Faculty of Electrical Engineering

IMPACTS OF SOLAR PHOTOVOLTAIC SYSTEM ON DISTRIBUTION NETWORK PERFORMANCE

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Master of Science in Electrical Engineering

2017

IMPACTS OF SOLAR PHOTOVOLTAIC SYSTEM ON DISTRIBUTION NETWORK PERFORMANCE

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
in Electrical Engineering

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this thesis entitled "Impacts of solar Photovoltaic system on distribution network performance" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :..

Name : LAU CHEIW YUN

Date :..

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature :...

Name : ASSOC. PROF. DR. GAN CHIN KIM

Date :...

DEDICATION

Special gratitude to my beloved parent, Lau Leong Sin and Lim Lai Keng for their enduring love, tenacity and patience throughout all my walks of life. And also to my siblings, Lau Cheiw Yuet and Lau Chin Kiat who have motivated and supported me throughout my life. I love you all.

ABSTRACT

With the growth in energy demand and the depletion of fossil fuels, renewable energy resources have been seen as one of the most promising ways to sustain the future energy needs. However, the integration of renewables into the existing distribution networks can cause potential network problems. The issue is particularly acute if the renewable energy is generated from solar photovoltaic (PV) system with high variability. In this regard, this thesis deals with the modelling of a typical Malaysian distribution network that aims to analyze the impact of PV integration at distribution networks level. More specifically, the number of tap change for On-Load Tap Changer (OLTC) transformers is evaluated under various weather conditions; PV penetration levels as well as PV installed locations. The weather conditions were further categorized using variability index. In this way, the impact of solar variability can be properly assessed. The correlations of network losses and PV penetration levels have also been comprehensively analyzed. It is also important to highlight that actual solar PV generation data of various time resolution were collected and used in this work. This maintains the actual intermittency nature of PV generation. Furthermore, case studies have been performed for both low and medium voltage networks. The results suggest that sudden voltage variation and reverse power flow are the main concern of PV integration on the distribution network. The presented study shows that network losses are at the minimum level with a 50% PV penetration level. In addition, the findings suggest that high solar variability day could increase the tap change operations as much as 274% in average as compared to the network without PV system. In addition, a year-round analysis further suggests that the total annual tap change may operate 164% more frequently in average than a network without PV system.

ABSTRAK

Dengan pertumbuhan dalam permintaan tenaga dan kekurangan bahan api fosil, sumber tenaga boleh diperbaharui telah dijadikan sebagai salah satu cara yang paling digalakan untuk mengekalkan keperluan tenaga masa depan. Walaubagaimanapun, integrasi tenaga boleh diperbaharui pada rangkaian pengedaran yang sedia ada boleh menyebabkan masalah pada rangkaian. Isu-isu bertambah buruk sekiranya tenaga yang boleh diperbaharui yang dihasilkan daripada system solar fotovoltan (PV) dengan kepelbagaian yang tinggi. Dalam hal ini, tesis ini berkaitan dengan pemodelan rangkaian pengedaran Malaysia biasa yang bertujuan untuk menganalisis kesan integrasi PV di peringkat sistem pengedaran. Lebih khusus lagi, bilangan operasi On-Load Tap Changer (OLTC) telahpun dinilai dalam pelbagai keadaan cuaca; tahap penembusan PV serta lokasi PV dipasang. Keadaan cuaca telah dikategorikan menggunakan indeks kepelbagaian. Dengan cara ini, kesan kebolehubahan solar boleh dinilai dengan teliti. Profil voltan dan kerugian rangkaian juga dianalisis secara menyeluruh. Ia juga penting untuk fokus pada data generasi PV solar sebenar pelbagai resolusi masa telah dikumpulkan dan digunakan dalam kerja ini. Ini mengekalkan keadaan alam semula jadi yang sebenar bagi generasi PV. Tambahan pula, kajian kes telah dijalankan untuk kedua-dua rangkaian voltan rendah dan sederhana. Kajian ini menunjukkan bahawa variasi voltan secara tidak dijangkai dan aliran kuasa terbalik adalah isu utama integrasi PV pada rangkaian pengagihan. Kajian menunjukan bahawa kerugian rangkaian adalah dalam tahap minima dengan 50% tahap penembusan PV. Di samping itu, kajian ini juga mencadangkan bahawa hari kebolehubahan solar yang tinggi akan menambahkan bilangan operasi OLTC dengan sebanyak 274% sebagai purata berbanding dengan rangkaian yang tiada pemasangan PV. Selain itu, analisis tahunan mencadangkan bahawa bilangan operasi OLTC tahunan bertambah sebanyak 164% dalam purata berbanding dengan bilangan operasi OLTC dalam rangkaian yang tiada pemasangan system PV.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my main supervisor, Assoc. Prof. Dr. Gan Chin Kim for his essential guidance, supervision, support and encouragement on both practical and scientific manners from the initial towards the completion of this thesis.

I would also like to express my deepest acknowledgment to Mr. Mohamad Fani bin Sulaima and Mr. Kyairul Azmi bin Baharin, my co-supervisor and the lecturer for their guidance and support and motivation in completing this research work. Sincere gratitude also goes to my research mentor from Universiti Teknologi Malaysia (UTM), Prof. Dr. Zainal bin Salam for his valuable suggestion and useful ideas in all nice discussions. Special thanks for the research funding (FRGS(RACE)/2013/FKE/TK3/1F00199) and scholarship (ZAMALAH UTeM) from the Ministry of Higher Education Malaysia and UTeM in supporting this research work.

My sincere appreciation also extends to all my colleagues in solar research laboratory especially Ms. Sa'adah binti Daud and Ms. Nur Faziera binti Napis for their assistance and companionship at various critical occasions. My sincere thanks also goes to my beloved friend Mr. Zhang Guo-Bo for his enduring love and passion support throughout this work.

Last but not least, I would like to express my ultimate thanks go to my beloved parents and siblings for their moral and outstanding support in completing this thesis.

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AC	Alternating Current
BW	Bandwidth
CI	Clearness Index
COM	Component Object Model
CSI	Clear Sky Index
CSV	Comma-Separated Value
CT	Current Transformers
DC	Direct Current
DG	Distributed Generation
DHI	Diffuse Horizontal Irradiance
DLL	Dynamic Link Library
DNI	Direct Normal Irradiance
EPRI	Electrical Power Research Institute
EU	European
FiT	Feed in Tariff
GHI	Global Horizontal Irradiance
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
I_p	Primary Current

LDC	Line Drop Compensation
LV	Low Voltage
MATLAB	Matrix Laboratory
MV	Medium Voltage
MW	Mega Watt
NERC	North America Electric Reliability Corporation
NERL	National Renewable Energy Laboratory
NLTC	No-Load Tap Changers
OLTC	On-Load Tap Changers
OpenDSS	Open Distribution System Simulator
p.u.	Per Unit
PV	Photovoltaic
RE	Renewable Energy
SEDA	Sustainable Energy Development Authority Malaysia
ST	Surunhanjaya Tenaga
TD	Time Delay
TNB	Tenaga Nasional Berhad
UNITEN	Universiti Tenaga Nasional
U_p	Primary voltage
U.S.	United States
UTeM	Univeristi Teknikal Malaysia Melaka
VI	Variability Index
VT	Voltage Transformers
WVM	Wavelet Variability Model

LIST OF PUBLICATIONS

Journal

[1] Lau, C. Y., Gan, C. K., Baharin, K. A., & Sulaima, M. F. (2015). A review on the impacts of passing-clouds on distribution network connected with solar photovoltaic system. *International Review of Electrical Engineering (I.R.E.E.)*, *10*(3), 449–457. (*Scopus-indexed)*

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[3] Lau, C. Y., Gan, C. K., Tie, C. H., Baharin, K. A., & Sulaima, M. F. (2015). Passing-cloud effects of solar photovoltaic system on distribution network voltages. *2015 9th International Power Engineering and Optimization Conference (PEOCO)*, 551–555.

CHAPTER 1

INTRODUCTION

1.1 Background

The world heavy reliance on fossil energy resources has brought numerous impacts on the environment such as climate change due to greenhouse gas emissions. To address this matter, Renewable Energy (RE) sources, such as solar, wind, biomass, tidal, and ocean thermal are being exploited as alternatives. Among these, the solar Photovoltaic (PV) appears to be the most promising option due to its inexhaustible resource from the sun. Driven by the governmental support and the advancement in PV technology, the number of PV installations have increased dramatically in the past few years. According to the futuristic expansion plans from various countries such as China, India, Germany, US, California, and Canada, there are many PV power projects installed with high PV capacity (Wong & Wills 2011; Bondre & Nambiar 2011; Grigoleit et al. 2014; Elkind et al. 2013; Small 2011). Furthermore, the total expected PV power generation capacity targeted in Europe is 84.4 GW by 2020 (Pearsall 2011).

In the Malaysia context, the introduction of Feed-in Tariff (FiT) scheme in year 2011 has prompted an increasing number of grid-connected PV system installation in Malaysia (KeTTHA 2011). In addition, a total of 985 MW of RE generations is targeted by the year 2015. In terms of PV development target, a total of 190 MW is expected to be connected to the utility grid by the year 2020 (The Economic Planning Unit 2010). The relative large integration of PV system in the distribution grid is expected to cause some network problems. For instance, the output of the PV panels is heavily depending on the solar irradiance level. In this regard, the