltaic system. Photovoltaic system can be use either as stand-alone or grid-connected system. Stand-alone PV generation system requires battery as energy storage while grid-connected PV system doesn't need battery since power is normally stored in the grid itself. Grid-connected PV system can reduce the dependencies on utility power and increase renewable energy production. Solar PV panel can be mounted anywhere as long as it can receive sunlight. Since PV system is classified as DG, it helps grid network to support active loads. If the PV system produced electricity more than demand, the excessive power will automatically flow to the grid. The main disadvantages of battery-less grid-connected PV system is the PV system will be affected by the failure occur at grid. When there is no power from grid, so does the PV system. So, consumers are not able to use output of PV system when grid is not operational [6].

Photovoltaic arrays are made of semiconductors that allow sunlight to be converted directly into electricity. The electron that was freed by solar energy can be induces to travel through an electrical circuit, powering electrical devices or sending electricity to the grid. The electricity produced by these arrays is in DC form. Since it will be connected with grid, an inverter is needed as power conversion in order to convert electricity from DC form into AC form. Besides that, power electronics inverter also function as interconnection and control optimization. In order to get proper grid synchronization, the output of the inverter which is voltage, frequency and phase angle must be properly sinusoidal [7].

Three-phase grid-connected PV system is able to support grid by supplying three-phase power to consumers. This distributed generation system also able to reduce losses in distribution network. This system requires three-phase PWM inverter that will convert the

DC power generated by PV panels into AC form. In order to obtain the desired performance and allow the system operates in stable condition, proper controller through inverter need to be implemented [8]. Three-phase PWM inverter will compare the reference wave of the system with triangular square wave. The amplitude of the output is determined by amplitude of the reference and carrier wave. Isolated transformer is used to isolate the output of inverter which is suitable for three-phase system [9]. Figure 2-1 shows the basic diagram for three-phase grid-connected PV system.

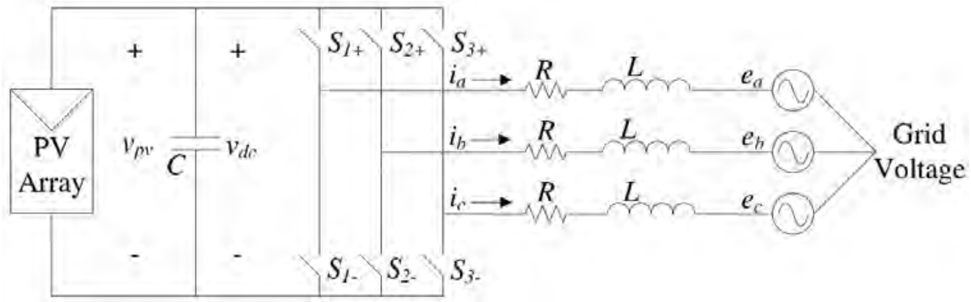

Figure 2-1: Basic Diagram for Three-Phase Grid-Connected PV System.

2.2 Components of Three-Phase PV System

2.2.1 PV Array

PV array is one of the most important part in photovoltaic system. In PV array, there are solar cells which is use to absorb the solar energy. Solar cell is made from semiconductor material and it comes in various sizes. Silicon is one of material that is use as solar cell. Solar cells have two different layer of silicon which is known as n-type and p-type. The silicon atoms will absorb some light and the lights energy knocks some electrons out of the atoms which is then flows between the two layers. The excess electrons from n-type region will diffuse with holes from p-type region and vice versa. The depletion region will be form as the movement of electrons to p-type region produce positive ion in the n-type region while movement of holes to n-type region produce negative ion in p-type region. This process will produce power in DC form. Only light with right wavelength will be absorbs by solar cells and transform into electricity power [4]. Figure 2-2 shows the structure of solar cell.

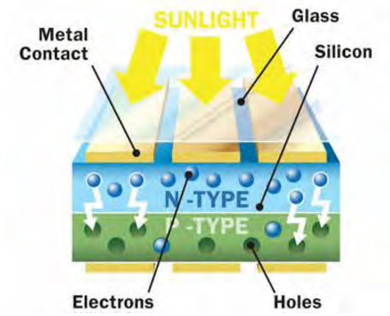

Figure 2-2: Structure of Solar Cell.

2.2.2 Three-Phase Inverter

Three-phase inverters are used for converting DC voltage and current into AC form. Since this system use PV solar, an inverter is needed in order to allow it connect with grid. There are three single-phase inverter switches each connected to one of the three load terminal in basic three-phase inverter. Operation of three switches is coordinated in basic control scheme $(S_1, S_4), (S_3, S_6), (S_5, S_2)$ which means one switch will operates at each 60 degree point of the fundamental output waveform [9]. Figure 2-3 shows the circuit for three-phase inverter.

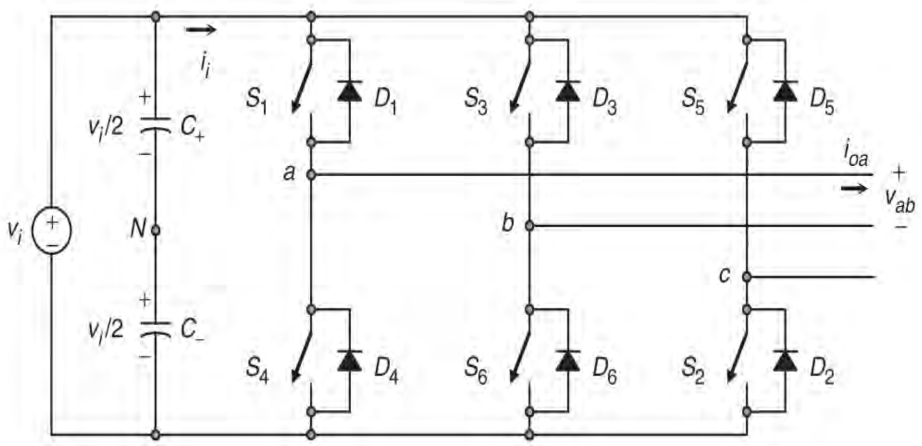

Figure 2-3: The Circuit for Three-Phase Inverter.

Each pair of switch must turned on at different time in order to allow the current flow through all phases. If both switch in each pair is turned on at the same time as short circuit will be occur in the system [9]. Figure 2-4 shows the switching sequence for three-phase inverter.

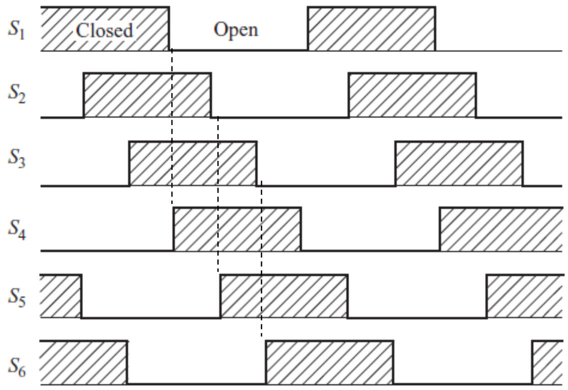

Figure 2-4: Switching Sequence for Three-Phase Inverter.

2.2.3 Insulated-Gate Bipolar Transistor (IGBT)

Insulated-Gate Bipolar Transistor (IGBT) is three-terminal semiconductor switch that was used as to control electrical energy in three-phase inverter. IGBT consists of three-terminal which is labelled as emitter 'E', collector 'C' and gate 'G'. IGBT have combination properties from Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET) and Bipolar Junction Transistor (BJT) [10]. Figure 2-5 shows the symbol of IGBT.

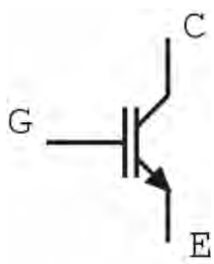

Figure 2-5: Symbol of IGBT.

IGBT is voltage-controlled device with maximum voltage rating equal to 3.5kV and 2kA maximum current rating. IGBT have high switching frequency which is up to 30 kHz compared to MOSFET and BJT. Since IGBT is a voltage-controlled device, small voltage on the gate is required to maintain the conduction through the device [11]. Table 2-1 shows the comparison between IGBT, MOSFET and BJT switching device.

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

Characteristics	IGBT	MOSFET	BJT
Control Variable	Voltage	Voltage	Current
Max. Voltage Rating	3.5kV	1kV	1.5kV
Max. Current Rating	2kA	150A	1kA
Switching Frequency	High (up to 30kHz)	Very High (up to 1MHz)	Medium (10kHz)

2.2.4 Pulse Width Modulation (PWM)

There will be disturbance in each electrical system which is also known as harmonics distortion. Using Pulse Width Modulation (PWM) and filter is one of the way to reduce the harmonic distortion. PWM can be divided into two types which are bipolar PWM and unipolar PWM [9]. In three-phase grid-connected PV system, PWM three-phase inverter can be used. Harmonics will be at higher frequencies than square wave for unfiltered PWM output. This will make filtering process easier. In PWM, modulating waveform can control the amplitude of output voltage. Modulating waveform which is in sinusoid is used to control the switches for PWM output while carrier wave which is in triangular wave is used to control the switching frequency [10]. Figure 2-6 shows the references and carrier signal for three-phase PWM inverter.

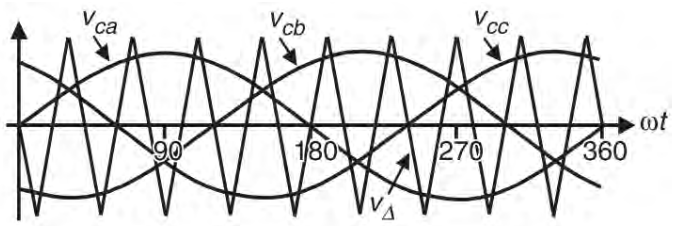

Figure 2-6: The References and Carrier Signal for Three-Phase PWM Inverter.

By using PWM in the three-phase inverter system can reduced the filter requirement and control the output of the voltage amplitude. But, PWM can make the control circuit for switches become more complex. Since it have six switching mechanisms which operate in pair. Each pair of switches require difference reference signal. For balanced three-phase output, the three reference signals are 120° apart. The condition of each switch in the inverter are as follow [10].

S_1 is on when $v_{ca} > v_{\Delta}$

S_4 is on when $vc_a < v_{\Delta}$

S_3 is on when $v_{cb} > v_{\Delta}$

S_6 is on when $v_{cb} < v_{\Delta}$

S_5 is on when $v_{cc} > v_{\Delta}$

S_2 is on when $v_{cc} < v_{\Delta}$

Pair of S_1, S_4 is used for phase A while S_2, S_6 and S_2, S_5 used for phase B and phase C. The phase voltage for phase A, phase B and phase C are shown in (2.1) when S_1, S_3 and S_5 in close condition. All the phase voltage will become negative for opposite condition of switch which means S_4, S_6 and S_2 in close condition as shown in (2.2). The output of three-phase inverter was shown in Figure 2-7 [10].

$$V_{abc,n} = \frac{V_i}{2} \tag{2.1}$$

$$V_{abc,n} = -\frac{V_i}{2} \tag{2.2}$$

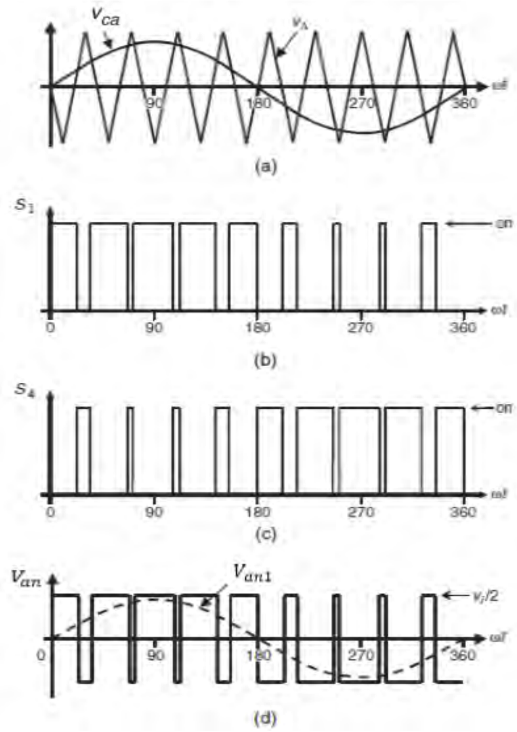

Figure 2-7: The Output of PWM Three-Phase Inverter.

PWM output voltage has same fundamental frequency with reference signal in Fourier series. Frequency modulation, m_f is a ratio of frequency of carrier signal and frequency of modulating signal. Formula used to calculate the frequency modulation was