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Power Quality Examination for (250KW) PV Grid-tied Connected at Various Irradiance Levels

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HIGHLIGHTS

- The Iraqi ministry of electricity building was taken as a case study to examine the power quality issue at various irradiance levels.
- MATLAB2018b/Simulink was employed to describe and build the system in detail.
- System development at various irradiance levels was examined in this study.

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ABSTRACT

Although using a PV grid-tide system has many advantages, connecting the PV to the grid creates a new challenge at the power quality level. The PV grid-tide plant (250 kW), implemented at the Iraqi ministry of electricity building, was taken as a case steady to examine the power quality issue at various irradiance levels. The plant was described in detail and built using MATLAB2018b/Simulink. The developed system was examined at various irradiance levels. The results showed that an increased irradiance level leads to an enhancement in the power quality. The total harmonic distortion (THD) decreases with the increase of irradiance. Such behavior has a good impact on the power quality, where the (THD) is considered a crucial parameter in the power quality issue and increased irradiance level, leading to increased injected power to the grid. Up to the date of writing this study, the power quality effect of the installed (250 kW) PV grid-tied system on Iraqi grid utility was not previously studied, whether for the studied system or another PV grid-tied system installed in Iraq.

1. Introduction

The use of photovoltaic (PV) systems as a safe and clean source of energy from the sun has been rapidly increasing, and the desire to reduce dependence on fossil fuels and the rise in global pollution rates has led to boost this increase. The application of PV systems in power systems can be divided into two main fields [1]:

1) Off-grid or stand-alone applications. Stand-alone PV systems can provide power for remote loads that do not have access to power grids like rural areas.

2) On-grid or grid-connected applications. In contrast, grid-connected applications provide energy for local loads and the exchange power with utility grids. The main structure of the PV grid-tied connected consists of PV panels (arranged parallel and in series) connected to DC to AC converter then connected to the grid at the point of common coupling (PCC) [13]. Although using PV plants in the distribution system has many advantages, using the PV system leads to a new challenge (Power Quality). The PQ defines, according to IEEE, "Power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment." [3]. While the IEC definition of PQ, given in IEC 61000-4-30, states [3] "Characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters." Recently, PQ has been referred to as "the ability of the electric utilities to supply electric power without interruption." The poor PQ has a bad impact on the economy (customer, utility) and the entire operation of the system. Consider the harmonics one of the most popular power quality problems in the PV grid-tied system [14]. The PV grid-tide system is significantly affected by irradiance change rate [15]; consequently, the system has been examined at various irradiance levels. The results revealed that reduced radiation levels lead to increased harmonic in the output signals (voltage and current).

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2. (250KW) PV Grid-Tied Plant Description

The plant was installed in Baghdad at the ministry of electricity which has a geographic location is 33.1 °N latitude and 44.3° E longitude[2]. The plant consists of solar cells [4]. The used PV Modules have the parameters illustrated in Table 1. A (1428) photovoltaic panel, type (Sharp 175Wp), was used. In addition, monocrystalline, considered more efficient than polycrystalline, 1858m² are the PV panels' area covered. The tilt angle for the PV array over carport structures is kept equal to10° to gain maximum solar irradiation [5]. The modules are oriented southeast with two orientation angles (-44°) and (136°), as illustrated in Figure 1 [2]. The second stage of the PV system is the inverter. Ten inverters have been used in the PV system. Each inverter has (7) strings. Every string has (20) panels connected in series. The inverters brand is (SMA). The inverter has been used from transformerless type. This type is more efficient than the transformer type [6]. Table 2 explains the technical data of the inverter. Figure 2 illustrates the arrangement of the PV modules and connection method with the inverter.

The inverters are connected to the PCC (point of common coupling) with output voltage (400 V) and frequency (50 HZ) to be compatible with Iraqi grid requirements. In contrast, the PV system injects its power into the load directly without using the transformer. The block diagram in Figure 3 illustrates the main structure of the (250 KW) PV grid-tide system.

Table 1 : Electrical data for (Sharp 175Wp) Mon crystalline silicon photovoltaic modules

parameter	value
Maximum power P_{max}	175 Wp
Open-circuit voltage V_{oc}	44.4 V
Short-circuit current I_{sc}	5.40 A
The voltage at the point of maximum power Vmpp 35.4 V	35.4 A
Current at point of maximum power I_{mpp}	4.95 A
Temperature coefficient–open-circuit voltage αV_{oc}	– 156 mV/ °C
Temperature coefficient – short-circuit voltage αI_{sc}	+0.053 %/ °C
Number of cells	72 in series

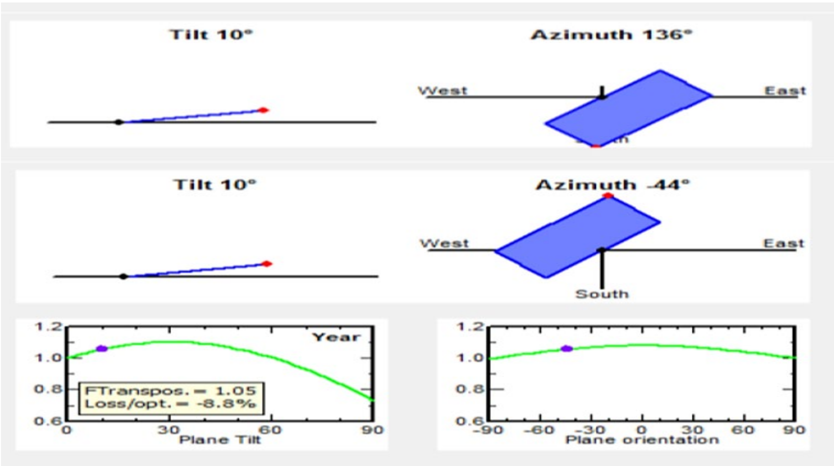


Figure 1: : modules inclination and orientation

Table 2: SMA SOLAR inverter technical data

Parameter	Value
Maximum DC power at cos φ = 1	25550 W
Maximum input voltage	1000 V
MPP voltage range	390V to 800 V
Rated power at 230V, 50 HZ.	25000W
AC voltage range	180V to 280 V
Rated grid voltage	230V
Maximum output current	36.2 A
Total harmonic distortion of the output current with total harmonic distortion of the AC voltage <2%, and power>50%of the rated power	≤3%
Rated power frequency	50 HZ
Feed-in phases	3
Maximum efficiency, ηmax	98.3%

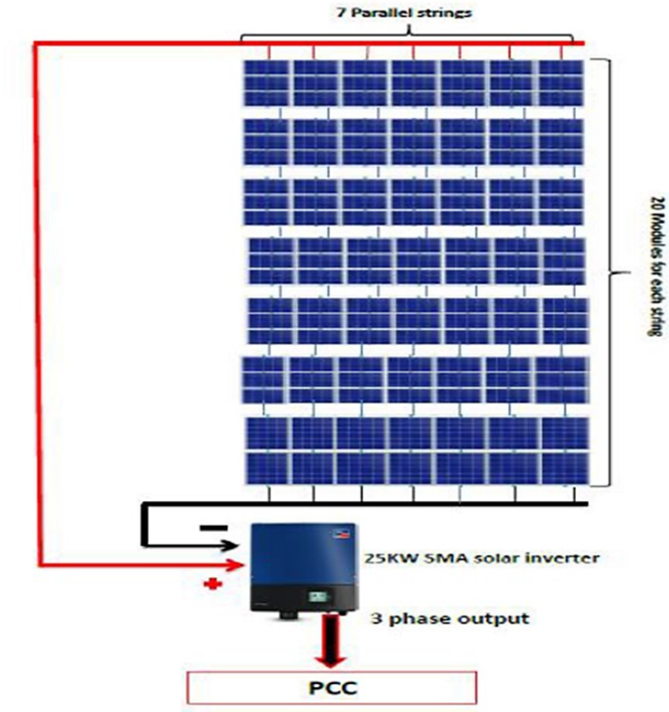


Figure 2: PV modules arrangement

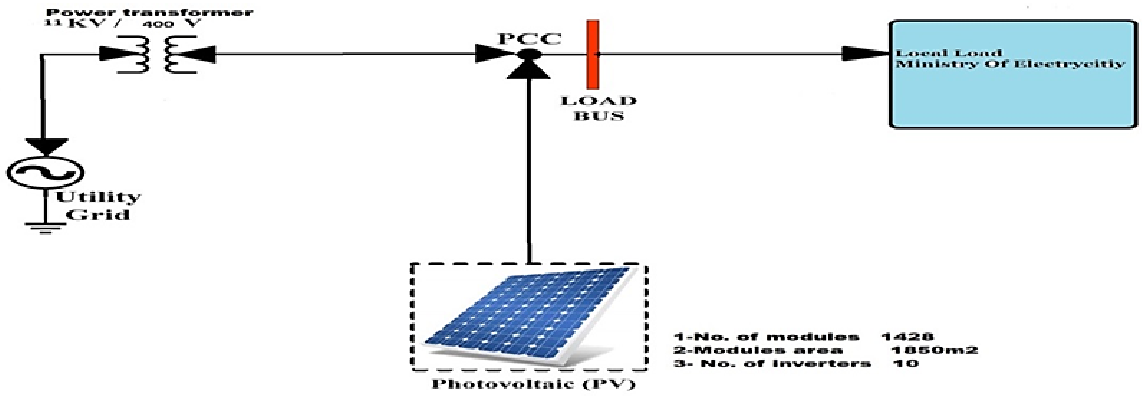


Figure 3: Block diagram of the 250KW PV grid –tide system

3. Simulink model of the developed PV grid-tide system

To evaluate the system's work, it was necessary to build the system units using the MATLAB2018b / Simulink. This representation enables the system to be subject to different irradiance levels to examine the system response and evaluate the impact of this response on the power quality.

3.1 PV modules Simulink

The first stage of building the model is implementing the PV modules and obtaining the (I -V) curve. A power profile identical to the actual characteristic of the PV panels has been used under standard test conditions (STC). Figure 4 shows the output characteristic for PV module Simulink (one module) compatible with the output characteristic for PV panels that have been used at cell temperature (25°C).

3.2 Power decoupling capacitor

Commonly PV system includes a capacitor to attain power decoupling. Using a power decoupling capacitor is necessary to decrease the oscillation in the output power in the PV panels [7]. The desired value for the decoupling capacitor can be calculated by Eq. (1).

$$\mathrm{Cdecp} = \frac{\mathrm{Pinput}}{2\times 2\pi \mathrm{fgVdcepVR}} \tag{1}$$

Where: Pin put: Rated power of PV array, fg: Grid frequency, Vdcep: DC link voltage decoupling capacitor, VR: Voltage maximum permissible ripple from peak to peak.

3.3 Three-phase inverter system model

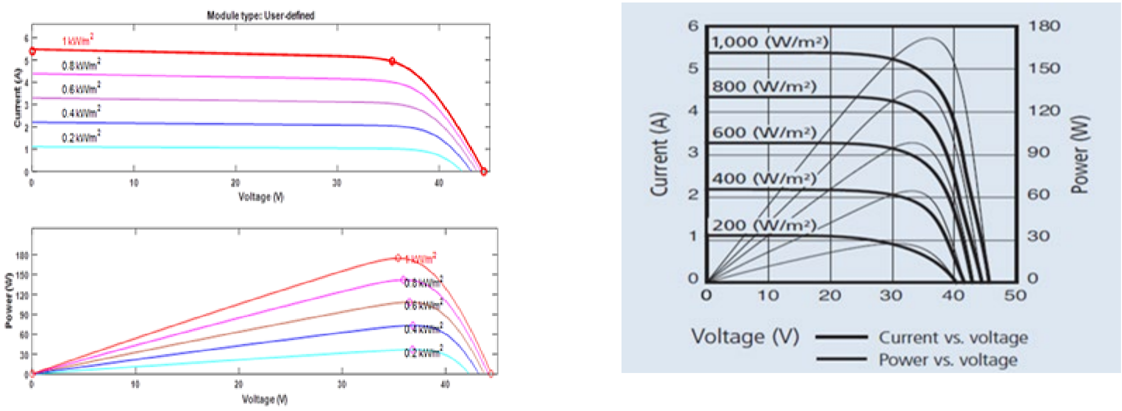
Three-phase two-level inverter has been used to the Simulink the inverter. In addition, a three-phase 2-level inverter based on carrier-based pulse width modulation (PWM) block has been used. The sinusoidal Pulse Width Modulation is one of the techniques used to produce the firing pulses for the power electronic switches of the inverters. Consider this method commonly utilized in the industry [17]. And from good to mention, the Simulink model has been implemented for one inverter and load (150KW) because the PV system consists of ten identical inverters. Figure 5 explains the two-level inverter topology [8].

3.4 Phase-locked loop (PLL)

To maintain synchronization (inverter current controller) with the phase angle of the electrical grid voltages phase-locked loop (PLL) has been used [9]. VI. LC filter design, a low pass filter (LC) is inserted between the three-phase inverter and the grid to improve system power quality. Consider the output waveforms of the PWM inverter rich in harmonics [10]. Harmonic waveforms represent the most popular power quality problems. The most compelling evidence for the harmonic effects is overheating in electrical equipment, increasing the electrical losses, distortion in (current, voltage) waveforms, overload in neutral lines, etc.[11]. The inductor value can be obtained depending on Eq. (2) [12].

$$Lf = \frac{Vdc}{8 \times fsinv \times 0.1 \times I\ rated} \qquad (2)$$

Where: Lf: Inductor per phase
fsinv: switching frequency of the inverter= 10KHZ
Vdc: DC link voltage =1000V
$I_{rated:}$ inverter rated current =36.2



a) (I-V) Curve and power profile for module Simulink
b) (I-V) Curve and power profile for the module have been used.

Figure 4: Simulink and Actual Output Characteristics of the PV module: a) Simulink model characteristics b) Actual characteristics

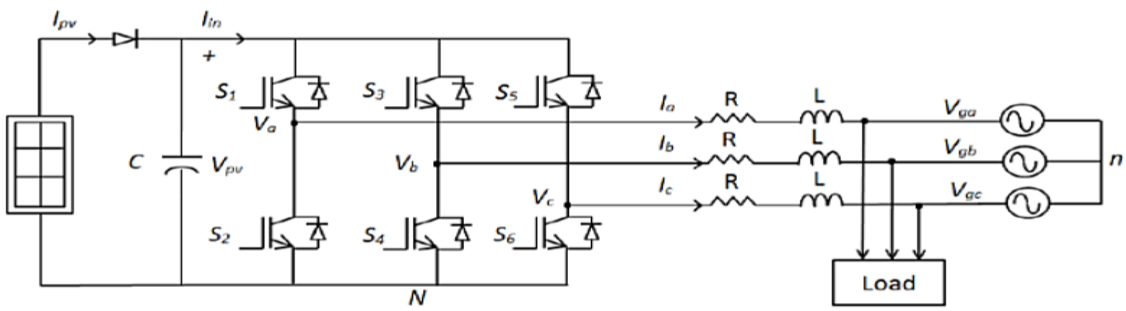


Figure 5: Two-level inverter topology

The capacitor value has been obtained by Eq. (3) [12].

$$c_f = \frac{P_{rated} \times 0.05}{3 \times 2\pi \times f_g\, v_{rated}^2} \qquad (3)$$

Where: C_f: capacitor per phase
P-rated: Rated power per phase
V-rated: phase voltage in the grid side
fg: grid frequency
Table 3 shows the (LC filter, decoupling capacitor) parameters value.
Figure 6 reveals the complete Simulink model of the developed PV grid-tide system.

4. Results and discussions

Table 4 explains the PV output power and inverter output power at various irradiance levels and inverter efficiency at constant temperature (25°C).

It is clear from the results in Table 4 that increasing radiation level leads to an increase in the injected power from PV to utility, additionally increasing in irradiance leading to a little bit decreasing the inverter efficiency. Nevertheless, the results show a good agreement and are compatible with [16], proving that the SMA inverter efficiency is inverse proportional to input power. Table 5 shows the inverter current, inverter power factor, and load power at various irradiance levels.

Table 5 explains that the increasing radiation level increases the inverter current. Consequently, the inverter power factor is enhanced and the load power factor enhanced. Finally, Table 6 explains the effect of changing the irradiance on the total harmonic distortion (THD) for both inverter and load.

Reducing irradiance leads to increasing THD, especially inverter THDi. Figure 7 show this effect.

It is obvious from results in Table 6 and Figure 7 that increasing PV output power or inverter current leads to a decrease in the (THDi, THDv), which has a good reflection on the system power quality. Figure 8 explains the inverter output current waveforms and FFT analysis at each irradiance level.

The improvement in the waveform shape can be seen in Figure 8, especially when comparing waveform shape at (200 W/M^2) with waveform shape at (1000 W/m2). The wave shape has become more sinusoidal, as well as the inverter's current THD has been decreased from 5.25% at 200 W/m2 to 0.97% at 1000 W/m2. This decrease in THD has a good reflection on the system power quality. Iraqi PV grid code [18] considers (5%) the maximum allowable limit for THD.

Table 3: The (LC filter, decoupling capacitor) parameters value

Parameter	Value
Inductor	4mH
Capacitor	$2.5*10^{-5}$ F
Decoupling capacitor	3000µF

Table 4: system output power at various irradiance

Irradiance W/m2	PV output power in(KW)	Inverter output power in (KW)	Inverter efficiency
200	4371.430	4351.008	99%
300	6597.878	6526.838	98.9%
400	8871.620	8769.492	98.8%
500	11207.663	11067.554	98.7%
600	13726.640	13522.532	98.5%
800	18781.418	18417.443	98%
1000	24195.5	23665. 32	97.7%

Table 5: **nverter current output and (inverter, load) power factor at various irradiance**

Irradiance W/m2	Inverter current in(A)	Inverter Pf	Load PF
200	6.255	0.9983	0.994
300	9.419	0.999	0.994
400	12.63	.9992	0.994
500	15.98	0.9997	0.995
600	19.4	0.9998	0.995
800	26.54	0.9999	0.995
1000	34.09	0.9999	0.995

Table 6: THD (current and voltage) at various irradiance

Irradiance W/m2	Inverter THD THDi	THDV	Load THD THDi	THDV
200	5.25	0.898	0.755	0.898
300	3.62	0.895	0.754	0.895
400	2.77	0.894	0.753	0.894
500	2.3	0.893	0.752	0.893
600	1.83	0.893	0.752	0.893
800	1.38	0.892	0.751	0.892
1000	0.97	0.890	0.750	0.890

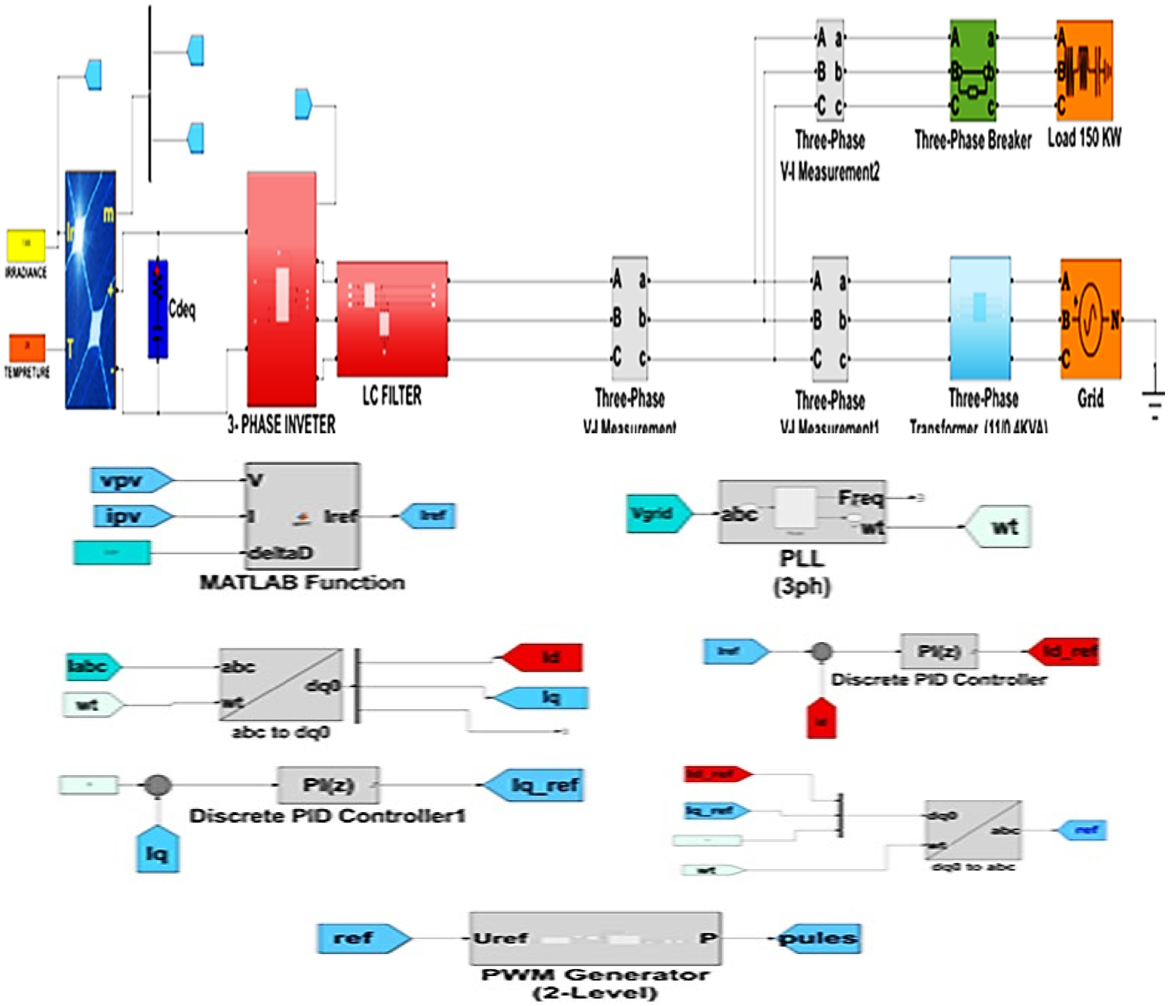


Figure 6: complete Simulink model of the developed PV grid-tied system

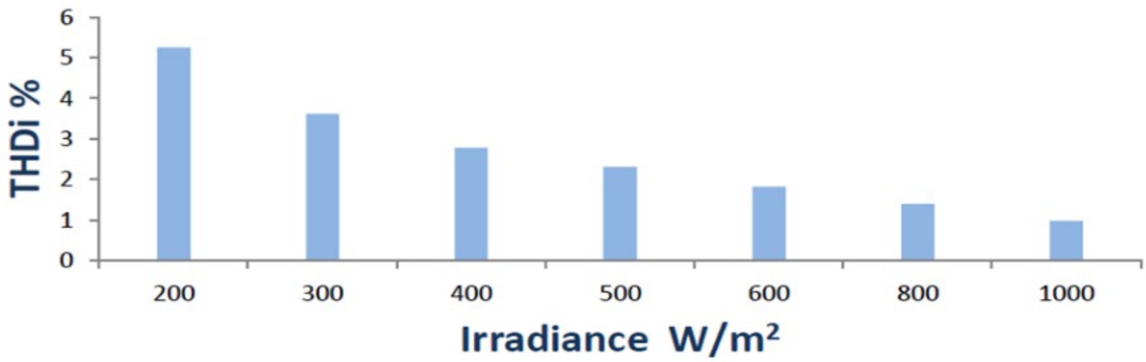
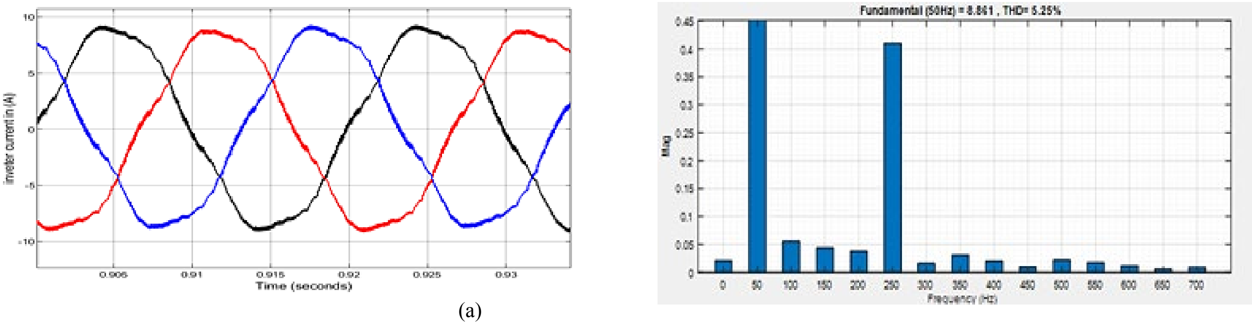
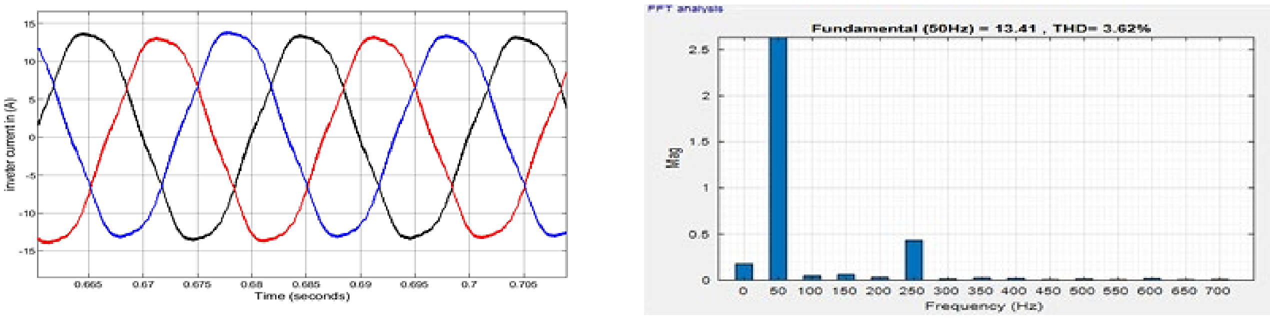


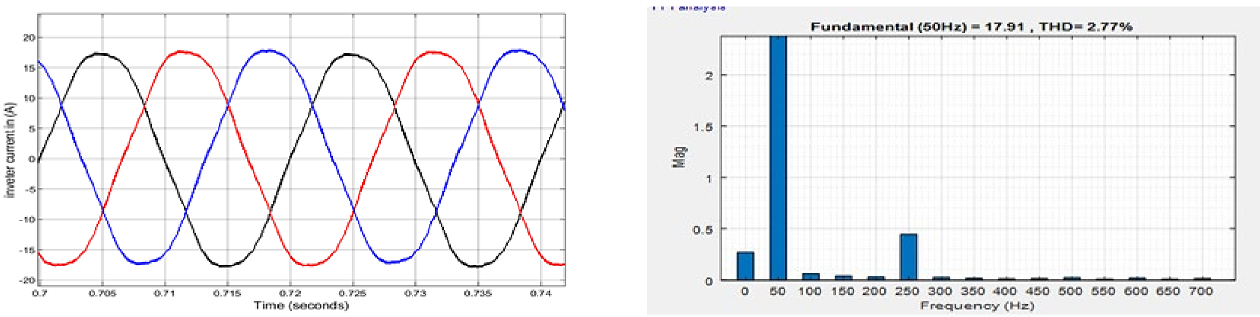
Figure 7: Effect of irradiance on inverter THDi


inveter current in (A)
Time (seconds)
Fundamental (50Hz) = 8.861 , THD= 5.25%
Mag
Frequency (Hz)

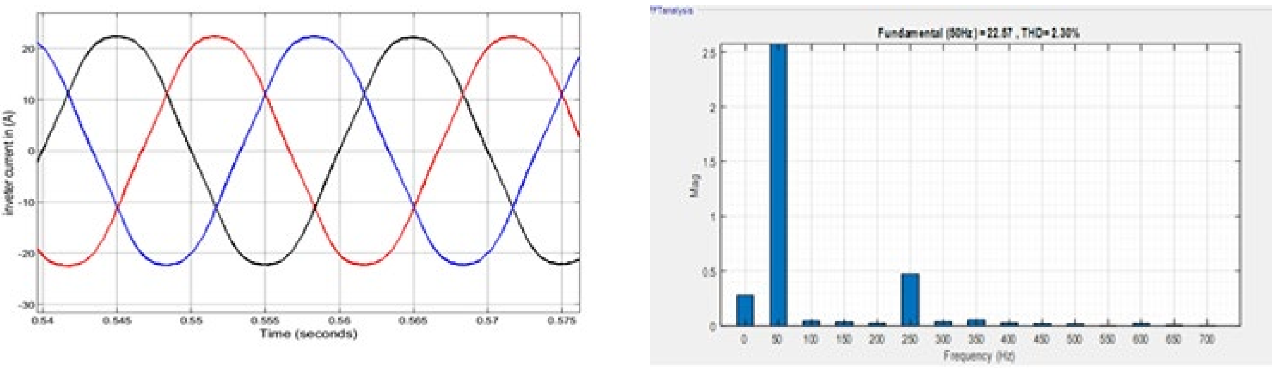
(a)


inveter current in (A)
Time (seconds)
FFT analysis
Fundamental (50Hz) = 13.41 , THD= 3.62%
Mag
Frequency (Hz)

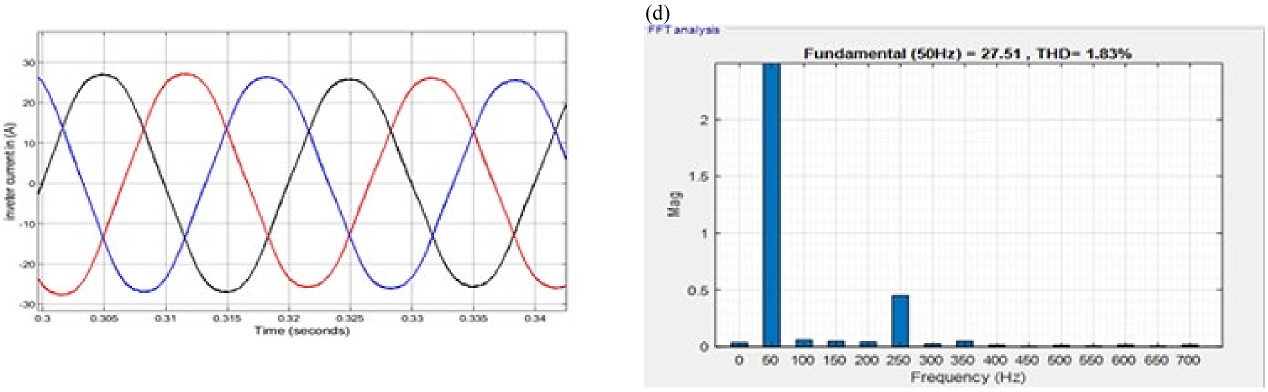
(b)


inveter current in (A)
Time (seconds)
Fundamental (50Hz) = 17.91 , THD= 2.77%
Mag
Frequency (Hz)

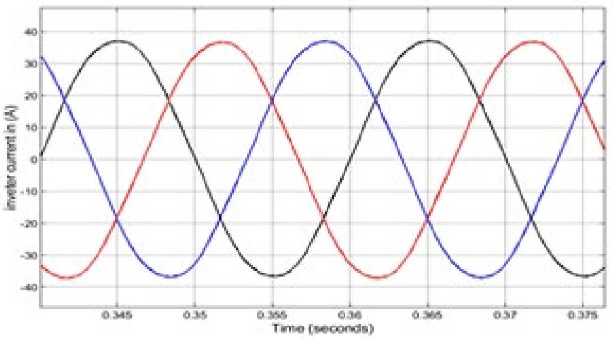
(c)

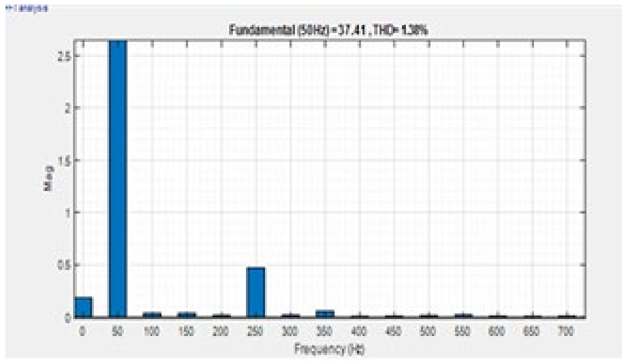

inveter current in (A)
Time (seconds)
Fundamental (50Hz) = 22.57 , THD= 2.30%
Mag
Frequency (Hz)

(d)

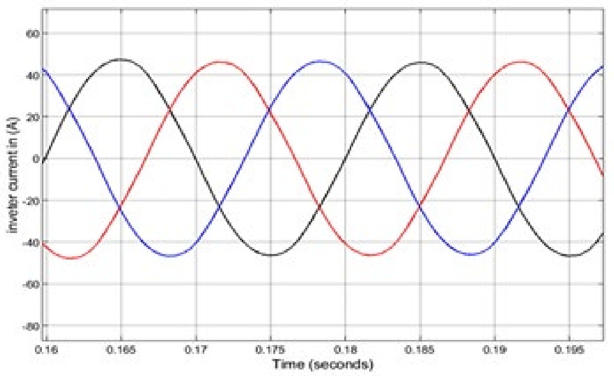

inveter current in (A)
Time (seconds)
FFT analysis
Fundamental (50Hz) = 27.51 , THD= 1.83%
Mag
Frequency (Hz)

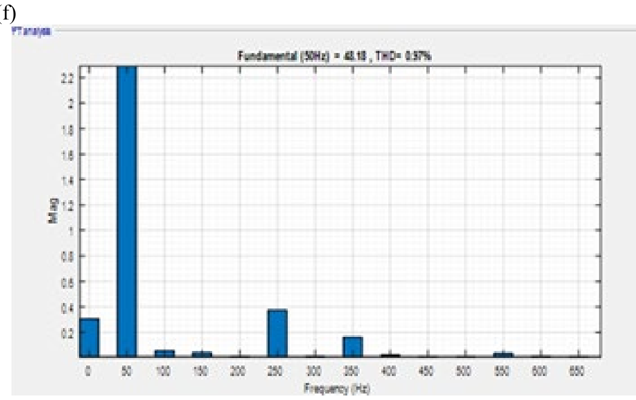
(e)





(f)





(g)

Figure 8: Inverter output current wave (a) at 200 W/m.2 (b) at 300 W/m.2(c) at 400 W/m.2 (d) at 500 W/m.2 (e) at 600 W/m2.(f) at 800 W/m2.(g) at 1000 W/m2

5. Conclusions

This paper addresses the implementation of (250 kW) PV grid-tied system using MATLAB2018b / Simulink. The PV panels built are identical to those installed onsite, with the same output characteristic curves (I-V and power profile). Increasing irradiance leads to an increase in the output power from the PV system. The inverter efficiency has been used in the project (SMA brand) decreased with increasing the irradiance, but with acceptable limits. The inverter efficiency has an inverse proportion with input power. The inverter current Total harmonic distortion (THD) is significantly affected by radiation level, which is inversely proportional to radiation. Consequently, high radiation level has a good impact on the power quality.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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