SYSTEM INTEGRATION OF PV IN MALAYSIA DISTRIBUTION NETWORKS

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Bachelor of Electrical Engineering

June 2012

"I hereby declare that I have read through this report entitled "System Integration of PV in Malaysia Distribution Networks" and found that it has comply the partial fulfillment for awarding the degree of Bachelor Electrical Engineering (Industrial Power)"

Signature :

Supervisor's Name :

Date :

SYSYTEM INTEGRATION OF PV IN MALAYSIA DISTRIBUTION NETWORKS

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A report submitted in partial fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Year 2011/2012

I hereby declare that this report entitled "System Integration of PV in Malaysia Distribution Networks" is the result of my own research except cited in the references. This report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name :

Date :

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ABSTRACT

The Malaysian Building Integrated Photovoltaic Project (MBIPV) has contributed to the growing number of PV units in Malaysia distribution networks towards the end of 2010. With the introduction of Renewable Energy Act 2011, PV penetration in distribution networks will certainly heighten when the government is taking initiatives in developing and commercializing BIPV applications in urban networks. BIPV will not only add aesthetic value to the buildings but reduces distribution system overloads and contributes to energy efficient power supply. However, high penetration of PV in the distribution networks may possibly deteriorate the overall performance of electrical system such as reverse power flow, losses as well as voltage problems. Proactive strategies to tackle high PV penetration must be carefully executed as network reinforcement might be needed in the future to ensure a practical, cost-effective PV integration system. This project evaluates the technical impacts of different levels of PV penetration in LV distribution networks in Malaysia. The generic distribution model is built with reference to distribution network parameters provided by the local utility, Tenaga Nasional Berhad (TNB). The network topologies have been used to evaluate cost and benefits of PV integration on typical Malaysia distribution networks.

ABSTRAK

Melalui Malaysia Building-Integrated Photovoltaic Project 2005 (MBIPV), Malaysia telah berjaya mencapai sebanyak 440% peningkatan dalam aplikasi BIPV di seluruh Malaysia. Dengan pelancaran Renewable Energy Act 2011 dan Sustainable Energy Act Malaysia pada bulan September tahun lepas, bilangan BIPV dalam rangkaian voltan-rendah akan meningkat secara berterusan pada tahun yang akan datang. BIPV berupaya menjana elektrik untuk menampung pengunaan harian konsumer, mengurangkan beban elektrik di sekitar grid malah menambah nilai estetik pada bangunan tersebut. Akan tetapi, peratusan BIPV yang terlampau dalam sesebuah LV network akan memudaratkan seluruh grid elektrik dari segi kehilangan kuasa, kenaikan voltan, dan kerosakan peralatan di bahagian pembahagian seperti alat ubah dan kabel. Oleh yang demikian, langkah-langkah proaktif perlulah diambil untuk menampung bilangan BIPV yang semakin bertambah. Kertas kerja ini akan memperlihatkan kesan-kesan teknikal BIPV pada rangkaian voltan-rendah selain daripada membincangkan kos penyengaraan grid untuk menampung bilangan BIPV yang banyak pada masa hadapan.

PUBLICATIONS

As the result of this project, one conference paper has been published in the 3rd International Conference on Engineering & ICT (ICEI2012) and published in the electronic version of the conference proceedings. Details for reference are as below. For the full paper, please refer to Appendix C.

S.Y. Kee and C.K. Gan, Impact Assessment of PV on Malaysia Distribution Network, *Proceedings of the 3rd International Conference on Engineering & ICT*, pp. 283-286, 2012.

This project has also been chosen, among all final year projects in the UTeM Faculty of Electrical Engineering for competition in DENOTECH 2012, and has been awarded the consolation prize. For the certificate of participation, please refer to Appendix D.

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CHAPTER 1

INTRODUCTION

1.1 Overview

This thesis is organized in six chapters. Chapter 1 describes the project objectives as well as the project scope which defines the area of research. Chapter 2 reviews the past researches regarding PV integration into low-voltage networks, covering the cost and benefits of PV integration and also the technical impacts of high PV penetration in the grids. The literature review also addresses the important theories and concepts as well as equations related to the entire project. Chapter 3 presents the methodology of the project, and how each procedure is executed to achieve the objectives. Chapter 4 illustrates all the simulation results while Chapter 5 discusses and analyzes the obtained data. Chapter 6 concludes findings and suggests recommendations for future research.

1.2 Problem Statement

Malaysia has made a good head start in solar energy industry when the Malaysian Building Integrated Photovoltaic project (MBIPV) achieved a 440% increase in BIPV application throughout the country from year 2005 to 2010. With implementation of Renewable Energy Act 2011 and Sustainable Energy Development Authority Act 2011, PV penetration in LV networks will no doubt, escalate in the coming years. This research is to evaluate the technical impact as well as the cost and benefits of PV integration in Malaysia distribution networks under different levels of PV penetration.

1.3 Objectives

The two main objectives of this final year project are as follows :

1) To study the cost and benefits of PV integration in Malaysia distribution networks.
2) To investigate the technical impacts of different levels of PV penetration on different distribution network topologies in Malaysia using software modeling.

1.4 Project Scope

Two distribution networks will be used for this project; residential and commercial networks. The case study will be carried out using Malaysia distribution networks therefore the data will be obtained from the local electrical utility, Tenaga Nasional Berhad (TNB).

Different levels of PV penetration will be modeled in two conditions:

i. Uniformly distributed PV integration
ii. Non-uniformly distributed PV integration

The technical impacts will be assessed in terms of voltage changes and power flows. As for the cost and benefits of PV integration, literature reviews will be done on existing PV researches.

1.5 Project Significance

From this project, it is found that all three case studies using the specific topologies could accommodate up to 100% integration of PV. However, voltage levels are at the maximum end of the upper limit -10% +5% voltage standard set by TNB. Power losses escalate as PV capacity in the distribution rises above 50%. Mitigation of the likely voltage rise, power losses increment and bidirectional power flow in a high PV penetration network should be considered in new designs as well as for potential network reinforcement for existing electrical grids.

CHAPTER 2

LITERATURE REVIEWS

2.1 Overview

This section of the report encompasses the growth of PV applications around the world and in Malaysia. It will also include studies on PV drivers, cost and benefits. The impacts of large-scale PV integration were also discussed, as well as the solutions to mitigate the impacts. These reviews are documented in nine sub topics.

2.2 PV Around the World

There are approximately 40,000 MW of photovoltaic (PV) installations around the globe in 2010 [1]. Germany has shown the world that environmental and industrial development can be achieved simultaneously when the Germans introduced the first FiT (Feed-in Tariff) and has the largest PV market world-wide, with 3.8GW in 2009 [1]. Among the solar PV pioneers are; Japan with 99% grid-connected 2.6GW of solar power in 2009 and USA with an estimated 3GW of PV installations in 2014 [1][2]. According to S. Strong [3], building-integrated PV systems (BIPV) will be the prime PV application for early PV market penetration and it is, without a doubt, proven to be true in [4]-[12] where BIPV is widely installed in Europe, Japan and United States. PV technology is advancing day by day and just recently, ArrayPower [13] has introduced a cost-optimized integrated AC module where the PV modules and integrator comes in a single component, for easy installation and maintenance.

2.3 PV in Malaysia

Geographically, Malaysia has ample supply of sun radiance and to fully utilize it to its full potential, the government is strengthening the R&D base in PV to support the growth of Malaysia PV industry, focusing on grid-connected BIPV applications in urban areas. The five-year MBIPV project [14] has created a solid foundation BIPV market by achieving a 440% increase in solar BIPV system application from year 2005 to 2010 [15]. According to the Tenth Malaysia Plan, the BIPV application is expected to be more economically viable by 2017 thus enabling end-users to have a cheaper, reliable supply of electricity with reduced losses as well as reducing the energy demand peak. Feed-In Tariff (FiT) is introduced to help develop new markets for the PV industry and Malaysia already has her very own FiT mechanism under the Renewable Energy Act, which commenced on 1st December 2011. BIPV end-users will have a chance to sell generated PV to power utilities for a specific duration at a fixed premium price. For PV installations, the the FiT duration is 21 years, rating from Rm1.25 - 1.75 per kWh with annual degression of 8% to promote grid parity [16]-[18].

2.4 PV Drivers and Benefits

There are many drivers when it comes to integrating grid-connected PV into electrical power systems. It is vital to create a sustainable energy platform with minimal impacts to the system as well as the environment. With PV microgeneration at residential and commercial areas, carbon emission is close to minimal thus reducing green house gases. By 2020, renewable energy generation in Malaysia is targeted to be around 2080MW with estimation of 42.2mt cumulative CO_2 emission avoided [16]. A 3kWp solar installation in a residential unit could offset 81 tonnes of CO_2 emmision [19]. National policy is another important driver whereby policy-makers are focusing on more sustainable energy resources. Malaysia has just introduced her first Renewable Energy Act 2011 and Sustainable Energy Development Authority Act 2011 with solar energy as the prime focus in the country [20]. The National Renewable Energy Policy is targeting a minimum of 220MW from solar power generation by year 2020 according to the Malaysia Economic Transformation Program [21]. Furthermore, PV microgeneration reduces the total capacity needed in the entire electrical network. Power station, transmission and distribution burden will lessen, decreasing the amount of centralized power generation and preventing distribution system overloads during peak times [22]. Losses on transmission and distribution networks are often credited to microgeneration thus integrating PV systems in the LV network is expected to improve the energy efficiency within the network [23]-[25].

2.5 Theory on Large-Scale PV Technical Impacts

There are many technical impacts related to PV integration namely, voltage unbalanced, system faults, network losses, stability as well as power quality but only power losses and voltage deviations will be discussed as these two impacts are the ones being assessed in this project.

2.5.1 Reverse Power Flow

Theoretically, power flows from the high voltage to the low voltage in an electrical grid. PV systems generally have little effect on the overall electrical grid but with high penetration of PV in the grids, the conventional theory may be defied. When PV generation starts to exceed local demand, the surplus energy from PV may be fed back to the grid, altering the power flow [26]-[28]. The distribution network is no longer a passive circuit supplying to end-users, but an active system with power flows determined by magnitude of demand and power generation. According to norm, distribution networks are designed for unidirectional flow thus a reverse power flow would inject power into the transmission grid, and potentially damaging transformers, cables and generators.

2.5.2 Voltage Deviation

The deployment of large-scale PV generation amplifies the technical impacts inflicted by its intermittent nature, which causes output power fluctuations. At low demands, PV output leads to voltage rise. Case studies [26]-[30] prove that high penetration of PV might deviate voltages from its permissible limit (-10% +5% on 240V). In case study [31], voltage rises are within allowable limits when PV penetration is 100% in a residential and commercial network, given that the PV are uniformly distributed.

2.6 Smart Integration of PV

PV systems are connected parallel to the load whereby generated energy decreases the apparent load. When generation of PV exceeds the load demand, energy flows into the distribution system. Malaysian distribution networks are conventionally designed for one-way power flow, thus a large reverse power flow might impose serious issues to the voltage levels and system regulation. Therefore, proactive measures have to be taken in order to incorporate a substantial amount of grid-connected PV. In other words, smart integration of PV [32] should be practised. Network reinforcement in existing networks might be crucial to mitigate the technical impacts, whereby transformers and generator ratings may have to be set higher to accommodate higher degree of PV in future. According to Macdonald's study in [26], power flows, faults and voltage levels are within allowable limits in areas of 100% PV penetration given the tap-changers are modified. Case study [33] uses Minimum Import Relay MIR) and Reverse Power Relay (RPR) to disable the PV system when it starts to export to the utility side, and also suggested Dynamic Controlled Inverter System (DCI) to reduce PV output power when required. As for DTI report [34], they have suggested long term solutions for network reinforcement. Table 2.1 below explains the suggestions:

Table 2.1 Solutions for Network Reinforcement

Fault Level Solution
Addition of superconducting device
Addition of switching device

Voltage Control Solution
Usage of voltage regulators
Usage of StatCom

Power Flow Solution
Initiate demand-side management

2.7 Cost and Benefits

When reverse power flows and voltage rises occur due to high PV penetrations, network reinforcements and active management are vital to maintain a healthy power system. This is where the cost and benefits aspect comes in.

2.7.1 Network Reinforcements

The increasing BIPV applications in Malaysia have not significantly inflicted technical impacts to the electrical grid. However it is expected that Malaysia distribution networks will have a large deployment of BIPV in the near future, whereby existing networks may need upgrading to mitigate problems of high PV capacity. According to case study [27], less reinforcements are required when distributed generations are allocated along 2/3 in a grid. Since network reinforcements are more plausible in high PV density, PV integration should be evenly distributed to minimize reinforcement costs. A cost-effective way of network reinforcement is to remain the expensive parts of the distribution system and enable an interactive communication and control of the entire system. SEGIS concept [35] recommends management of power flow transitions and interfacing between the utility and the distributed generation. The 11kV lines are mostly driven by voltage constraints while the 33kV/11kV substations are driven by thermal constraints. In case study [26], Macdonald states that it is more economical to reduce the average 11kV voltage in large number of pole-mounted transformers than changing individual transformer tap changer. He also states that in future, it is possible for microgeneration to offset expected load in new sites thus network reinforcement could be reduced.

2.7.1.1 Implications of Network Reinforcement

Generally, network reinforcement improves power quality but electrical supply to end-users will be interrupted during upgrades which require shutdown. Distributed generators might face intricate planning of new lines construction and deep connection cost [34]. Besides, network enhancement increases short-circuit levels which amplify fault levels issues whereby local utility may have to deal with. In a nut shell, network reinforcement may seem to be a technically viable solution to mitigate technical impacts from large PV deployment but it is also very costly.

2.7.2 Active Management

Traditionally, the distribution system is a passive network with unidirectional power flow and has minimal control intervention. System integration of PV results in multidirectional power flow in the electrical grid. Active management is essential in a distribution network with increasing PV penetration [36]. It is a coordinated, real-time control of multiple network components used by the network utilities when dealing with distributed generation in the electrical grid [37][38]. The Active Power-Flow Management (APFM) scheme has been thoroughly analyzed by Currie [37] and he has come out with a framework in implementing such scheme in UK distribution network.

According to the case study [27], implementation of active management in rural networks could save up 50% of the upgrading cost when DG is 5GW. But there are implementation costs for active management too, which depends on cost of components and number of problem feeders. As for urban networks, high penetration of PV causes system faults which need replacement of equipments with higher rating such as switchboards. Thus the cost of active management is the sum of cost of switchboard replacements and cost of active management implementation. Figure 2.2 and Figure 2.3 [39] explain the two different approaches in new network designs. The difference between these two is that active management takes distributed generations (DGs) into account during network designs.

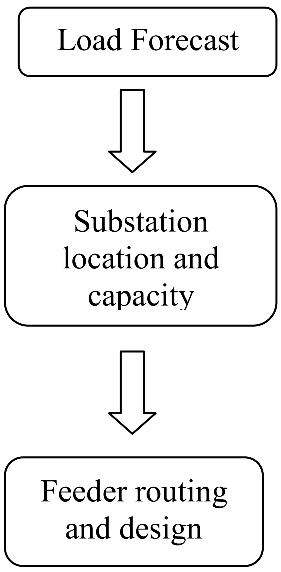

Figure 2.2 Classical Approach

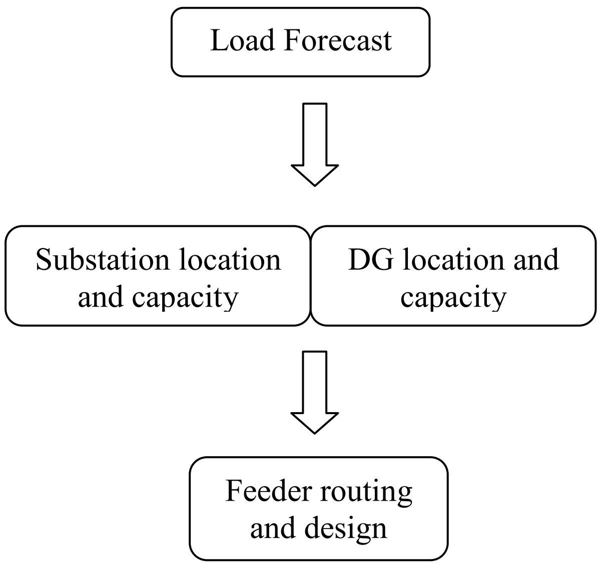

Figure 2.3 Active Network Planning

2.8 Distribution Networks

The distribution system consists of medium and low voltage networks, delivering electricity to different voltage users such as to residential, commercial and industrial networks. The performance of a distribution network is determined by the network design, technology and regulatory requirements set by TNB in Malaysia [43]. TNB holds the sole responsibility in managing the electrical grid assets, network connections, grid operations, metering and billing. The TNB Distribution Code states all the criteria for network planning, design and operation to meet the power quality standards and ensure supply security. In low-voltage network supply security, power will be restored in less than 24 hours in case of any forced outage [43]. With increasing PV capacity at the end-user, distributed generation should be a factor to consider in future network designs.

2.8.1 Distribution System Planning with High PV Capacity

Network planning is important to optimize network performance and to obtain maximum benefits. Planning horizon for distribution network in a district is two years while in a state is five years [40]. To determine the network architecture, equipment sizing and network operation, these planning considerations are taken into account:

- **Types of load, load density and load growth**
  Load forecasting is carried out by using software analysis using actual data obtained from the electrical feeders.
- **Security standards**
  According to APS report [40], connected distributed generation in Malaysia should be 15% below the minimum expected daily demand of the distribution system to ensure that the security supply level is satisfied.
- **Technology**
  With PV installations at the end-users side, bidirectional power flow calls for smart metering system as well as Intelligent Electronics Device [38][41] for communication and control of the active network.
- **Minimization of cost**
  Every network planning would prioritize optimal performance with minimal expenditure. Installing a bigger size transmission cable in a new network to

mitigate the impacts of PV penetration may be more cost-effective than network reinforcement in future.

2.9 Malaysia Statutory Requirement for Distribution Network Design

To guarantee a continuous, quality supply to consumers, TNB has set the network performance requirements and limits in the Electricity Supply Application Handbook [43]. Table 2.2 shows the various statutory requirements for Malaysian distribution network planning.

Table 2.2 TNB standards for distribution network planning (415V & 240V)

Steady-State Voltage Variation	-10% +5%
Voltage Flicker	$0.8P_{st}$
Voltage Unbalance	< 1% in 30 minute period
Voltage Regulation	±5%
Short-Circuit levels	31.5kA for 3 seconds
Earthing type	T-T connection
Total Harmonic Distortion (THD level)	5%

Evidently, many countries have carried out thorough research [24]-[34] on PV integration in their electrical grids, preparing themselves for prospective grid developments and future investments. As a developing country that is making headway in grid-connected BIPV systems, Malaysia needs to be prepared to accommodate high degrees of PV penetration especially in medium to low voltage network. This research is to assess the impacts of PV integration in Malaysia distribution grid, using Malaysian public network topology with typical distribution parameters and load profiles.