Investigation of Performance and Power Quality of Grid-Connected Solar PV System

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Abstract: ***This paper presents performance of a grid connected (5.5 kW) solar PV system for electricity generation at the College of Science and Technology in Bhutan. Energy profile and power quality of the system was analysed using Engage Hub Solo, Fluke 430 series II and Powerlog software. Total energy flow in system, variation of voltage, frequency deviation, current and voltage harmonics, and THDi and THDv with and without solar PV have been studied.***

Keywords: Solar photovoltaic, Power quality, Harmonics, Total harmonic distortion.

1. Introduction

A 12.5 kW solar photo voltaic (PV) power plant was installed at the College of Science and Technology, Bhutan. It comprises of a 5.5 kW grid-connected and 7 kW standalone system. Grid-connected system has 22 solar panels of 24V each while standalone system has 28 solar panels of same rating. The PV panels are flush mounted on the roof of the library building at 13° with azimuth of 15° South East [1]. Power Quality is defined as all aspects of events in the system that deviates from its normal operation [2]. This paper presents efficiency, power quality, current and voltage harmonics, total harmonic distortion (THD), voltage instability, and frequency deviation of a grid-connected solar PV system.

Figure 1 shows the block diagram of a grid connected solar PV system installed on college library building. The output of the 5.5 kW grid connected system is being injected to the commercial grid. The single-phase inverter works only when there is grid supply. This ensures that no power is injected into the grid when grid supply is not available. There are 22 solar panels, each of 250Wp, 24V where eleven PV panels are connected in series while two are connected in parallel.

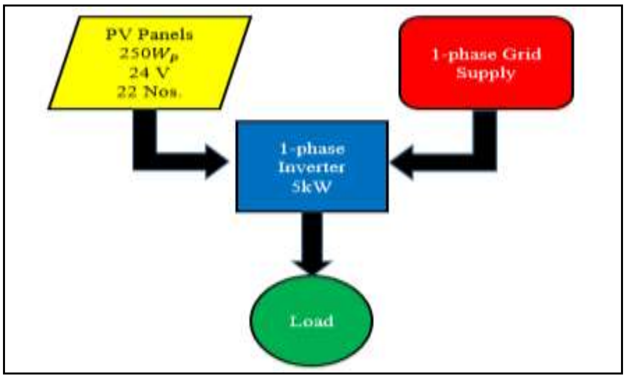

Figure 1: Block diagram of a grid-connected solar PV system

2. Energy profile

Energy home energy monitoring system was used to monitor the energy flow in the distribution network. It enables to access real time data from anywhere anytime. Figure 2 shows the power sub-distribution network of the CST library building. The output of the 5.5 kW grid connected system is being injected to R- phase of the commercial grid. Current transformer (CT) sensors of the Energy home monitoring system were connected on live wire to measure the current in the system. Based on the current drawn and fixed voltage input, power drawn was automatically calculated. The real-time measured data were recorded at 5 minutes interval and can also be accessed online. A total of 9 CT sensors, 4 transmitters and an Efergy hub were used to track the energy flow in the system as shown in Figure 3.

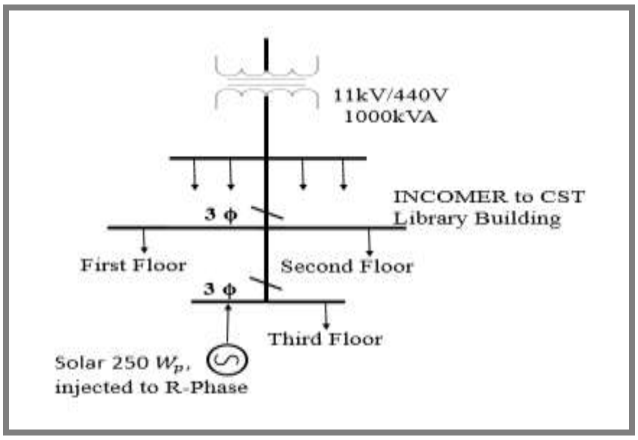

Figure 2: Power sub-distribution network of library building

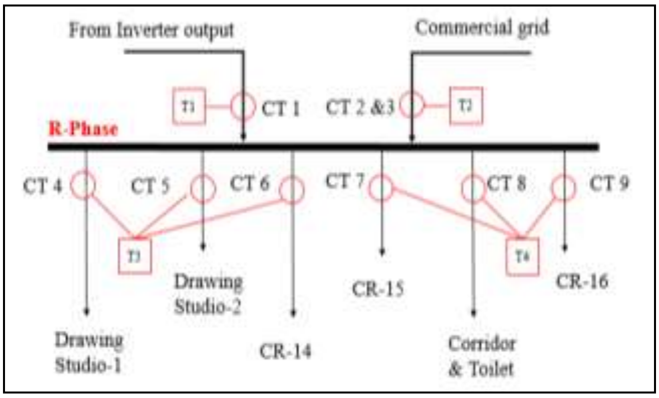

Figure 3: CT and transmitter connection

Data was collected at 5 minutes interval for three months (1 November, 2016 to 31 January, 2017) and converted to average hourly data. The sum of the energy supplied by the grid-connected solar PV is nearly equal to sum of energy injected to the commercial grid and the energy drawn by the connected load as shown in Figure 4.

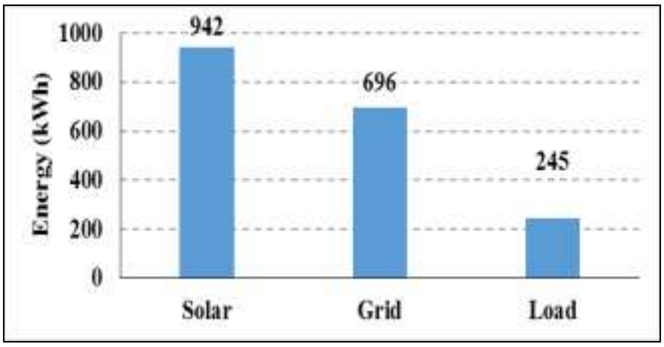

Figure 4: Energy flow

The grid-connected solar PV system generated 942kWh in three months, while 696kWh of energy was injected into the commercial grid and 245kWh of energy was supplied to the load. The difference of 1kWh could be attributed to the instrument error and line losses in the distribution. The measurement uncertainty of the instruments is ± 8.66%.

Weather data of the area was measured using WatchDog 2900ET Weather Station at 5 minutes time interval at the same location. The efficiency of grid-connected solar PV system after operating for three months was found to be 13.14 % which is lower than the manufacturer's design value, 15.54%. Although external factors such as ambient temperature, irradiance and soiling affect the performance of solar PV panels, it is seen that the system has a good performance.

3. Power Quality

3.1 Voltage profile

The three-phase power quality analyzer Fluke 435-II was installed on 5.5 kW grid-connected solar PV system and data was collected at 5 minutes' interval. For the system, the analyses were carried out in two different conditions, with and without solar PV at different times. The data was measured from 22 February to 18 March, 2017.

Case-I Voltage profile with solar PV

Figure 5 represents the voltage profile of the facility with solar PV system on 24 February, 2017. Dips were not observed at any time of the day. The lowest voltage was 232.05 V and is 0.08% higher than rated voltage (230V). The maximum voltage was 238.3V which is 3.6% higher than the rated voltage (230V). The maximum and minimum voltage with PV was found to be within the standard (230±6%). Therefore, voltage profile is good. No swells and zero dips were found during the period.

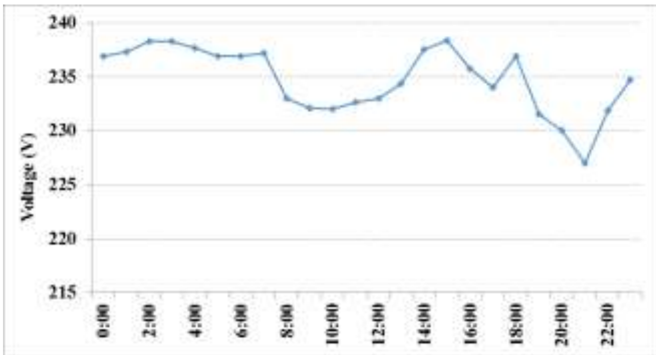

Figure 5: Voltage profile with solar PV

Case-II Voltage profile analysis without PV

Figure 6 represents the voltage profile of the facility without PV on 12 March, 2017. Dips were not observed at any time of the day. The lowest voltage recorded was 223 V which is 3% lower than rated voltage (230V). The maximum voltage is 237.5V which is 3% higher than the rated voltage (230V) [5]. As expected, the lowest voltage, 223V occurs at peak load time, 8 PM. Like in Case-I, no swells and zero dips were observed during the period.

Figure 6: Voltage profile without solar PV

3.2 Frequency analysis

Figure 7 and 8 shows frequency variation with and without solar PV system respectively. It was found that frequency variation is within the permissible limit.

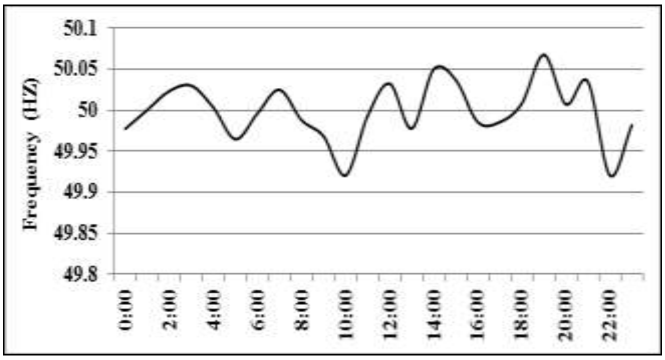

Figure 7: Frequency profile with solar PV system

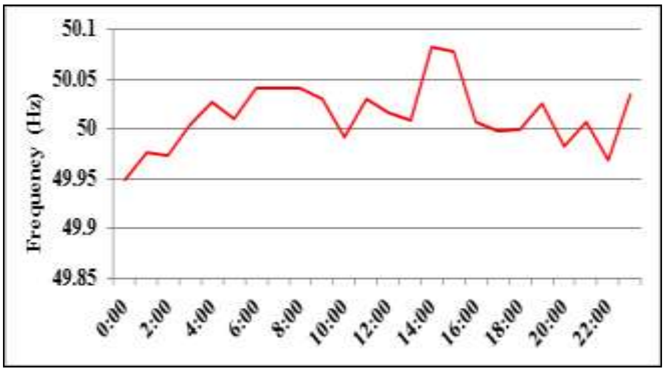

Figure 8: Frequency profile without solar PV

3.3 Harmonics

Harmonics are "sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the Fundamental frequency" [2]. Current harmonics affect the system by loading the distribution system as the waveforms of the other frequencies fully uses up to their capacity without contributing any power to the load. Figure 9 and 10 shows the odd current harmonics with and without PV respectively. Current harmonics was measured from 3rd harmonic up to 9th harmonic by using fluke 430 – II. The maximum current harmonics is of 17.96 % produced by 3rd order, when the solar PV was injected to the system, and 17.78% when there was no solar PV injection to the system. For the system, it is seen that there is a slight increase in current harmonics when the solar PV is injected to the grid.

3.4 Voltage harmonics

The distortion in the voltage waveforms are caused by the current harmonics. The effect of voltage harmonics is not only to the particular load which are causing them, but to the entire system. Their impact depends on the distance of the load causing harmonics from the power source. Figure 11 and 12 shows odd voltage harmonics with and without PV injected in the system respectively. The voltage harmonics was measured from 3rd harmonic up to 9th harmonic by using fluke 430-II. The maximum voltage harmonics is of 17.96 % produced by 3rd order, when the solar PV was injected to the system, and 17.78% when there was no solar PV injection to the system.

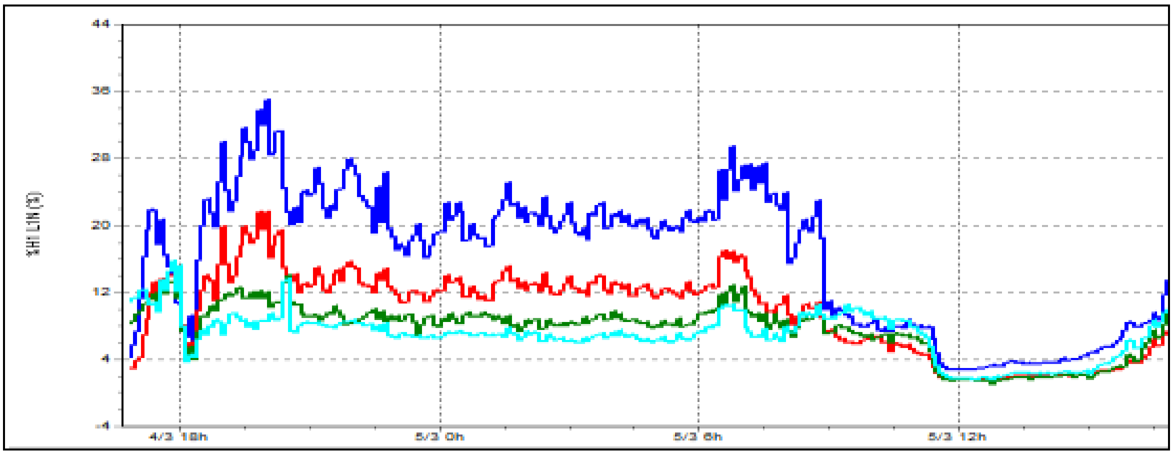

Figure 9: Current harmonics with solar PV

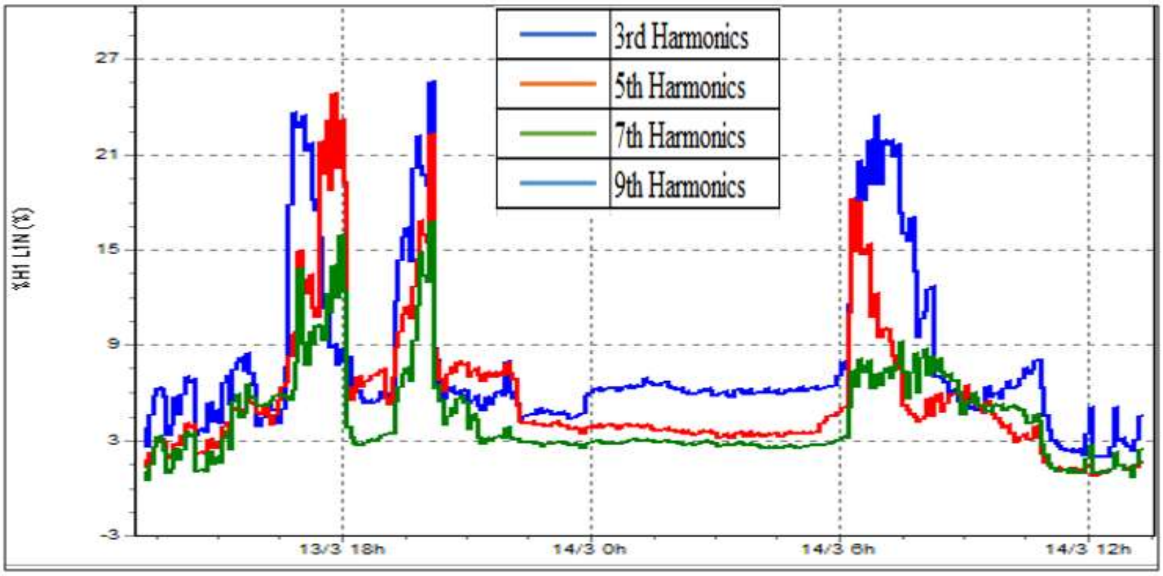

Figure 105: Current harmonics without solar PV

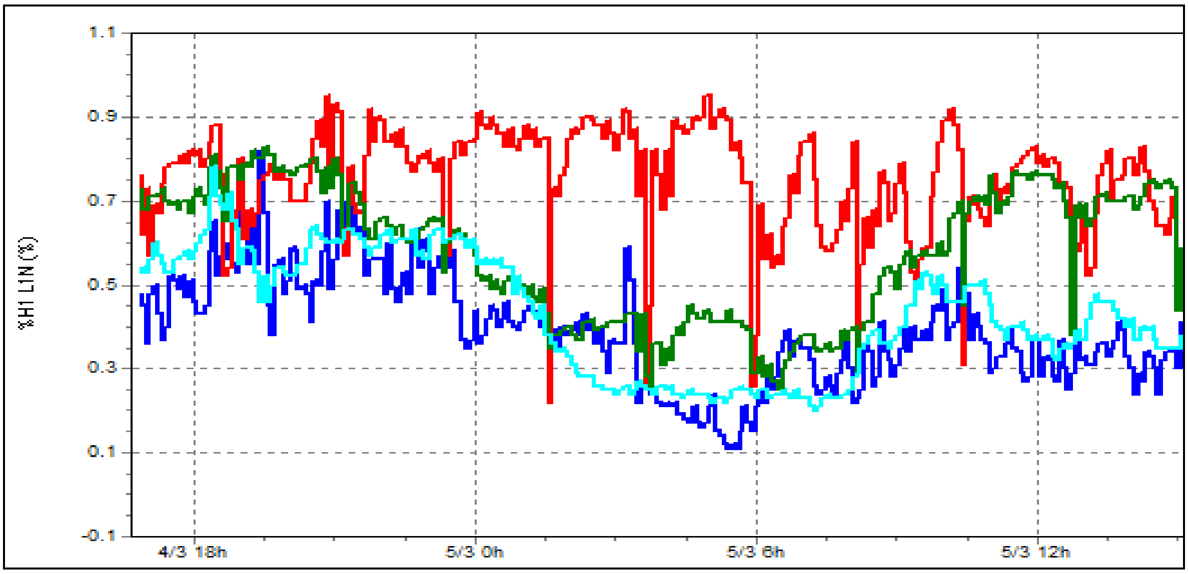

Figure 116: Voltage harmonics with solar PV

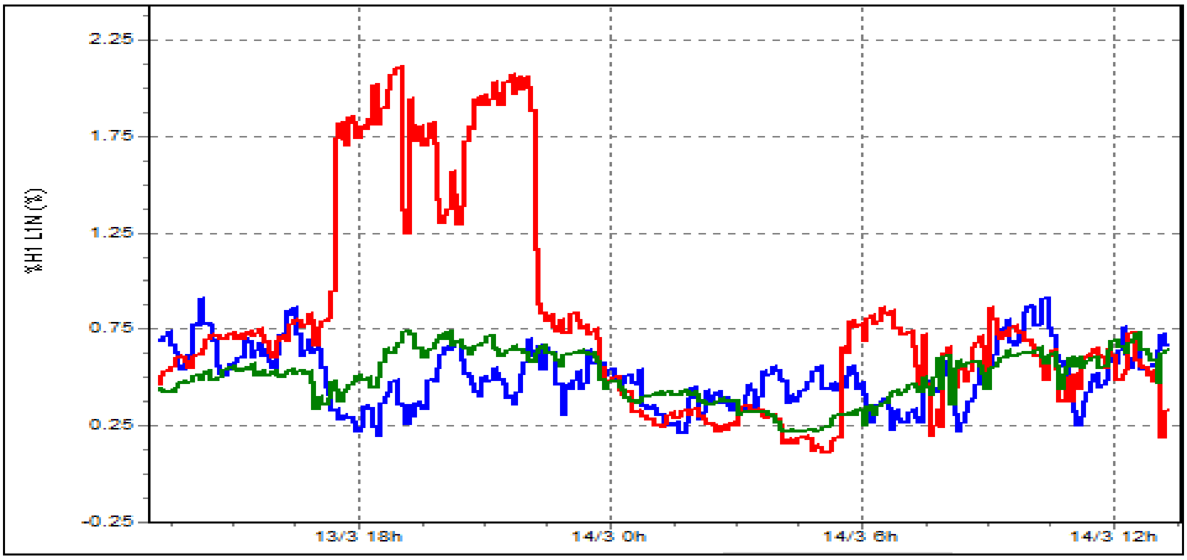

Figure 12: Voltage harmonics without solar PV

3.5 Total Harmonic distortion

The THD is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental component. It provides an indication of the degree to which a voltage or current signal is distorted. Figure 13 shows comparison of total voltage harmonics distortion with and without solar PV injection. The maximum harmonic is 2.46 % occurred at 06:00 hours and minimum harmonic is 1.61% at 16:00 hours with the solar PV injection to the system. On the other hand, maximum harmonic is 2.41% occurred at 21:00 hours and minimum is 1.54% at 13:00 hours without solar PV injection to the system.

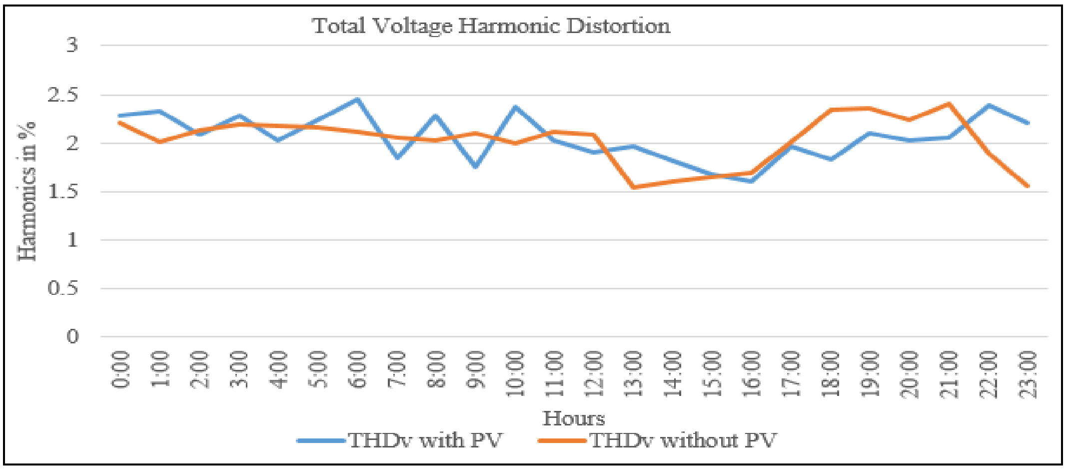

Figure 13: Voltage THD

Similarly, Figure 14 shows total current harmonic present in the system. The maximum current THD is 283.88 % at 07:00 hours and the minimum is 27.27% at 13:00 hours with the solar PV injection to the system. Whereas without solar PV injection, maximum harmonics is 214.33% at 18:00 hours and minimum is 27.42% at 20:00 hours.

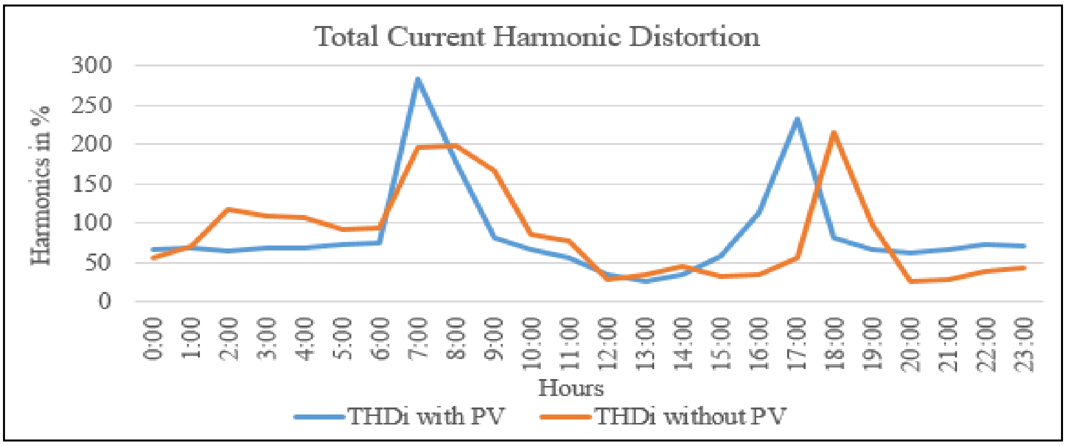

Figure 14: Current THD

4. Conclusions

The efficiency and power quality of a 5.5 kW grid-connected solar PV System was invested for a period of three months. The efficiency of the system was found to be 13.14% which is slightly lower than manufacturer's design value. The power quality parameters such as voltage swell and dip, frequency deviation, current and voltage harmonics and THDv and THDi were also investigated. From the three months data, the system was found to be performing as expected and power quality parameters are within the permissible limits.

References

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