UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

IMPACT OF PHOTOVOLTAIC SYSTEMS INTEGRATION ON ELECTRICITY DISTRIBUTION NETWORKS

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By

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DECLARATION

I declare that this dissertation entitle —Impact of Photovoltaic Systems Integration on Electricity Distribution Networks" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this dissertation and in my opinion this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

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DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Esmaeel Ibraheem and Najiyah Tareq whom words of encouragement and a push for tenacity to improve myself throughout all my walks of life. Thank you for giving me a chance and I love you.

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And I do not forget to dedicate this work to my sweetheart Ban Haider who has always been with me in overcoming times in my loneliness. Her patience is the meaning of love, kindness and gentle soul, thus I love you.

ABSTRACT

Traditionally, power systems are designed to operate in a unidirectional power flow. In the past few years, integration of solar photovoltaic (PV) systems on distribution network has grown rapidly given its potential technical and economic benefits, which include higher network utilization, enhanced reliability and loss reduction. However, the high PV generation during low demand periods may cause potential network problems. In addition, PV generation depends directly to the sun irradiance which could potentially cause problems in the cases of high PV penetration level. The intermittency of the power generated from the PV plants may introduce voltage fluctuation and power quality issues. These issues may limit the PV penetration level and hence necessary measures are needed to alleviate the potential problems. This dissertation investigates the steady state impact of the PV plant penetration on the operation of power distribution networks. This includes the impact of PV generation of the network losses. In addition, the light and heavy load cases have been considered in this work to analyze their respective impact on the network voltage. The maximum PV penetration level that can be injected into the grid is identified. Mitigation strategy has also been proposed to control the voltage fluctuation that caused by PV plants. Standard IEEE distribution test cases have been modeled by utilizing OpenDss simulator. These test cases were used to perform the case studies of distribution systems in order to evaluate the impact of grid connected PV systems. The results indicate that the integration can have a positive impact and negative impact on the connected grids. The interest lies in the voltage improvement at load buses and the reduction in the system losses. The maximum capacity and the impact of the PV on the grid connected system depend on the PV size, installation location and system topology. The results also show that the STATCOM technique can effectively reduce the voltage fluctuation in the network.

ABSTRAK

Secara tradisinya, sistem kuasa direka untuk beroperasi dalam satu arah aliran kuasa. Beberapa tahun kebelakangan ini, sistem solar photovoltan (PV) telah berkembang pesat memberikan manfaat yang berpotensi dari segi teknikal dan ekonomi termasuk penggunaan rangkaian yang tinggi, kebolehpercayaan yang dipertingkatkan dan pengurangan kerugian. Walaubagaimanapun , penjanaan PV yang tinggi dalam tempoh permintaan yang rendah boleh menyebabkan potensi rangkaian yang bermasaalah. Di samping itu, generasi PV bergantung secara langsung kepada sinaran matahari yang berpotensi boleh menyebabkan masalah dalam kes-kes tahap penembusan PV yang tinggi. Peralihan janaan kuasa yang cepat dari loji PV boleh memyebabkan voltan turun naik dan isu-isu pada kualiti kuasa. Isu ini boleh menghadkan tahap penembusan PV dan oleh itu langkah-langkah adalah diperlukan untuk mengurangkan potensi masalah yang mungkin berlaku. disertasi ini mengkaji kesan penembusan loji PV dalam keadaan tetap pada operasi rangkaian pengagihan kuasa. Ini termasuk kesan generasi PV ke atas kerugian rangkaian. Tambahan pula, benda ringan dan berat telah dipertimbangkan dalam kajian ini untuk menganalisis kesan masing-masing pada voltan rangkaian. Tahap maksimum penembusan PV yang boleh disuntik ke dalam grid tersebut telah dikenalpasti. Strategi kawalan juga telah dicadangkan untuk mengawal voltan turun naik yang disebabkan oleh loji-loji PV. Kes-kes pengujian piawaian IEEE telah dimodelkan dengan menggunakan simulasi OpenDss. Kes-kes pengujian tersebut telah digunakan untuk melaksanakan kajian kes sistem pengedaran bagi menilai kesan grid yang berkaitan sistem PV. Keputusan menunjukkan bahawa integrasi boleh memberi kesan positif dan kesan negatif ke atas grid yang berkaitan. Kepentingan terletak pada peningkatan voltan bas beban dan pengurangan kerugian sistem. Kapasiti maksimum dan kesan PV pada sistem grid yang berkaitan bergantung kepada saiz PV, lokasi pemasangan dan sistem topologi. Keputusan juga menunjukkan bahawa teknik STATCOM berkesan boleh mengurangkan turun naik voltan dalam rangkaian.

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LIST OF ABBREVIATION

ANSI	American National Standards Institute
BIPV	Building Integration PV
CHP	Combined Heat and Power
CSV	Comma-Separated Value
COM	Component Object Model
DER	Distributed Energy Resource
DG	Distributed Generation
DLL	Dynamic Link Library
EPRI	Elictrical Power Research Institute
EPS	Electric Power Systems
PES	IEEE Power and Energy Society
IEEE	Institute of Electrical and Electronics Engineers
ISE	Interconnection System Equipment
IEA	International Energy Agency
MBIPV	Malaysia Building Integrated Photovoltaic
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
NERL	National Renewable Energy Laboratory
NOCT	Nominal Operating Cell Temperature
OLTC	On Load Tap Changers
OpenDss	Open Distribution System Simulator
PV	Photovoltaic
PCC	Point of Common Coupling
RES	Renewable Energy System
STATCOM	Static Synchronous Compensator
STC	Standard Test Condition
SVR	Step Voltage Regulators
TCC Fuse	Time-Current Characteristic Fuse
TNB	Tenaga Nasional Berhad
TVR	Thyrisor Voltage Regulator
UL	Underwriters Laboratories
VBA	Visual Basic of Application
Yprim	Primitive y Matrix

LIST OF PUBLICATION

Journal

[1] W. E. Ibraheem, C. K. Gan, ―Effect of technical impact of PV penetration on distribution network under various load levels" Applied Mechanics and Materials, ISSN 1660-9336, May 2014. (Accepted and to be appeared in May 2014 issue), *Scopus-indexed*

[2] W. E. Ibraheem, C. K. Gan, M. R. Ab. Ghani ―Impact of Photovoltaic (PV) Systems on Distribution Networks" International Review on Modeling and Simulations (IREMOS), ISSN 1974-9821, March 2014. (Accepted and to be appeared in March 2014 issue),*Scopus-indexed*

CHAPTER 1

INTRODUCTION

1.1 Research Background

These days the demand for electrical energy is increasing to meet the load expansion in the electrical power system. The rise of the world weather temperature and the depletion of fossil fuel and the price of the fuel had motivated more researches and development in renewable energy system (RES). This is to reduce the CO_2 emission. Many countries have engaged in renewable electricity and they have set ambitious for producing power from green sources to meet the expected demand in the coming years.

Photovoltaic (PV) solar energy is one of the important sources of the renewable energy; it has grown in many countries steadily in the last few years. In Europe, the combined target yield a total expected PV power generation capacity is 84.4 GW by 2020, where the maximum projected PV target is in Germany which is around 51.8 GW from solar energy (Pearsall, 2011). In Malaysia according to the 10^{th} Malaysian plan (2011-2015) the PV generation in the country will reach 65 MW in 2015 and it is projected to be 190 MW by 2020 (Shamsuddin, 2012). U.S. imports of PV products from South Korea are small, but the country has a stated goal to capture 10% of the global PV market by 2020 (Platzer, 2012).

PV systems generation is not different of other renewable energy resources (naturally replenished). Solar energy is comparatively clean by owning a lower effect on the environment as well as it saves the depletion of fossil fuel and coal. The variability in the output of the PV panels is a natural behavior of these resources and it is a significant issue. The rising and setting of the sun lead to a regularly variation of the PV panel generation over the daily time period. In addition, the output can be decreased to 50%-80% when the clouds pass over PV plants (Kleissl, 2012). In this case a backup power will be required to cover the output variable to maintain the operation voltage under the limit. If the response of the backup elements is too slow to cover the problem, power quality can adversely affected.

Despite these difficulties, solar PV plants still have the fastest growing of renewable energy technology in 2012. As shown in Figure 1.1 a predestined that 29 GW of the solar capacity in 2012 have been added to the power capacity which was in 2011. The power was almost 150% has increased of the installed capacity of 2010 bringing the totally generation about 100 GW (Mcginn et al., 2013).

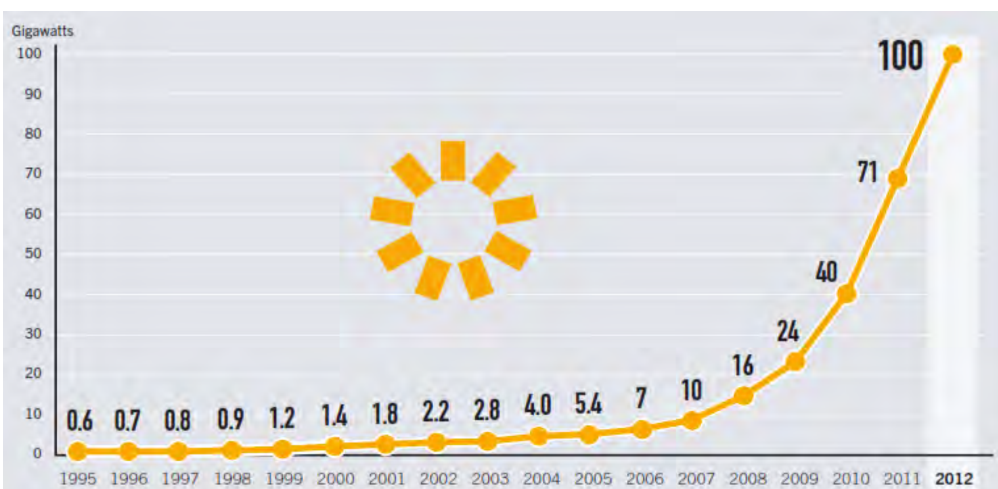

Figure 1.1 Solar PV Global Capacity, 1995–2012 (Mcginn et al., 2013)

As the rapid increasing of the PV integration, it could potentially bring problems in terms system operation where a reverse power can be introduced by higher penetration levels resulted a rise in bus voltages and feeder loses (Agalgaonkar, 2013). Numbers of researches have been done in the recent years to evaluate the impact of PV system on power grids. The notable studies were by *National Renewable Energy Laboratory (NREL)* in February 2008, and the other one in 2002 which had been conducted by the *International Energy Agency (IEA)* (E. Liu & Bebic, 2008) (Arne Faaborg, 2002). In Malaysia, Tenaga Nasional Berhad (TNB) has provides a guideline and recommendations to the interconnection of PV systems with distribution grids (Tenaga Nasional Berhad, 2013). These studies included many reports of the PV impact on the distribution grids to address the analytical and technical issues of the high penetration level of distribution generation as in reference (Tie & Gan, 2013).

1.2 Problem Statement

Radial distribution systems have only one power source for a group of customers supported by one direction power flow networks, the voltage regulation which is implemented by utilizing tap changer at the substation point or by compensating the estimated voltage drop or rise according the load demand profile. The injected power by the PV plants modules at the load side buses will decrease the demand of the local load which leads to a losses reduction and voltage profile improvement. Obviously, this case is true as long as the real power flows from the substation to the customer side (when the load is less that PV power). If the PV generation is more than the load downstream of the PV location, the power flow may be reversed towards the substation. Consequently, Ushape trajectory of distribution networks losses is expected. In addition, voltage rise can be expected along the distribution system feeder as a result of the reverse power flow.

The rise of the voltage at the end-user limits the amount of the penetration level which wanted to be installed in the distribution network. The natural behavior of the solar source makes the generation of the PV plant systems in fluctuated profile. The rapid variation of the PV power introduces a voltage fluctuation along the PV working time and hence it effects on the voltage regulation in some cases.

1.3 Research Objectives

In a light of the issues described above, this research aims to analyze the impact of the PV system on distribution systems. The focus of this research is to evaluate the voltage and losses impact on the distribution feeders. The main objectives of this work are:

- To model and simulate the commercially available PV panels and results validation with the product catalogue.
- To investigate the impact of PV integration on distribution networks in terms of network losses at different PV locations and to evaluate the voltage impact under different PV penetration level and load levels.
- To implement voltage control strategies in order to alleviate voltage fluctuation issues from solar PV system.