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Relation between Solar PV Power Generation, Inverter Rating and THD

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Abstract: ***The increasing threat of global warming call for the policy chances that increase the share of renewable energy-based generation including the integration of solar PV generation in the distribution networks. However, the distribution networks are designed and operated for centralised power generation and unidirectional power flow. The integration of solar PV systems leads to distributed power generation and bidirectional power flow, which results in operation challenges, such as power quality problems. These problems required to be quantified to develop appropriate solutions. Therefore, in this paper, a power quality auditing is conducted for a 50 kVA solar PV power plant and the resultant observations are presented in this paper. The study is conducted for two types of days, which are: (i) weekend day; (ii) weekday. The former type of day has relatively lower demand compared to the later type day. A number of observations are made and they are presented in this paper. Few important observations and conclusions are presented in this paper. The relation among the power generation, harmonics and inverters rating are observed and presented. Moreover, the quantification of voltage dips is also presented in this paper.***

Keywords: ***Harmonics, power quality, dips, auditing, solar PV system.***

I. INTRODUCTION

As the impact of global warming is affecting our lives, the call for increasing the share of renewable energy-based generation is also increasing. Particularly, the developing countries like India are investing in renewable energy-based generations. New policies are supporting the development of energy projects based on renewable energy. Indian Ministry of New and Renewable Energy (MNRE) has a target of surpassing 175 GW of renewable energy by 2022. The similar trend is being observed all across the world. For example, the negative energy prices of Germany clearly indicate that their renewable energy generations have exceeded their demands. Table- I presents the continuous negative price trend in Germany's wholesale energy market [1], [2]. The rooftop solar photovoltaic (PV) systems are playing a significant role in the increasing share of renewable energy. They not only contribute by generating green energy but also mobilize people to embrace and support green energy initiatives. In other words, they act as a propagation medium. The physical view of solar PV system may encourage common people to install the solar PV system in their home. Moreover, the solar PV system has been perceived as a sign of social responsibility [3]. In such scenario, the social responsibility is diffused to a neighbourhood via peer effects and thus the possibility of solar PV system getting concentrated in a neighbourhood increases [4]-[5]. In such cases, the geographical distribution of solar PV systems is aligned as pockets. Such pockets and their solar PV systems are most likely connected to the same distribution transformer. As the share of solar PV systems increases, the coincidence factor of solar power generation and electrical proximity (connected to the same distribution transformer) of rooftop solar system will lead to network operational challenges. The challenges vary from overvoltage, cable overloading, unbalance and harmonics [6]–[13]. The aforementioned technical challenges restrict the further integration of renewable energy generations into the existing network infrastructure. Therefore, it is imperative that new control measures should be developed to address the aforementioned challenges. However, to develop new solutions, it is important to quantify the existing challenges (i.e., power quality problems) [14]–[19]. Therefore, in this paper, power quality auditing is conducted for a solar PV installation of 50 kVA, which is connected to the grid via 3 phase inverter. The measurements are taken for 48 hours with the sample size of one minute. Note that the measurements are scheduled such that 24 hours corresponding to working day and another 24 hours corresponding to weekend. In section II, the measurement setup is described. The recorded measurements are analysed and the observations are presented in section III. The paper is concluded in section IV by highlighting the key conclusions.

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II. MEASUREMENT SETUP

Table- I Trend of wholesale market energy price in Germany

Year	2015	2016	2017	2018
Negative price duration (hours)	126	97	146	134

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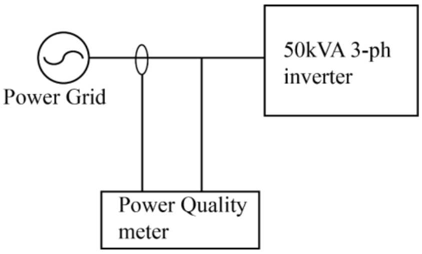

Fig. 1 The measurement setup

Fig. 2 The measurement setup

The Fluke 438-II power quality is connected to the ac output terminal of a 3 phase SMA inverter. The inverter is connected to the utility grid and the inverter exports the power to the connected utility grid as long as the utility network maintain the desired voltage level (0.4 kV) The rated power of the inverter is 50 kVA, the MPP range is 200-950 V, the maximum ac apparent power is 55 kVA, the continuous ac current is 80 A and the power factor can be varied from 0.8 (lagging) to 0.8 (leading). The power quality measuring setup is shown in Fig. 1 and Fig. 2. In this measurement, a Fluke 438-II instrument is used, which is a class A type measuring instrument [20]. The used measurement instrument follows EC 61000-4-30 Class A, where the measurements are aggregated over a period of 3 seconds. In the case of class A instruments, when the measured parameters do not vary and two class A instruments are used, they should produce the same measurements.

III. Measurement Analysis

A. *Harmonics and Power Generation*

In this measurement, the measurement is aggregated for one minute for the duration of 48 hours. The relation between the active power and voltage total harmonic distortion and the relation between the active power and the current total harmonic distortion are illustrated in Fig. 3. Note that the measured inverter has the rated capacity of 50 kVA (3-phase) and thus per phase rated capacity is 16.67 kVA. Fig. 3 shows that the voltage total harmonic distortion does not exhibit noticeable relation with power generation. However, the current total harmonic distortion has (exponential) relation with active power generation. Fig. 3 shows that at lower power generation (less than 4 kW/phase) the current total harmonic distortion factor is higher and it reduces below 8% when the power generation exceeds 30% of the rated power.

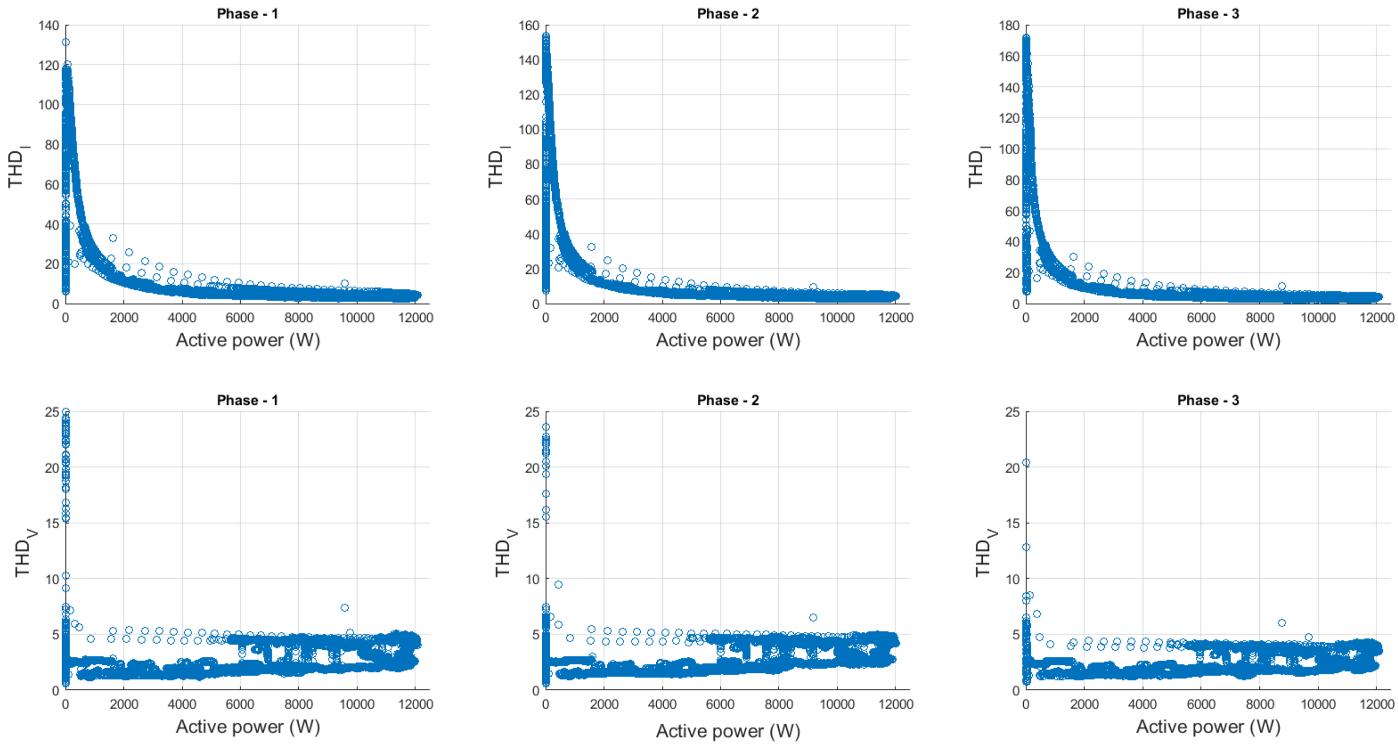

Fig. 3 Relation between THD and power generation

B. *Harmonics – Weekday and Weekend*

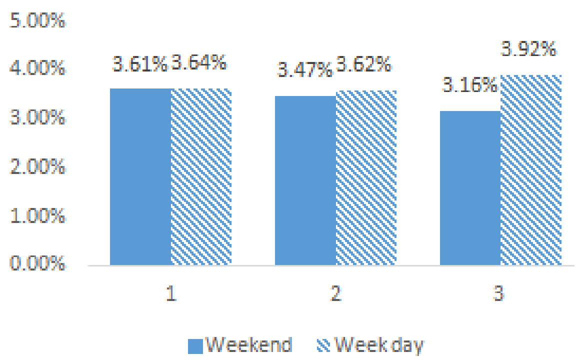

Fig. 4 Voltage Harmonics

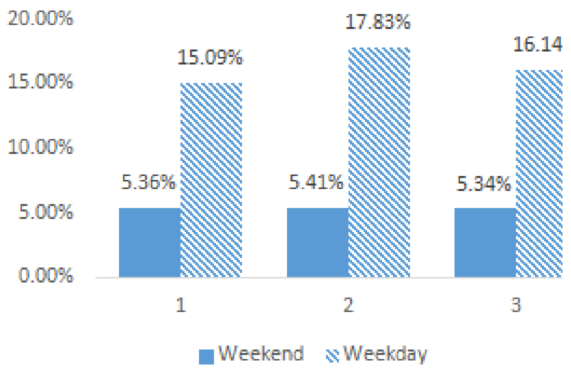

Fig. 5 Current Harmonics

The total harmonic distortion (THD) values for weekdays and weekends are compared and illustrated in **Error! Reference source not found.**3 and **Error! Reference source not found.**4. Here, Fig. 4 shows voltage harmonic and Fig. 5 shows the current harmonics. Fig. 5 shows that the current harmonics on weekdays are almost three times higher than current harmonics on the weekend, which indicates that the harmonics are created at the load side. As the load increases in weekdays, the THD-current also increases. IEEE 519 dictates voltage total harmonic distortion (THD) should be lower than 5% and the current THD should be lower than 8%. Note that these standards apply at the point of common coupling [21]. In generator excitation slots, the discrete special distribution of coil slots and non-uniform distribution of magnetic flux can create distorted voltage waveform. However, the load side voltage harmonics are proved to be smaller compared to the load side harmonics.

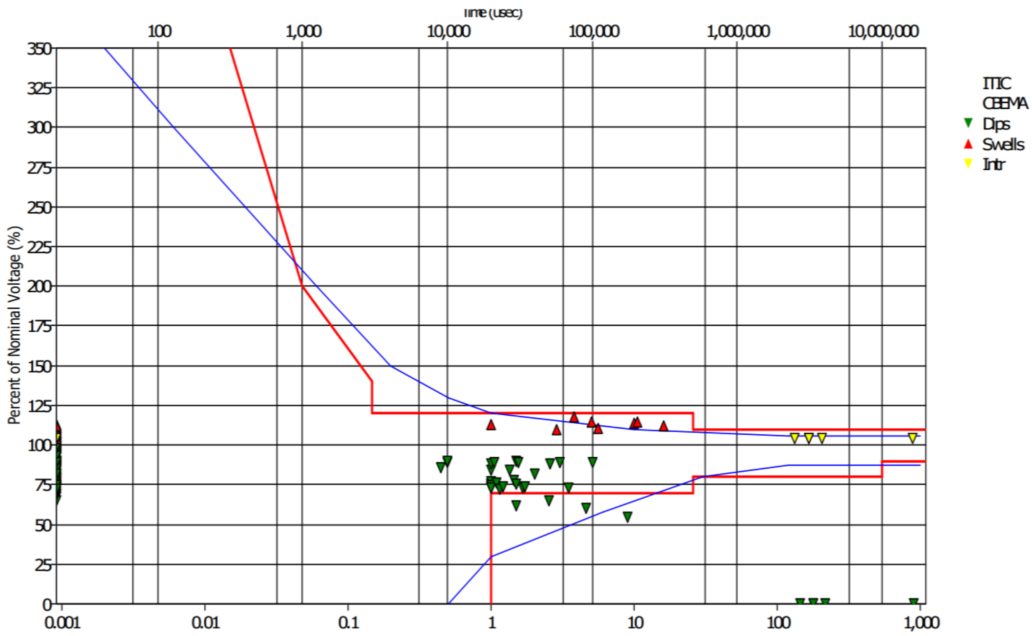

Fig. 6 Illustration of measurements in ITIC curve format

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C. *Voltage Dips and Voltage Swell*

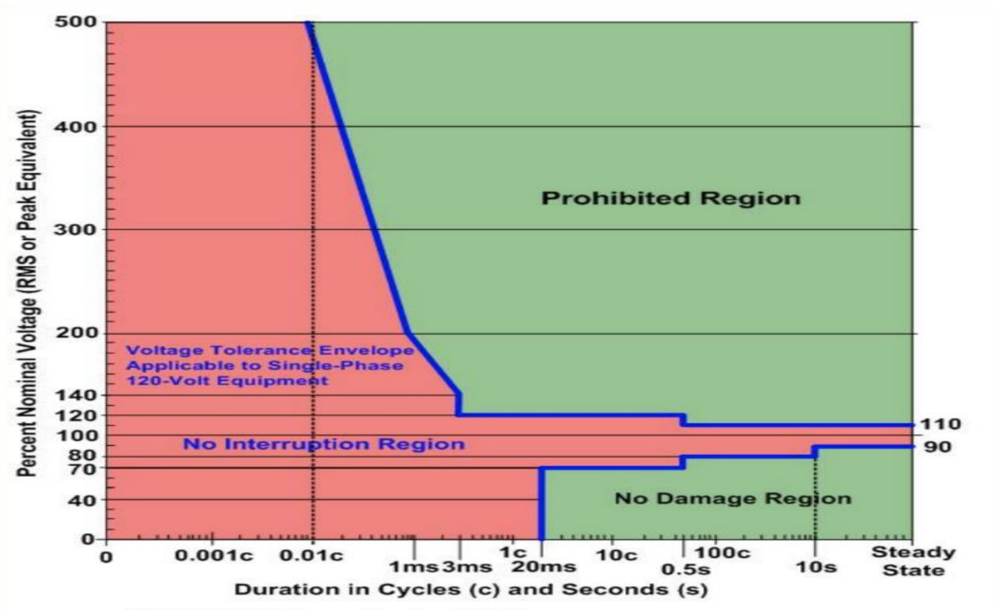

Fig. 7 ITIC standard curve

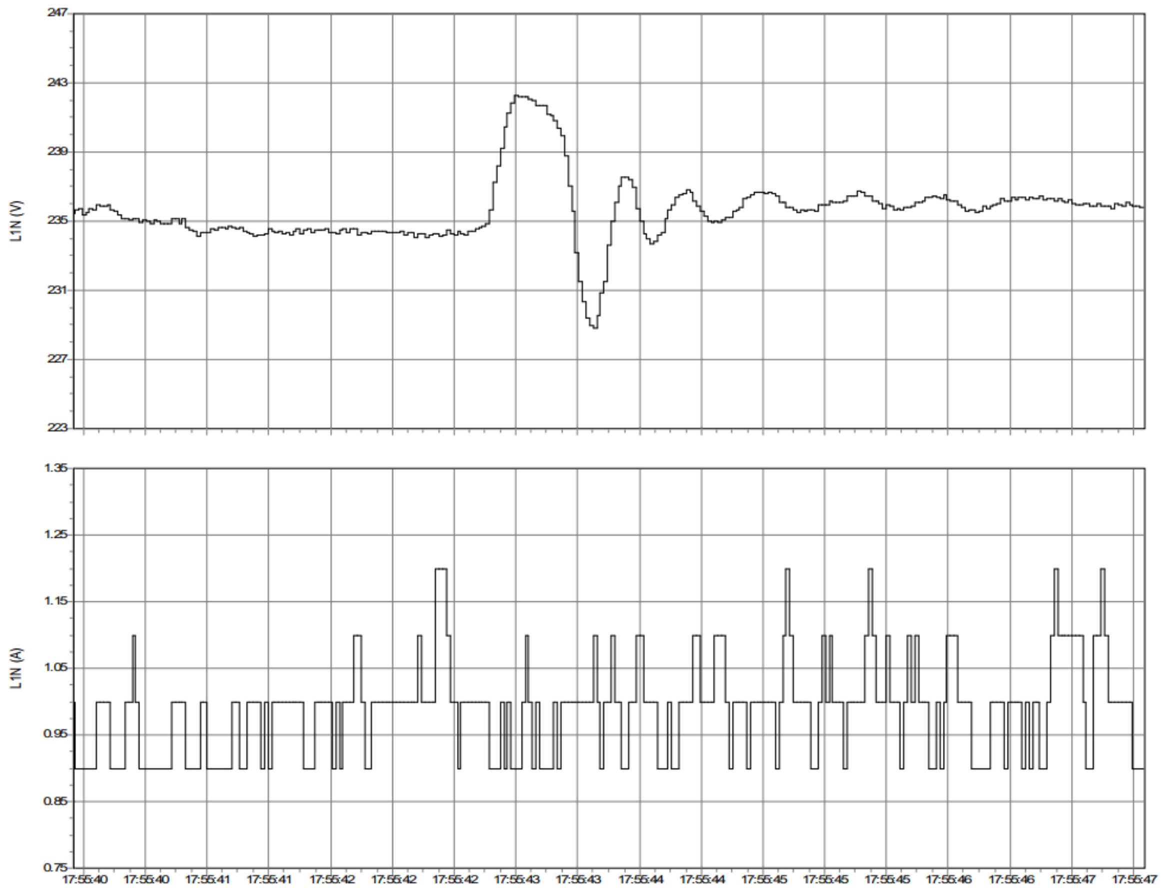

Fig. 8 Inverter maintaining the voltage level at 13% of rated power generation.

Voltage dip is the voltage measurement that is recorded between 0.1 pu to 0.9 pu for the duration of 0.5 cycles to 30 cycles [9]. Voltage swell is the voltage measurement that is recorded between 1.1 pu to 1.8 pu for the duration of 0.5 cycles to 30 cycles [22]. The voltage events may not severely *affect induction motors however they severely affect computing devices. The standards corresponding to voltage events and the expected immunity of IT devices against voltage events are standardized by the Information Technology Industry Council (ITIC) curve, as shown in Fig. 7 [23]. As given in* **Table- *I*** and Fig. 6, ~90% of dips are cleared within 200 ms.

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Table- I Dips statistics

Dip voltage U[%]	Duration (ms)					
	t < 10	10 <= t <= 200	200 < t <= 1000	1000 < t <= 5000	5000 < t <= 60000	60000 < t
90 > U >= 80	56	12	0	0	0	0
80 > U >= 70	25	16	0	0	0	0
70 > U >= 40	4	0	0	0	0	0
40 > U >= 5	0	0	0	0	0	0
5 > U	56	0	0	**8**	**4**	**6**

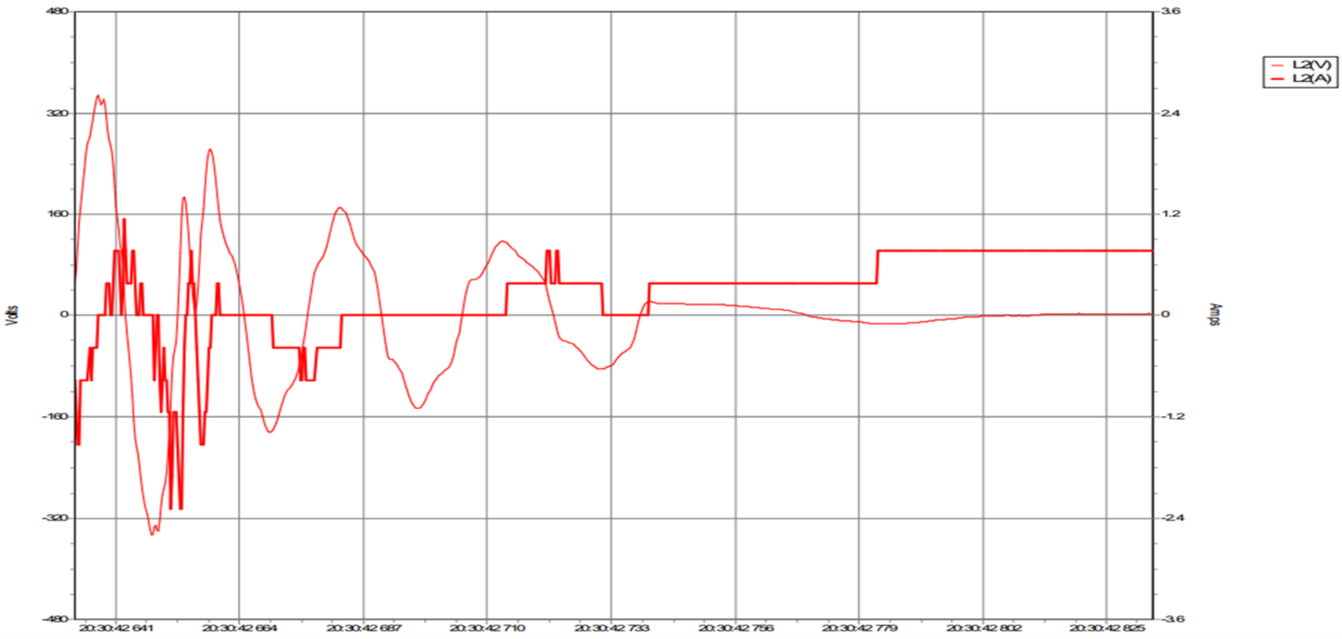

Fig. 9 The current and voltage profiles as the inverter shuts down

IV. CONCLUSION

The power quality measurements have revealed that the harmonic filters of the inverter, under investigation, is optimized for power generation higher than 30% of inverter's rated power. Moreover, the absence of correlation between current total harmonic distortion and voltage total harmonic distortion have indicated that the current harmonic is originated from the load side (i.e., inverter). In addition, the voltage dips are recorded, which could have been originated from MV side capacitors or large loads. Neverthertheless, 10% of the recorded dips do not fall under the device immunity region. Therefore, the measurements recommend the consumer to use dips mitigation measures, like online uninterrupted power supply, to filter the future dips.

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