Power Quality Analysis of Grid Connected Solar Power Inverter

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Abstract – Photovoltaic (PV) energy has been widely interested today because it is clean and endless energy without causing pollution. To produce electricity from solar energy, it would be required an inverter to convert the direct current into alternating current. The inverter is the cause of problems that affect the stability of the power system because it is a switching device served to adjust the frequency of the AC power as needed. At the same time, it can cause harmonics which result in waveform distortion and affect electronic devices that receive power. Then, it could make electronic device malfunction. This paper studies the characteristics of harmonics on grid, PV system, and load. The result shows that most grid's harmonics are affected from PV system and load when the inverter power up to almost the rated power, meanwhile, percentages of harmonics are reduced and harmonics of load depend on the type of load. Next, comparing harmonics on three sides, and found that harmonics of PV system hardly affect to load and harmonics of grid are more affected from load than PV system.

Keywords – Distributed Generation (DG); Harmonic distortion; Photovoltaic energy (PV); Power quality; Solar inverter

I. Introduction

Most electricity production by solar energy is separated into two forms. First one is solar rooftop, which is a small electricity production and can manage unused space on the rooftop for gaining benefits. This configuration generates less energy than grid system, but if there are many solar rooftops in the area, it can generate much energy and reduce electrical power consumption in transmission line. Another form is solar farm, which is a large electricity production and generates huge energy. Since both forms send electrical power to transmission line, so it is required to control electrical power quality and stability in power transmission system. Regarding power quality, the significant factor is harmonics that are generated by solar system, and then the generated power will be sent to customers in the area. If the solar system has more harmonics, it would affect to electric/electronic equipment, and power transmission system.

A number of research papers in field of harmonics from PV system and the effect of inverter have been reviewed. Fei Wang and et al [1], introduced a way to forecast impedance network quasi-resonance between DG inverters and the grid. Harmonic interactions between the grid and a certain number of DG inverters can be preliminarily estimated. In [2], by using the fourth-order band pass filter, the proposed harmonic detector can effectively extract harmonic components without phase delay. In [3], a closed-form analytical approximation of the output harmonic spectrum of a single-phase two level inverter under the action of hysteresis current control has been done. The selective harmonic elimination problem using artificial neural networks (ANNs) to generate the switching angles in an 11-level full-bridge cascade inverter was powered by five varying dc input sources [4]. In [5], it analyzed the limitations of the standard resonant current control operating under abnormal grid conditions and introduced a control scheme from a three-phase PV inverter. Abhijit Kulkarni and et al [6], showed a novel design of inverter current control that mitigated lower order harmonics. The complete design had been validated with experimental results and good agreement with theoretical analysis of the overall system was observed. In [7], a harmonic impedance synthesis technique for voltage-controlled distributed generation inverters in order to damp harmonic voltage distortion on a distribution network was investigated. Md Shirajum Munir and et al [8], studied an in-depth analysis and comparison of different compensation schemes based on the virtual harmonic damping impedance concept, carried out in photovoltaic (PV) interfacing inverters. Solution eliminates the bulky electrolytic capacitors while smaller amount of AC capacitors were needed to compare with the buck-type AC–AC converters that continuous grid-side current was obtained, which implied that no extra grid-side filters were needed [9]. In [10], it applied the selective harmonic elimination (SHE) technique to determine the switching angles for a multilevel inverter that cooperated with specially connected transformers. In [11], it studied the combination of the grid voltage feedforward and the multi-HR control was proposed to suppress low-order harmonics. The comparative analysis, simulations and experiments indicated that the proposed strategy greatly improved the ability of the inverter to reject the current harmonics induced by multi-harmonic sources as long as the grid feedforward and the resonant control were complementary. In [12], it showed a frequency adaptive selective harmonic control (FA-SHC) scheme that could be designed for grid-connected inverters to optimally mitigate feed-in current harmonics. Experimental tests had demonstrated the effectiveness of the proposed FA-SHC scheme in terms of accurate frequency adaptability and also fast transient response. Haitao Hu and et al [13], presented a clarification study to identify the potential resonance phenomenon between photovoltaic (PV) inverters and the distribution system that can be attenuated if the damping resistance, such as damping resistor and residential linear loads, was large enough.

The harmonics in PV system are presently a concerned problem of power system because they affect to electric equipment of the end users and stability of the transmission system. Therefore, in this study, different configurations by connecting to PV system and loads are carried out in order to reveal the real behavior of the harmonics in the considered system.

II. EXPERIMENTATION

For experiment, we used a PV Simulator to generate direct current of solar energy. Then, an on-grid inverter transformed direct current to alternating current for sending to grid connected and/or electrical loads. There are 5 types of loads, which are herein incandescent, ballast, incandescent and ballast, Light Emitting Diode (LED), and motor. In this system, we connected solar energy from PV simulator to on-grid inverter, grid system, and loads at the connecting point. The testing results were recorded using oscilloscope to keep current and voltage waveforms of the system at the connecting point, and using Power Quality Analyzer to keep electrical parameters and harmonics as shown in Figure 1.

Solar energy was sent to each load according to the load power.

- Incandescent of 500 W
- Ballast of 850 W
- Incandescent and Ballast of 1000 W
- LED lamp of 300 W
- Motor of 200 W

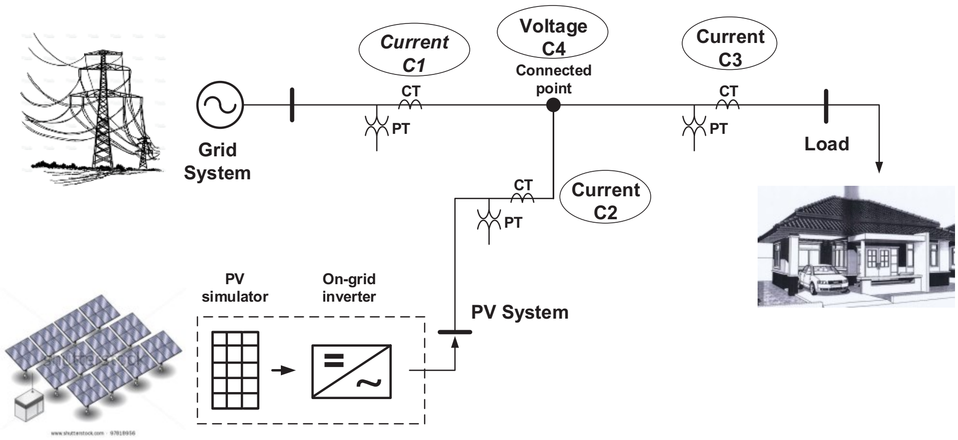


Fig. 1. Overview of experimentation

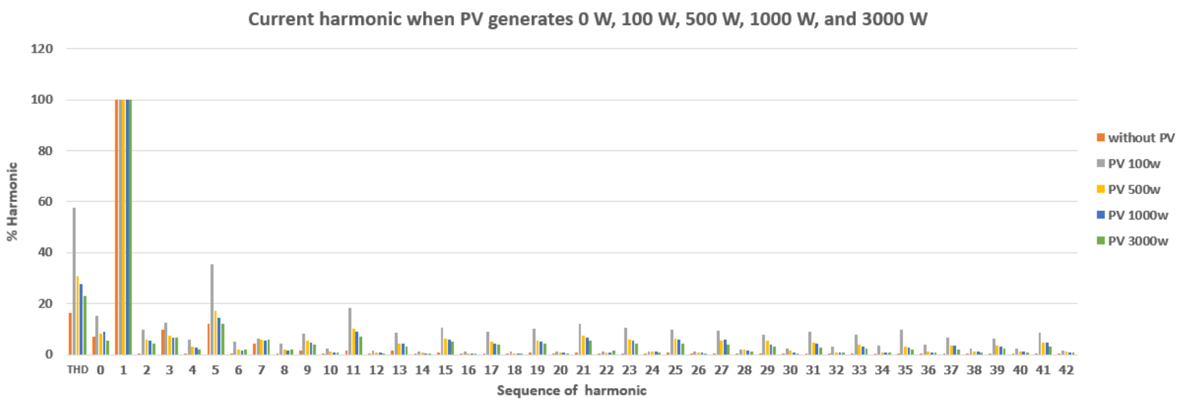


Fig. 2. Current harmonics when PV generates 0W, 100W, 500W, 1000W, and 3000W without loads connected

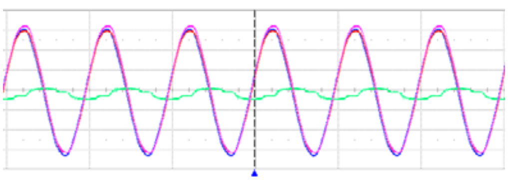
III. RESULT

The result shows that the system is study include 2 states. Frist, when the PV system doesn't feed power to connected point, loads receive power from grid and generate harmonics that pay back to the grid. Therefore, the harmonics in this state are load's harmonics. Next, when the PV system feed power to connected point. In this study, it is mainly considered into 2 configurations: with and without PV system, to observe the harmonics generated in the system. In two cases, the voltage harmonics measured at the connecting point are both low whereas the current harmonics are high.

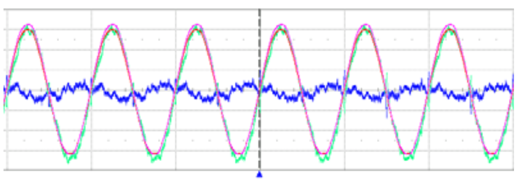
When PV generates more electrical power to the system, the voltage harmonics are still unchanged. But the current harmonics can be more, depending on the supplied power and the type of load; the non-linear load with active component such as LED with its driver can cause and increase the total harmonics in the system. Therefore, we will mainly pay attention to the current harmonics in grid system, PV system and load.

When the PV does not generate energy, grid feeds low power to the connected inverter; the current harmonics percentage generated from inverter in each harmonic order are shown in Fig. 2. It is found that the grid-connected inverter behaves like an electrical load because it receives power from the grid for system connection verification; hence, there is low current flowing from grid to inverter. While PV generates 100 W, total current harmonics are increased, especially the 5th and 11th orders, then PV operation was changed to 500 W, 1000 W, and 3000 W, harmonics production were also investigated though they are lower than 100 W. operation. Thus, it seems to be conclude that the switching devices inside the grid-tie inverter cause the increment of current harmonics. When the PV generates high current and power, the fundamental current is high. Comparison study of current harmonics in the system is divided into two configurations; with and without PV connection, measuring at three positions (grid system, PV system, and load). There are five types of load, which are considered in the experiment, consisting of incandescent, ballast, incandescent with ballast, LED lamp, and motor.

The first comparison was the case of incandescent as a load. When PV did not generate power, the current harmonics percentage in 3rd, 5th, and 7th orders were 9.7%, 12.26%, and 6.28% respectively, and total harmonics distortion was 17. 25% measured at PV system position whereas the grid and load position were relatively small amount because there was more power delivered from grid to load than the inverter as shown in Fig. 4. After the PV generated energy, current harmonics at load side was unchanged. Overall current harmonics of grid and PV system were stepped-up and dramatically increased in 5th and 11th orders.



a) PV does not generate solar energy



b) PV generates solar energy

Fig. 3. Voltage and current waveforms in case of incandescent load when PV generates and does not generate solar energy

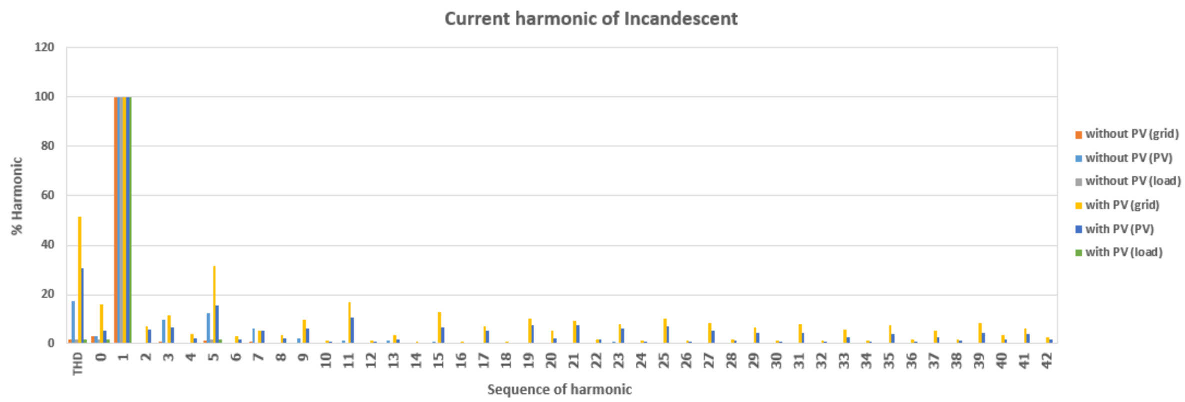
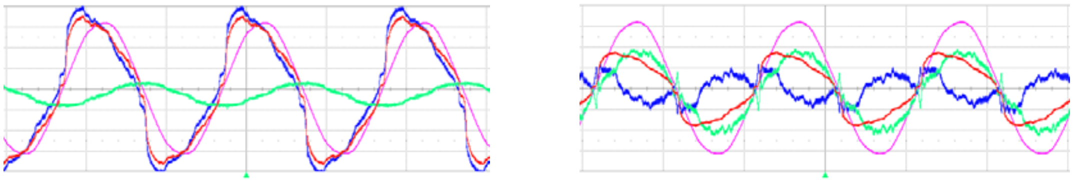


Fig. 4. Current harmonics in case of incandescent load when PV generates and does not generate solar energy



a) PV does not generate solar energy

b) PV generates solar energy

Fig. 5. Voltage and current waveforms in case of LED lamp load when PV generates and does not generate solar energy

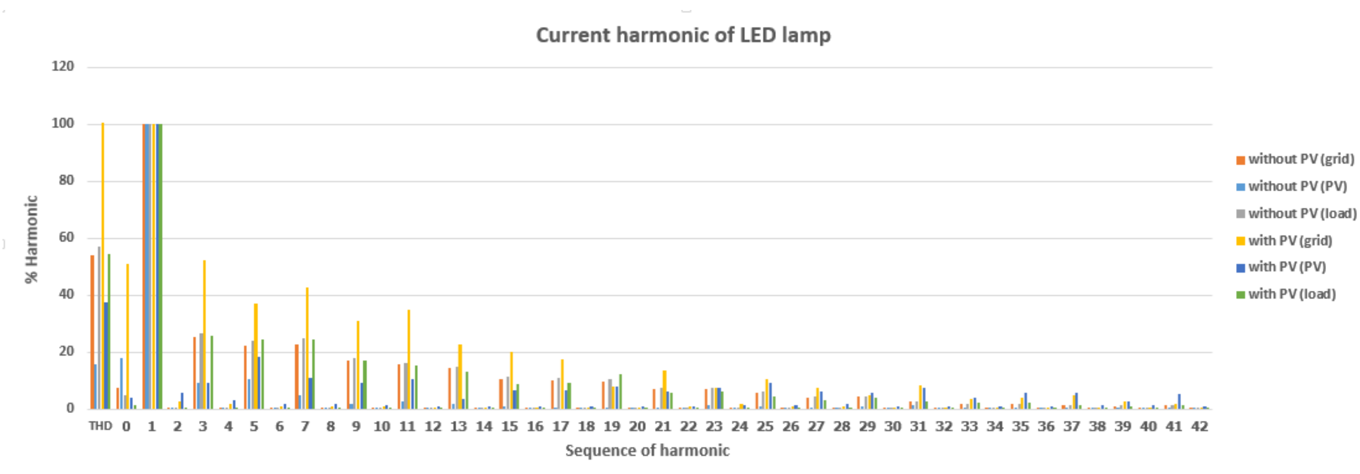


Fig. 6. Current harmonics in case of LED lamp load when PV generates and does not generate solar energy

The second comparison was the case of ballasts as a load. The current harmonics percentage when PV did not generate power in 3rd, 5th, and 7th orders are 9.46%, 2.73%, and 1.11% respectively, measured at load position. In PV system position, current harmonics at 3rd, 5th, 7th, 9th, and 11th orders were 8.72%, 11.23%, 5.65%, 2.21%, and 2.28% respectively. Current harmonics measured at load and PV system positions affected to grid position at 3rd and 5th orders, which were 9.54% and 3.46% respectively. Current harmonics of gird side and load side were similar because grid sent more current to load than inverter. After the PV generated energy, current harmonics at load and grid position petty increased. Current harmonics at PV system position in 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, and 11th orders increased to 4.33%, 5.593%, 2.14%, 14.65%, 1.29%, 8.89%, 1.31%, 6.27%, 0.97%, and 7.624% respectively.

The third comparison was for the combination of incandescent and ballasts loads. The current harmonics percentage when PV did not generate power in 3rd, 5th, and 7th orders are 8.11%, 1.95%, and 1.18% respectively measured at load position. In PV system position, current harmonics at 3rd, 5th, 7th, 9th, and 11th orders were 88.92%, 11.21%, 5.48%, 2.25%, and 2.3% respectively. Current harmonics measured at grid position at 3rd, 5th, and 7th orders were 8.04%, 2.48%, 1.03% respectively. Current harmonics were more significant than the first case but less than the second one. After the PV generated energy, current harmonics at load position were unchanged. Current harmonics at 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, and 11th orders of PV system position drastically increased to 4.27%, 5.77%, 2.07%, 17.28%, 1.29%, 7.31%, 1.23%, 6.06%, 0.92%, and 7.87% respectively and grid position was slightly increased in odd orders. So, it could be conclude that current harmonics of grid side are more affected from load side than PV system side.

For the fourth case, the load taken into account was LED lamp with its driver. In Fig. 5(a), current harmonics at load position when PV did not generate power were different from the previous cases and had high values in order 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, 19th, 21st, 23rd, 25th, 27th, 29th, 31st, 33rd, 35th, 37th, 39th, and 41st orders that were 26.46%, 23.88%, 24.78%, 18.25%, 16.58%, 15.51%, 11.94%, 11.67%, 11.02%, 8.12%, 8.10%, 6.63%, 4.73%, 5.01%, 3.29%, 2.48%, 2.29%, 1.57%, 1.31%, and 1.48% respectively. In PV system position, current harmonics were similar to the former cases, including 3rd, 5th, 7th, 9th, and 11th orders of current harmonics, which were 9.21%, 10.54%, 5.04%, 1.77%, and 2.50% respectively. Current harmonics measured at grid position at 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, 19th, 21st, 23rd, 25th, 27th, 29th, 31st, 33rd, 35th, 37th, 39th, and 41st were 25.37%, 22.06%, 22.79%, 17.08%, 15.91%, 14.77%, 11.16%, 10.96%, 10.40%, 7.62%, 7.64%, 6.27%, 4.43%, 4.79%, 3.11%, 2.36%, 2.15%, 1.51%, 1.22%, and 1.37% respectively as shown in Fig. 6. It can be seen that current harmonics of LED lamp had more than other cases. After PV generated energy as shown in Fig. 5(b), current harmonics of load side were unchanged. Current harmonics of PV system position at 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, and 11th orders drastically increased to 5.6%, 9.1%, 3.26%, 18.48%, 1.75%, 11.23%, 1.77%, 9.25%, 1.37%, and 10.77% respectively. In grid position, current harmonics were more increased at 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, and 11th orders to 2.93%, 52.41%, 2.06%, 39.95%, 1.13%, 42.45%, 1.14%, 30.94%, 0.95%, and 34.79% respectively because there were effects from current harmonics of load and PV system.

The last comparison case was for load of motor. The current harmonics percentage when PV did not generate power in 3rd and 5th orders was 3.97% and 2.75% measured at load position. Current harmonics at 3rd, 5th, 7th, 9th, 11th, and 13th orders were 8.78%, 11.56%, 6.85%, 2.08%, 2.16%, and 1.29% respectively. In PV system position. Grid current harmonics at 3rd and 5th orders were 4.9% and 1.98%. This case is similar to the third case. After the PV generated energy, current harmonics at load position were unchanged. Overall current harmonics at PV system and grid position slightly increased.

IV. Conclusion

This paper presented the comparison results of no-load and with different loads system between PV generating system and without PV generation. The experimental results concluded that grid-connected inverter behaves as load when PV does not generate solar energy because it receives power from grid to verify the system connection. The operation of passive components and switching equipment affects to the current harmonics generation because the system has low current flow. During PV does not generate solar energy, percentage of current harmonics decrease because current flow in the system increases.

Regarding the comparison study of current harmonics in the system with various loads, it can be analyzed that grid harmonics are mostly affected from harmonics of load and PV system but harmonics of load has more affect than PV system. Resistive and inductive loads generate less current harmonics than capacitive one and switching load, and harmonics of PV system do not affect to load.

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