Necessity of Time-Series Simulation for the Investigation of High Penetration of Photovoltaic Systems in Malaysia

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***Abstract*— The distributed energy resources (DER) have been introduced as one of the promising ideas to sustain the future energy demands. However, the energy produced by DER particularly the photovoltaic (PV) system is intermittent and often fluctuates in nature. In this regard, this paper presents the modelling of Malaysian reference network (RN) that aims to analyse the impact of PV integration at the medium voltage (MV) networks. More precisely, the losses ratio is evaluated with different types of time resolution PV generation profiles. The case studies have considered typical urban, semi-urban and rural MV networks in Malaysia. Different actual time resolution solar PV generation profiles were utilised in the case study. By analysing different ranges of time resolution PV generation profiles, it is suggested that 15-minute time resolution PV generation profiles data are sufficient to be used in the network assessment study with approximately 5% error. The use of hourly PV generation data will result in up to 31% loss of accuracy.**

***Index Terms*— Loss Ratio; Malaysian Network; Network Losses; PV System; Time Resolution.**

I. INTRODUCTION

Immense amounts of fossil fuels are being exploited every day to meet the increasing power necessity in the world mainly in the industry and residential area. 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 [1], [2].

In Malaysia, the electricity generation, industry, transport and residential are the four major sectors require a high demand of energy and a huge contributor to CO_2 emissions. 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 [3]. Look upon this matter, Malaysian Government forms a statutory body named, Sustainable Energy Development Authority (SEDA) and set a clear objective on renewable energy, to achieve up to 985 MW of RE production by 2015 [4]. SEDA is responsible for managing the Feed-in Tariff (FiT) mechanism which is authorised under the Renewable Energy Act 2016 (Act 725) [5], [6]. As of 2015, 1.15GW of RE projects in total were approved by SEDA. From that, approximately 400MW which is one-third of the total is contributed by solar PV system [6].

However, the emerging technologies in distributed generation (DG) and renewable energy (RE) such as photovoltaic (PV), electric vehicles (EV), mini hydros are mainly connected to the low voltage (LV) and medium voltage (MV) networks. These distributed local generators may introduce negative impacts to the operation of the existing networks. Most of the energy produced by the distributed energy resources especially solar PV is intermittent and often fluctuates [7], [8]. The integration of PV in medium voltage (MV) or low voltage (LV) network system might jeopardize the entire system which was not specifically designed for this distributed generation (DG). Mismatch of PV output and load demand causes reverse power flow which introduces new challenges to the network operation [7], [9]. Besides that, PV hosting capacity is different according to the network types where SEDA impose limits that PV capacity cannot exceed the total load demand of the consumer [6]. Increasing PV capacity will affect the network performances and efficiencies such as instability of voltage and increased in network losses.

Related to that, different types of impact analysis studies are required on the distribution network systems. Several studies such as impact due to passing clouds, PV variability, and siting up the PV system is required [10], [11]. Moreover, analysis the technical performance on the network need to specify time series analysis at a time resolution of seconds, minutes or hours. It is not feasible and high in cost to observe and collect one-second data over long periods of time [12]–[14]. Thus, the optimal time resolution of PV generation profile required to measure and analysis the MV network losses should be identified.

Besides that, currently, most of the reference networks or test networks which are available for this research purpose are based on the US and European context. These test networks are not relevant to countries like Malaysia because of the different characteristics of the distribution system and different impacts from the integration of the DG.

In light of the issues discussed above, this research aims to model the Malaysian Reference Network (RN) with the intention to analyse the impact of PV integration at the MV network.

II. METHODOLOGY

A. Reference Network

A Malaysian MV reference network is used in this research. The three RNs were categorized by voltage transformations and the geographic location (urban, semi-urban and rural community) [15]. The network characteristics are captured from the real Malaysian network data and referred to the relevant standards and Grid Code. These reference networks were modelled using generic characterization and summarized parameters of RN in Malaysia obtained from the literature [16], [17]. Three reference networks--urban, semi-urban and rural networks with voltage transformations of 132/33/11kV were modelled to study the impacts of PV system installed location on the 11kV feeder and the different time resolution of PV generation profile.

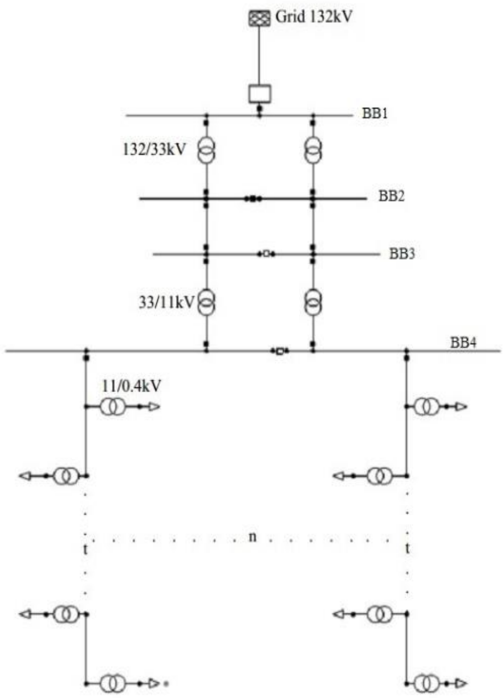

Figure 1: Model of Reference Network

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 comprises two stages of voltage transformation which are from 132/33kV and 33/11kV primary substations.

The parameters for the expansion of the urban network is shown in the second column of in Table 1 [16]. Five 11kV feeders were connected to each of the 33/11kV transformers. Each 11kV feeder was connected to five 11/0.4kV transformers. 33/11kV and 11/0.4kV transformer capacities were set to 30MVA and 1MVA, respectively [18]. The total load for each of the low voltage (0.4kV) transformer was 560kW with an assumed power factor of 0.90 lagging. The average distance between the 11/0.4kV distribution transformers was 600 meter whereby the average total length of each 11kV feeder was 3km.

For semi-urban network (Table 1), four 11kV outgoing feeders were connected to each 33/11kV transformers. Each 11kV feeders consist of 8 units of 11/0.4kV transformers. The length of the 33kV line from Transmission Main Intake (PMU) to the 33/11kV transformer was 9.4km. The total length of per 11kV feeder was 9.6km whereas the distance between 11/0.4kV transformers was 1.2km each. The 33/11kV and 11/0.4kV transformer capacities were 30MVA and 1MVA respectively. The LV transformer had the maximum demand of 300kW.

Table 1 shows the parameters for the rural network, RN#3. The maximum demand is 123kW for each 11/0.4 transformer. The length of the 33kV line from 30MVA rated 33/11kV transformer is much longer as compared to urban and semi-urban which is 18km. One 11kV feeder with the length of 31.5km is attached to 15 units of 11/0.4kV transformers. The distance between each 1MVA rated 11/0.4kV transformer is 2.1 km.

Table 1
The Parameters of RN [16]

Parameters	Urban	Semi-urban	Rural
132/33kV transformer capacity, MVA	45	45	45
Total Maximum Demand for Reference Network, MW	28	19.2	11
No of 11kV Feeders per 33/11kV Transformer, n	5	4	3
No of 11/0.4kV Transformer per 11kV Feeder, t	5	8	15
Length 33kV Line, km/ each	5	9	18
33/11kV Transformer Capacity, MVA	30	30	30
11kV Feeder Length per Feeder, km/feeder	3	10	26
11/0.4kV Transformer Capacity, MVA	1	1	0.5
Distance between TX 11/0.4KV, km/each	0.6	1.2	2.1
Consumer Type, % (Residential/Commercial)	80/20	75/25	67/33
Proportion, per 11kV Feeders (Residential/Commercial)	4/1	3/1	2/1

B. Limitation of the Modelling

For the urban, semi-urban and rural reference networks, two units of 132/33kV transformers are set up in Transmission Main Intake. The output 33kV busbar is a normally-closed point where the two transformers will operate in parallel on the same busbar. Next, two 33kV/11kV transformers with 30MVA are used for all the reference networks. These two 33/11kV transformers will operate simultaneously on two separate half-busbars. The two transformers were individually supplied the 11kV voltage busbars, which are separate. Moreover, when one of the transformers is out of service, with any closure of the bus-tie make it one single busbar which can supply by another transformer solely.

Basically, all the transformers and line are choosing base on the load demand. The transformers at Transmission Main Intake, which feed the whole network, are equipped with automatic on-load tap changer which monitored a constant voltage on the 11kV bus bar.

In accordance with normal Malaysia practice, the three reference networks (RNs) were planned and modeled in radial distribution networks. This means the feeders, distributors and service mains are radiating away from the substation and it has no loops. Therefore, any breaks in the network will cut off the supply.

Despite these limitations, these modelled urban, semi-urban and rural reference networks are considered relevant and adequate for the studies of the network losses in Malaysia.

C. Photovoltaic Systems PV

Solar radiation data can be taken from various locations on an hourly basis via satellite images and metrological stations [19]. In Malaysia, models are used as a tool to estimate the solar radiation, in which the models depend on the global hourly prediction [20]. Mainly the satellites images are used as one of the optimal methods for predicting the average annual daily solar irradiation of particular places in Malaysia.

The generation profile of PV datasets used in this experiment was collected from the PV monitoring system that installed at Photovoltaic and Smart Grid (PVSG) research laboratory situated at Faculty of Electrical Engineering, UTeM (2.3139ºN, 102.3212ºE). The global horizontal irradiance (GHI) and other solar related parameters are gathered from the weather station that installed at UTeM. There are two units of high-quality pyranometers that were installed at UTeM so that the data gathered from both equipments can be compared and validated.

The data gathering method follows the IEC 61853-1 standard which standardises the measurement setup to measure irradiance, temperature performance and power rating [21]. Besides that, UTeM's solar laboratory is also equipped with high quality of 'Kipp & Zonen' brand pyranometers with a digital interface for good quality measurements in solar energy and field testing. Other high-quality equipment such as an ultrasonic anemometer, rain sensor, and data acquisition monitoring systems help to gather accurate variables of UTeM's daily weather conditions.

A simulation carried out for the impact of PV integration is discussed in this section. For the case study of the different time resolution of PV generation profile time, five sets of different time resolution data for a one day sample is illustrated Figure 2. The PV penetration level is fixed to 100% while different time resolution of PV output was used in this research. Fifteen-minute resolution profile of PV generation profile is used as a base for this research.

As shown in Figure 2 the resolution of one-minute solar radiation data is higher than the other four sets of the data which are five-minute, fifteen minute, thirty minute and hourly radiations. This is followed by the high to low resolution; from five-minute, fifteen minutes, thirty minutes and lastly hourly radiation. The thirty-minute radiation data is observed as slightly higher that the hourly radiation. That is because the peak values of the radiation are not recorded in the one-hour data set. This happens because the data only records point values for every hour, while within the time period the solar radiation may have significant fluctuation. In the thirty-minute radiation, fewer peak values are lost compared to the hourly radiation data. Similarly, in five-minute radiation, lesser peak values are overlooked compared to the half-hour and one-hour data. Certainly, the high resolution of one-minute radiation data has the minimum amount of peak values data loss as compared to the other four data sets. Thus, one-minute data is the most precise and accurate among the other sets of data radiation.

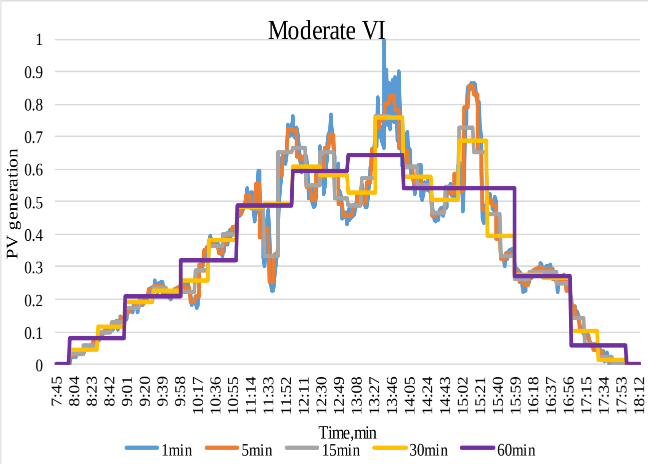

Figure 2: PV Profile with Different Time Resolution

III. Result And Discussion

A. Reference Network

The time series simulation is a sequence of analysis with a uniform time interval [22]. Different type of MV network, urban, semi-urban and rural are being used to study the effect of the time resolution of PV generation profile. Moderate VI of PV generation profile with a different time resolution of one minute, five minutes, fifteen minutes, thirty minutes and sixty minutes as shown in Figure 3 is used in this case. Figure 3 shows the loss ratio based on different time resolution for the urban, semi-urban and rural network. Loss ratio is defined as the estimated ratio losses from the mean averaged data to the high-resolution one-minute ratio losses or the theoretical losses [23]. The loss ratio is defined as estimated ratio losses from the mean averaged data to the high-resolution one-minute ratio losses or the theoretical losses [23]. The equation below shows the formula to obtain the losses ratio and voltage ratio.

$$Ratio\,(Losses\ or\ \ Voltage) = \frac{\text{Measured data}}{Theoritical\ \ \text{data (High resolution data)}} \tag{1}$$

The losses and voltage ratio are then sketched in the line graph with respect to the increase in time resolution (1-minute, 5-minute, 15-minute, 30-minute and 60-minute) of the PV generation profile. It is expected from the equation that the increase in the time resolution of the PV generation profile causes inaccurate studies on the network losses.

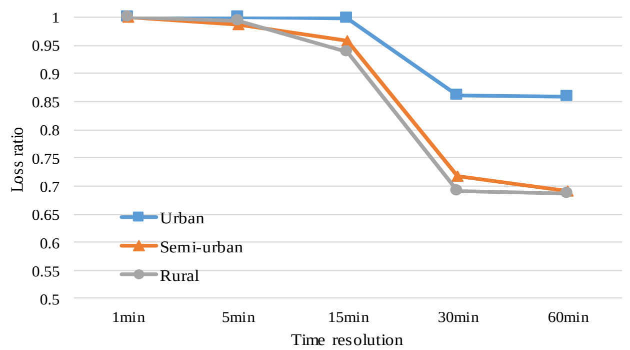

Figure 3: Loss Ratio of the Reference Networks

Different types of MV network--urban, semi-urban and rural--are being used to study the effect of the time resolution of PV generation profile. This section explains the loss ratio and voltage ratio with respect to the different type of time resolution. Moderate VI of PV generation profile with a different time resolution of one minute, five minutes, fifteen minutes, thirty minutes and sixty minutes are used in this case. Figure 3 portrays the loss ratio based on different time resolutions for the urban semi-urban and rural network respectively.

Based on Table 2, for the urban network, the estimated losses for the 15-min data is 99% of the losses as compared to 1-min and 5-min data. For 30-min and 60-min data, the estimated losses are at 86% of the losses with 1-min data, therefore having lower estimated losses by 14%. Using the high-resolution 1-min data as a reference, the loss ratio at semi-urban determined where the estimate losses for the 5-min is 99% and for the 15-min is 96%. However, the error ratio in loss is estimated at 28% and 31% for 30-min and 60-min data respectively. For the rural network shown in Figure 3, the loss ratio for the 5-min is 1% only. Moreover, the losses estimation for 15-min are 94% and for both 30-min and 60-min are at 69%.

According to the Table 2, the loss ratio is less than 10% for the data time resolution of 1-min, 5-min, and 15-min. for all the urban, semi-urban and rural network type. The standard and previous studies show that loss ratios exceeding 10% is not required for proper evaluation [12], [23]. Thus, a 15-minute resolution of PV generation profile is sufficient for the energy losses analysis. The loss ratio for the high time resolution (1-min and 5-min) data do not contain many significant changes as compared to the 15-min data. This shows that the high-resolution PV generation profiles are very accurate at the high variability points. These profiles do not require for the energy impacts and network losses assessment because the loss ratio for the high time resolution (1-min and 5-min) and 15-min time resolution data result in same value with less than 1% error.

However, the loss ratio for the low time resolution (30-min and 1-hour) data shows huge percentages as compared to the 1-min reference data. The loss ratio for the 30-min and 60-min data is from 14% to 31% which is considered as huge losses according to the studies [24]. The low time resolution such as 30-minutes and 1-hour generation profiles give high loss ratio as compared to the 1-min reference data. The low resolution will miss out on the medium and high variability points which are of greatest concern in the network losses. So from this study, 15-minute PV generation profile is the required time resolution to measure and analyse the MV of network losses for the urban, semi-urban and rural network.

Table 2
Loss Ratio against Time Resolution

Time resolution	Loss ratio, %		
	Urban	**Semi-urban**	**Rural**
1-min	0	0	0
5-min	0	1	1
15-min	1	4	6
30-min	14	28	31
60-min	14	31	31

IV. CONCLUSION

This paper presents the analysis of the impact of utilizing different time resolution PV generation profiles on a Malaysian MV reference network. The case study was analysed on actual PV generation profiles. The network losses ratio has been identified and studied. The overall results clearly indicate that the 15-minute PV generation profile is the optimum time resolution for the purpose of MV network losses study for the urban, semi-urban and rural network in Malaysia. The losses ratio for the high time resolution (1-min and 5-min) data results in less significant changes when compared to the 15-min time resolution PV data. Since high time resolution data (1-min and 5-min) are expensive and time-consuming, the standard resolution of 15-minute of PV generation profile is sufficient to be used throughout the network losses analysis.

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