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RESEARCH ARTICLE - ENGINEERING

Assessment of Power Quality for Large Scale Utility Grid-Connected Solar Power Plant Integrated System

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Abstract

This paper introduces the simulation and analysis of a three-phase large-scale grid-connected solar Photovoltaic (PV) system in order to assess the effect of integrated PV grid-connected mode on the power quality of the utility grid. The study takes into account the effect of solar system power variation as well as the PV inverter's introduction of penetrating harmonics into the system. The simulation of the system is done in MATLAB software using the SIMULINK environment and is tested by the Pysyst program. Where it is done in real-time with an actual case study on a 1620-kW PV array connected to an 11-kV grid via a three-level Voltage Source Converter (VSC). The technical data was recorded, and the system's power quality was examined. The grid-connected PV system's Performance Ratio (PR) is assessed to determine the PV system's reliability and grid connectivity.

Keywords: PV Grid; Voltage Source Converter; Main grid; Matlap Simulink; PV Syst Program

1. Introduction

The normal method of generating electricity from fossil fuels such as oil, coal, and natural gas has far too many disadvantages. Furthermore, due to the depletion of fossil fuel reserves, pollution, and environmental concerns, the world has been searching for alternative sources of electric energy over the last decade [1]. The solar energy is clean and is simple to deploy in remote locations where the grid is unavailable.

In both stand-alone and grid-connected systems, the use of solar energy to generate electric power using photovoltaic systems has increased rapidly recently [1,2]. Solar photovoltaic (PV) technology is one of the most widely used forms of renewable energy, and there is a growing demand for it. PV installations, both grid-connected and stand-alone, are in high demand [3].

The design and construction of photovoltaic power plants (PVPPs) has increased dramatically in recent years all over the world. PV systems now account for about 55 % of newly added renewable energy capacity worldwide, with about 100 GW of produced power added only last year [4]. PVPP generation and integration are expected to continue to expand at a rapid pace in the future.

PVPPs have a number of features that distinguish them from conventional power plants, posing new obstacles for grid-connected PV networks (GCPS). Furthermore, the high penetration of this renewable energy source begins to affect the power system's efficiency, sustainability, reliability, and consistency. Control factor, Voltage sag, voltage flicker, harmonics, and voltage unbalance at the point of common coupling (PCC) will all have a detrimental effect on the power network and should be discussed. As a result, many countries' grid codes and other international regulations are implementing additional and stricter regulatory criteria for PVPP incorporation into the power grid. These engineering standards are in place to ensure that no electricity of poor quality is pumped into the grid. PVPPs must also act like conventional power plants in order to sustain the grid during outages [5,6].

Nomenclature			
PV	photovoltaic	PCC	point of common coupling
VSC	voltage source converter	RESs	renewable energy sources
PR	performance ratio	MV	medium voltage
PVPPs	photovoltaic power plants	PQ	power quality
GCPS	grid-connected PV networks	MPPT	maximum power point tracking
THDV	total harmonic distortion of voltage	STC	standard test conditions
THDI	total harmonic distortion of current	GlobHLCor	horizontal global irradiation
T_ Amb	ambient Temperature	DiffHor	horizontal diffuse irradiation
GlobEff	effective Global, corr.for IAM and shadings	T_Amb	ambient Temperature
GlobInc	global incident in coll.plane	GloEff	effective global, corr.for IAM and shadings
E_Grid	energy injected into grid	EArray	effect energy at the output of the array

Grid codes from countries such as Australia [7], Germany [8], the United States [9], and Italy [10], as well as other international guidelines such as IEC standards [11] and IEEE standards [12] have imposed strict power efficiency regulations for PV and other renewable energy sources (RESs) integration. The most recent standards include, for example, the injection of reactive current into the PV system to overcome the voltage drop caused by network faults and to maintain network stability [13, 14]. Limits of flicker, voltage fluctuation, harmonics, power factor, voltage imbalance as set out in [13,15], different countries have developed their own laws, specifications, and norms. Verification and execution, on the other hand, could be more critical than establishing rules and regulations. In an effort to apply these criteria for GCPS, some recent studies have been performed, due to the introduction of highly sensitive electronic devices, there has been a focus on power quality problems [16]. At the PVPP's standard coupling point with the main grid, D-STATCOM was also used to minimize harmonics [17]. The experiments listed above have shown significant results; however, the majority of these methods are expensive and may add to the difficulty of the method. Furthermore, some of these studies failed to consider power balance and semiconductor system safety during sag [18]. Furthermore, research into the effects of voltage unbalance and flicker on PV system penetration has yet to be undertaken. For example, the voltage unbalance problem was addressed in [19,20], and the flicker issue was addressed in [21]. However, these phenomena were not thoroughly studied, and the criteria and conditions were not taken into account.
The aim of this research is to design a 1.62 MW large-scale PV system connected to the medium voltage (MV) side of the grid (11KV) in accordance with current standards. The paper mostly reflects on the evaluation and control of power quality problems that must be addressed at the PCC in order to meet the new requirements. This involves investigating the harmonic distortion of current and voltage, and power factor, in order to conduct a thorough evaluation of the problems of power quality (PQ) on a large-scale PV system based on the normal specifications.

2. The Proposed Integrated System

Fig. 1 shows the schematic diagram of an integrated large-scale PV system that is connected to the 11 KV grid through the three-phase inverter by PCC. In order to extract power from the PV array, the maximum power point tracking (MPPT) is used with a boost converter, note that the MPPT technology used the single-stage. The output of PV and which is turned to deliver to the three-phase inverter and integrated to the utility grid by coupling transformer. 260 parallel branches, each branch contain 14 panels connected in series. The maximum voltage is 630 V, the maximum current is 2291 A, and the output power is 1.454 MW. There are pictures of the practical part of the work as shown in fig. 2, also, shown in a test or check design by a program PV syst shown the design pictures of the practical part of the work as shown in fig. 3.

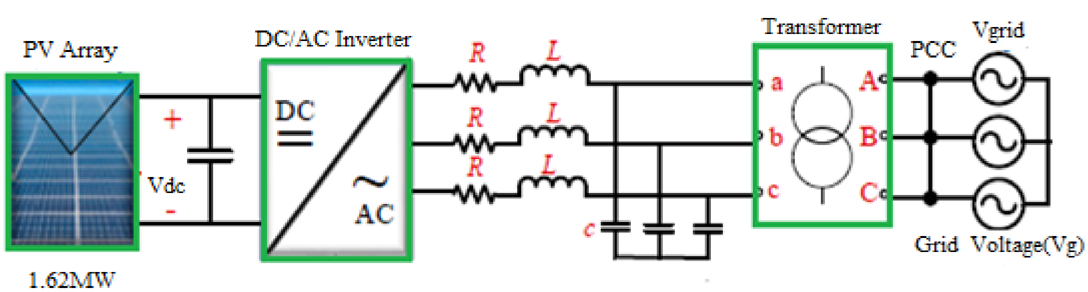


Fig. 1 Schematic diagram of PV system in grid connected mode [1]

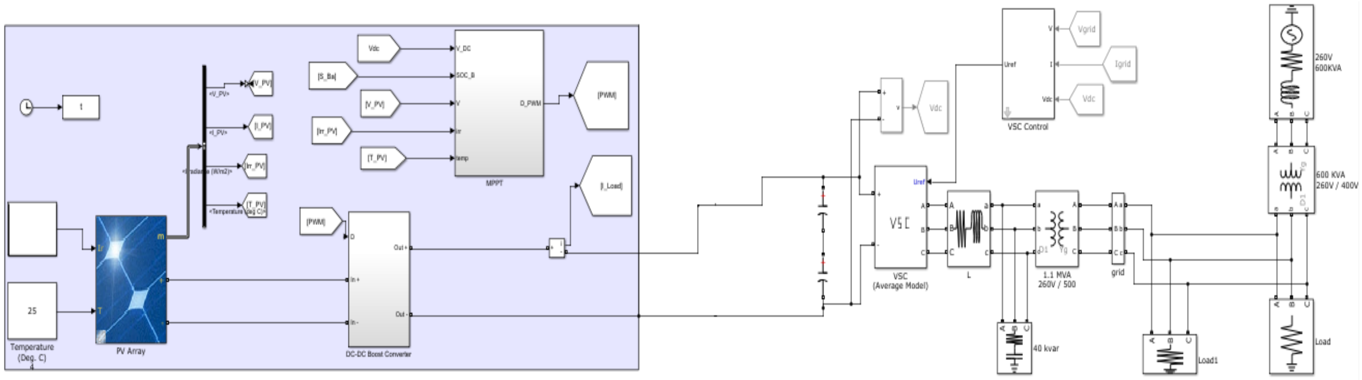


Fig. 2 Grid-connected hybrid micro grid

Fig. 3 As shown a simulation of grid connected system by PVSYST V6.81.

PVSYST V6.81		08/05/21	Page 1/5

Grid-Connected System: Simulation parameters

Project :	**hybrid 600**			
Geographical Site	**Ahmed ramadi**		Country	**Iraq**
Situation	Latitude	33.33° N	Longitude	40.00° E
Time defined as	Legal Time	Time zone UT+2	Altitude	30 m
	Albedo	0.20		
Meteo data:	**Ahmed ramadi**	Meteonorm 7.2 (1998-2000), Sat=100% - Synthetic		

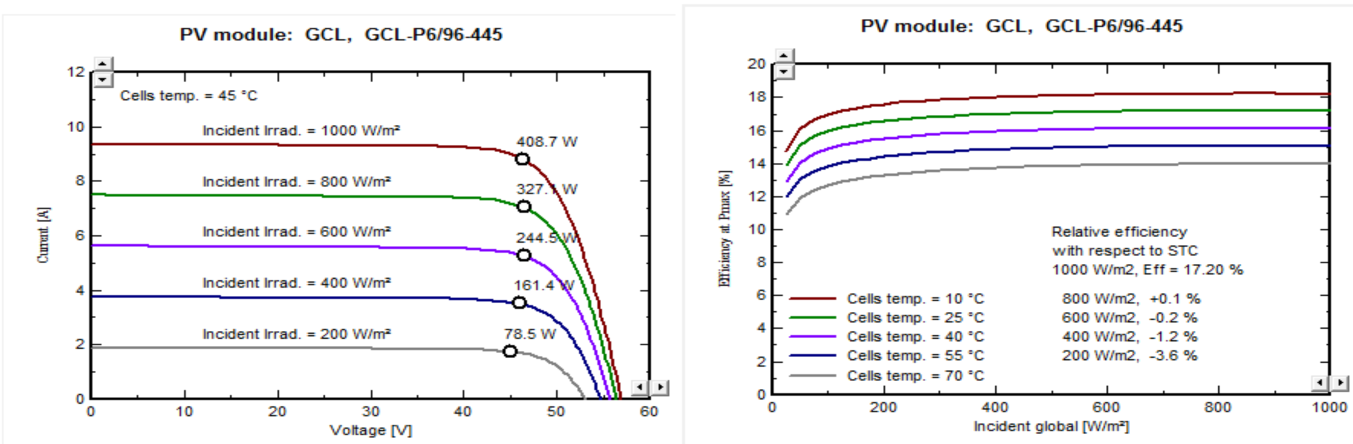
Simulation variant :	**Fixed orientation, 4 sheds, pitch 6m, lim. angle 21.3°**			
	Simulation date	08/05/21 08h37		

Simulation parameters	System type	**Sheds, single array**		
Collector Plane Orientation	Tilt	30°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			
User's needs :	Unlimited load (grid)			

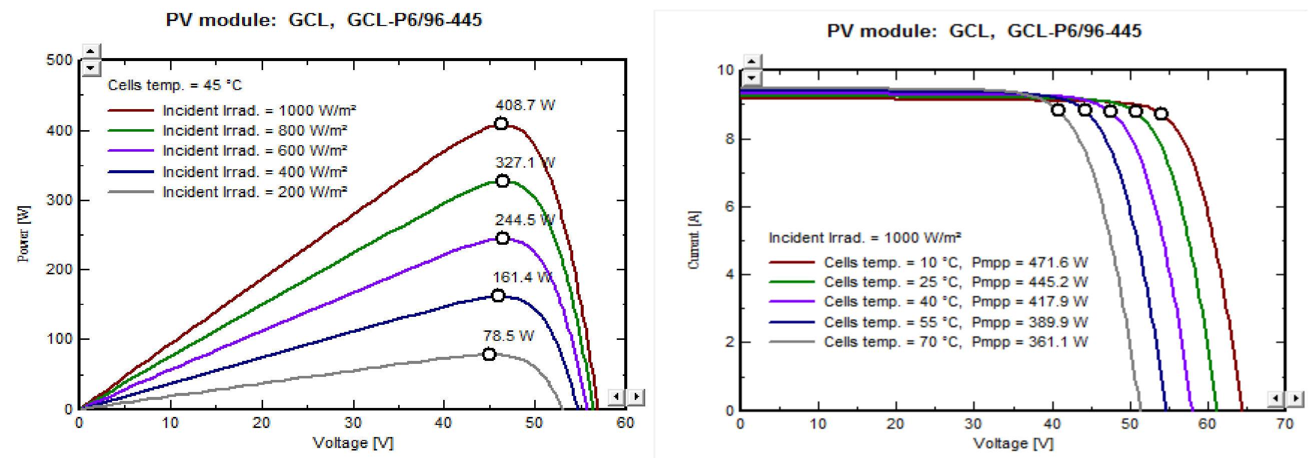
PV Array Characteristics				
PV module Si-poly	Model	**GCL-P6/96-445**		
Original PVsyst database	Manufacturer	GCL		
Number of PV modules	In series	14 modules	In parallel	260 strings
Total number of PV modules	Nb. modules	3640	Unit Nom. Power	445 Wp
Array global power	Nominal (STC)	**1620 kWp**	At operating cond.	1454 kWp (50°C)
Array operating characteristics (50°C)	U mpp	635 V	I mpp	2291 A
Total area	Module area	**9422 m²**	Cell area	8806 m²
Inverter	Model	**PVS800-57-0500kW-A**		
Original PVsyst database	Manufacturer	ABB		
Characteristics	Operating Voltage	450-825 V	Unit Nom. Power	500 kWac
			Max. power (=>25°C)	600 kWac
Inverter pack	Nb. of inverters	4 units	Total Power	2000 kWac
			Pnom ratio	0.81

Fig. 3 as shown the result simulation of Pvsyst.

In order to show the effect variation of temperature and variables irradiance on the behavior of PV system in terms of current, voltage, and power the output characteristics of PV panel (Model: Si-Poly-GCL -MAX 445 W) is shown in Fig. 4. It's obvious from this figure, when the sun irradiance is increased, the maximum current is increased and as the results, the maximum power is increased and vice versa. While, when temperature is decreased, the output voltage is increased and therefore the maximum power is increased and vice versa.



(a)



(b)

Fig. 4 MPPT DC power curves at daily irradiance, a) current vs. voltage at different temperatures and irradiation, b) Power vs. voltage at different temperatures and irradiation.

3. Photovoltaic Inverters

To generate the most power, inverters must operate photovoltaic generators at their optimal operating points. To set a voltage at which to operate the generator, grid-connected inverters are frequently combined with MPP trackers. In any given year, photovoltaic inverters operate at their rated power PN for only a few hours. Because of the fluctuating solar irradiance. Part-load inverters are the most common type of inverter. It is critical that photovoltaic inverters operate at high efficiencies even when only partially loaded. No preferable use a reflector that is too large, but It is preferable to use a number of inverters instead of one large and this increases the efficiency of the system, the ideal of a photovoltaic system is as follows:
The ideal energy yield E_{ideal} of a photovoltaic system with photovoltaic area A_{PV}, module efficiency η_{PV} and solar irradiation H_{solar}[22] is given by:

$$E_{ideal} = A_{PV} \cdot \eta_{PV} \cdot H_{Solar} \quad (1)$$

The average real efficiency of solar modules is lower than the nominal efficiency due to soiling, shading, and elevated operating temperatures. The claimed performance ratio (PR) describes the ratio of the real and ideal energy:

$$E_{real} = PR. E_{ideal} \quad (2)$$

Good systems have PRs of more than 0.75. If no shading losses are to be considered, this value can be used to build a new device. Even very good systems will achieve PRs greater than 0.8. PRs of less than 0.6 are indicative of problematic structures. The connection of solar modules to a central inverter, a number of modules are connected in series to form a string until the desired voltage is reached. Several identical strings can be connected in parallel to increase the power of the generator. Blocking diodes that were often used in older systems can be omitted because their protection capability is low and they cause permanent forward losses. Both string and module inverters are shown in Fig. 5.

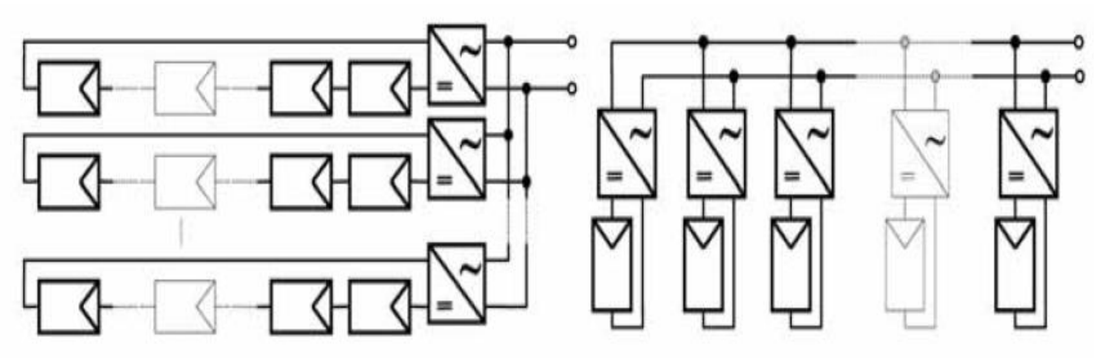


Fig. 5 Photovoltaic system with string inverters on the left and module inverters on the right [22].

4. Power Generation and Injection into The Grid

An energy quality study was carried out at the low voltage grid's interconnection point with the 1620 KW P distributed generation system. Model GCL-P6/96-445 is made up of 3640 modules tilted at a fixed angle of 21 and oriented with an azimuth of 0°. It is divided into 14 series and 260 parallel Model GCL-P6/96-445 that are connected in series and cover an area of 9422 m^2according to standard test conditions (STC). The circuit also includes a Model ABB- PVS800-57-0500kW-A inverter with a rated maximum efficiency of 85 percent and a maximum AC power of 1620kW, which measures the total energy generation for the Month of April 286,9 MWh as shown in Fig. 4. The input and output data of grid inverter are shown in tables 1 and 2. The parameters of PV panel that used in the simulation system is presented in table 3.

These are defined as the conditions under which all modules are tested and specifications given so that comparison between different cells and modules is possible:

● cell temperature $25^{\circ}C$

● Irradiance 1000W/m^2

● Air mass 1.5KW/m^2

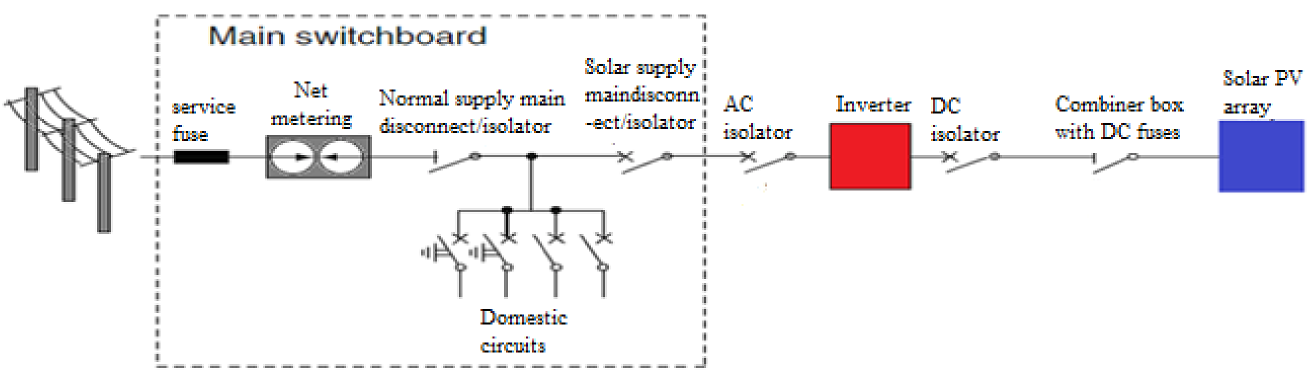


Fig. 6 Integration of PV for main grid [22]

Table 1 the technical data sheet of inverter for input solar of grid inverter'ABB 500KWP'

INPUT DATA	value
MAX. usable input current total (I dc max1/I dc max 2)	1375
Min input voltage(Udc)	450
Feed in start voltage (Udc)	450
Norminal input voltage (Udc)	630
MAX input voltage (Udc)	1000
MPP voltage range (Umpp min-Umpp max)	450-825
Max. PV generator output(Pdc)	600KW

Table 2 the technical data sheet of inverter for output Solar of grid inverter'ABB 500KWP'

OUTPUT DATA	value
AC nominal output (Pac)	500 kVA
Max output power	600 kVA
Grid connection (voltage range)	300 V
Frequency range	50 Hz
Total harmonic distortion	3
Powerfactor(cosø)	0.9

Table 3 the technical data sheet of PV Solar Panels' Si-Poly-GCL -MAX 445 wp' si-poly Electrical Data (Stc)

Description	Value
Peak Power Watts-PMAX(wp)	445
Power Output Tolerance -PMAX(W)	0~+3
Maximum Power Voltage -VMPP(V)	50.7
Maximum Power Current -IMPP(A)	8.78
Open Circuit Voltage -VOC(V)	61.2
Short Circuit Current -ISC(A)	9.27
Module Efficiency η m(%)	18.40%

4.1. Net way meter

It's a device that lets people who generate some or all of their own electricity use it whenever they want, rather than when it's generated. This is especially important with non-dispatch able renewable energy sources like wind and solar (when not coupled to storage). Fig. 7 shows the placement connected of meter nearly to PCC point.

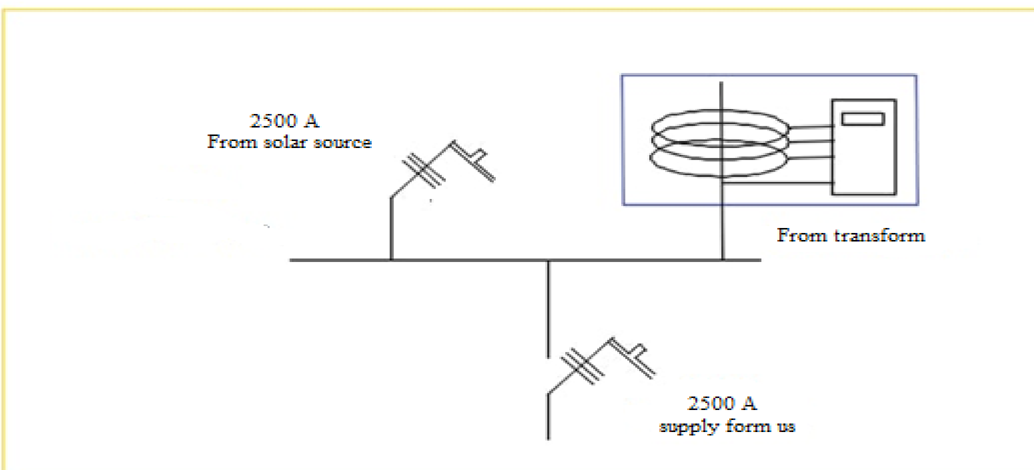


Fig. 7 The point of connection for the net meter [23]

Consumers may use solar power produced during the day at night, or wind from a windy day later in the month, thanks to monthly net metering. Annual net metering allows you to carry over a net (kWh) allowance from one month to the next, enabling you to use solar power produced in July in December or wind power generated in March in August.

4.2. Circuit breakers and fuses

Over-current protection requirements for PV systems should be specified in national codes. A direct current is more difficult to break with DC fuses than it is with AC fuses. Although DC fuses can be used in AC applications, they are more expensive. AC circuit breakers and DC circuit breakers are incompatible. Because PV is a current-limited source, the short-circuit current I_{SC} is the maximum current an array can produce. It is critical that those installing a PV system are qualified to work with electrical systems and are familiar with the local codes that govern the selection and installation of over current protection.

5. Result and Discussion

In Fig. 8. The lowest value of the monthly Energy is effective energy at the output of the array in (kWh/day) seems linear when the ≤5.48kWh/day, but after this point the curve is negatively deflected.

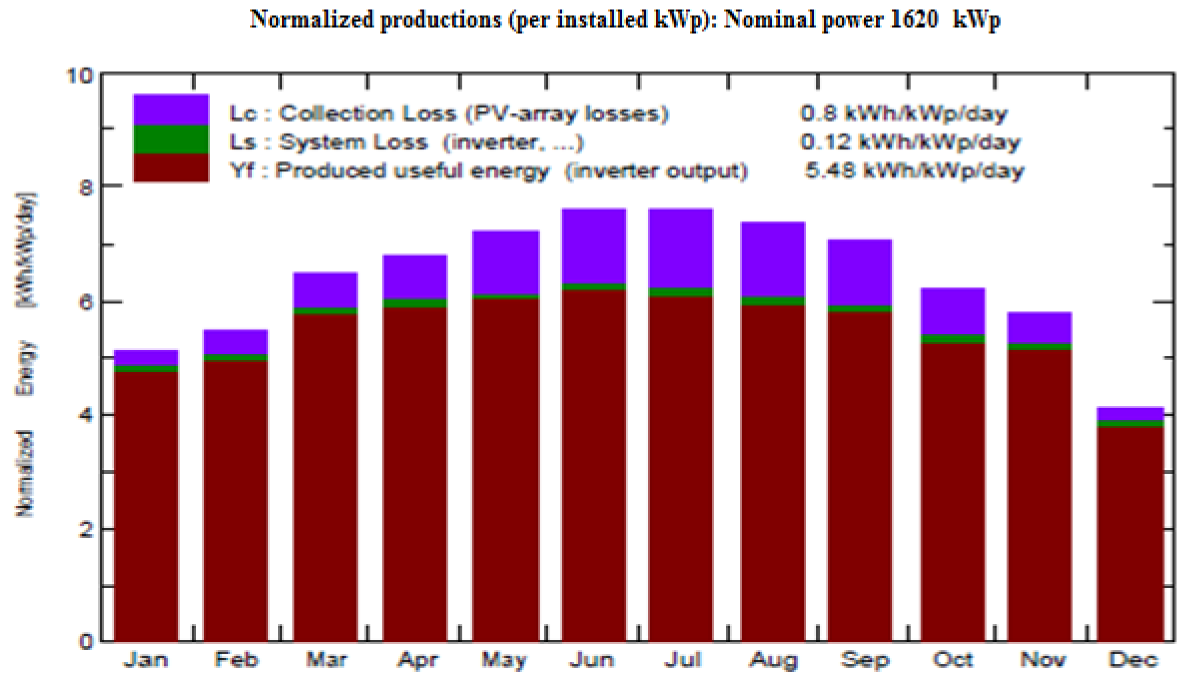


Fig. 8 result of PV system by Pvsyst.

5.1. The Grid-Connected System's Performance Ratio

The lowest monthly reference mean values during the rainy season are 1650Wh/kWp/day and 1620kWh/kWp/day in December 2020 and January 2021, respectively. The highest reference output values were reported in May 2020, with 302 MWh/day and 306 MWh/day, respectively. The monthly Energy has the lowest value of 191 MWh due to the low percentage of irradiance at this time of year. The monthly Energy has a maximum value of 306 MWh because this month has the clearest sky of the year. As shown in Table 4.

Table 4 PV system main result

	GlobHo r kWh/m^2	DiffHor kWh/m^2	T_Amb $°_c$	GlobInc kWh/m^2	GloEff kWh/m^2	EArray MWh	E_Grid MWh	PR
January	104.4	25.25	8.02	159.3	155.3	245.1	239.6	0.929
February	114.4	38.15	11.43	152.8	149.1	230.7	225.3	0.910
March	168.6	55.13	16.28	201.4	196.3	295.7	289.5	0.888
April	191.7	72.86	20.98	204.5	199.1	295.7	286.9	0.866
May	227.9	72.69	27.05	222.6	216.2	308.6	302.1	0.838
June	243.9	56.35	31.89	228.1	221.3	307.3	300.9	0.814
July	248.3	55.75	34.65	235.9	228.8	313.0	306.7	0.803
August	221.6	61.83	34.03	228.1	221.8	304.7	298.6	0.808
September	183.8	48.69	29.02	210.8	205.6	289.4	283.5	0.830
October	148.2	41.18	24.21	191.6	187.0	271.5	265.9	0.857
November	116.4	23.37	14.90	173.4	169.1	257.2	251.8	0.897
December	85.7	34.49	9.86	127.8	124.3	195.9	191.2	0.924
year	2055.7	585.74	21.92	2336.3	2336.3	3312.3	3242.2	0.857

- Harmonics: A periodic wave or quantity whose frequency is an integral multiple of the Fundamental frequency has a sinusoidal component.
- THD: The THD is the ratio of the sum of all harmonic component powers to the fundamental component's power. It indicates the amount of distortion in a voltage or current signal.
- Effect of Harmonics**:** low power factor, computer function destruction, light circuit motor drives, and static sensitive loads in addition, there are transmission losses. Increased neutral current due to three-phase balance deformation. [24].
- Total Harmonic Distortion of Voltage (THDV)**:** When solar PV was injected into the system, the maximum voltage harmonics generated by 3rd order were 3.5 % as shown in Fig 9. It's obvious that as the rated power increases, the performance rises slightly. Harmonic distortion ranges from 1.5 to 5% in available inverters. The majority of inverter designs use the PWM principle.

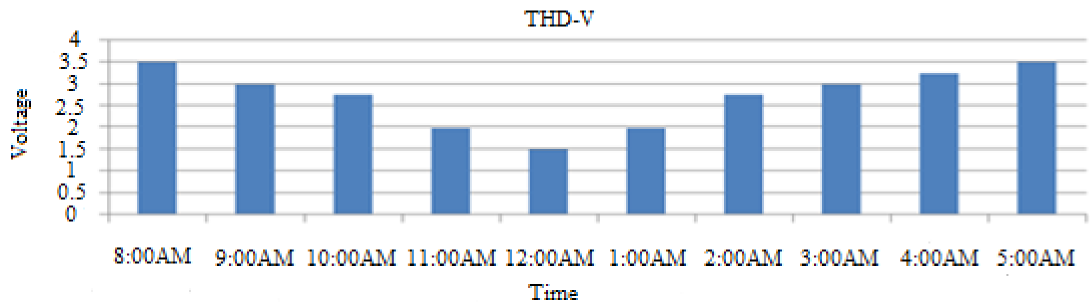


Fig. 9 Total harmonics distortion for output voltage (THDV))

- Total Harmonics Distortion for output Current (THDI)): Current harmonics was measured from 3 rd harmonic up to 7th harmonic by using Power analyzer. The maximum current harmonics is of 7.5 % produced by 3 rd order, when the solar PV was injected to the system, and 12% when there was no solar PV injection to the system as shown in fig. 10. For the system, it is seen that there is a high increase in current harmonics when the solar PV is injected to the grid with no load at 8 am and 5 pm.

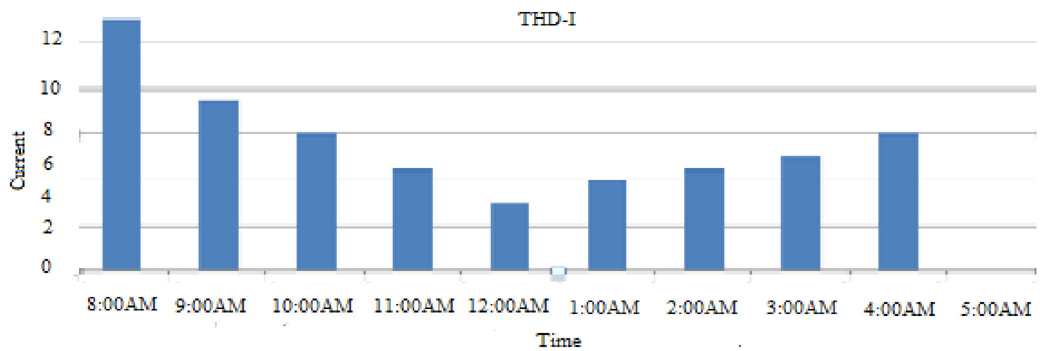


Fig. 10 Total harmonics distortion for output current (THDI))

- Techniques for Harmonics Reduction**:**
  1. Line Reactors
  2. Active Filter
  3. Hybrid Filter
  4. Positive Filter
  5. K-Factor and isolation transformers

Fig.11 We see that THD for current Hysteresis is now within acceptable limits after adding Line Reactor to the new model.

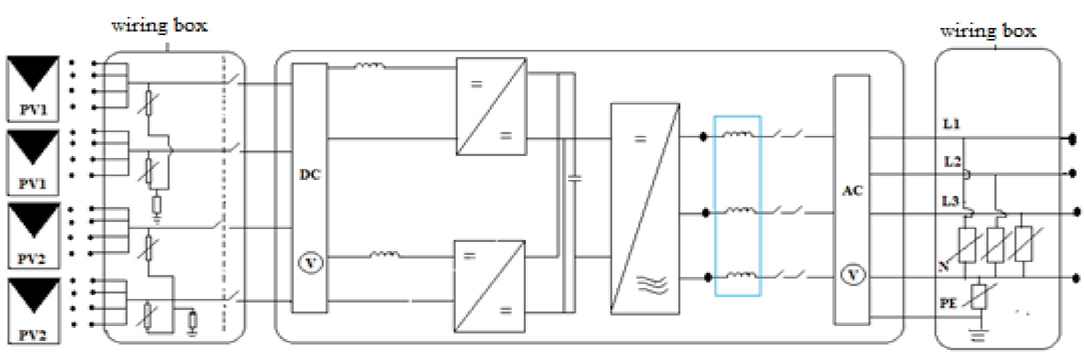


Fig. 11 Added line reactor wiring diagram

After adding line reactor to the new model, we will observe that THD for current hysteresis is now within permissible limits, as shown in fig. 12.

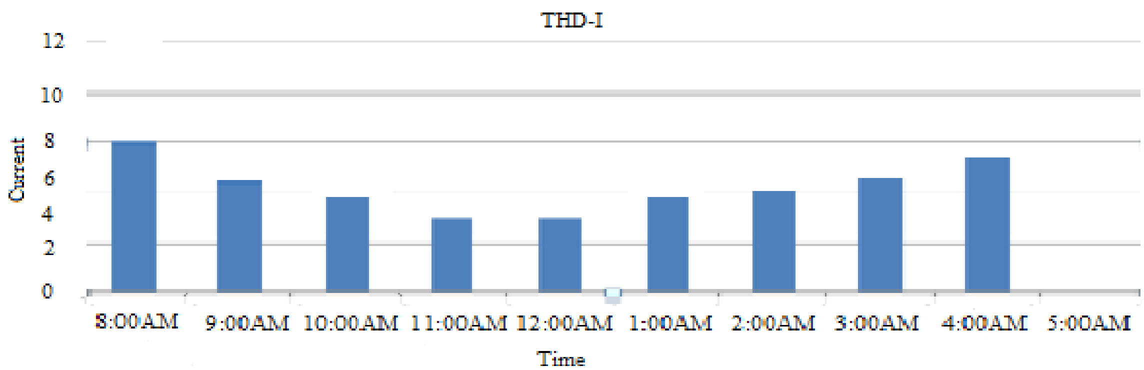


Fig. 12 Total harmonics distortion current after improvement

- Total Performance Ratio PR**:** PRs of more than 75% are considered good. Even very good systems will achieve PRs greater than 0.857, As shown in Fig. 13.

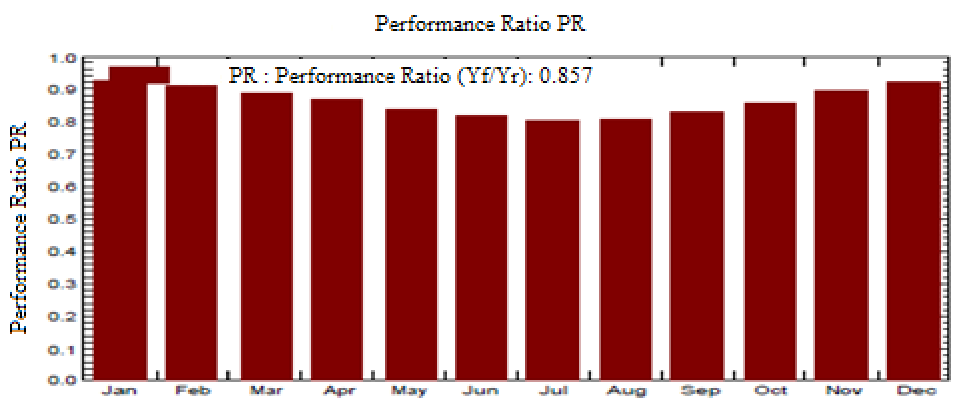


Fig. 13 Performance ratio PR

- System Output Power Distribution: As a result, when the temperature increases, the voltage and power decrease while the current increases and vice versa when there are climate impacts on the cells or partial shading will also reduce the efficiency of the system. As shown fig. 14.

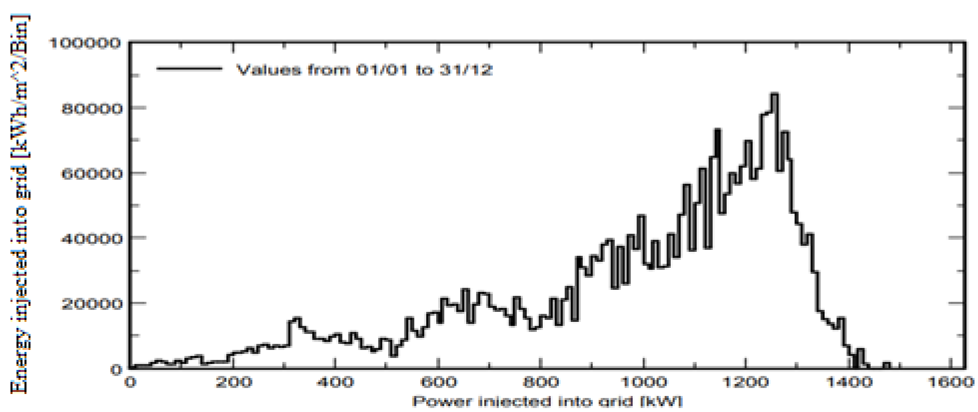


Fig. 14 Output power distribution

- Array temperature Distribution during running**:** Finally, when the temperature increases, the voltage and power decrease while the current increases and vice versa when there are climate impacts on the cells or partial shading will also reduce the efficiency of the system .as shown in fig. 15.

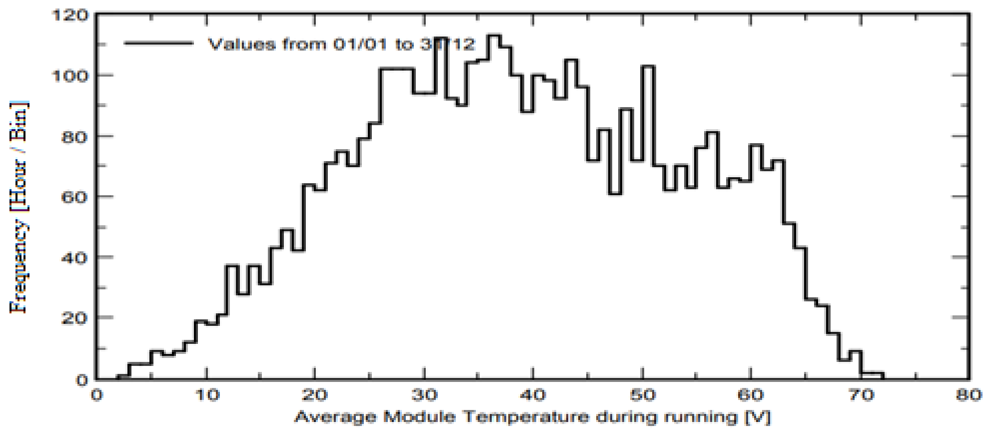


Fig. 15 Array temperature distribution

6. Conclusion

The purpose of this research was to improve the power quality of PV grid-connected systems. We see the increase of PV demand is going to increase the grid harmonics. Thus, resulting in low power factor, destruction of computer functions, light circuit and static sensitive loads, and an increase in neutral current due to three-phase balance deformation. The simulation was performed on a 1.62-MW PV array connected to an 11-kV grid through a three-phase three-VSC. The system's power quality and recorded technical data were examined. The total harmonic distortion of both voltage and current (THDv and THDi), as well as other power quality parameters, were investigated. From the gathered data, the system was found to be performing as expected and power quality parameters are within the permissible limits. To determine the PV system's reliability and grid connectivity, the Performance Ratio (PR) of the grid-connected PV system was also evaluated. The results were confirmed by the PV Syst program, which indicated that they were excellent. When the results of another algorithm are compared to the results of the adopted process, it is clear that MATLAB software is the best and most efficient for practical applications.

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