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Effect of Solar PV Inverters on the Quality of Power of Smart Urban Grid Delivery

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Abstract: *The electrical energy system is transforming worldwide into smart grids. The vision of smart grid demands a cutting edge technology for integrating the different renewable energy sources. Integration of renewable such as solar photovoltaic (PV) pose various power quality problems in the system, one such problem is harmonics generation. Harmonics are generated by the associated power electronics based interfacing devices. Moreover the load connected to the distribution system is nonlinear and harmonic is rich in nature. Therefore, a lot of harmonics is injected into the system either from the source or from the load ends and affects the performance of power system. Harmonic distortions create excessive power loss and abnormal temperature rise, results the overheating of transformer, overheating of neutral conductor and malfunction of protective devices, which endangers the stability and reliability of the system. The smart distribution grid must absorb such concerns through critical technological solutions. In this paper, harmonics are analyzed for a solar PV integrated smart urban utility distribution feeder. Results show that a lot of voltage/current harmonics are injected at various buses, lines and transformers by the solar PV and associated interfacing devices which even violates the harmonic limit of IEEE standards519-1992. The authors feel that in order to achieve the smart distribution grid objectives of clean power supply to the customers, there is a serious necessity to study the issues related to harmonic generation, and further to develop control strategies to mitigate them.*
Key Word*: Harmonics, Harmonics (THD), grid integration, solar PV*

I. Introduction

Harmonics are non-sinusoidal current and voltage waveforms which occur in power systems due to nonlinear characteristics of equipment and connected loads. The solar PV system introduces harmonics in the distribution network. The harmonics are generated in the conversion of DC to AC power by the inverters. The order of harmonics and its magnitude will depend on the power inverter technology, modulation technique, method of commutation and the existence of high or low frequency coupling transformer and interconnection configuration [1-4]. Moreover, the number of solar PV units connected to the grid system and the interaction between grid components and PV units further intensify the harmonic distortions. Such harmonic distortion affects the operation of distribution systems in variety of ways [5].Oliva and Balda [6] presented the study of two PV system connected to the distribution grid through a PWM inverter and reported the malfunction of harmonic-sensitive equipment due to excessive injection of harmonic current in in the system. In a weak power system where the operation is not perfectly symmetrical, these harmonics can be represented by positive, negative, and zero sequence harmonic components [7-8]. The unbalance components produce adverse effects on the transformers and connecting cables. The neutral of transformer carries zero sequence and the residual unbalance of positive and negative sequence currents [9-11], which affects the performance of protection system. The objective of this paper is to investigate the harmonics contribution for a solar PV integrated smart utility distribution grid which feed power to the consumers of varying nature. Results show a lot of harmonics are injected by the solar PV and associated interfacing devices which even violates the harmonic limit of IEEE standards 519-1992 [12] and distorts the quality of supply. This paper is organized as follows; Modeling of smart distribution grid system is presented in Section 2 using a practical distribution system data. Section 3 presents the results and discussions. Section 4 summarizes and concludes the work.

II. Modeling Of Smart Utility Distribution Grid

The model of a generic utility distribution grid is presented in Fig.1, which supplies power in a residential area, a shopping complex and a small industry. Two transformers, each of capacity 15 MVA, 33/11 KV are operating in parallel to cater the power demand. The loads are variety of nature particularly the industry has mixed lighting and motor loads, variable speed drives are used to control the speed of induction motors, the capacity of load connected at various buses is presented in Table 1. The rating details of the solar PVs installed at various buses are given in Table 2.

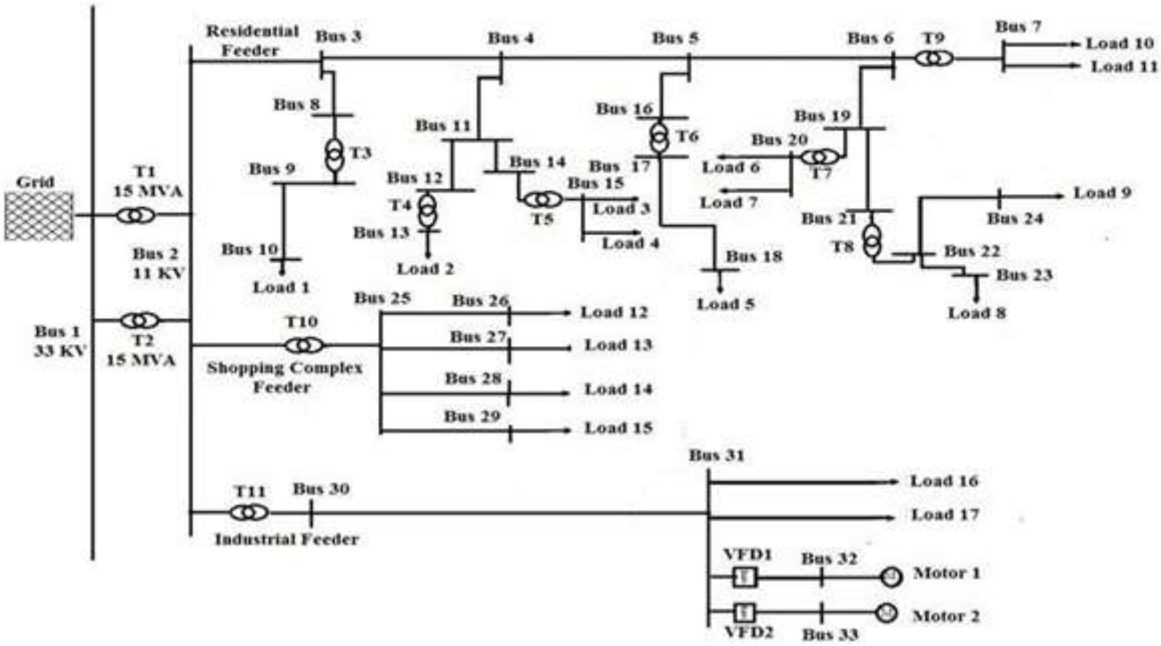

Figure 1 Model of a smart urban utility distribution feeder

Table 1 Load on the various buses of utility distribution feeder

Load Id.	Bus Id.	Capacity(MW)
1	10	1
2	13	1
3	15	0.6
4	15	0.5
5	18	0.8
6	20	0.8
7	20	0.6
8	23	0.6
9	24	0.8
10	7	0.8
11	7	0.8
12	26	0.6
13	27	0.6
14	28	0.8
15	29	0.6
16	31	0.6
17	31	0.6
Motor 1	32	0.5
Motor 2	33	0.5

Table 2 Rating of solar PV connected at various buses

Bus Id.	PV panel (Watt/panel)	Rating of solar
7	280	0.5
9	280	1
13	280	0.5
15	280	1
23	280	0.5

III. Results And Discussion

This section presents the detailed analysis of harmonics generation due to solar PV inverters at the various buses, branches and transformers of the modeled smart rural distribution network. Figs.2-3show the distorted voltage waveform and corresponding harmonic spectrum at various buses such as bus13 and 23. It is observed that dominant order is the fifth then other higher order harmonics are also present with more or less degree. Fig. 4 presents the current waveform in the line 10 and corresponding harmonic spectrum. In current spectrum it is clear that seventh order harmonics is the dominant harmonics. Figures 5-6 show the harmonic current waveform and spectrum in the transformer T9 and T10. The harmonic current and voltage contributions are very high with solar PV system even exceeds the IEEE519-1992 limits as presented in table 3 and 4. Such distorted power quality situation is harmful to the system equipment such as transformer, in which the heating of neutral conductor occurs. Notwithstanding the other connected equipment also affected by the poor quality of supply.

Impact of Solar PV Inverters on the Power Quality of Smart Urban Distribution Grid

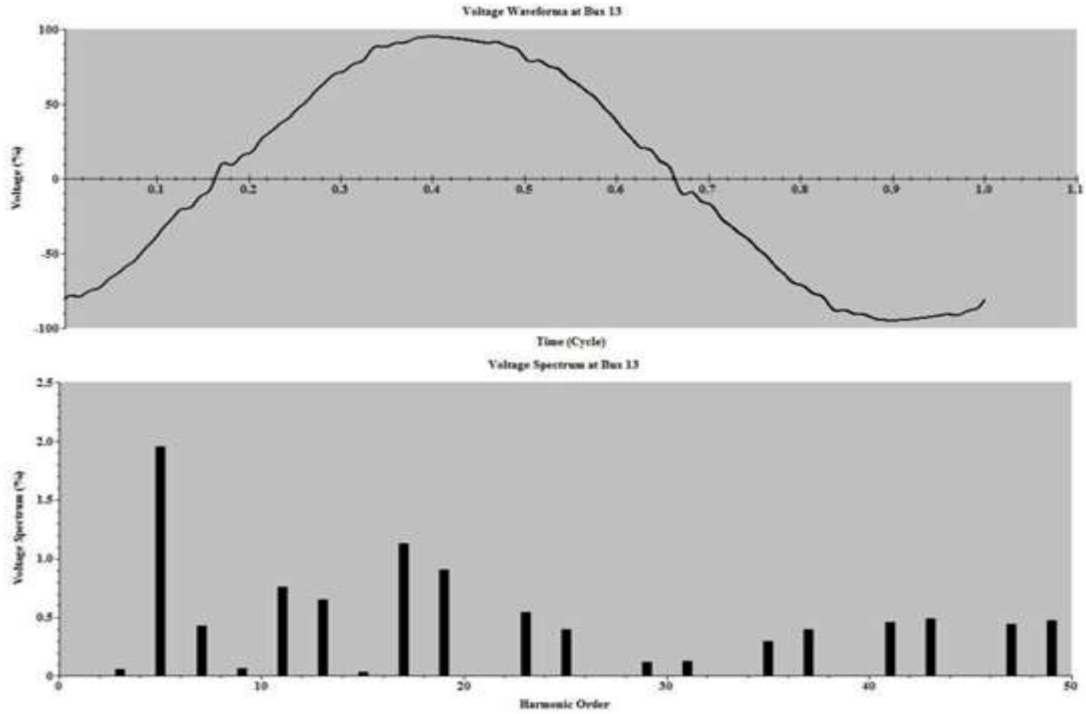

Figure 2 Voltage waveform at bus 13 and harmonics spectrum

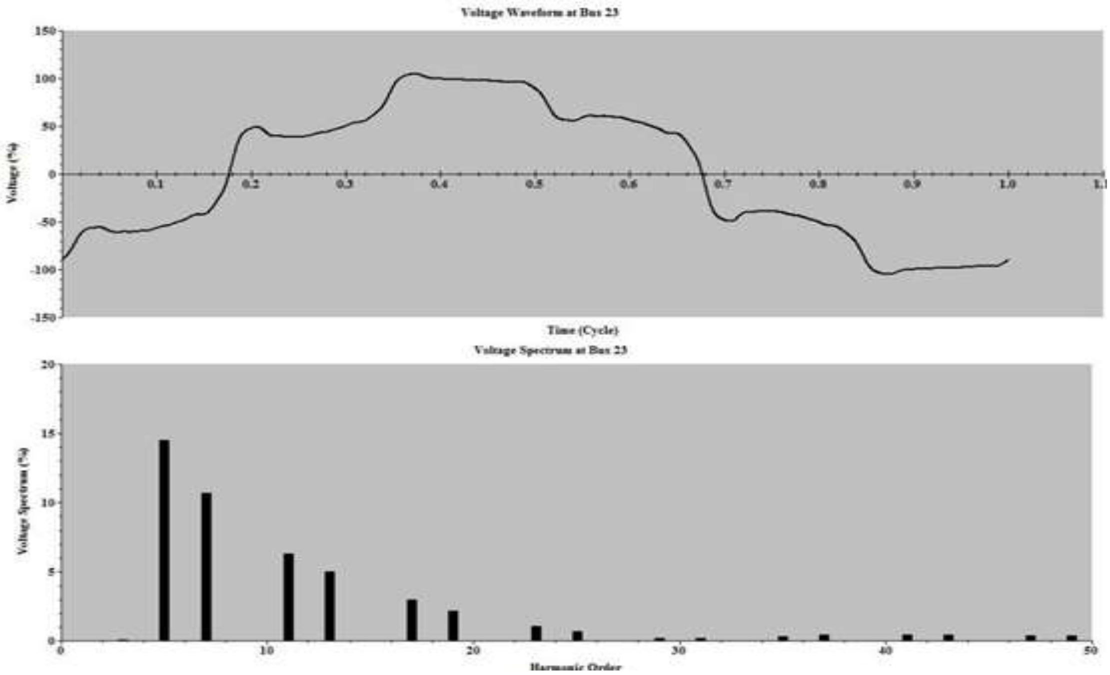

Figure 3 Voltage waveform at bus 23 and harmonics spectrum

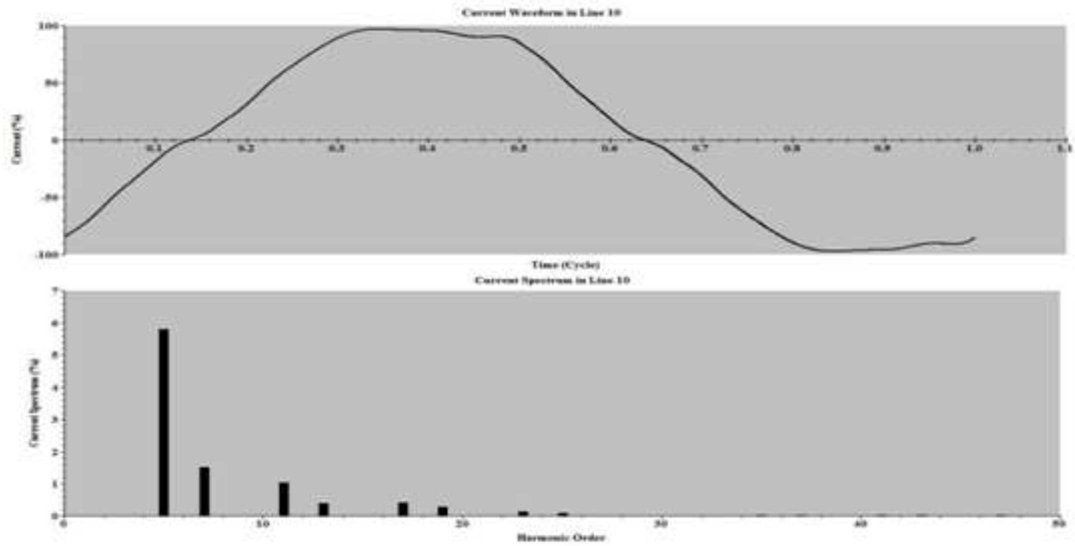

Figure 4 Current waveform in line 10 and harmonics spectrum

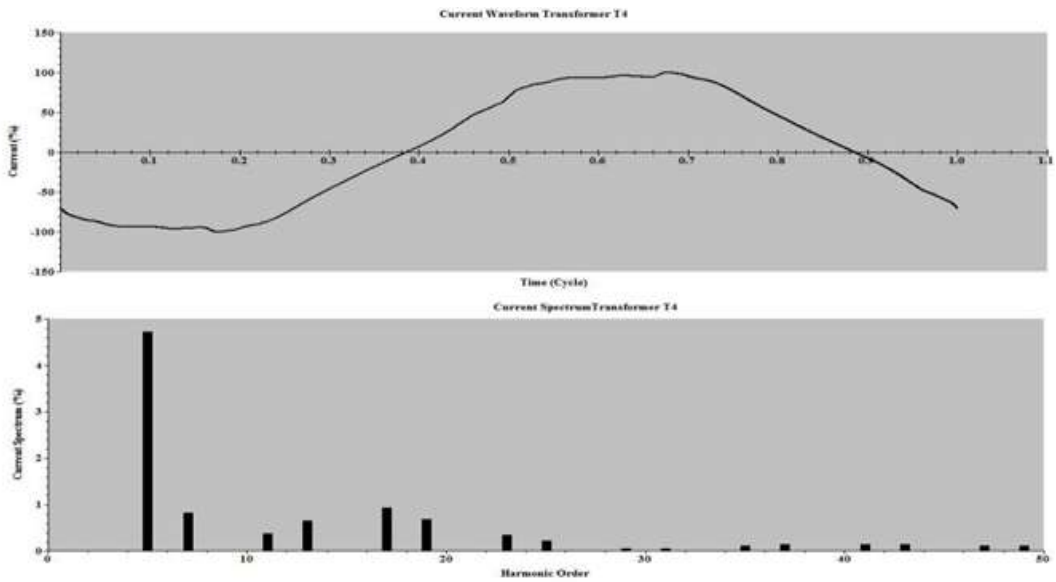

Figure 5 Current waveform in transformer T4 and harmonics spectrum

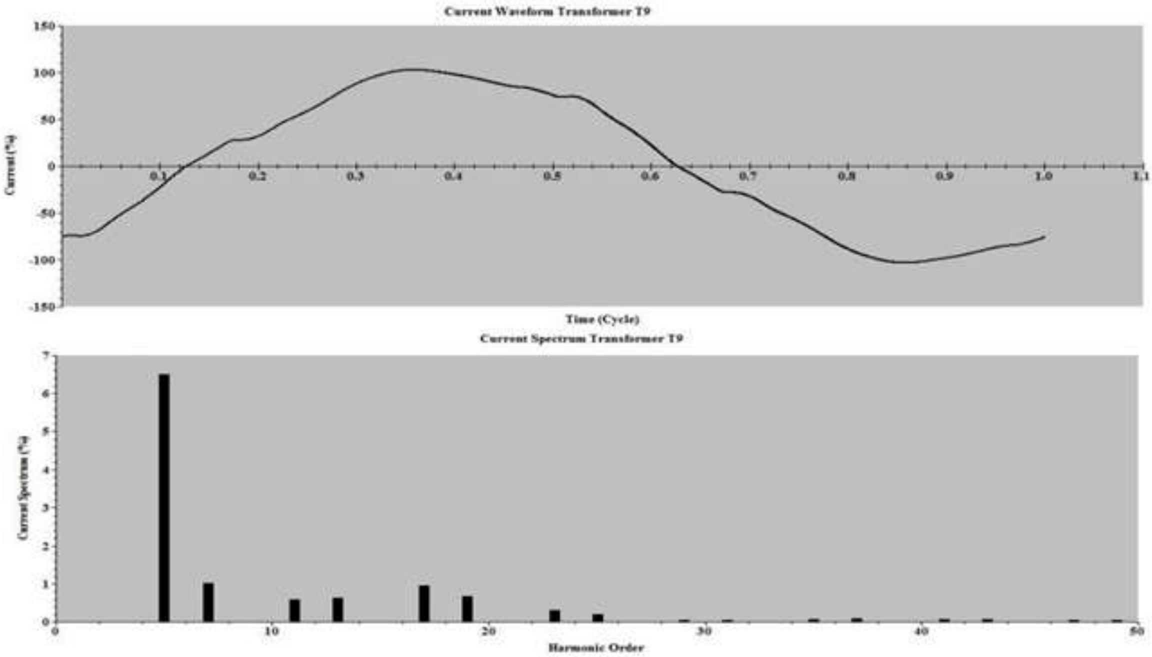

Figure 6 Current waveform in transformer T9 and harmonics spectrum

Table 3 Voltage Harmonics Distortion at various Buses

Sr. No.	**Bus Id.**	**Voltage THD (%)**	**IEEE std. 519-1992 Voltage THD (%)**
1	7	15.57	5
2	9	19.81	5
3	13	20.58	5
4	15	21.28	5
5	23	18.19	5

Table 4 Current harmonics distortion in various branches

Sr. No.	**Line Id.**	**From**	**To**	**Current THD (%)**	**IEEE std. 519-1992 Current THD (%)**
1	3	Bus3	Bus8	55.07	5
2	4	Bus4	Bus11	40.18	5
3	8	Bus11	Bus14	36.22	5
4	9	Bus11	Bus12	38.92	5

IV. Conclusion

In this paper the power quality of solar PV inverters such as harmonics distortion is analyzed for a urban utility distribution grid. It is observed that solar PV increases the harmonic proportion in the distribution grid beyond the prescribed limits, which is a major challenge and needs to be addressed in integration process. The grid must be able to absorb these challenges in order to achieve the smart grid objectives of clean power supply. For designing a filter to eliminate the harmonics their exact nature, individual contribution and THD are required. The analysis presented in this paper will be helpful for designing a filter and make the system harmonic free.

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