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Impacts of Solar Variability on Distribution Networks Performance

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Abstract
The Distributed Generation (DG) and renewable energy resources have been identified as one of the promising ways to sustain the future energy needs. However, most of the energy produced by DG and renewable energy, particularly the Photovoltaic (PV) system is intermittent in nature and often fluctuates. In this regard, this paper utilizes the Malaysian Reference Network (RN) that aims to analyse the impact of PV integration at the medium voltage (MV) network under solar variability conditions. More precisely, the network losses and voltage issues were evaluated on various PV variability indices (VI). This case study has been carried out in the urban and rural MV networks. Various PV variability days have been considered in the case study. The results show that fluctuation of network losses and voltage could pose a concern for PV integration on the MV network.

Keywords: Reference network, Malaysian network, PV system, Network losses, Variability index

INTRODUCTION

Enormous amounts of non-renewable resources are being utilized every day to meet the increasing energy requirement, mainly in the industrial sector. Other sectors like transportation, commercial and residential also accounts for energy-related carbon emissions. In Malaysia, the electricity generation, industry, transport and residential are the four major sectors that require a high demand of energy and consequently become huge contributors of CO_2 emission. A study shows that by the year 2020, the total CO_2 emissions of will reach 285.73 million tons [1]–[3]. In this regard, the Malaysian government had set a proactive target to reduce carbon emission intensity by 40% [4] in parallel with the vision to become a high-income nation by 2020 [4], [5].

Installation of distributed Solar Photovoltaic (PV) has become one of the popular alternative energy resources in Malaysia [6],[7]. 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. This FiT scheme acknowledges great responses, especially for the grid-connected PV systems [7], [8].

Meanwhile, the energy produced by solar energy is intermittent and often fluctuates [9], [10]. The integration of PV in medium voltage (MV) or low voltage (LV) network system might jeopardize the entire system which was not particularly designed to this integration of PV system [11]–[13]. The main concern is that PV system may affect the network performances and efficiencies such as voltage instability and increased network losses [14], [15]. The integration of PV system in Malaysia network system also implies big challenges in analysing technical and economical impact of the system. This is mainly due to the conventional nature of the Malaysian network system which has not been designed to accommodate the integration of the distributed energy resources (DER). Several studies such as impact due to passing clouds, PV variability, and technical performance on network require time series analysis for time resolutions of seconds, minutes and hours [16], [17]. On this subject, plenty of studies have been done to investigate the technical performance of the network system when integrated with the PV system. Nevertheless, these researchers simulate their results based on the IEEE 8500-node test feeder which is found on a North American medium voltage (MV) [18]. These test networks are not realistic to countries like Malaysia because of the different fundamental architecture of the distribution system and hence impose different impacts from distributed energy resources as well [19], [20]. Therefore, this study using the Malaysia reference network (RN) synthesizes from generic characteristics to evaluate the PV impact that relates to the Malaysian network.

The work presented in this paper is part of an ongoing research to investigate and quantify the effect of high penetration level of PV system on the MV distribution networks.

MODELLING

The loads and PV models outlined below provide input data for load-flow analysis, which calculates losses throughout the network. As mentioned, the IEEE 8500-node test feeder which is commonly used by researchers was found to be less suited to countries like Malaysia. Consequently, two reference networks (RN) were modeled in the DIgSILENT software package. These reference networks were modeled using the generic characterization and summarized parameters of RN in Malaysia which were obtained from the literature [19]. Two reference networks, urban and rural networks with voltage transformations of 132/33/11kV were modeled to study the impacts of solar variability.

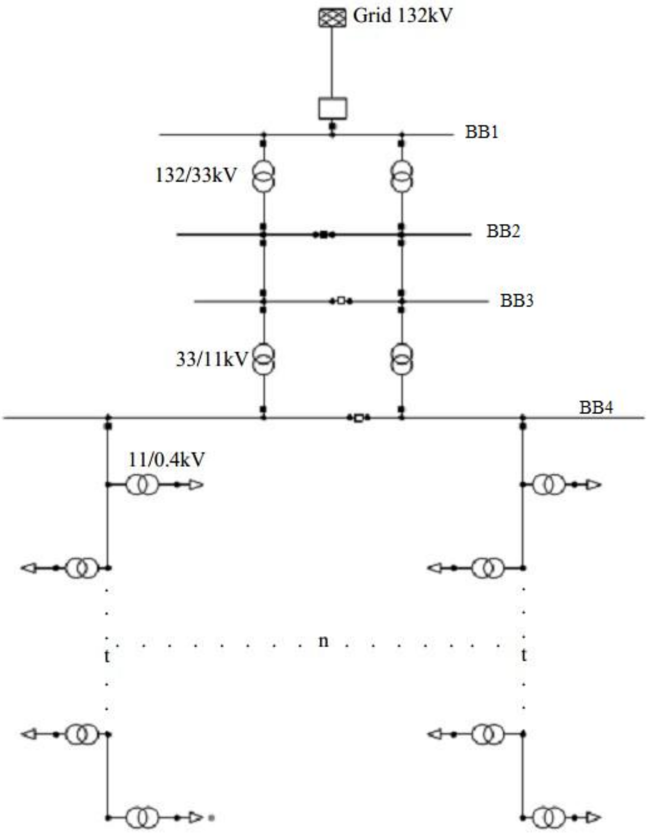

Figure 1: Model of Reference Network[21]

Note:
BB1 = Busbar 132kV (Transmission Main Intake)
BB2 = Busbar 33kV
BB3 = Busbar 33kV at 33/11kV primary substation
BB4 = Busbar 11kV
n = No of 11kV feeders
t = No of 11/0.4kV TX per 11kV feeder

The line diagram in Figure 1 shows the reference network for 132/33/11kV voltage transformation. It consists of two-voltage transformation stages, i.e., from 132/33kV and 33/11kV primary substations.

The second column in Table-1 shows the parameters [19] for the development of the urban network. Five 11kV feeders is connected to each of the 33/11kV transformers. Each 11kV feeder is connected to five 11/0.4kV transformers. 33/11kV and 11/0.4kV transformer capacities is set to 30MVA and 1MVA, respectively [22]. The total load for each of the low voltage (0.4kV) transformer is 560kW with an assumed power factor of 0.90 lagging [23]. The average distance between the 11/0.4kV distribution transformers was 600 meter where the average total length of each 11kV feeder was 3km.

The third column (Table-1) shows the parameters for the rural network, RN#3. The maximum demand is 123kW for each of the 11/0.4kV transformer. The average length of 33kV line in rural network is much longer compared to network type. In addition, it has the average 11kV feeder length of 31.5km connected with 15 units of 11/0.4kV transformers. The distance between each 1MVA rated 11/0.4kV transformer is assumed to be 2.1 km.

Table 1: The Parameters of RN

Parameters	Urban	Rural
Total MD for Reference Network, MW	24.18	9.2
No of 11kV Feeders per 33/11kV Transformer, n	5	3
No of 11/0.4kV Transformer per 11kV Feeder, t	5	15
Length 33kV Line, km/ each	5	18
33/11kV Transformer Capacity, MVA	30	30
11kV Feeder Length per Feeder, km/feeder	2.6	26
11/0.4kV Transformer Capacity, MVA	1	0.5
Distance between TX 11/0.4KV, km/each	0.6	2.1
Consumer Type, % (Residential/Commercial)	80/20	67/33
Proportion, per 11kV Feeders (Residential/Commercial)	4/1	2/1

The cable selection must be calculated according to the standards which is based on the maximum allowed current and maximum voltage drop. The important factors that influence the cable sizing are voltage rating, ampacity, thermal conditions, short circuit withstand and type of installation [24], [25]. From the power line calculation and utility requirement, there are two cable sizes selected and used to design the reference networks. In this research, the 33kV line and 11kV line were sized per the standard. The 500mm^2 cable size, rated for 33kV is connected from the transmission main intake to the main distribution sub-station. Next, the 240mm^2 line is used for 11kV feeders for the both RNs which within the range as reported from the utility requirement. Both 500mm^2 and 240mm^2 size cables were used with Aluminium (Al) as the conductor and Cross-Linked Polyethylene (XLPE) as the insulation.

The transformers are connected in parallel for 132/33kV and 33/11kV transformers. In Malaysia most of the transmission and distribution network are connected with parallel transformers [26], [27]. By referring to the standard and utility requirement, the transformers are modeled based on three major parameters:
a) Has adequate capacity to handle the maximum demand
b) Considers increases of maximum demand in future
c) Includes operational costs

By referring to the above requirements and calculation, appropriate transformers rating is chosen for this modeling.

Four types of transformer are used in the reference networks models, rated 45MVA, 30MVA, 1MVA and 0.5MVA. All the transformers are used to step-down the voltage, where 45MVA is used to step-down from 132kV to 33kV, 30MVA for 33kV to 11kV while 1MVA and 0.5MVA for the 11kV to 0.4kV. The 45MVA power transformer is connected in a wye-wye connection. For the distribution transformers 0.5MVA (11/0.4kV), 1MVA (11/0.4kV), 30MVA (132/33kV) transformers are delta-wye connected [28].

Photovoltaic System (PV)

The PV system outputs have been obtained based on one-minute resolution radiation data measured at The Research Laboratory of Solar PV Systems and Smart Grid at Universiti Teknikal Malaysia Melaka (UTeM). Three different solar variability days, namely clear sky day, moderate VI day and high VI day have been extracted from the data as shown in Figure 2.. Since these three profiles contribute high and fluctuating PV generation, which is the most demanding case in terms of network losses. A maximum of 100% PV penetration cases has been assumed in all the cases which the PV panel pitched roof orientation within 15º of facing south. The 100% PV penetration in this work is determined by the total PV system installed capacity in relation to the total network maximum demand.

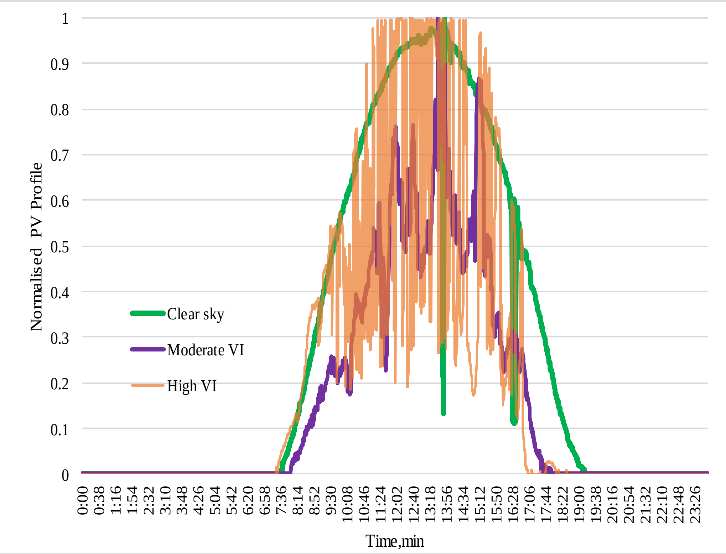

Figure 2: PV generation profile

Impact of PV System

The modeled validated reference networks act as a base case (0% PV penetration) to assess the impact of PV system integration in the MV network. The case study is used to analyse the impact of PV integration.

a) Case study - Evaluation of technical parameters under different PV variability on MV network.

i) Network Losses

ii) Voltage issues (Voltage Fluctuation)

PV Variability

This section is to study the effect PV variability on the Malaysia MV network. In this case study, network losses are the measured parameters for evaluation purposes. Two different PV variability namely clear sky day and high VI generation profiles with 1-minute resolution were utilized to investigate the impact on the Malaysian distribution network. Figure 3 shows the urban network losses in percentage for the base case, clear sky and high VI conditions.

For both the clear sky and high VI condition, the network losses are gradually reduced from sunrise until it dropped by about 0.5% during the afternoon. Then, as sundown approaches the losses went back up to the base case level. It is apparent that for a high VI day the fluctuation of network losses is more observable than a clear sky day. For the clear sky day, although the energy losses are intermittent but not reach as high as the base case. In brief, the results clearly showed that the network losses in urban were decreased after the PV injection. However, the network losses were varying with the solar variability. When there is a clear sky condition, the percentage of the average network losses is reduced to 14.3% from the 1.42% base case network losses. However, there is only 9.1% reduce in average losses during a high VI day. This explains the increasing of VI causes the network losses to fluctuates, resulting in rising network losses.

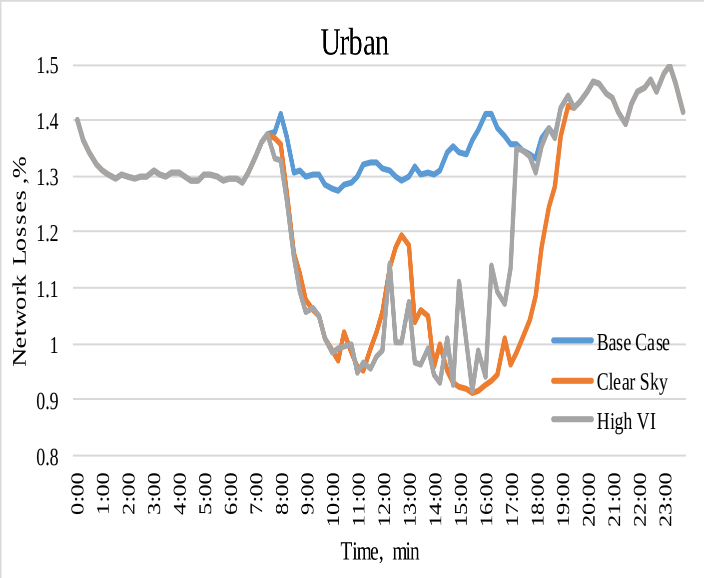

Figure 3: Network losses with different VI (urban)

Figure 4 shows a comparison of energy losses in the rural network under clear sky day and high VI day of the PV profile. The network losses simulation is done using 1-minute resolution. Generally, the rural network may contribute to higher network losses as compared to the urban network. The losses reduction for the clear sky and high VI from the base case are 10.1% and 9.1% respectively. For clear sky condition, the losses drop throughout the injection of PV. However, for the high VI day the losses drop at early of PV system integration but after the midday, the losses start to fluctuate and increase again. For the rural network, the network also experienced losses problem when it injects with PV generation with different variability index.

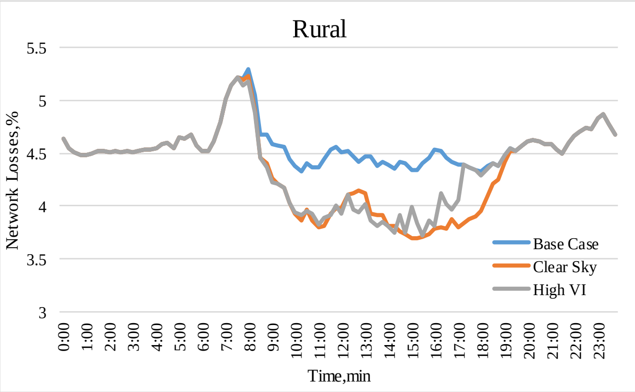

Figure 4: Network losses with different VI (rural)

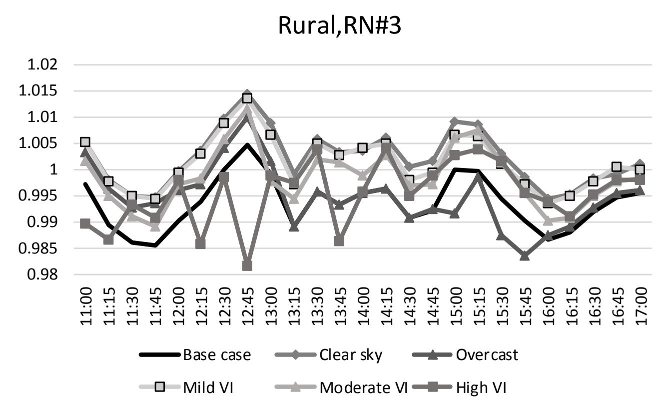

Figure 6: Voltage profile at rural (Peak PV time)

Figure 5 demonstrates the voltage profile at the urban network using five different variabilities; clear sky, overcast and mild VI, moderate VI, and high VI. This case study is simulated with 1-minute resolution of PV profile. The urban voltage profiles for the all five cases explain the integration of PV with various clearness index (CI) and variability index (VI) are less likely to cause voltage problems. Moreover, for the Malaysian urban reference network, this voltage fluctuation are still fall within the statutory voltage limits.

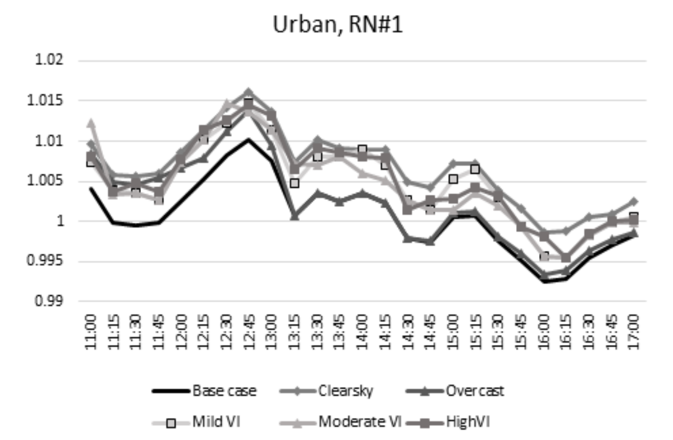

Figure 5: Voltage profile at urban (Peak PV time)

For the rural network, the network experienced the voltage fluctuation when it is injected with PV generation under various variability indices. Therefore, the voltage profile in every simulated PV-VI case was recorded. The one day 1-minute resolution voltage profile at the peak PV time for all the five variabilities in rural area are shown in Figure 6. For the clear sky day the voltage is increased 1% to 3% but there is no voltage limit violation. Besides that, for the overcast day, mild VI and moderate VI, the voltage increase and fluctuation are not significant. The voltage fluctuates actively for the high VI condition, however it does not exceed the +5% standard viable limit.

In conclusion, the 1-minute resolution simulation in a rural and urban network with different types of PV generation profiles causes the fluctuation in losses but still reduces the overall losses in the MV network. The network losses in high solar variability day are seen to be higher than the clear sky day. The network losses for both urban and rural networks in high solar variability day are seen to be higher than the clear sky day but still reduces the overall losses in the MV network. Besides that, five different types of PV variability generation profiles get the positive voltage rise from the base case still within the limits for all the cases. In a nutshell, the voltage in the rural network fluctuates more compare to the urban because of the small load and longer feeder length in the rural area.

CONCLUSION

The studies presented in this paper mainly emphasized on the impact of PV system integration on the Malaysian MV reference networks. The solar generation profiles for different variability types were utilized for the network impact assessment. The network losses and voltage issues have been identified and studied. The overall results clearly indicate that solar irradiance variability is the main factor that could influence the performance of distribution networks. Different categories of clearness index and variability index of the PV generation profiles will have different impact on both the urban and rural MV networks.

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