Investigating the Impact of Photovoltaic Connection to the Malaysian Distribution System

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***Abstract*—This paper investigates the grid-connected photovoltaic (GCPV) effects to the Malaysian distribution systems. Increased in distributed generation installations into electricity distribution network could have a better impact on the planning and operation of a power system. The scenario discussed in this paper is the solar irradiance level effects on grid-connected photovoltaic (GCPV) system which located in Universiti Teknikal Malaysia Melaka. The research consists of analysis in current and total harmonic distortion performance due to sun irradiance which may give an impact on photovoltaic systems to generate output power. PV generation depends directly to the sun's radiation. Hence, the intermittent fluctuations may potentially cause problems to the network operation, especially in high penetration levels. In addition, a larger number of distributed GCPV is added into the grid, the effect or impact may become more significant. There are several previous researched regarding the impacts of PV that have been done in North America, China and Japan. However, the country like Malaysia generally follows the European standard distribution system layout. Besides, Malaysia located near the equator and ideally receives sunshine continuously throughout the year. The different suggest that each system handles unbalanced networks differently and thus require a personalized analysis. The results of data irradiance (W/m^2) and harmonic distortion (THD%) of this study finally were analyzed and compared in graphical results. At the end of this study, a few suggestions were provided to overcome this problem.**

***Index Terms*—Grid-Connected Photovoltaic; Malaysian Distribution Systems; The Solar Irradiance Level Effects; Universiti Teknikal Malaysia Melaka.**

I. INTRODUCTION

Nowadays, photovoltaic (PV) solar energy known as the most demand renewable energy sources and it has been used as distributed generation in many countries for the last few years. In Malaysia, according to the 10th Malaysia plan between years 2011 to 2015, the PV generation expected to reach 65MW in 2015. For year 2020, the PV generation expected to reach 190MW [1]. Generally, solar energy consists of two types which is concentrating solar power (CSP) and solar photovoltaic (PV). The basic concept of PV operation is PV cell made of semiconductor material will convert the solar energy into electricity. The Integration of grid-connected PV system introduced a lot of technical problems. For example, the technical problem such as grounding, lightning protection and the optimization of system controls. Based on previous study, the major system impacts in cluster PV systems include voltage variations and unbalance, voltage and current harmonics.

In the future, the harmonics problem will be significant as the integration of PV system is increasing day by day. Harmonics can be caused by PV inverters in the distribution system. The voltage harmonics can be minimized when the connection point of the large scale PV cluster is strong enough. As the rapid increasing of the PV integration, it could potentially bring problems in terms of system operation where a reverse power can be introduced by higher penetration levels resulted a rise in voltage busses and feeder losses [2]. The injected power by the PV plant modules at the load side buses will decrease the demand of the local load which leads to a loss reduction and voltage profile improvement [3-6]. Obviously, this case is true as long as the real power flows from the substation to the customer side (when the load is less than PV power). If the PV generation is more than the load downstream of the PV location, the power flow may be reversed towards the substation. Consequently, a voltage rise can be expected along the distribution system feeder as a result of the reverse power flow [7]. The rise of the voltage at the end-user limits the amount of the penetration level which wanted to be installed in the distribution network. The natural behavior of the solar source makes the generation of the PV plant systems in fluctuated profile. The rapid variation of the PV power introduces a voltage fluctuation along the PV working time and hence its effects on the voltage regulation in some cases [8-9]. All these issues will be evaluated and mitigation control will be proposed in this paper to mitigate the voltage rise which caused by PV interconnection and to investigate the regulation benefits in term of daily time.

II. IMPACTS OF PV ON DISTRIBUTION SYSTEMS

The larger integration of PV into grid-connected system brings several problems for the utilities. Reverse power flow known as the major factors affecting voltage regulation. On the other hand, the increasing numbers of PV with inverters in the system may provide the higher probability of islanding while the PV continues to supply local loads after a utility fault [10]. If the islanding was not detected in appropriate method with protection relays, then the inverters will remain active. Hence, it is may damage the equipment. If the utility has been used maximum voltage levels due to the maximum demand conditions, the inverters must be disconnected.

Since the loads remain on-line, the utility may see an increasing in demand, the chances of a blackout will increase. Significant efforts are required in terms of studying these impacts for the successful integration of PV to the grid.

Based on previous study, the research was conducted by a utility in Spain about the potential problems arising from PV penetration [11]. This study focused on the imbalance in loading and the voltage regulation on the feeders [12]. Meanwhile, the impact of solar PV systems on the Sacramento Municipal Utility District feeders is analyzed [13]. In these studies results, it was indicated that PV systems provided overall benefit to the consumers by reducing energy consumption. The voltage impacts were minimal at low penetration levels and were increased at high PV penetration level.

III. Impacts Grid Connected PV Systems On Harmonic Distortion

Harmonic distortion is a problem of power quality that has been produced from power electronic devices used in power converter [14]. There are several factors that will effects the performance of Photovoltaic systems in term of power quality which are inverters, solar irradiance and temperature. These three main factors may increase or decrease the performance of current profile, voltage profile and power generated [15]. In this paper, the effect of solar irradiance level on clear day condition is studied to investigate the effect of these phenomena on the PV system total harmonic distortion performance.

To investigate the performance of Photovoltaic generation in terms of voltage and current profile and its harmonic distortion behaviors, a Photovoltaic test model has been developed. Previous study shows that the output power of Photovoltaic system is proportional to the solar radiation variations [16]. The performances of renewable energy such as PV system normally depend on environment condition. The level of solar irradiance is depends on the movement of clouds and it give an impact on a PV system to generate output power. Based on previous study, the output power of PV can have a sudden drop of up to 25% causes by the passing cloud [16]. The most severe fluctuations in the output power of PV systems usually occur at maximum irradiance level at noon. This period usually coincides with the off-peak loading period of the electric network, thus, the operating penetration level of the PV system is in best performances [17-18].

IV. Methodology

A. Selecting grid connected photovoltaic system

The model of grid connected system that has been selected for this study is PV systems that are located at the rooftop of Faculty of Electrical engineering, UTeM. The laboratory has 4 types of PV systems with each one of them connected to 3 Sunny Boy 2000HF inverters for 3 single phase systems. These single phase systems are then combined to form a 3-phase grid-connected PV system, and thus generate power of approximately 6 kW. The description of the system was shown in Figure 1 and the schematic of a system is provided in Figure 2.

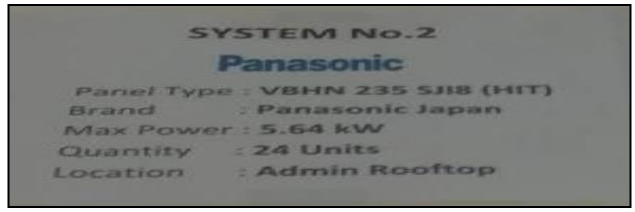

Figure 1: The description of PV system.

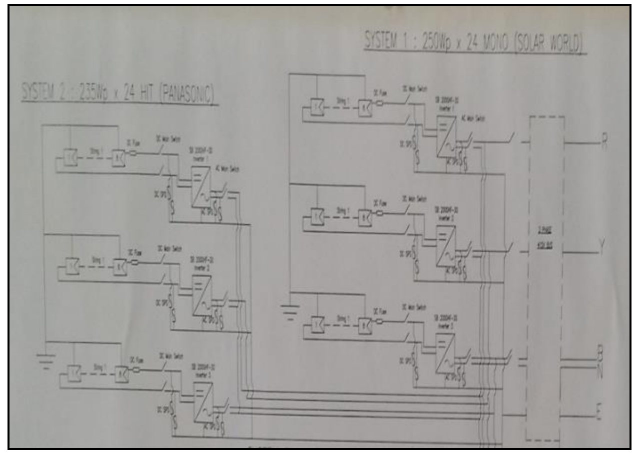

Figure 2: Schematic diagram of GCPV system.

In this paper, the Fluke 43B (power quality analyzer) will be used to measure the current and harmonic distortion data from inverter of a grid connected PV systems. The measurement was setup as shown in Figure 3. The measurement was recorded between 8 am until 4 pm for 30 days. The final data recorded in Fluke meter will be saved and transfer into Fluke View that has been installed in a personal computer as shown in Figure 4. The recorded data then will transform into graphical data via Microsoft Office Excel. All data has been finalized and only the most clear and cloudy day data were selected for analysis. The data were compared between solar irradiance data and current harmonic to investigate the performance of PV systems.

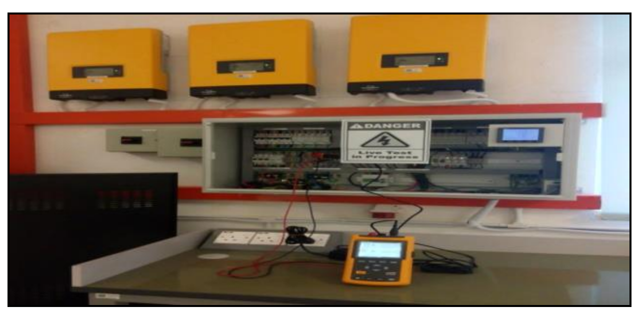

Figure 3: The setup connection of Fluke 43B for measurement and recording data.

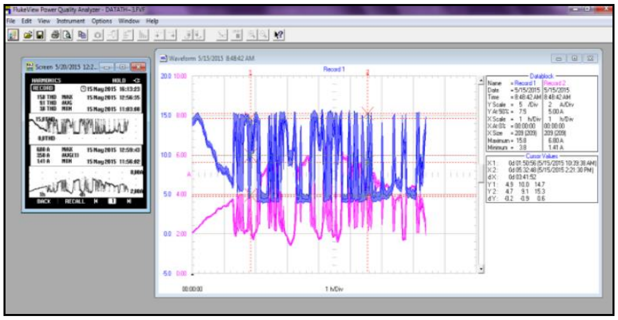

Figure 4: The data of harmonic and current recorded using Fluke 43B

B. Collecting Solar Irradiance Level Data

The data of tilt irradiance were recorded all days from UTeM solar laboratory. Hence, the data will be collect from the laboratory. The data needed for this analysis is between only 2 days which is clear day and cloudy day. The data then will be transforms into graphical data for analysis. The graphical data of tilt irradiance (W/m^2) will be determined for maximum and minimum reading. Lastly, the data will be compared between harmonic and current that was recorded before to study the performance of UTeM grid connected photovoltaic systems.

V. Results And Discussion

A. Tilt Irradiance Data and THD (%) Performance

The irradiance data is taken from UTeM solar laboratory. The data were selected within 30 days and the most higher constant data of irradiance was taken as a clear day while the lowest constant data has been set as cloudy day. The data such as THD (%) and current performance pattern is captured between 8.00 a.m. until 4.00 p.m. The solar irradiance (W/m^2) data then is compared with THD (%) for analysis. Figure 5 shows the solar irradiance (W/m^2) effect on THD (%) performance that has been captured during clear day and cloudy day.

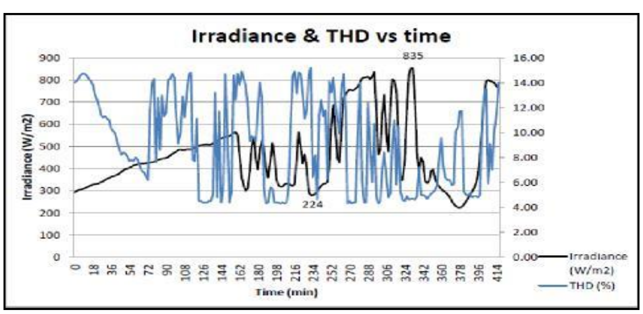

Figure 5: The graph of Irradiance (W/ m^2) effect on THD (%) versus time (minute) during clear day.

Figure 5 shows that the maximum and minimum value of solar irradiance (W/m^2) for clear day is 835 W/m^2 and 224 W/ m^2. From the graph, the pattern of THD (%) was observed and it is decrease significantly when the data of solar irradiance increase upward. The value of THD (%) during maximum irradiance 835 (W/m^2) is 3.8% and during minimum irradiance of 224 (W/m^2) is 14.7 %. The graph shows the comparison between range of irradiance (W/ m^2) and average THD (%) versus time during clear day.

Figure 6 is the analysis of average THD (%) performance in a certain range of solar irradiance which is 0-100, 100-200, 200-300, 300-400, 400-500, 500- 600, 600-700, 800-900, 900-1000, and 1000-1100 (W/ m2). The data of average THD (%) is calculated for every range of solar irradiance (W/m^2) and finally tabulated in Table 1.

Based on Table 1 most result for average THD (%) were significantly decreases as the solar irradiance increase. Unfortunately, some of the data shows a higher average of THD (%) for a lower range of solar irradiance (W/m^2) data. For example, between range 600-700 and 700-800. From a theory, the data of solar irradiance is inversely proportional to the total harmonic distortion. For this graph, there must be an error during the recording of data. The PQ analyzer or Fluke meter sometimes not operate properly and it may give an effect on the measurement and recording data.

B. The Comparison between Irradiance and THD during Cloudy Day

In Figure 7, the graph shows that the maximum and minimum value of solar irradiance (W/m^2) for cloudy day is 903 W/m^2 and 62 W/m^2. From the graph above, the pattern of THD (%) was observed and it is decrease significantly when the data of solar irradiance increase upward. The value of THD (%) during maximum irradiance 903 (W/m^2) is 4.6% and during minimum irradiance of 62 (W/m^2) is 16.5 %. The graph below shows the comparison between range of irradiance (W/m^2) and average THD (%) versus time during clear day.

In Figure 8, the graph above is the analysis of average THD (%) performance in a certain range of solar irradiance which is 0-100, 100-200, 200-300, 300-400, 400-500, 500-600, 600-700, 800-900, 900-1000, and 1000-1100 (W/m^2) . The data of average THD (%) is calculated for every range of solar irradiance (W/m^2) and finally tabulated in Table 2.

Based on Table 2, the most result for average THD (%) were significantly decreases as the solar irradiance increase. Unfortunately, some of the data shows higher average of THD (%) for a higher range of solar irradiance (W/m^2) data such as range between 700- 800 and 900-1000 (W/m^2). However, the value does not change in a high difference value.

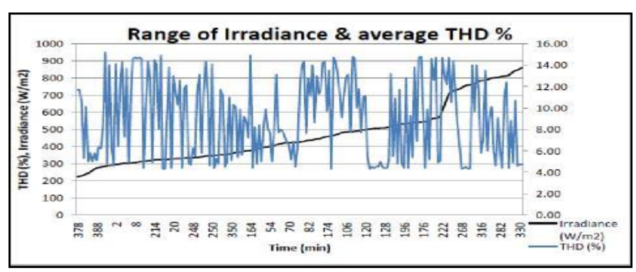

Figure 6: The comparison between range of irradiance (W/ m^2) and average THD (%) versus time during clear day.

Table 1
The value of average THD (%) in a certain range of Irradiance (W/ m^2) data during clear day.

Irradiance (W/m^2)	Average THD (%)
0-100	-
100-200	-
200-300	10.23
300-400	9.31
400-500	9.29
500-600	7.91
600-700	8.22
700-800	9.00
800-900	6.88

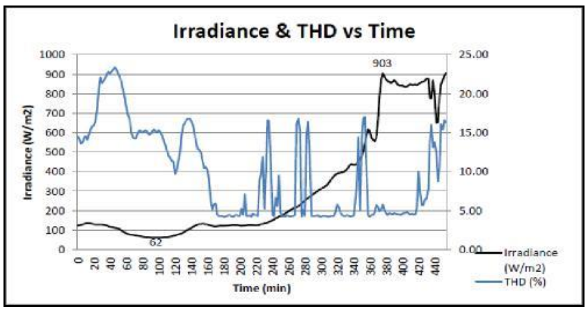

Figure 7: The graph of Irradiance (W/ m^2) effect on THD (%) versus time (minute) during cloudy day.

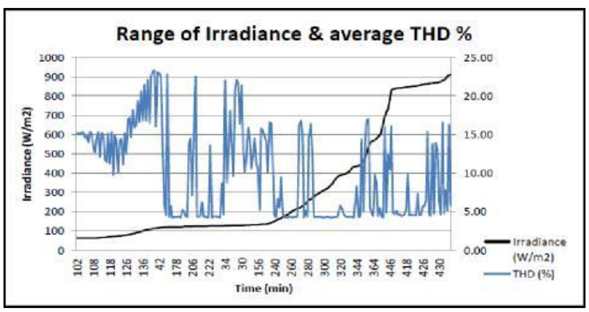

Figure 8: The comparison between range of irradiance (W/ m^2) and average THD (%) versus time during cloudy day.

Table 2
The value of average THD (%) in a certain range of Irradiance (W/m^2) data during cloudy day.

Irradiance (W/m^2)	Average THD (%)
0-100	14.62
100-200	10.98
200-300	8.19
300-400	7.29
400-500	6.67
500-600	8.57
600-700	8.20
700-800	9.23
800-900	6.94
900-1000	9.07

C. Total harmonic distortion and current performance

This section shows the data of total harmonic distortion and current performance for selected clear day and cloudy day. The data was recorded by using Fluke 43B (power quality analyzer) in UTeM solar laboratory. The measured value was recorded at inverter of grid connected photovoltaic systems 2 in UTeM solar laboratory. The laboratory has 4 types of PV systems with each one of them connected to 3 Sunny Boy 2000HF inverters for 3 single phase systems. These single phase systems are then combined to form a 3-phase grid-connected PV system, and thus generate power of approximately 6 kW. Figure 10 shows the graphical data measured of THD (%) and current performance.

Figure 9 shows the effects of current performance towards THD (%) value on clear day. The value of THD (%) is significantly decreases when current performance (A) was increase. This graph proved that the theory which is current is inversely proportional to the total harmonic distortion. The maximum and minimum value for current performance (A) during clear day is 5.65A and 1.44A. For maximum current, the value for THD (%) recorded is 4.4% meanwhile during minimum current, the value for THD (%) recorded is 9.6%.

Figure 10 shows the effects of current performance towards THD (%) value on clear day. The value of THD (%) is significantly decreases when current performance (A) was increase. This graph proved that the theory which is current is inversely proportional to the total harmonic distortion. The maximum and minimum value for current performance (A) during clear day is 6.79A and 0.65A. For maximum current (A), the value for THD (%) recorded is 4.2% meanwhile during minimum current (A), the value for THD (%) recorded is 22.5%.

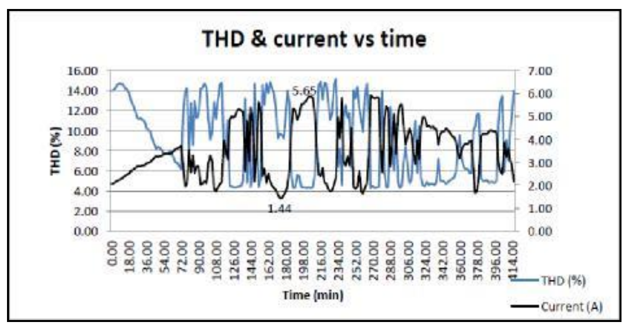

Figure 9: The value of THD (%) and current performance versus time recorded for clear day.

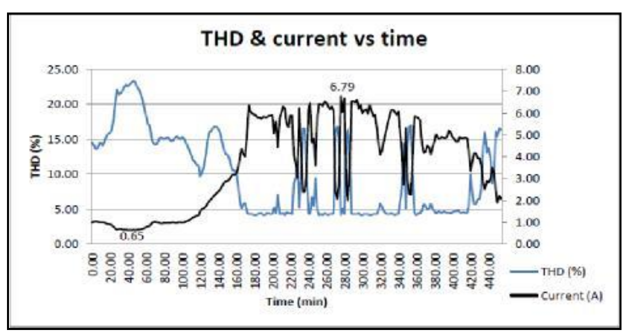

Figure 10: The value of THD (%) and current performance versus time recorded for cloudy day.

The performance of output power of GCPV system was influenced by several factors, such as movement of clouds, size of PV system, penetration level, and location of the PV system, topology of the PV system and topology of the electric network. However, the performances of renewable energy such as PV system normally depend on environment condition. The level of solar irradiance is depending on the movement of clouds and it give an impact on a PV system to generate output power. When the output power is lower, it may cause a potential problem for PV system become ineffective. Meanwhile, the maximum value of solar irradiance will provide a higher output power of a PV system. It is because when solar irradiance level higher, the current produce also become higher. Hence, total harmonic distortion THD of current will be lower and finally generate higher output power. Based on previous study, a harmonic problem generally can be defined as a particular disturbance, which is created by the presence of non-linear components in the electrical system that determines a permanent modification of the voltage and current sinusoidal wave shapes in terms of sinusoidal components at a frequency different from the fundamental. In this study, using real data and a simulation program on a computer, harmonic problems in grid connected PV systems have been investigated. In a GCPV power system, the direct current (DC) output power of the photovoltaic array should be converted into the alternating current (AC) power of the utility power system.

Based on the final result that has been tabulated in Table 3, the data shows that the solar irradiance (W/ data brings an impact towards current (A) and THD (%) performance. If solar irradiance level is higher, then current performance also will become higher. If current performance was observed higher or increases, then THD (%) performance will become lower and decreases. The result shows that the lowest range of irradiance which is 0-100 (W/ normally occur at 8am until 9am. During that time, the THD (%) is highest compared to next range of solar irradiance. The data of THD (%) mostly decrease since the range of irradiance increased.

Table 3
The final result of maximum and minimum value for analysis

	Max Irradiance Level (W/m^2)	Min Irradiance Level (W/m^2)	Max Current (A)	Min Current (A)	THD (%) for max current	THD (%) for min current
Clear Day	835	224	5.65	1.44	4.4	9.6
Cloudy Day	903	62	6.79	0.65	4.2	22.5

VI. CONCLUSION

As a conclusion from this study, the variations in the solar irradiance caused by the movement of clouds, leads to fluctuation of output power of PV system which highly potential to some operational problems which make the PV system ineffective. The most severe fluctuations in the output power of PV systems usually occur at maximum irradiance level at clear day. This period usually coincides with the off-peak loading period of the electric network, thus, the operating penetration level of the PV system is greatest. The lack of PV power output performance on grid line was influenced by several factors, such as type of clouds, penetration level, and size of PV system, location of the PV system, topology of the PV system and topology of the electric network. In this study, during clear day the level solar irradiance is constant higher. Hence, the performance of current also higher and it is lower down the performance of harmonics. The output power of a PV system will become a maximum if there is no cloud passing through because at that time solar irradiance level is in maximum stage.

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