The Impact of Grid Connected Photovoltaic Generation System to Voltage Rise in Low Voltage Network

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Abstract: - Photovoltaic (PV) generation is now growing rapidly throughout the world with most new PV installations are grid-connected small-scale system. From power utility point of view, the main issue and concern related to PV grid-interconnection is voltage rise or over voltage in their network. This paper describes the simulation studies focus on the aspect of PV penetration level in low voltage (LV) networks before violating its voltage limit. Many scenarios for LV networks such as different network configuration and different loading conditions are modeled and analyzed using commercially available power system software to determine the PV penetration level. Total capacity of PV systems that can be accommodated at the connection points of LV network with respect to the loads is determined.

Key-Words: - Photovoltaic (PV), low voltage (LV), voltage rise, PV penetration

1 Introduction

Photovoltaic (PV) power generation is growing at a rapid rate globally. Most new PV installations are grid-connected small-scale system. In Malaysia, attractive incentives in feed in tariff (FIT) mechanism introduced by The Sustainable Energy Development Authority (SEDA) of Malaysia since 2011 has resulted in many grid-connection applications of PV generation system to Malaysia power utility, Tenaga Nasional (TNB). PV grid interconnections must be properly designed and controlled to avoid negative effects on the distribution network such as voltage rises, increase in technical losses and power quality problems. Thus it is vital to study the impact of high levels PV penetration on the utility grid.

Previous studies have focused on modelling and simulation of the PV generation system to achieve optimum interface between PV generator and grid. In [1], the simulation tools are developed using popular electromagnetic transient simulation program PSCAD/EMTDC and include a PV array model, maximum power point tracking controller model, and a grid connected inverter. However, the study does not consider the whole bulk system.

For an in-depth study of the grid performance with PV penetration, better models to represent PV systems are required. PV systems should be represented in bulk system studies to the extent they can impact the grid performance. Recent study [2] describes the power flow representation and generic positive-sequence dynamic stability models for use in grid-interconnection and planning studies. This effort covers representation of both central-station and distributed PV, from the point of view of the bulk system. The dynamic generic models are designed to become part of the standard model library in commercial simulation software.

As maintaining voltage level to certain variation and limits is crucial to power utility, this study focuses on the impact of voltage rise to the TNB low voltage (LV) network due to grid-connection of the PV generation system. Effects of various levels of

PV penetration on LV feeders are modeled and analyzed using commercially available software to determine the total capacity of PV systems that can be accommodated at the connection points, with respect to the network loads.

2 PV Modeling Using Power System Software

Two different power systems software are used for simulation, namely PSCAD and DIgSILENT for comparison and validation purpose.

2.1 PV Modelling in PSCAD and DIgSILENT Based on Manufacturer's Data

In this study, the PV modeling is performed using monocrystalline PV technology based on the Sun Power 305 solar panel model manufacturer data. The Sun Power 305 Solar Panel utilizes 96 back-contact monocrystalline solar cells. It can deliver a total panel conversion efficiency of 18.7%. The PV cell and array parameters have been set according to the data in Table 1 and 2.

Table 1: Monocrystalline cell parameters

Effective area per cell (m^2)	0.015
Series resistance per cell (ohm)	1×10^{-5}
Shunt resistance per cell (ohm)	1×10^{5}
Diode ideality factor	1.121
Band gap energy (eV)	1.103
Saturation current at ref. conditions per cell (A)	1×10^{-9}
Short circuit current at ref. conditions per cell (A)	5.96
Temp. coeff. of photo current (A/K)	0.0035

Table 2: Monocrystalline array parameters

Modules connected in series per array	11
Strings connected in parallel per array	1
Cells connected in series per module	96
Cell strings in parallel per module	330

2.2 Validation of Monocrystalline Cell Open Circuit Voltage and Short Circuit Current Simulation

To validate the developed model in PSCAD and DIgSILENT, cell open circuit voltage and short circuit current simulations are carried out. Open circuit voltage is achieved when short circuit current is zero and vice-versa. No power is generated under short or open circuit condition. The test is carried out at the standard test condition (STC); i.e., radiation is at 1000W/m^2 and temperature at 25°C.

The results of the cell open circuit voltage and short circuit current simulated using PSCAD are shown in Fig. 2 and 3 respectively.

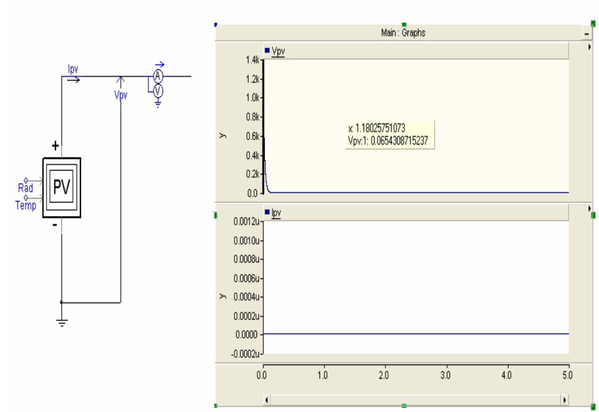

Fig. 2: Monocrystalline Cell – Open circuit voltage (V_{oc}) test using PSCAD

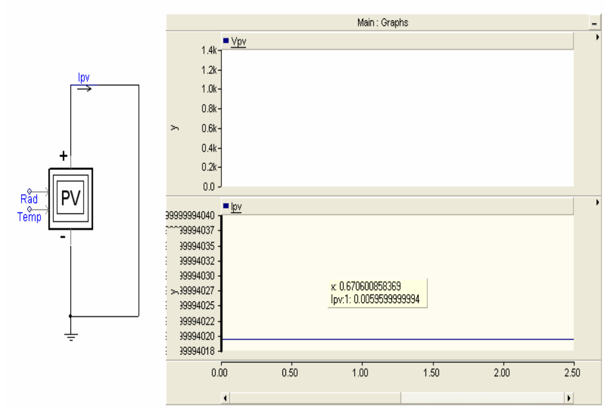

Fig. 3: Monocrystalline Cell – Short circuit current (I_{sc}) test using PSCAD

Fig. 4 and 5 illustrate the simulation results using DIgSILENT of cell open circuit voltage and short circuit current correspondingly.

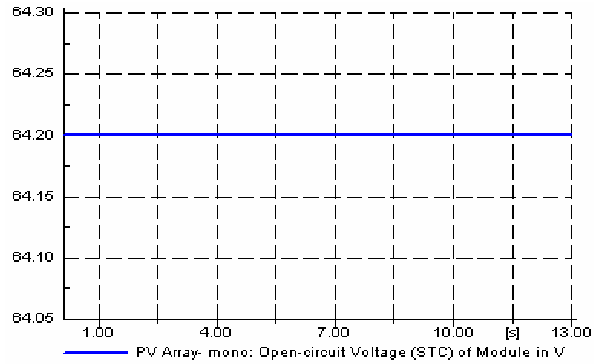

Fig. 4: Monocrystalline Cell – Open circuit voltage (V_{oc}) test using DIgSILENT

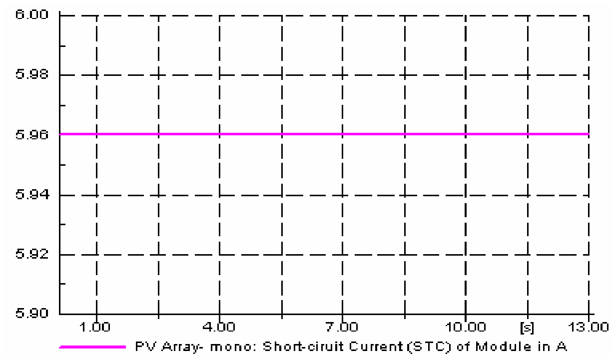

Fig. 5: Monocrystalline Cell – Short circuit current (I_{sc}) test using DIgSILENT

The I-V Characteristic curves from PSCAD and DIgSILENT simulations are shown in Fig. 6 and 7 respectively. The open circuit voltage test of the simulation shows 65.43V_{rms} and 64.2V_{rms}, while the short circuit current test shows 5.959A and 5.96A for the PSCAD and DIgSILENT models respectively. This result matches the result of the manufacturer data.

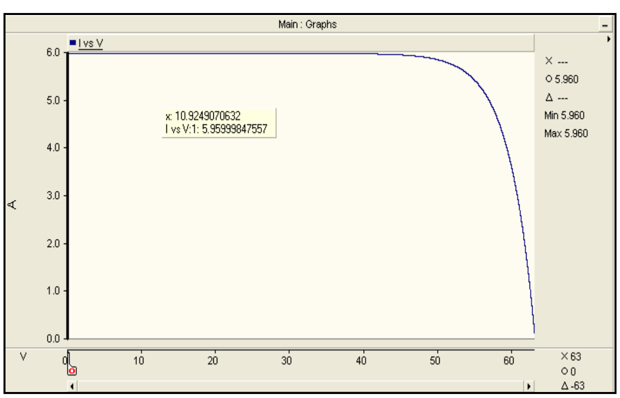

Fig. 6: I-V Characteristic of Monocrystalline Model using PSCAD

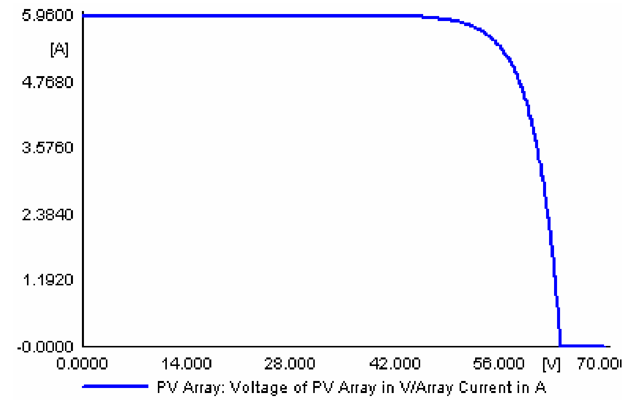

Fig. 7: I-V Characteristic of Monocrystalline Model using DigSilent

2.3 Environmental Variables

The solar radiation data is of high-resolution, 3-minute samples. This data is obtained from Putrajaya area through a pyranometer recording. However, the temperature data is of lower resolution. Fig. 8 and 9 are graphs of the data that is acquired and subsequently input into the PV module in PSCAD and DIgSILENT.

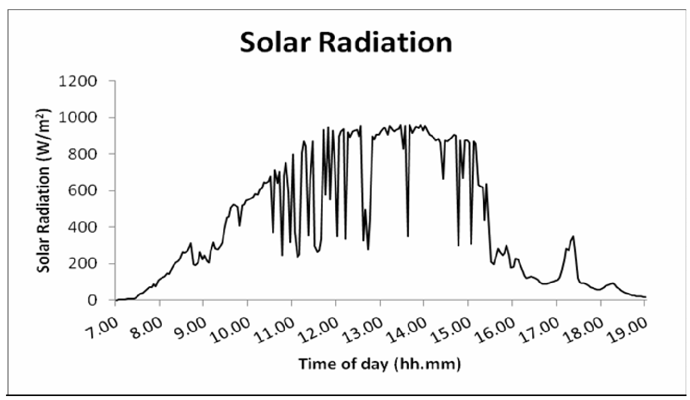

Fig. 8: Solar radiation data

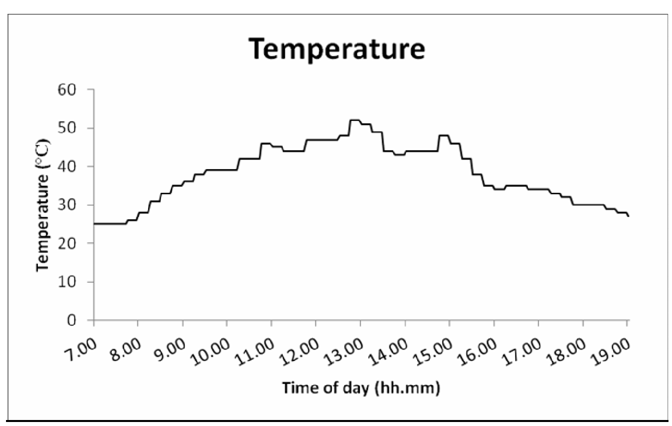

Fig. 9: Temperature data

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The highest level of solar radiation in the data is 962.352 W/m^2, which occurs at 1.54 pm and a cell temperature of 43°C. There are large fluctuations throughout the day, due to cloud shading effects. The fluctuations reach levels of above 500 W/m^2.

3 Low Voltage (LV) Distribution Network Modelling

3.1 LV Network Component Models Using PSCAD

The following Fig. 10 shows LV network model that has been created in PSCAD.

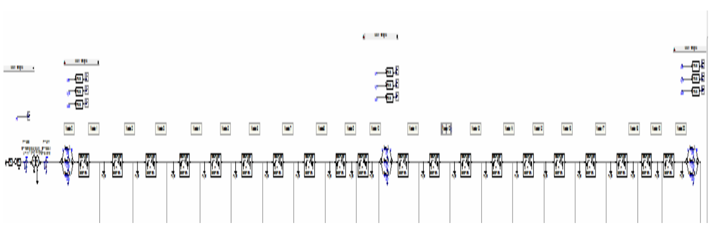

Fig. 10: PSCAD modelling of TNB typical LV network

In this typical TNB radial LV network, underground cable of 185mm^2 4 core XLPE Aluminium (Al) are used between the LV distribution board and the first pole. This network consists of 19 spans of overhead aerial bundled cables (ABC) of 3x185mm^2+16mm^2 + 120mm^2 with 20 poles of spun concrete. A 500 kVA transformer with delta-wye neutral configuration is used for this network.

Parameters of the transformer, underground and overhead cables used in the simulation are based on manufacturer's data. The source parameters such as positive and zero sequence source resistance and reactance are obtained from TNB main-intake substations fault level database.

In order to verify the model of LV networks that have been developed, simulation of voltage drop is conducted with no PV penetration and varying the fixed load. The theoretical calculations of voltage drop of the LV network with different loads are then compared with the simulation results. The calculations of voltage drop of the LV network with 10% loading of the LV network are compared with the simulation results of the LV network with 10% loading verify that the model developed in PSCAD is in close approximation to the actual one.

3.2 Simulation of Grid-connected PV System in LV Networks

To simulate the impact of LV distribution network together with the loads and penetration of PV systems, the complete network is modelled and simulated using PSCAD, as shown in Fig. 11. The simulation is based on the parameters below:

- Maximum PV connected: 9 kW/pole
- Maximum total PV connected: 180kW
- Maximum total Load: 180kW
- Uniform and Fixed load

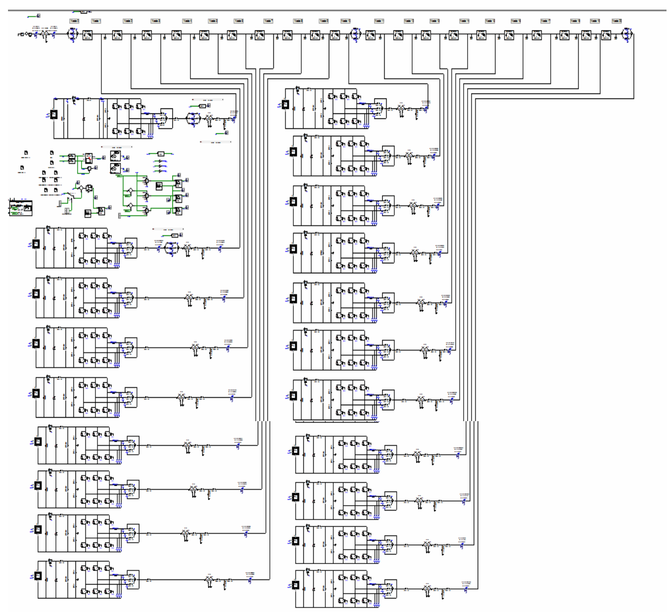

Fig. 11: PV System Connected to LV Network Simulation Using PSCAD

To determine the total capacity of PV systems that can be accommodated at the connection points, the voltage rise magnitudes (%) at every pole are determined with respect to the total capacity of the loading on the LV networks.

4 Voltage Profile Results Using PSCAD

Voltage rise studies are carried out to determine the effects of PV on the system voltage levels. The statutory tolerance for voltage excursion on the TNB LV distribution network is +10% and -6% of the nominal value of 230V, which is in the range of 253V to 216V. To determine the total capacity of PV systems that can be accommodated at the connection points, the voltage rise magnitudes (%) at every pole and loads are determined with respect to the total capacity of PV systems on the networks.

The allowable PV volumes that can be accommodated on the networks before the voltage magnitude at any points of the networks violate the limits are determined based on the following scenarios:

- Scenario 1: PV penetration to LV network with fault level of 18kVA
- Scenario 2: PV penetration to LV network with fault level of 2kVA
- Scenario 3: PV penetration to LV network with penetration from the end of the LV network (fault level 2kA)
- Scenario 4: PV penetration to LV network with different size of overhead cable

For each scenario, the LV network and PV system parameters are based on the following assumption:

- 19 span of ABC 3x185mm^2 +16mm^2 + 120mm^2
- Uniform and fixed load
- Maximum loading of 180kW
- Maximum PV connected: 9 kW/pole or 180kW PV

The allowable PV volumes are determined based on varied network loads as well as PV capacity.

4.1 Scenario 1: PV Penetration to LV Network with Fault Level of 18ka

With the previously mentioned parameters of LV network and PV system, simulation is done based on penetration from the nearest pole to the substation with the fault level of 18kA. The results are tabulated in Table 4.

Table 4: Simulation Results for PV Penetration from the Nearest Pole to the Substation (Fault Level 18kA)

Network Loading	PV Penetration level before violating upper Voltage limit	PV Penetration level before violating lower Voltage limit
No Load	30%	-
20%	35%	-
40%	50%	-
60%	70%	-
80%	90%	-
100%	100%	-

Table 4 shows the percentage of allowable PV volumes that can be accommodated by the LV networks before the voltage magnitude at any points exceeds the limits.

In normal operation where the PV generator is connected, the voltage falls along the line because of the line impedances. It is also shown that, for uniform distribution of PV, the total amount of PV that can be installed on the LV networks before causing any voltage rise violation is about 30% of the total load demand.

4.2 Scenario 2: PV Penetration to LV Network with Fault Level of 2kA

In scenario 2, PV penetration level results are based on the PV penetration from the nearest pole to the substation where the fault level is 2kA. The results are tabulated in Table 5.

Table 5: Simulation Results for PV Penetration from the Nearest Pole to the Substation (Fault Level 2kA)

Network Loading	PV Penetration level before violating upper Voltage limit	PV Penetration level before violating lower Voltage limit
No Load	20%	-
20%	35%	-
40%	45%	-
60%	65%	-
80%	85%	-
100%	100%	-

As shown in Table 5, the total amount of PV that can be installed on the LV networks before causing any voltage rise violation is about 20% of the total load demand for the feeder loading.

4.3 Scenario 3: PV Penetration from the Furthest Pole with Fault Level 2kA

In scenario 3, the PV penetration is simulated from the furthest pole to the substation, using the same parameters in scenario 2. The results indicate that the total amount of PV that can be installed on the LV networks before causing any voltage rise violation is about 10% of the total load demand for the feeder loading, as shown in Table 6.

Table 6: Simulation Results for PV Penetration from the Furthest Pole to the Substation (Fault Level 2kA)

Network Loading	PV Penetration level before violating upper voltage limit	PV Penetration level before violating lower voltage limit
No Load	10%	-
20%	35%	-
40%	55%	-
60%	80%	-
80%	95%	-
100%	100%	-

4.4 Scenario 4: PV Penetration to LV Network with Different Cable Size

Different cable size of $95mm^2$ is used in scenario 4, and the simulation is based on fault level of 2kA and PV penetration from nearest substation. In general it can be seen that the penetration level is much higher when smaller cable size is used supplying the same loadings.

Based on the simulation results, PV penetration levels for the LV networks with high fault level is higher compared to the LV network with lower fault level before causing any voltage rise violation with penetration from the nearest pole to the substation, as shown in Table 7 below.

Table 7: Summary of PV Penetration Level for Different Scenarios

	PV Penetration level before violating upper Voltage limit			
Scenario	Scenario 2 ABC 185,18kA from nearest pole	Scenario 3 ABC 185, 2kA from nearest pole	Scenario 4 ABC 185, 2kA from furthest pole	Scenario 5 ABC 95, 2kA from nearest pole
No Load	30%	20%	10%	60%
20% Loading	35%	35%	35%	80%
40% Loading	50%	45%	55%	95%
60% Loading	70%	65%	80%	>100%
80% Loading	90%	85%	95%	>100%
100% Loading	100%	100%	100%	>100%

PV penetration levels for the LV networks with penetration from the furthest pole to the substation is higher compared to the LV network with penetration from the nearest pole to the substation before causing any voltage rise violation, especially when high loading.

The simulations of PV penetration level as described above are also performed using DIgSILENT software. Simulation results using DIgSILENT are considerably consistent and equivalent to PSCAD.

5 CONCLUSIONS

In general, PV penetration levels between 10% to 30% of its capacity, with respect to network load are feasible in typical Malaysia LV networks. PV penetration levels for the LV networks with high fault level are higher compared to the LV network with lower fault level. PV penetration levels for the LV networks with penetration from the furthest pole to the substation is higher compared to the LV network with penetration from the nearest pole to the substation before causing any voltage rise violation, especially when high loading.

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