The Analysis Harmonic for Connect Grid Photovoltaic Rooftop Synergy Distribution System

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***Abstract*—This paper presents the harmonic analysis for connecting grid photovoltaic rooftop synergy distribution system. The harmonic of photovoltaic rooftop affects the power distribution system's power quality. Under limitations, it has technical impacts such as unbalanced current, flicker, and load in the photovoltaic rooftop system. Therefore, this paper is presented to analyze the harmonics problem in the power distribution system from the photovoltaic rooftop by measuring unbalanced current, flicker, and harmonic photovoltaic rooftop synergy distribution system. The results showed that measurement points at the point of common coupling (PCC) between photovoltaic rooftop and distribution system could analyze the distribution system's harmonics.**

***Keywords*—Harmonic, Connect Grid, Photovoltaic Rooftop, Distribution System**

I. INTRODUCTION

Currently, the number of solar photovoltaic (PV) systems installed on rooftops and connected to the power distribution system has increased dramatically. These systems pose a new problem, the power quality problem. In particular, the harmonics from the inverters of the solar photovoltaic system and the non-linear loads have significantly increased the amount of use. This results in overheating the device and can cause the control system to malfunction. In 2014, Chidurala et al. analyzed the harmonic distortion problem accompanying photovoltaic inverters. Simulations were performed on IEEE-13 bus distribution systems with nonlinear loads to determine the harmonic emissions for varying solar conditions. Take the harmonics measurement data from the university of queensland installed with 1.2 MW solar PV compared to simulation results. [1]

In 2017, a 200 kWp PV plant was tested and commissioned at Vasavi College of Engineering, Ibrahimbagh, Hyderabad [2]. The plant is generating on average 25,000 units per month resulting in a saving of solar rooftop (RS) 2.5 lakhs per month electricity bill. Problems encountered such as cable heating, electrical power flow back to the DG unit have been handled. Also discussed in detail is the reduction in plant efficiency due to various causes and methods for improvement has been implemented. Improving solar PV efficiency by using power balancer on PLC for DG protection. Harmonics studies were conducted on PV plants In 2019, solar PV harmonics were studied [3], focusing on total harmonic distortion (THD) and total demand distortion (TDD). It has been observed that the measured THD is higher when the energy consumed by the load and solar radiation is low. These results in low-voltage customers using PV systems being penalized for higher solar radiation and high power consumption based on PV system loads. This paper concludes that analysis of THD alone can be misleading and the TDD analysis is more reliable. In 2020, the use of TDD in PQ analysis was conducted to analyze the harmonics of grid-connected photovoltaic systems installed on building roofs. [4] The harmonic analysis by using TDD provides better efficiency and provides a guideline for improving the power quality of the system. Power generation from small-scale solar power plants will transform the grid to become more complex and dynamic [5], resulting in a change of power and the direction of power flow. This causes various impacts on the power system such as harmonics, inter-harmonics and subharmonics. As shown in Fig. 1.

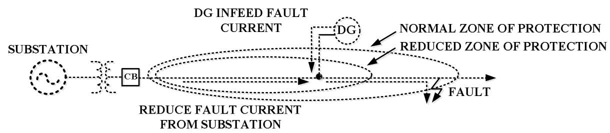

Fig. 1. The scope of work of protective equipment

In 2021, the three-phase four-line inverter (FLI) power will be regulated in a solar rooftop (RS) system connected to the distribution network (Grid) through distribution transformers via DC to AC inverters [6] when RS operates in parallel as the power supply, it can inject harmonics. The RS injection current fluctuates and is unbalanced in three phases due to irradiation changes. This condition causes the current supplied by the transformer for each phase to have differed. The fundamental power requirements both active and reactive on the transformer at the PCC point are not the same when harmonics are present in the system. The FLI must inject or draw current on the PCC to balance the transformer currents. The main objective of this control system proposal is to balance the current and eliminate the output current harmonics to the distribution transformer. Due to the unbalanced RS injection capability and unbalanced load. The proposed control strategy is to use the single-phase PQ theory to independently control the FLI of each phase. The instantaneous power demand with all loads and RS on the transformer is calculated and averaged. The results were found to be consistent across both the transformer and FLI. Thus, the load, RS, and transformers are balanced even under conditions of load and sunlight fluctuations or unbalanced loads. The simulation results with Matlab/Simulink, using FLI and PQ theory, were found to be able to improve transformer current unbalance.

II. HARMONIC

The harmonics [7] of a power system are defined as sinusoidal voltages and currents at frequencies that are integer

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multiples of the generated fundamental frequency. Harmonic causes distortion of utility voltage and load current waveform. As shown in Fig. 2.

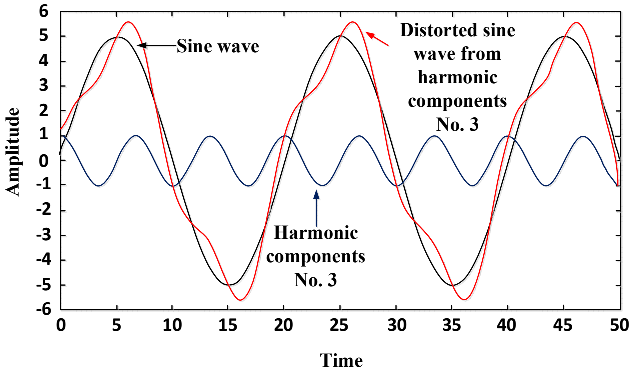

Fig. 2. Harmonic current

From Fig. 2. is an example of a harmonic current. Where the current is distorted from the original waveform due to the mixing of third-order harmonics, the most common harmonic index associated with the waveform. Is the total harmonic distortion (THD), defined as the root mean square (RMS) of the harmonics expressed as a percentage of the fundamental component. As shown in equation (1).

$$THDi(\%) = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \ldots}}{I_1} \cdot 100 \qquad (1)$$

Harmonic effects on the power system such as malfunctions of critical control and protection devices, unexpected fuse operation, lower power factor (PF) in the power system. The electrical system is not working at full efficiency. It increases the risk of overvoltage at the power factor correction capacitor (PFC). The fault current flows through the fuses when DG is connected in the distribution system as shown in Fig. 3.

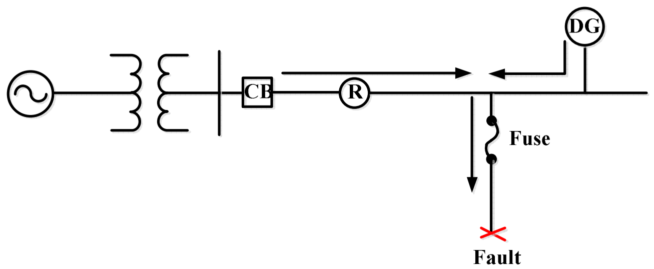

Fig. 3. Fault current flowing through the fuse when DG is connected in the electrical distribution system

III. Photovoltaic Rooftop

Photovoltaic is a method of generating electricity directly from solar energy using semiconductors. With electromagnetic waves in the light wavelength using the photovoltaic phenomenon. Solar energy is natural, safe and sustainable. PV is a device that converts sunlight into electricity using the intensity of sunlight. Photovoltaic systems include PV array systems, which consist of two or more solar panels that convert sunlight into electricity. Used with dynamic voltage recovery systems (DVRs) for energy storage. This system powers the DC power source used by the inverter system to convert DC power to ac power to continue operating the DVR system. The simulated equivalent circuit of the photovoltaic cell is shown in Fig. 4. [8]-[9]

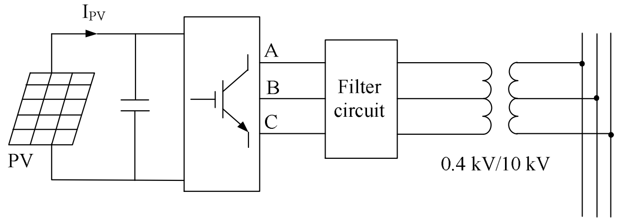

Fig. 4. Photovoltaic rooftop system

IV. Connect Grid

A. In the case of connecting to a 230/400 volt system

A rooftop solar power generation system for residential homes can be connected to the grid system if the installed capacity does not exceed 5 kilowatts. If multiple single-phase power generating systems are connected to the grid system, the power distributed to the grid system in each phase must be balanced. This allows the difference in installed capacity per phase up to 5 kilowatts (kWp). The total installed capacity of all types of power generation systems (In kilowatts) both from the solar power generation system and other types of power generation systems connected in the same distribution transformer must not exceed 15 percent of the distribution transformer rating. (In kilovolt-amperes)

B. In the case of connecting to a 12 or 24 kV system

The total installed capacity of all types of power generation systems both from solar power generation systems and other types of power generation systems installed in the same feeder must not exceed 8 megawatts (MWp) for 24 kV and 4 megawatts (MWp) for 12 kV. The total installed capacity of all types of power generation systems (In kilowatts) both from the solar power generation system and other types of power generation systems connected in the same distribution transformer must not exceed 20 percent of the distribution transformer rating. (In kilovolt-amperes). If connected to a 12 or 24 kV system as shown in Fig. 5.

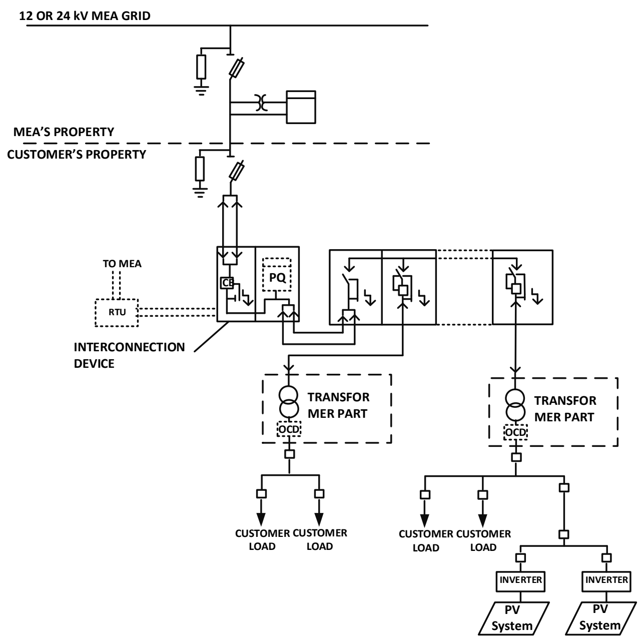

Fig. 5. Connection arrangement for 12 or 24 kV

V. Mathematical Model

Total harmonic distortion (THD), defined as the root mean square (RMS), harmonics are expressed as a percentage of the fundamental component. as shown in equation (2)-(3).

$$THD_v = \frac{\sqrt{\sum_{h=2}^{h_{\max}} (V_h)^2}}{V_1} \cdot 100\% \qquad (2)$$

$$THD_i = \frac{\sqrt{\sum_{h=2}^{h_{\max}} (I_h)^2}}{I_1} \cdot 100\% \qquad (3)$$

Where V_h is the RMS voltage at harmonics frequency, h_{max} is the maximum harmonic order and V_1 is the fundamental component of the RMS voltage [7].

VI. Case Study

In this paper, the analysis of harmonic for connected grid photovoltaic rooftop was conducted. As shown in table 1.

TABLE 1. TEST CASE

No	Test Case
1	Unbalance Current
2	Flicker
3	Harmonic

From table 1, 3 test cases were conducted as follows: Case 1 measure the unbalance current of the rooftop solar power system in the distribution system, Case 2 measure the short-term flicker (P_{st}) and long-term flicker (P_{lt}) and Case 3 measure harmonics.

VII. Results

The value of each harmonic current limit is based on a calculation method in accordance with IEC 61000-3-6 (2008). The ripple voltage limit is based on a calculation method in accordance with IEC 61000-3-7 (2008). The determination of the unbalanced current limit is based on the calculation method according to IEC 61000-3-13 (2008). The limitation of harmonic current, flicker and the unbalanced current are assessed from a maximum value of 95% of the mean over a 10 minute period of the 7 days test data. The results from measurements of unbalanced current, flicker and harmonics are shown in tables 2 – 4.

TABLE 2. UNBALANCE CURRENT

	Measurement Results (A)	Limit (A)	Inspection Results
Negative Sequence Current	1.67	9.3	pass

TABLE 3. FLICKER

	Measurement Results	Limit	Inspection Results
P_{st}	0.29	0.73	pass
P_{lt}	0.26	0.58	pass

Where P_{st} is short term flicker indicator and P_{lt} is long term flicker indicator.

TABLE 4. HARMONICS

No	Results (A)	Limit (A)	Results	No	Results (A)	Limit (A)	Results
1	101.90	-	-	26	0.04	0.2	pass
2	7.79	2.7	not pass	27	0.07	0.2	pass
3	0.91	3.5	pass	28	0.03	0.2	pass
4	3.21	1.1	not pass	29	0.13	0.1	pass
5	4.32	5.2	pass	30	0.01	0.1	pass
6	0.19	0.7	pass	31	0.10	0.1	pass
7	1.58	3.7	pass	32	0.02	0.1	pass
8	1.00	0.5	not pass	33	0.04	0.1	pass
9	0.21	0.7	pass	34	0.02	0.1	pass
10	0.45	0.4	not pass	35	0.09	0.1	pass
11	1.19	2.6	pass	36	0.01	0.1	pass
12	0.04	0.4	pass	37	0.09	0.1	pass
13	0.63	2.2	pass	38	0.02	0.1	pass
14	0.08	0.3	pass	39	0.04	0.1	pass
15	0.17	0.3	pass	40	0.03	0.1	pass
16	0.08	0.3	pass	41	0.07	0.1	pass
17	0.42	1.6	pass	42	0.02	0.1	pass
18	0.04	0.2	pass	43	0.08	0.1	pass
19	0.25	0.7	pass	44	0.03	0.1	pass
20	0.05	0.2	pass	45	0.06	0.1	pass
21	0.13	0.2	pass	46	0.04	0.1	pass
22	0.04	0.2	pass	47	0.10	0.1	pass
23	0.25	0.9	pass	48	0.03	0.1	pass
24	0.02	0.2	pass	49	0.09	0.1	pass
25	0.17	0.2	pass	50	0.04	0.1	pass

From the measurement results of harmonic current and second-order harmonic power at connection point shown in Fig. 6, the measurement result of harmonic current and 4[th] harmonic power at connection point shown in Fig. 7, the measurement results of harmonic current and 8[th] harmonic power at connection point shown in Fig. 8, the measurement results of harmonic current and 10[th] harmonic power at connection point shown in Fig. 9.

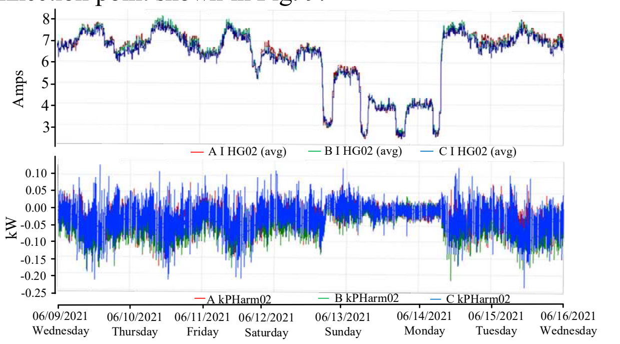

Fig. 6. Measurement result of harmonic current and second order harmonic power at connection point

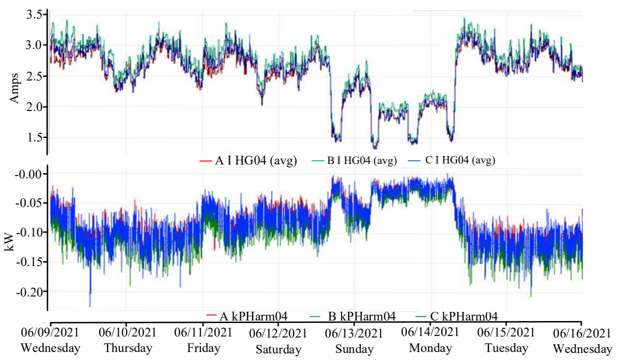

Fig. 7. Measurement result of harmonic current and 4[th] harmonic power at connection point

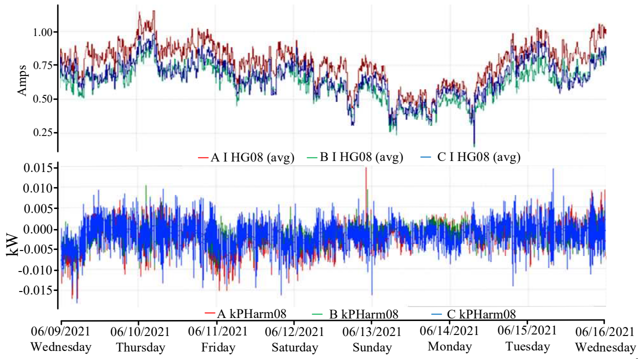

Fig. 8. Measurement result of harmonic current and 8th harmonic power at connection point

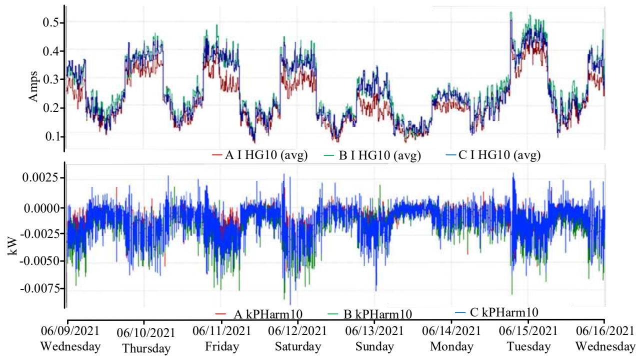

Fig. 9. Measurement result of harmonic current and 10th harmonic power at connection point

VIII. CONCLUSION

This paper presents a harmonic analysis of a grid-connected rooftop photovoltaic system. By measuring the unbalanced current, flicker and harmonics of the solar rooftop system. The results showed that the measured negative sequence current was 1.67 A, the P_{st} was 0.29, the P_{lt} was 0.26, and most of the harmonic results were below limitations. Therefore, the measurement point between the distribution system and the connected-grid solar rooftop is able to analyze the harmonics in the distribution system.

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