Faculty of Electrical Engineering

MALAYSIAN REFERENCE NETWORK MODELLING FOR PHOTOVOLTAIC IMPACTS STUDY

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MALAYSIAN REFERENCE NETWORK MODELLING FOR PHOTOVOLTAIC IMPACTS STUDY

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Malaysian Reference Network Modelling for Photovoltaic Impacts Study" 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 : VINODH A/L ANNATHURAI

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 parents, Mr.Annathurai and Mdm.Pancharvaramah for their enduring love, tenacity and patience throughout all my walks of life. Also to my siblings, Viknesh and Vinoodini who have motivated and supported me throughout my life. I love you all.

ABSTRACT

The burning of abundant fossil fuel amount to accommodate the energy demand causes emission of the greenhouse gas (GHG) which is contribute to the climate change. The Distributed Generation (DG) and renewable energy resources is one promising approach to reduce the emission, thereby mitigating climate change. However, most of the DG and renewable energy resources, especially the photovoltaic (PV) system is intermittent and often fluctuates. In this regard, this thesis focuses on the analysing the impact of PV integration at the medium voltage (MV) network. More precisely, the network losses and voltage issues are used to evaluate the effects of four variables; PV system installed locations, PV variability index (VI), different time resolution of PV generation profiles used and the PV penetration levels. The Malaysian Reference Network (RN) is modelled with the intention to analyse the impact of PV integration at the Medium Voltage (MV) network. Moreover, the breakdown of network losses for the Malaysian MV network is quantified by utilising the RN models. All case studies have been carried out for the urban, semi-urban and rural MV networks. The findings suggest that PV system installed at the end of the 11kV feeder for the rural and semi-urban produces significant network losses reduction than urban networks, which is driven by feeder length and load size. The findings also show that different categories of VI produce different impact on the networks. Voltage fluctuation and voltage step change are the two main concerns of various PV variability on the MV network. In addition, the different time resolution of real solar PV generation profile was collected to be used in the case study. By analysing different ranges of time resolution, it is suggested that a 15-minute time resolution PV generation profiles data are sufficient in network assessment study with approximately 5% error. The use of hourly PV generation data will cause up to 31% loss of accuracy. Furthermore, a case study was done to evaluate the impact of different PV penetration levels. The results show that PV integration above 60% and 100% penetration level will likely cause voltage rise violation in rural and urban networks, respectively. The research also suggests that the maximum PV penetration levels for a MV Malaysian network are based on several network performance indicators. In conclusion, the results show that location of PV system, PV variability, time resolution and PV penetration level are the key parameters to study the impact of PV in the MV networks.

ABSTRAK

Pembakaran bahan api fosil yang tinggi untuk menampung permintaan tenaga, menyebabkan pelepasan gas rumah hijau (GRH) menyumbang kepada perubahan iklim. Penjana teragih (PT) dan sumber tenaga boleh diperbaharui adalah pendekatan yang menjanjikan pengurangan pelepasan, dimana ia membantu mengelakkan perubahan iklim. Walau bagaimanapun, kebanyakan PT dan sumber tenaga boleh diperbaharui, terutamanya sistem Fotovolta (FV) terputus-putus dan sering berubah. Tesis ini memberi tumpuan dalam menganalisis kesan integrasi FV di rangkaian voltan sederhana (VS). Lebih tepat lagi, kerugian rangkaian dan isu voltan dinilai dengan mengunakan empat pembolehubah iaitu tempat sistem FV dipasang, indeks kepelbagaian FV (IK), profil generasi FV yang berbeza resolusi masa dan tahap penembusan FV. Rangkaian Rujukan (RR) Malaysia dimodelkan bertujuan untuk menganalisis kesan integrasi PV di rangkaian voltan sederhana (VS). Selain itu, pecahan kerugian rangkaian untuk rangkaian VS Malaysia dinilai dengan menggunakan model RR. Semua kajian kes telah dijalankan bagi rangkaian VS untuk bandar, separa bandar dan luar bandar. Hasil kajian menunjukkan bahawa sistem FV yang dipasang pada akhir penyuap 11kV bagi luar bandar dan separa bandar menghasilkan pengurangan kerugian rangkaian yang banyak berbanding rangkaian bandar, ini disebabkan oleh panjang feeder dan saiz beban. Selain itu, hasil kajian menunjukkan bahawa kategori berlainan di IK menghasilkan kesan yang berbeza pada rangkaian. Perubahan voltan dan langkah voltan adalah dua masalah utama bagi kepelbagaian FV pada rangkaian VS. Di samping itu, generasi PV solar sebenar dengan resolusi masa yang berbeza dikumpulkan untuk digunakan dalam kajian ini. Dengan menganalisis julat yang berbeza resolusi masa, adalah dicadangkan bahawa masa 15-minit generasi FV profil data mencukupi dalam kajian penilaian rangkaian dengan ralat kira-kira 5%. Penggunaan data generasi FV setiap jam akan menyebabkan kehilangan sehingga 31% ketepatan. Tambahan pula, satu kajian telah dilakukan untuk menilai kesan terhadap tahap penembusan FV yang berbeza.Keputusan menunjukkan bahawa integrasi FV yang melebihi 60% dan 100% tahap penembusan, akan menyebabkan pelanggaran kenaikan voltan dalam rangkaian bandar dan luar bandar, masing-masing. Kajian ini juga menunjukkan bahawa tahap penembusan maksimum FV untuk rangkaian Malaysia VS adalah berdasarkan beberapa petunjuk prestasi rangkaian. Kesimpulannya, keputusan menunjukkan bahawa lokasi sistem FV, FV kepelbagaian, resolusi masa dan tahap penembusan FV adalah parameter utama untuk mengkaji kesan FV dalam rangkaian VS.

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LIST OF ABBREVIATIONS

Al	-	Aluminium
CI	-	Clearness Index
Cu	-	Copper
DG	-	Distributed Generation
DIGSILENT	-	Digital Simulation of Electrical Network
FiT	-	Feed in Tariff
IEEE	-	Institute of Electrical and Electronics Engineers
LV	-	Low Voltage
MV	-	Medium Voltage
OLTC	-	On-Load Tap Changer
p.u.	-	Per Unit
PV	-	Photovoltaic
RN	-	Reference Network
SEDA	-	Sustainable Energy Development Authority Malaysia
ST	-	Suruhanjaya Tenaga
TNB	-	Tenaga Nasional Berhad
UK	-	United Kingdom
U.S.	-	United States
VI	-	Variability Index

LIST OF PUBLICATIONS

Journal

[1] Annathurai, V., Gan, C. K., Ibrahim, K. A., Baharin, K. A., & Ghani, M. R. A, (2016). A Review on the Impact of Distributed Energy Resources Uncertainty on Distribution Networks. *International Review of Electrical Engineering (IREE)*, *11*(4), 420. (*Scopus-indexed)*

[2] Annathurai, V., Gan, C.K., Ruddin, M., Ghani, A., and Baharin, K.A., (2017). Impacts of Solar Variability on Distribution Networks Performance. *International Journal of Applied Engineering Research*, 12 (7), pp.1151–1155. *(Scopus-indexed)*

[3] Annathurai, V., Gan, C. K., Baharin, K. A., Ruddin, M., & Ghani, A. (2016). Shading Analysis for the Siting of Solar PV Power Plant. *ARPN Journal of Engineering and Applied Sciences*, *11*(8), 5021–5027. (*Scopus-indexed)*

Conference

[1] V. Annathurai, C. K. Gan, K.A. Ibrahim, M.R.A. Ghani, "Technical Assessment of Reference Network in Malaysia," *6th IEEE International Conference on Power and Energy (PECON2016)*, Melaka, 2016 (*In-Press)*.

[2] V. Annathurai, C. K. Gan, M.R.A. Ghani, K. A., Baharin "Necessity of Time-Series Simulation For Investigation of High Penetration of PV System in Malaysia," *International Symposium on Research in Innovation and Sustainability*, Melaka, 2017 *(Accepted)*.

CHAPTER 1

INTRODUCTION

1.1 Background

Enormous amounts of non-renewable resources are being utilized every day to meet the increasing energy requirement, mainly in the industrial sector. Other sectors such as transportation, commercial and residential also accounts for this requirement and contributed to energy-related carbon emission. The combustion of fossil fuels contributes to the increase of greenhouse gas emissions, which results in global warming. In future, the greenhouse gas emissions from the developing countries will probably exceed those produced by developed countries (Chandler et al., 2002; Hardisty et al., 2012).

Many countries all over the world have been involved in generating power from renewable sources to accommodate the expected higher demand in the future. At present, renewable energy contributes approximately 30% of the total global power-generating capacity and around 23% of the total global electricity production. For the last decade, PV has seen a dramatic rise of 51% in terms of average annual growth in installed capacity (REN21 Secretariat, 2016). As shown in Figure 1.1, over the last fifteen years the PV capacity is increasing rapidly in the world. Tremendous drop of PV panel price in the past two decades has caused corresponding increases in the PV system projects in many countries. Figure 1.2 shows the average price trend of polysilicon solar modules in the past few years.

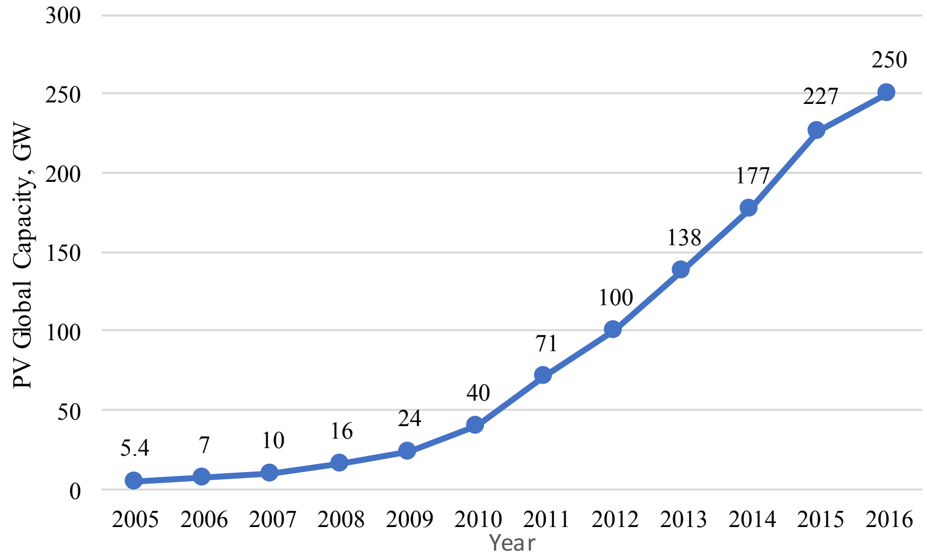

Figure 1.1: Solar PV global capacity, 2005-2016 (REN21 Secretariat, 2016)

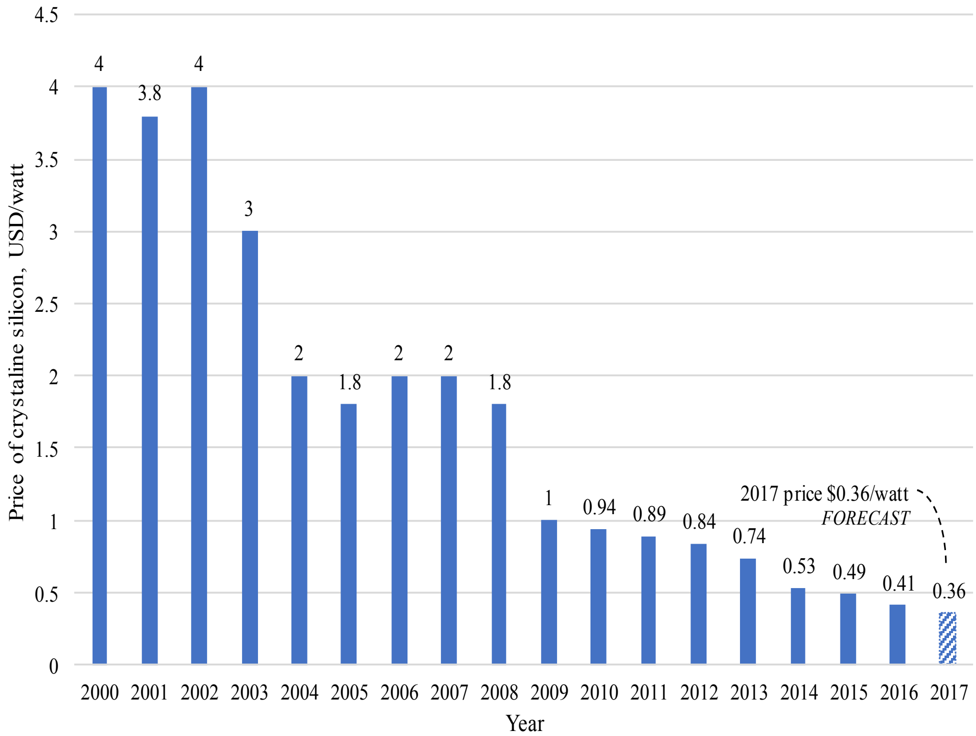

Figure 1.2: Average polysilicon PV system price from 2000 to 2017 (Bano and Rao, 2016)

In Malaysia, the electricity generation, industry, transport and residential are the four major sectors require a high demand of energy and a huge contributor of carbon dioxide (CO_2)

emissions as shown in Figure 1.3. A study was done to support that by the year of 2020 the total emissions of the CO_2 will reach 285.73 million tons (Safaai et al., 2014). In this concern, the Malaysian government had assured and set the target to reduce 40% carbon emission intensity along with high-income nation by 2020 (Ministry of Natural Resources and Environment Malaysia, 2000; National Economic Advisory Council, 2009).

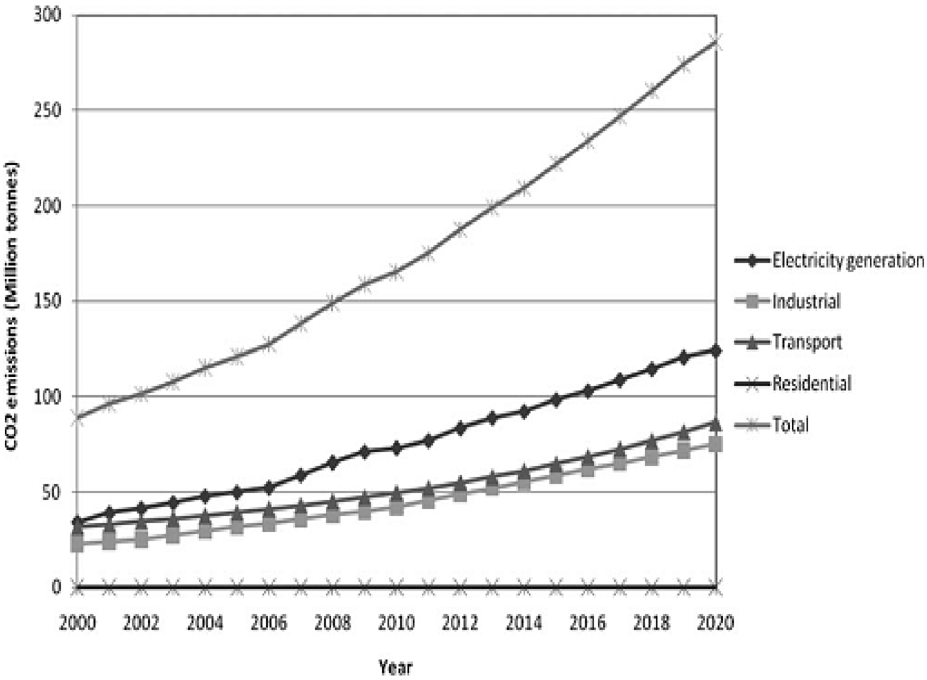

Figure 1.3: Projected CO_2 emissions for four sectors in Malaysia (Safaai et al., 2014)

Consequently, the Malaysian Government formed a statutory body named, Sustainable Energy Development Authority (SEDA) in year 2011 and set a clear objective for renewable energy, which is to achieve up to 985 MW of renewable energy (RE) production by 2015 (The Economic Planning Unit, 2010). SEDA is responsible for managing the feed-in tariff (FiT) mechanism which is authorised under the Renewable Energy Act 2011 (Act 725) (Parliament Malaysia, 2011). The distributed solar photovoltaic (PV) has become one of the most favourable alternative energy resources for Malaysia (Zahari and Ahmad, 2012). This is contributed by strong governmental effort and by Malaysia being geographically located near the equator, enabling it to receive the solar irradiance of 4000 to 5000Wh per square meter per day (Teh, 2012). Moreover, PV panels and systems require minimum maintenance and easy to fit in the roofs (El-Khattam and Salama, 2004). Furthermore, the decreasing price of PV panel with the increasing of efficiency results in the increased installations of PV panels in residential and commercial areas. These are the main reasons for the solar PV to become the most promising RE in Malaysia. This is proven by the creation of enactment of Renewable Energy Act 2011 which encourages investment in the Renewable Energy (RE) sector through the Feed-in Tariff (FiT) incentive scheme (Ministry of Energy, Green Technology and Water, 2011). This FiT scheme acknowledges great responses, especially for the grid-connected PV systems (Ministry of Energy, Green Technology and Water, 2011; Tam, 2013).

Figure 1.4 shows the statistics of the large PV system size (more than 500kWp) is increasing rapidly in Malaysia over the years. Since of the introduction of the FiT scheme (2012) the total generation of PV system is increased by 100% at end of the year 2016 (SEDA, 2011). By year 2016 for the solar power plants with an installed capacity of 2MW, 3MW, 5MW and more than 5MW are rapidly increases than the residential PV capacities.