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Articles and Statements

Voltage Quality Analysis of Small-Capacity Grid-Connected Photovoltaic Systems in Low Voltage Distribution Networks

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Abstract

At present, the demand for small-capacity grid-connected photovoltaic system is growing, because it reduces the cost of storage systems. The article focuses on analyzing the voltage quality of small-capacity grid-connected photovoltaic system in low voltage distribution networks at yard of Quang Tri Branch – Hue University, Viet Nam. The analysis proceeds over dark time, when the system consumes electricity, and over light time, when the system put electricity into the grid. Analysis results indicate that system parameters has match the requirements and the emergence of small-capacity grid-connected photovoltaic system contributes to improving the total harmonic distortions of low-voltage network.

Keywords: Total Harmonic Distortions, Voltage Quality, Grid Connected photovoltaic.

1. Introduction

Quang Tri Province, Vietnam has a relatively high number of sunshine hours, average 5-6 hours per day, relatively abundant radiation source, from 1471-1688 kWh/m²/ year. Months with high sunshine are usually in May, June, August, and over 200 hours per month. The government has set out orientations for the development of solar energy, which is expected to generate 1.4 billion kWh (0.5 % of total electricity) by 2020, about 35.4 billion kWh (6 % of total electricity production) by 2030 (Decision, 2015). In our country, the demand for photovoltaic (PV) systems is becoming increasingly popular, the Circular 16/2017/TT-BCT "Regulations on project development and Power Purchase Agreement for Solar Power Projects" makes the market for solar electricity increasingly active (Circular, 2017).

Small-capacity grid-connected photovoltaic systems include PV panel, grid tie inverter. PV panel generates DC current, the inverter converts the DC current into AC at the same frequency to the grid.

The analysis of the output voltage of the inverter is very important, it ensures that the grid-connected system is allowed to connect to the national grid or not. According to the regulation of electricity distribution system of Vietnam in accordance with Circular No. 39/2015/TT-BCT (Circular, 2015), regulations on voltage of grid-connected photovoltaic system must meet the requirements in the Table 1.

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Table 1. Voltage requirements of grid-connected photovoltaic system

№	Parameters		Required value
1	Operating voltage		187-242V
2	Unbalanced voltage (V_{unb})		<5%
3	Voltage harmonics	THD	<=6,5%
		Harmonic order 3	H(3)<=3%
		Harmonic order 5	H(5)<=3%
		Harmonic order 7	H(7)<=3%

Many studies have examined THD for the line-ground voltages THD_V and line-line voltages THD_U, together with average values over the measured có time intervals in a working day, daytime and peak load time (Neagu, 2016), voltage raise, voltage flicker, and power factor reduction (Farhoodnea, 2013). The simulation results proved that the presence of 1.8-MW high-penetrated grid-connected PV systems in a radial 16-bus could cause power quality problems such as voltage raise, voltage flicker, and power factor reduction (Farhoodnea, 2013).

The paper (Pinto, 2015) presents a power quality analysis of two different facilities with PV generation localized in a rural area of Portugal, describing the voltage and frequency behavior, the harmonic contents, and the total harmonic distortion. Statistical data are presented regarding the number of voltage events and occurrence of dips and swells in both facilities as a percentage of rated voltage. The paper conclude that some PV systems can severely affect voltage quality, forcing the grid to work at and even above the maximum voltage standard limit.

The paper (Anwari, 2009) presents power quality analysis of a distributed generation system consisting of PV–Inverter system as the renewable source connected to a network of with adjustable speed drives load.

The analysis of the data shows trends in the harmonics behavior in the grid-connected PV system with adjustable speed drives as loads and can be used to analyze power quality in a system with similar components and setup. Worst case in this project was determined and identified when the system had to change the energy supply from PV to grid. At condition when system nearly changes the supply, current THD has the higher value. The best case happened when energy supply from PV is strongly used rather than grid (Anwari, 2009).

The power quality parameters of 10 kWp PV grid-connected system measured are the active and reactive power, the power factor and the total harmonic distortion. The analysis of the results shows that implementation of the PV grid-connected system could improve the power quality in distribution systems. the grid THD voltage lies in the range of 2-6 % which is acceptable. Unlike the current THD increases significantly at low PV generation conditions reaching a value of 60 % for the inverter and 90 % for the grid (Bouchakour, 2012).

The results in paper (Srisaen, Sangswang, 2006) have shown the PV installation location and a large number of the PV generation have affected the distribution system in a positive manner. The PV generation has shown much potential as a grid-support system which can be used to enhance the distribution operation and power quality including voltage profiles and system loss reduction.

The paper (Altarawneh, Alshawawreh, 2017) provides an experimental observation study of 2.1 kW grid-connected PV system connected to low voltage-grid, the power quality parameters at the inverter output side have been measured using Fluke 435- II Class A three phase energy and power quality analyzer, the voltage waveforms in general are combatable with the standard, with a THD ranging from 1- 3.2 % as an average values was about 1.25 %. The relation between voltage THD and the output power from PV shows that they are independent of each other.

The paper (Elkholy, 2016) presents a comprehensive evaluation of the performance of the system over a period of one week, measurements of the power quality parameters obtained from the PV site, results has shown the voltage THD of the system is not strongly dependent on the fluctuations of solar irradiance.

The paper (Megha, Kumar 2017) investigates the presence of voltage and current THD due to the linear, nonlinear loads and the reactive power transferred between plant, grid and load. The experimental results shown above depicts that due to the presence of voltage and current THD the power factor of the system gets affected and also the reactive power is highest in the presence of nonlinear load, which in turns affect the power flow in the system i.e. from plant to grid and grid to the load.

The project in papers (Cuong, Hong 2016; Cuong, 2016) has studied the improvement of output energy of PV system by tracker, the output energy increase likely affect the quality of the grid voltage, when PV system connected grid, this issue needs further study.

Above analysis show that, there is no study of voltage quality of grid-connected photovoltaic systems at dark time (when the system consumes electricity and does not put electricity to the grid) and at light time (when the system put electricity into the grid). So this article will present and evaluate the voltage quality of the small- capacity grid-connected photovoltaic systems in low voltage distribution networks such as: operating voltage, THD, operating frequency, unbalanced voltage in dark and light time.

2. The small-capacity grid-connected photovoltaic systems

Object of this research is grid-connected photovoltaic power systems (GPVPS). The major elements of a grid-connected PV system that does not include storage are shown in Figure 1.

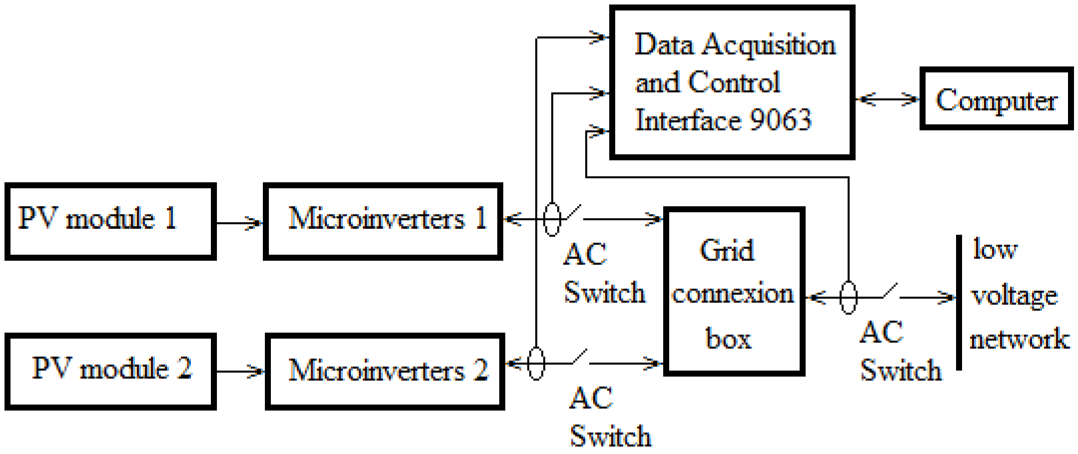

Fig. 1. Grid-connected PV system configuration

This research uses two similar grid-connected photovoltaic power systems, including a 250W PV panel and a 250W MPPT microinverter. Both of the PV modules were mono-crystalline based and the specification can be seen in Table 2. Table 3 shows parameters of microinverters.

Table 2. PV electrical specification

Properties	Value
P_{mp}(W)	250
V_{oc}(V)	37,4
I_{sc} (A)	8,83
V_{mp} (V)	30,0
I_{mp} (A)	8,33

Table 3. Parameters of microinverters

Properties	Value
P_{mp}(W)	250
U_{in} (VDC)	22-45
U_{out} (VAC)	190-260
Output frequency	50/60 (auto)
TDH	<3%
Steady output efficiency	>90%
MPPT range (VDC)	28-36
Power factor	>97%

The installation is located on the yard of Quang Tri Branch – Hue University, Viet Nam (latitude 16°N, longitude 107°E). The electricity produced by photovoltaic solar panels is injected directly into the Branch low voltage distribution networks without storage device.

The main measurement instrument is Data Acquisition and Control Interface. The Data Acquisition and Control Interface with the LVDAC-EMS software provide a complete set of modern computer-based instruments to measure, observe, analyze, and control electrical parameters such as voltmeters, ammeters, power meters, frequency meters, energy meters, an oscilloscope, a phasor analyzer and a harmonic analyzer.

3. Results and discussions

Results obtained with tests and voltage quality analysis performed on two grid-connected PV systems (GCPVS) and grid at point of common coupling (PCC). The measurements were made on 19 November 2018 with a sampling frequency of 1 min.

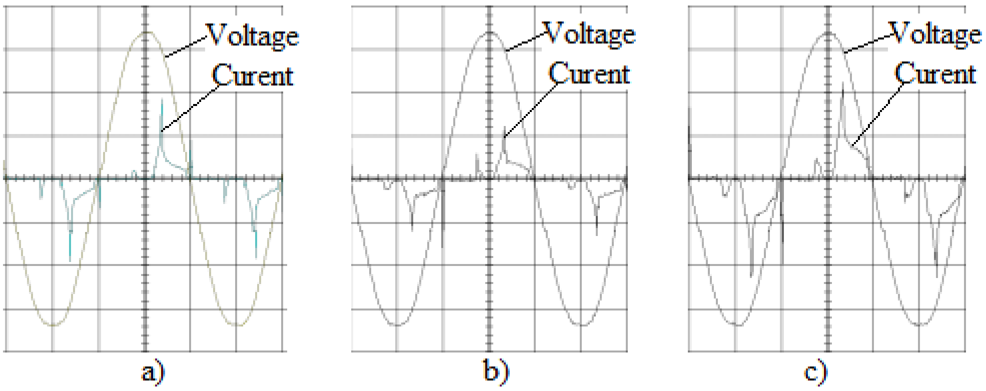

Fig. 2. Voltage and current at 7h42 with time base 5ms / div, voltage scale 100V/div, current scale 0.5A/div. a) GCPVS 1; b) GCPVS 2; c) grid at PCC

Figure 2 shows the voltage and current waveforms at 7h42. The current and voltage RMS value of GCPVS 1 are U_1 = 242.5V, I_1=0.18A. The current and voltage RMS value of GCPVS 2 are U_2=242.94V, I_2=0.14A. The current and voltage RMS value of grid at point of common coupling are U_3=242.73V, I_3=0.3A.

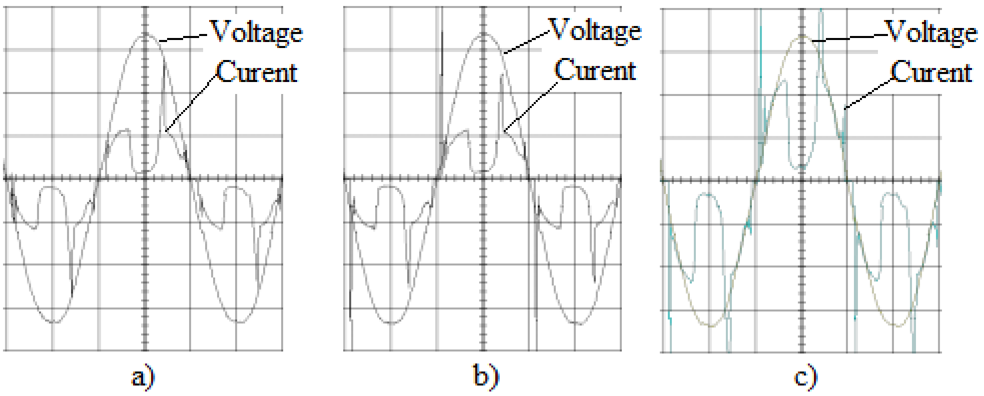

Fig. 3. Voltage and current at 13h31 with time base 5ms/div, voltage scale 100V/div, current scale 1A/div.
a) GCPVS 1; b) GCPVS 2; c) grid at PCC

Figure 3 shows the voltage and current waveforms at 13h31. The current and voltage RMS value of GCPVS 1 are U_1 = 240.52V, I_1=0.83A. The current and voltage RMS value of GCPVS 2 are U_2=241.12V, 0.9A. The current and voltage RMS value of grid at point of common coupling are U_3=240.83V, I_3=1.66A.

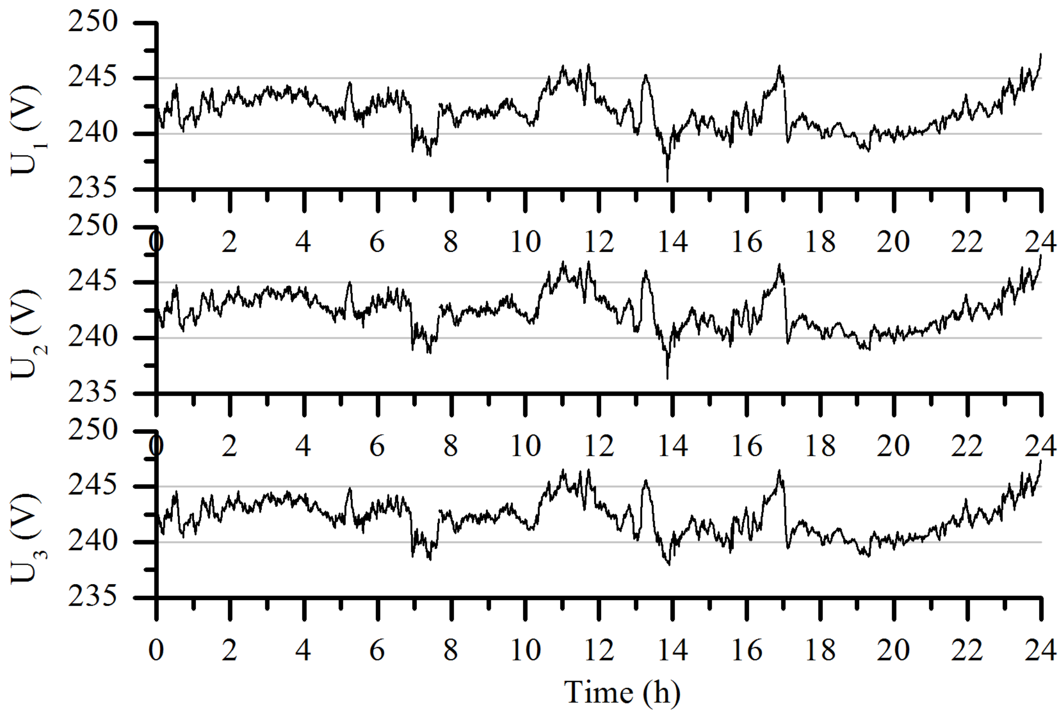

Fig. 4. Voltage values during the day (U_1 of GCPVS 1, U_2 of GCPVS 2, U_3 of grid at PCC)

Voltage values for time of day show on Figure 4. Figure 5 shows the voltage value analysis at dark time (when the system consumes electricity and does not put electricity to the grid) and at light time (when the system put electricity into the grid) for GCPVS 1, GCPVS 2 and grid at PCC in box plot form.

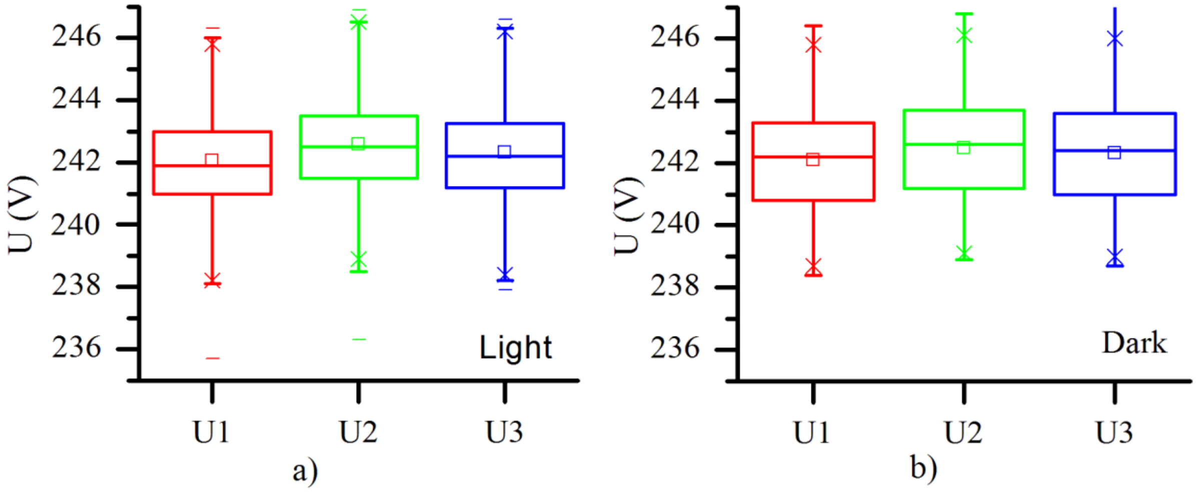

Fig. 5. Voltage box plot of GCPVS 1 (U_1), of GCPVS 2 (U_2), of grid at PCC (U_3).
a) In light time; b) In dark time

Specific results are given in Table 4. These results show that the unbalance voltage value is 1.64 % to 1.69 % at light time (when the GCPVS puts electricity into the grid). But the voltage points are too low such as 235.7V, 236.3V, 237.9V, these points correspond to the time 13h51' can be affected by the load of the system increased suddenly.

Table 4. Specific results of voltage values

Voltage		1. Max outlier (V)	Max (V)	Average (V)	Min (V)	1. Min Outlier (V)	V_{unb} (%)
in light time	U_1	246.3	246.0	241.9	238.1	235.7	1,69
	U_2	246.9	246.5	242.5	238.5	236.3	1,64
	U_3	246.6	246.3	242.2	238.2	237.9	1,69
in dark time	U_1	247.2	246.4	242.2	238.4		1,73
	U_2	247.5	246.8	242.6	238.9		1,73
	U_3		247.4	242.4	238.7		2,06

These results show that the unbalance voltage value is 1.64 to 1.69% at light time (when the GCPVS puts electricity into the grid). But the voltage points are too low such as 235.7V, 236.3V, 237.9V, these points correspond to the time 13h51'can be affected by the load of the system increased suddenly. Acceptable operating voltage on table 1 is 187-242V, but system maximum voltage about 246 V in light time and 247V in dark time. The lab low-voltage network is not full-load, this is the reason why system maximum voltage is larger than acceptable operating voltage.

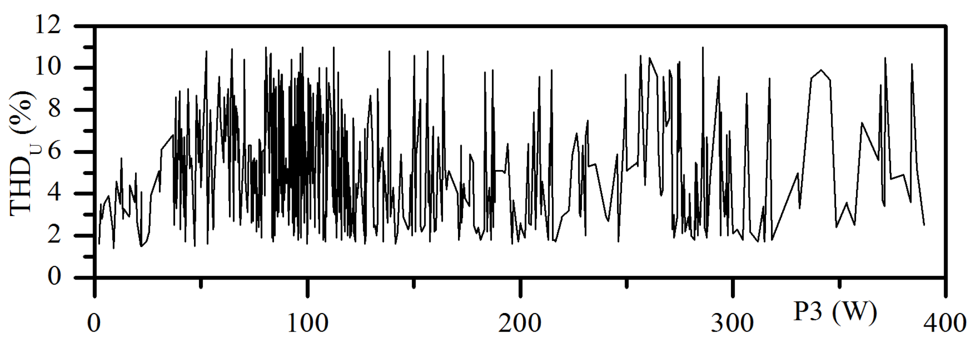

Fig. 6. Voltage THD as a function of two GCPVS output power

Figure 6 show voltage THD_U as a function of two GCPVS output power. Results has shown the voltage THD of the system is not dependent on GCPVS output power.

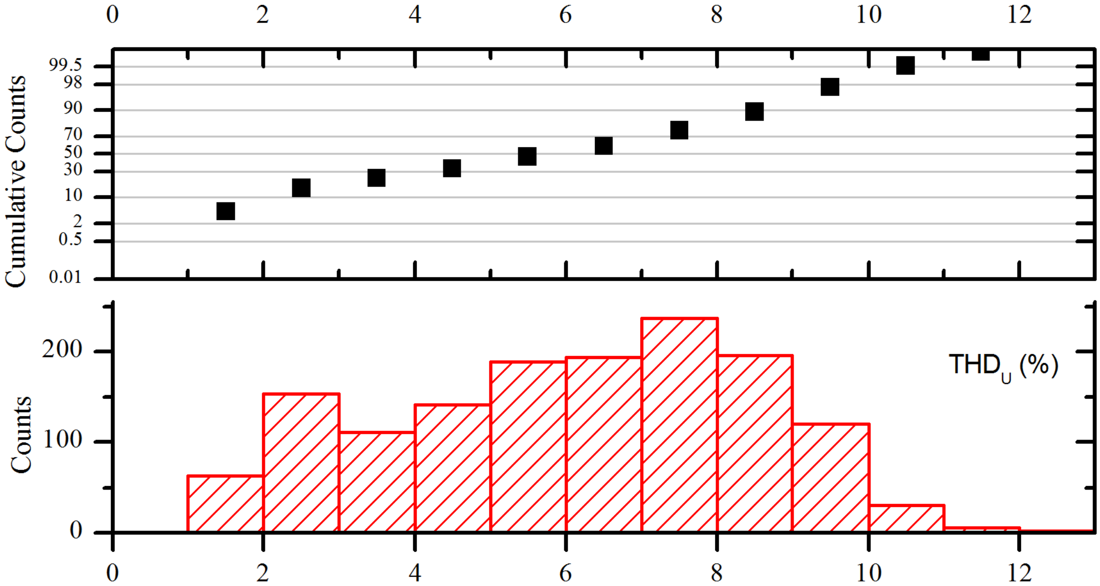

Fig. 7. Histogram representation of voltage THD values distribution during the day

Histogram representation of the voltage THD values distribution during the day given on Figure 7. Harmonics analysis is shown in Figure 8. It is clear that the odd harmonics affect the THD, the fifth harmonic (H5) is the largest.

Average voltage THD in light time about 4.7 % and average voltage THD in dark time about 6.5 %, that values are consistent with the acceptable voltage THD on table 1. Average voltage THD in light time less than average voltage THD in dark time, this proves that, the emergence of GCPVS contributes to improving the THD of lab low-voltage network.

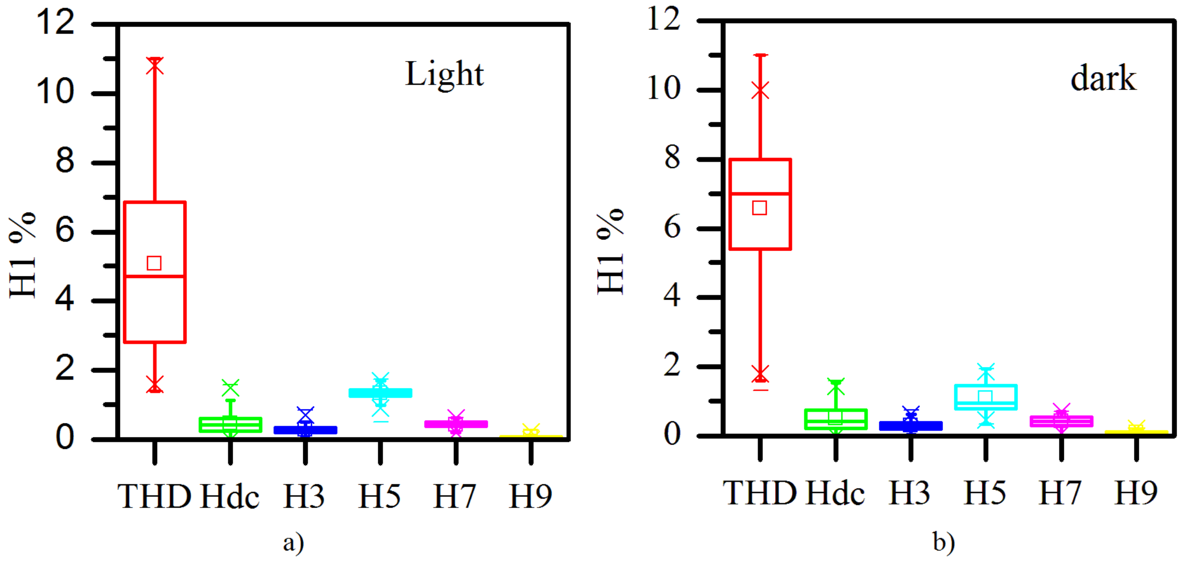

Fig. 8. Voltage THD box plot at Point of common coupling. a) In light time; b) In dark time

4. Conclusion

The paper presents the analysis of the voltage quality of small-capacity grid-connected photovoltaic systems at yard of Quang Tri Branch – Hue University, Viet Nam. The results indicate that the voltage THD and voltage values are within acceptable limits. Moreover the analysis of voltage THD shows the odd harmonics affect the THD, the fifth harmonic is the largest, the emergence of GCPVS contributes to improving the THD of lab low-voltage network.

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