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Power Quality and Performance of Grid-Connected Solar PV System in Palestine

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Abstract

Rooftop solar PV systems has been used in the last years as one of popular renewable sources in Palestine, This paper is investigating the performance and effect of these systems on distribution network, experimental observation study of 72.8 kW roof top grid-connected photovoltaic (PV) system that is installed at engineering faculty, Nablus, Palestine (Latitude 32.2271° N, Longitude 35.2222°E), is presented. The considered system consists of 224 × 325 Wp Poly crystalline PV modules, Tripower three-phase 4X20 kW grid-connected inverter and SMA Cluster Controller& IM-10 for data acquisition and remote monitoring. Energy profile and power quality of the system was analyzed using HIOKI 9340 power quality analyzer. Total energy flow in system, variation of voltage, frequency deviation, current and voltage harmonics, and THDi and THDv at the Point of Common Coupling (PCC) and at PV system output have been studied and analyzed. Some measured values were compared with the limits set in the international standards in order to have a better understanding of the potential quality problems that this technology may introduce on the Palestinian distribution networks and to be able to solve them.

Keywords: Grid-connected photovoltaic system performance; Monitoring PV system; Power quality.

1. INTRODUCTION

Palestine is located in a high solar power concentration area in the world, with an annually average irradiance of 5.45 kWh/m2- day [1]. This encouraged consumers to focus on utilizing the solar power as a source of electricity to cover their demands, with fast growing penetration of PV systems and other distributed power generation capacity, the effect of PV on distribution network is under discussion between distribution companies. Main concerns are the maximum tolerable level and the quality of the supply voltage. The technical problems with quality parameters (voltage, power factor , harmonic distortion, flicker and frequency) originating at the point of common coupling between the distribution network and solar PV system should be thoroughly studied before its implementation.

These concerns as well as the acceptable penetration limits have been verified by measurements in PV developments in several countries [2,3,4].

The illustration of adding a PV generation plant to an existing electrical network is shown in fig. 1, the output generation electricity could be part of a distribution or sub transmission network, includes several branches of customer loads [4]. Due to certain characteristics of PV generation, the output power fluctuations at PCC vary widely, depending on the incident solar radiation. If the PV penetration is high, a sudden decrease in solar radiation can cause the voltage to drop below the prescribed variations (5 to 10 percent) and protective relay under voltage elements to open the circuit breaker at the PCC [5,6].

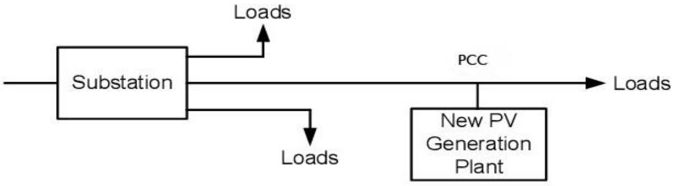


Fig. 1. PV Generation Plant Inserted Into Electrical Network

The technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid. Clarifying the technical requirements for grid interconnection and solving the problems such as islanding detection, harmonic distortion requirements and electromagnetic interference are therefore very important issues for widespread application of PV systems. Grid interconnection of PV systems is accomplished through the inverter, which convert DC power generated from PV modules to AC power used for ordinary power supply to electrical equipment. Inverter system is therefore very important for grid tied PV systems.

Main objective of the PV grid-connected system is to generate the greatest quantity possible of energy. Consequently, the energy production of the photovoltaic systems is the parameter that judges the efficiency of these systems. The purpose of this paper is to present and evaluate the measurements based on power quality quantities which are obtained from the PV grid-connected system and compared it with the limits set in the international standards. The measured power quality parameters at the inverter output side and at PCC are apparent, active and reactive powers, current, voltage and power factor. The total harmonic distortion (THD) for the voltage and current has also been measured as well, over a period of 24 h, with the aim of evaluate the impact of PV systems in the quality supply at PCC.

2. GRID CONNECTED PHOTOVOLTAIC SYSTEM DESCRIPTION

A system with capacity of 72.8 kW peak (kWp) grid-connected PV power generation was installed at the faculty of engineering at An-Najah National University, Nablus Palestine, and Fig. 2 shows photo of the PV power panels. The terminals of the PV panels that are installed on this rooftop are made available for connection different measuring instruments for experimentation and data collection. The system is designed to inject the generated power directly to the electric grid. The considered system consists of 3 main parts that are solar PV power panels, grid-connected inverter and monitoring system.

Fig. 2. Photo of the installed PV array at roof top of Engineering Faculty building.

2.1 Solar PV power panels

The grid connected PV system includes 224 modules covering a total area of 435 m2 with an installed capacity of 72.8 kWp. The specifications of the PV module are summarized in Table 1.

Table 1. PV module specifications at standard test conditions (STC).

Engineering Faculty PV Array Specifications	
Number of panel	224
Tilt Angle	32
Azimuth	True south
PV Brand	Hanwha Q-POWER
model No.	L-G5 325
Wp/panel	325Wp
System capacity	72.8 Kwp
Voltage at Maximum Power (Vmpp)	37.5
Current at Maximum Power (Impp)	8.67
Open Circuit Voltage (Voc)	46
Short Circuit Current (Isc)	9.20
Panel Efficiency (%)	16.7
Cell Type	Poly-crystalline
panel dimension (m)	1.960×0.991×0.35m
panel area (m2)	1.94
panel weight (Kg)	22.5KG ± 5%

2.2 Grid-connected Inverter

The output terminals of the solar PV power panels are connected to a Sunny Tripower 2000TL-10 grid-connected inverter. This inverter efficiency of 98%, but it also offers enormous design flexibility and multi-string capabilities and wide input voltage range. The Sunny Tripower comes with cutting-edge grid management functions such as Integrated Plant Control, which allows the inverter to regulate reactive power at the point of common coupling. Table 2 shows the grid-connected inverter parameters. The electrical data are measured by measurement function of the inverter. Fig. 3 shows a photo of the considered inverter. This inverter shows on its screen the PV system power transmitted to the electric grid, system voltage, amount of produced energy during the day and total run time, etc.

Table 2. Grid-connected inverter specifications.

Engineering Faculty Grid Inverter Specifications	
AC system capacity	80 kW
brand	SMA
Model No.	Sunny Tripower 20000TL-30
NO. of independent MPP inputs/string per MPP	2/A:3,B:3
DC MPPT Range/Input voltage range	320-800 V
Max input current (DC) / string	33 A
Rated AC power (W)	20000
AC voltage range	180-280
Max output current	29 A
Efficiency (%)	98%
No. of inverter per project site	4

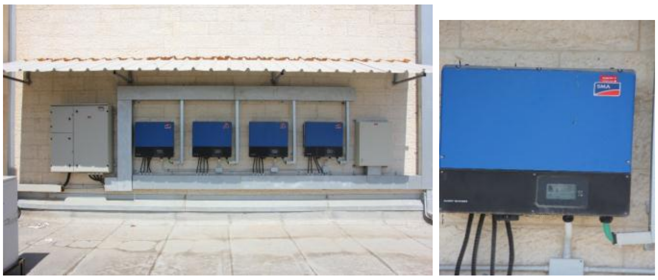


Fig. 3. Photo of the considered inverter.

Since the array voltage and current vary considerably depending upon the weather conditions, the inverter needs to move its working point in order to function optimally. In order to feed the maximum power into the electricity grid, the inverter must work at the maximum-power point (MPP) of the PV array. The MPP tracker ensures that the inverter is adjusted to the MPP point and the greatest possible power is fed into the mains electricity grid.

2.3 Monitoring and data acquisition system

Advanced instruments for monitoring and data acquisition system was installed as shown in Fig. 4, 5. It consists, from power quality analyzer HIOKI 9340 and the Solar-Log SMA Cluster Controller. The SMA Cluster Controller& IM-10 Control is ideal for data-logging SMA inverters and acting as an internet gateway when analog inputs for weather sensors or digital inputs for pulse counting meters and status inputs are also needed. Cluster Controller is built in display enabling easy configuration of inputs, outputs, and communications; in addition to quick review of energy and power. Cluster Controller Collects performance information such as energy harvest, power, and voltage and inverter status.

All real-time (electrical and meteorological) data are logged into this monitoring system. The grid-connected inverter is connected with the Solar- Log. The Solar-Log can access the internet via network connection. A sensor box is connected also to the Solar-Log. This sensor box is used to record the meteorological data generated by all the sensors such as solar irradiance, ambient temperature, module temperature and wind speed. The sensor box is installed to be with the same alignment and inclination of the used PV modules .


Fig. 4. The used monitoring and data acquisition.


Fig. 5. Power quality analyzer HIOKI 9340

A single line diagram of the set-up grid-connected system with monitoring devices is shown in Fig. 6

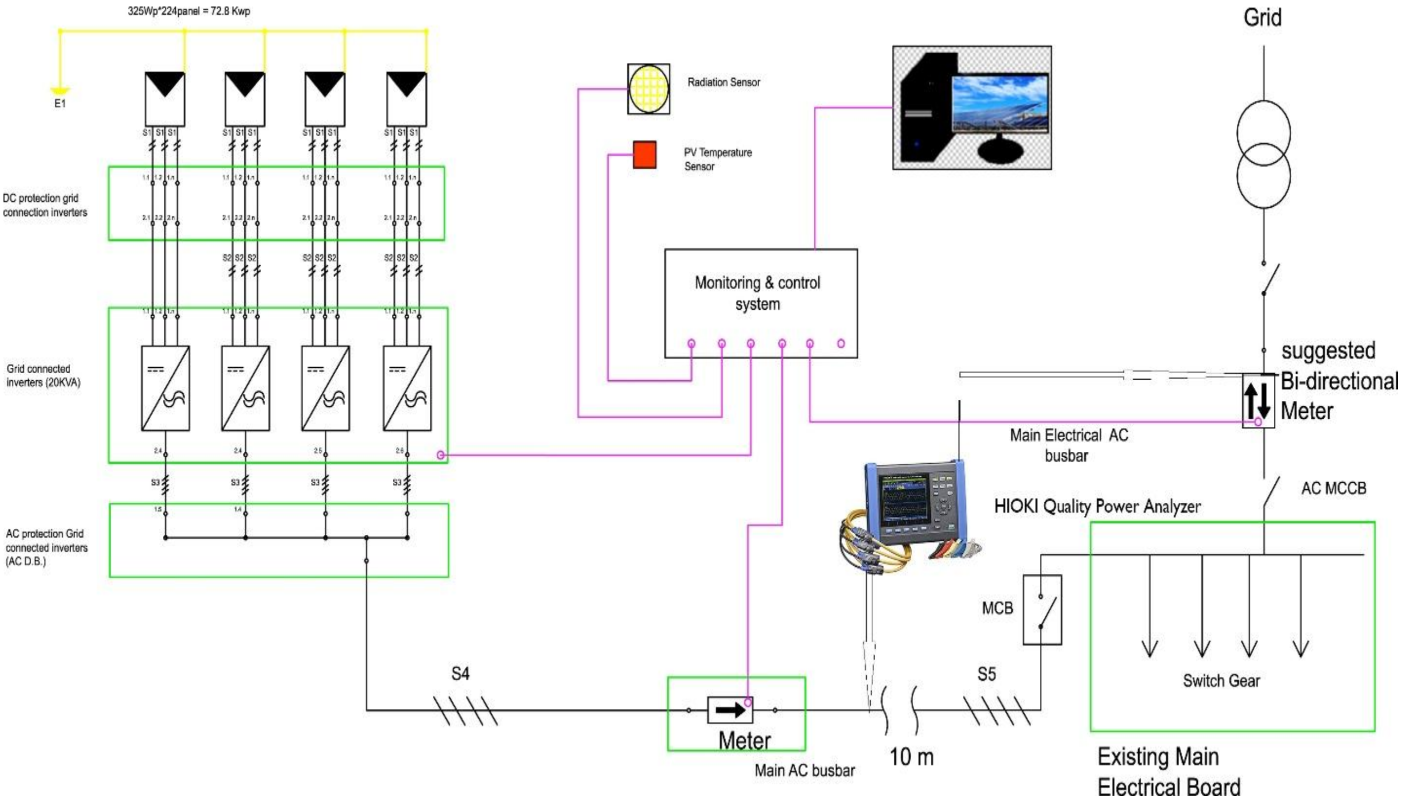


Fig. 6. The single line diagram of the grid connected PV system.

The recorded data are exported and averaged every 10 min and stored as excel file for analysis and evaluation.

3. Power Quality Components

Power quality is affected by several factors [7, 8, 9]. Table 3, present the power quality standard for distribution network.

Table 3.Power quality index.

PQ Indicators	Voltage levels	Standards		
		IEC61000	EN50160	IEEE
Frequency Variation	-	± 1%	± 1%	-
Voltage Variations	LV & MV	± 10%	± 10%	-
	HV & EHV	± 10%	-	-
Interruption	all	± 10%	± 1%	± 10%
	LV & MV	± 2%	± 2 %	-
Imbalance	HV & EHV	± 1%	± 1%	-
	LV	(8,6,2)	(8,6,2)	(5,3,3)
	MV	(6.5,5,1.6)	(8,6,2)	(5,3,3)
Harmonics	HV	(3,2,1.5)	-	(2.5,1.5,1.5)
	EHV	(3,2,1.5)	-	(1.5,1,1)
	LV	(1,0.8)	(-, 1)	-
Flicker	MV	(0.9,0.7)	(-, 1)	-
	HV & EHV	(0.8,0.6)	-	-

These parameters will be illustrated and analyzed for the above PV installed system.

4. Performance analysis methodology

The electrical parameters recorded by the solar-log which located in the control room involves DC/AC voltage, current, power and energy production. Also, the meteorological parameters such as the incident global irradiance in the array plane and module temperature via the sensor box and ambient temperature using PT1000. The parameters being monitored are shown in Table 4.

Table 4. Monitoring parameters of the system.

Electrical measurements	Meteorological measurements
DC current (A), DC voltage (V)	Irradiance, G (W/m2)
DC power, P(DC) (W)	Solar radiation (kWh/m2)
Output energy, EA (kWh)	Ambient temperature, Ta(◦C)
AC active power, Pac (W)	Module temperature, Tc (◦C)
Reactive power (var)	
Power factor	
Output rms voltage (V) and current (A)	
Output THD voltage and current (%)	

The instantaneous values of all these parameters are calculated by normalizing the corresponding energy values (yields and losses) to the recording period over which the recorded samples have been averaged. The energy flow and solar irradiance for 1 year monitoring (2018) at engineering building are illustrated in figures. 7,8.

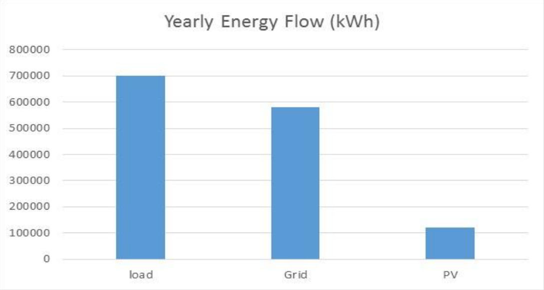


Fig 7. Yearly Energy Flow

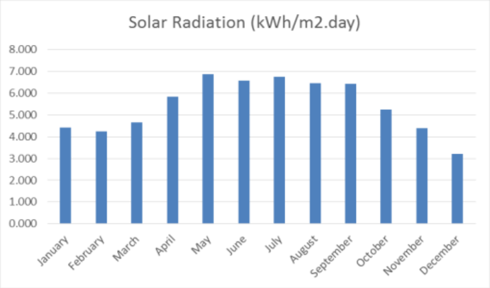


Fig 8. Solar Radiation – Nablus 2018

The total energy output , actual yield, from solar PV system illustrated in fig. 9, and in fig. 10 illustrated the monthly average performance ratio of solar system .

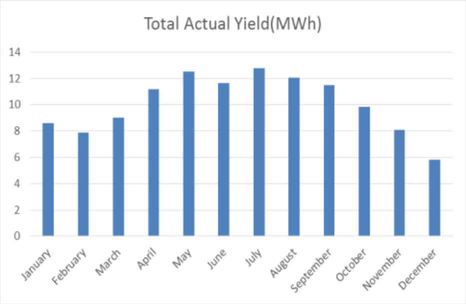


Fig 9. PV System Energy Output 2018

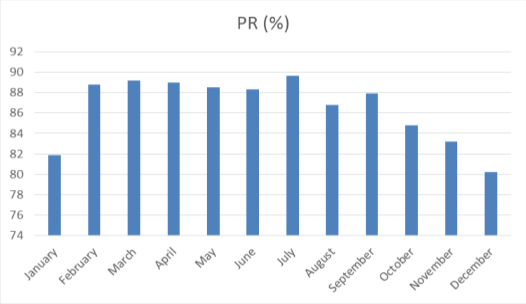


Fig 10. Average Performance Ratio 2018

Efficiency of the inverter can be defined based on the values of electrical DC power delivered to the inverter from PV generator (PDC) and the AC power obtained from inverter (PAC). The instantaneous inverter efficiency (η inv) is defined as the ratio of output to input power [10].

η inv = PAC / PDC ………………………………………(1)

η inv = 97 % (Average yearly)

The PV array efficiency (η PV) is calculated as:

ηPV = PDC / (G × Aa)……………………………………(2)

ηPV =14.6 % (Average yearly)

Where, Aa is the total active area of PV array, m2. G is total in-plane irradiance, kW/m2.

The instantaneous reference yield (yr), which is the ratio of the total irradiance (G (kW/m2)) to the reference irradiance (Gstc = 1 kW/m2), is given by [11]):

Yr =G / Gstc ……………………………..………………..(3)

Yr = 5.84 kWh/m2.day

While, the instantaneous array yield (yA), which is the ratio of the PV array output power (PDC) to the peak power (Pmax,stc) of the installed PV array [12].

yA = PDC / Pmax,stc ……………………………………(4)

yA = 5.10 kWh/kWp/day

The instantaneous final yield (yf), which is the ratio of the net output power of the PV system to the peak power (Pmax,stc) of the installed PV array. The instantaneous final yield can be calculated as follows [13];

yf = PAC / Pmax,stc ………………………………….…(5)

yf = 4.98 kWh/kWp/day

The system efficiency (η sys) represents the performance of the entire PV system installed can be calculated by the Equation (6) :

η sys = 100×E(AC) / Ht×Am (%) ……………………(6)

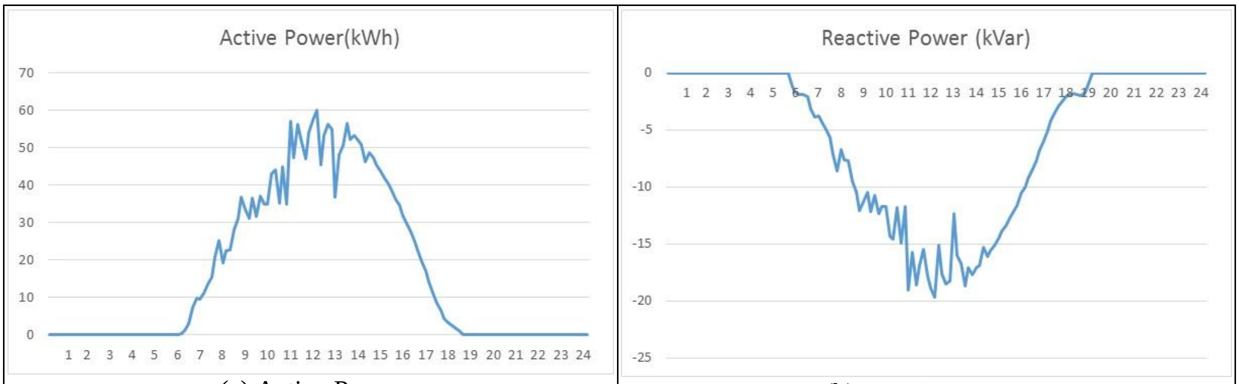
Where, E (AC) is the AC energy output in kWh, Ht is the plane solar irradiance, Am is the PV module total area (m2).

η sys = 14.27 % (Average yearly)

5. RESULTS AND DISCUSSION

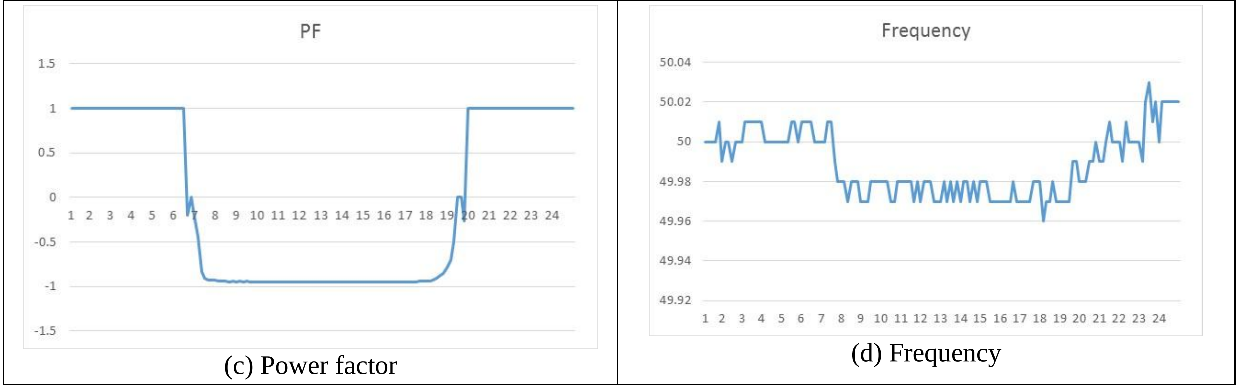
Power quality parameters are measured for the output of the installed PV system at PCC and correlated to the solar irradiance data that are obtained from the same site. The power quality parameters recorded are the apparent power, active power, reactive power, voltage and current. The power factor and total harmonic distortion for voltage and current are measured as well over a period of 24 hour. The solar irradiance incident on the PV modules is also measured for the test period.

The power quality measurements for a typical day in August 2019 at PV inverter site is shown in Fig. 11.



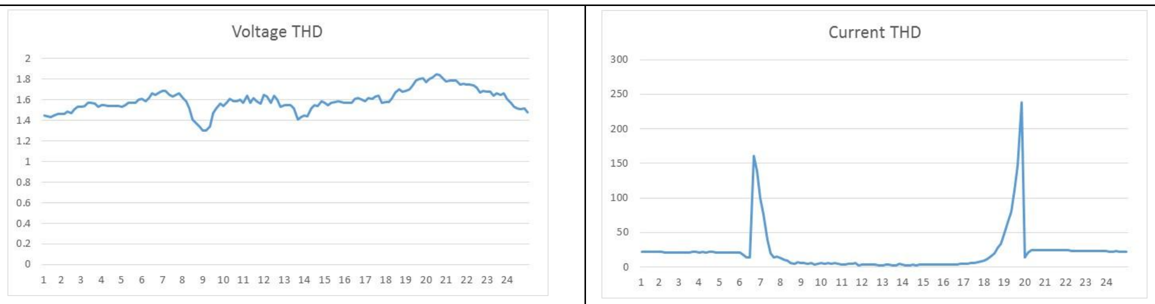
(a) Active Power

(b) Reactive power



(c) Power factor

(d) Frequency



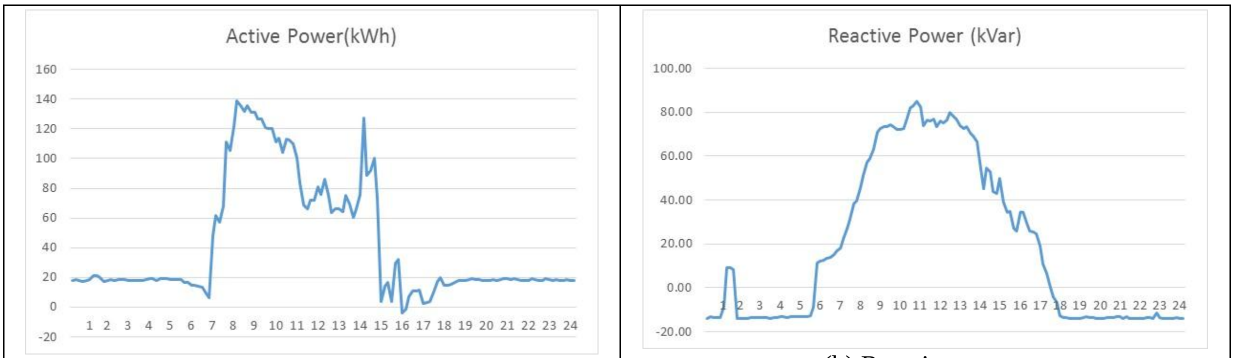
(f)

(e) Voltage THD (%)

Current THD (%)

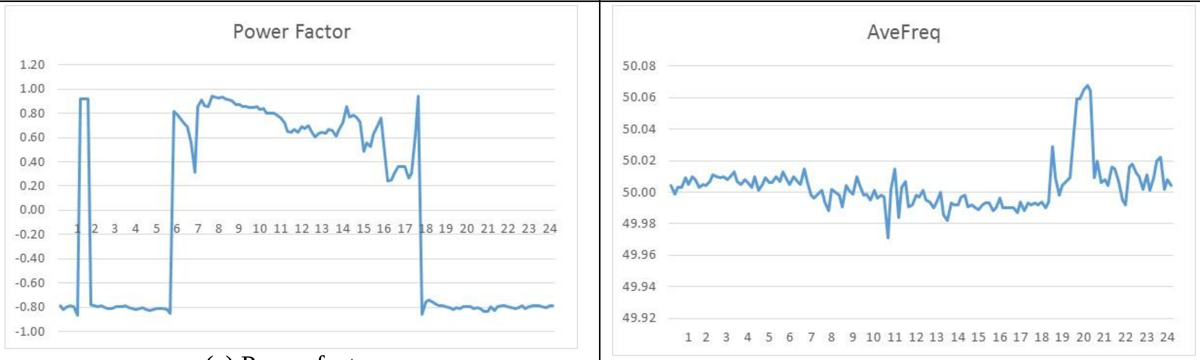
Fig. 11. Power quality measurements at the PV output for a typical day (3th of August, 2019).

The power quality measurements for a typical day in August 2019 at PCC site is shown in Fig. 12 .



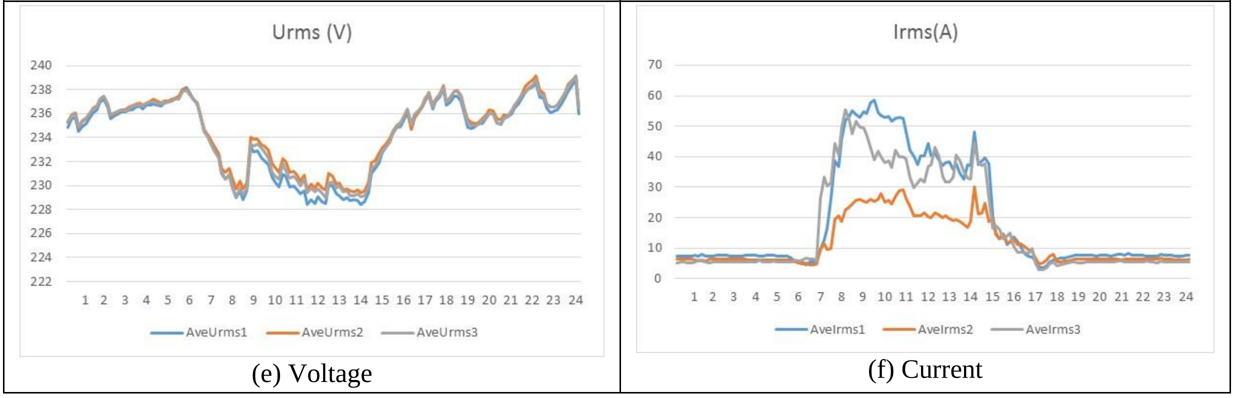
(a) Active Power

(b) Reactive power



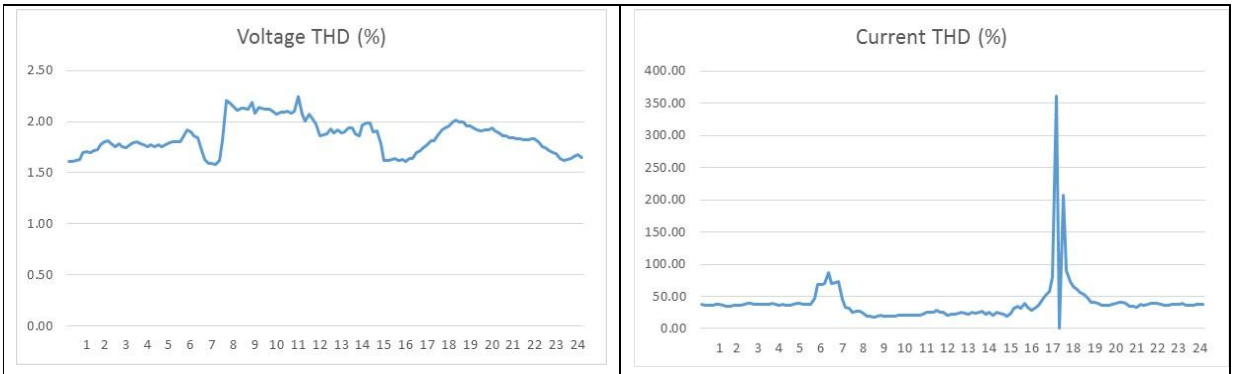
(c) Power factor

(d) Frequency



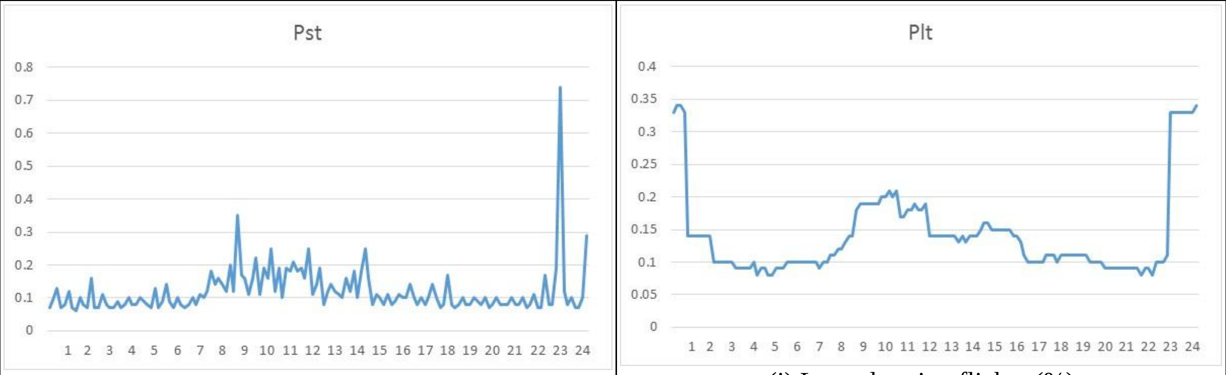
(e) Voltage

(f) Current



(g) Voltage THD (%)

(h) Current THD (%)



(i) Short duration flicker (%)

(j) Long duration flicker (%)

Fig.12. Power quality measurements of the electrical load at the PCC .

When comparing the measurements of active power of the photovoltaic solar system with the power consumption at PCC , its clear that from 8:00 a.m. to 7:00 p.m., the maximum consumption of building coinciding with the period of operation of the photovoltaic system and matching with the high consumption at engineering faculty. Therefore, it is confirmed that the photovoltaic system contributes to the active energy consumption, being visible in periods of maximum demand.

Regarding the variation of the steady-state voltages, before and after the installation of the photovoltaic system, there is no negative impact on the lines voltages , according to the guidelines of standards NTC 5001, IEC 038 and EM 50160, there were no under voltages or over voltages at PCC.

The voltage unbalance is maintained within the ranges established by NTC 5001 before and after the connection of the photovoltaic system . When installing the PV system the value of the average voltage is very close to the value of the nominal voltage, that is to say, the value of the voltage at PCC is more stable, this causes the unbalance factor to be improved.

Short and long term flicker measurements after PV installation of the photovoltaic network is within the range established by NTC 5001 . The maximum and minimum values obtained during short-duration flicker measurements were 0.38 and 0.05 p.u., respectively. The long duration flicker recorded a maximum value of 0.20 p.u. and a minimum of 0.09 p.u. These values obtained from the flicker variation that short and long duration are below those reported in the literature.

The values of total voltage harmonics (THD) that were recorded at PCC after the operation of the photovoltaic system are lower than the 5.0% value established by NTC 5001. The maximum value obtained was 2.25% and the minimum of 1.5%.

The total current harmonics (THDI) recorded and compared to the NTC 5001 are within the established range , with a maximum value of 3.5 and minimum of 0.3.

The power factor affected by the operation of the photovoltaic system , and a maximum value of 0.96 and a minimum of minus 0.8 were obtained, in compliance with the guidelines of NTC 5001. The power factor of the inverter is a function of the load level and increases proportionally to the relative power, approaching 100% when it is working with the nominal output power.

However, the power active and reactive must be injected to feed and support the electrical network simultaneously. Excess production must be eliminated from the system to avoid overvoltage and inverter trip. If the network voltage is less acceptable value , the inverter injects capacitive reactive current to increase the voltage and if the voltage increases above limit, the inverter injects inductive current to decrease it, these voltage variations of the network change the active and reactive power after installation of PV solar system.

6. CONCLUSION

A study of a photovoltaic system of 72.8 kWp connected to the network belonging to the engineering faculty, from January to December 2018, determining its performance parameters and the energy quality at the point of common coupling , is determined and analyzed. From the measurements of various power quality parameters, like total harmonic distortion THD for voltage and current waveform, flickers, frequency, and power factor, all these parameters are within the standard limits. It is important to know the impact on the power quality caused by the installation of photovoltaic systems to the network , in order to define the requirements of the network, the type of communication between the photovoltaic system and the operator of network , necessary protection system, and other issues necessary for stability of network. Therefore, it is expected that this paper can serve as a reference for the application of solar PV systems in distribution companies in Palestine.

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