Modelling and simulation of an on grid 100-kW photovoltaic system

Adnan Majeed Abed, Afaneen Anwer Alkhazraji, Shatha Suhbat Abdulla Al-Kubragyi
Department of Electrical and Electronic Engineering, University of Technology, Iraq, Baghdad

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ABSTRACT

This work proposes a design of a solar radiation generator system to extract a maximum power of 100 kilowatts for the uses of 400 volts, 50 Hertz electrical network, under standard conditions (1000 Watts/m^2 and 25 °C). The main goal is to inject and control active and reactive power to the grid by a three-phase, one-stage solar grid-connected 100-kW photovoltaic (PV) plant, to keep the current's total harmonic distortion (THD) within the international requirements, and maintain a constant voltage regardless of solar radiation changes. This design consists of three control loops those are: the maximum power point tracking (MPPT), the DC-link voltage, and the current controller. The proposed system was simulated in MATLAB/Simulink environment and was applied on part of the Baghdad electrical network. The obtained results showed the efficiency of the proposed design and modelling.

Corresponding Author:

Adnan Majeed Abed
Department of Electrical and Electronic Engineering, University of Technology
Iraq, Baghdad
Email: eee.20.55@grad.uotechnology.edu.iq

1. INTRODUCTION

The population expansion and technological advancement lead to increase of energy demand. The tendency for regionalized power generation, nearness to the source of consumption, an ambition to minimize power loss, and an involvement in improving energy reliability, in addition to fossil fuel depletion and the negative impacts of nuclear fuels, have enhanced renewable power sources (RES) [1]. Solar energy is one of the most important and widely used renewable energy sources [2]. There are many challenges to increasing the penetration of photovoltaic stations into the distribution networks, for example maintaining the voltage value within a specified range and reducing the harmonics that are generated due to the use of equipment that is composed of semiconductors.

Many researches dealt with different manners to achieve one or more goals of this paper. Single stage three level grid connected was presented in [3]. Sreedevi *et al*. [4] used a simulation of the present scheme in Real to research the connectivity effects of solar systems on the electrical grid. While Cabrera-Tobar *et al.* [5] provided an overview of the transformers, converters, and photovoltaic (PV) modules used in largescale PV power systems, as well as their distribution in various kinds of power systems.

To maximize the generation efficiency of PV arrays, the photovoltaic power conversion system must operate near its maximum power point as explained in [6], [7]. The maximum power point tracking (MPPT) technique, which provides the best PV power, necessitates the use of power electronics inverters. They must also synchronize the photovoltaic power to the electrical grid. The works in [8]–[10] suggested a number of different grid-tied topologies with varying emphasis on inverter topology, maximum power extraction, and its control method.

This study provides a comprehensive breakdown of the several components that comprise a single-stage, three-phase, grid-connected PV system. Perturb and observation algorithm (P&O) is used for tracking maximum power, while PI controllers were presented in the control systems. The study's following sections are organized as follows: section 2 presents systems modeling. Inverter control, MPPT, and power control are all discussed in section 3. The outcomes of the simulation are discussed and summarized in sections 4 and 5, respectively.

2. DESIGN OF PROPOSED SYSTEM

The system consists of four basic parts, which are the PV array, DC-Link, VSI inverter and LCL filter. The PLL is required to keep the inverter in synchronization with the grid utility. A total of three different control loops are employed. The power produced by the PV panel will be combined with the reference voltage offered by the MPPT controller in the feed-forward controller reference. The output will be used to create current for the current controller. Indicators of the voltage that the switching current is able to control for synchronization and grid injection, the inverter's output-to-grid angle (wt) was determined using a 3-phase PLL inverter shown in Figure 1 [11]–[14].

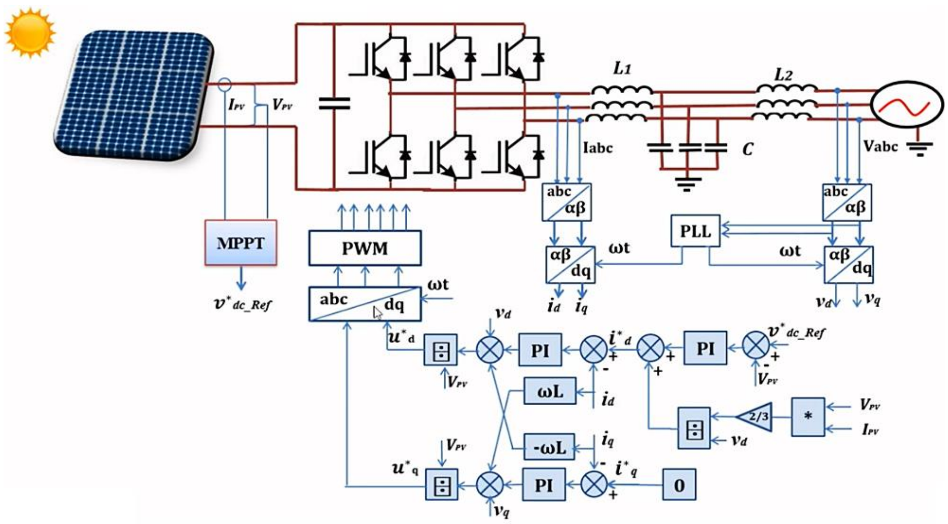

Figure 1. The control structure for the single stage three phase grid connected PV system

2.1. PV Array

2.1.1. Design of PV array

The following series and parallel combinations of PV modules will be employed in the PV system to achieve high power capacity [15].

$$Maximum\ No.\ of\ modules\ /\ string = \frac{(v_{max})_{inverter}}{(v_{oc})(t_{m.min})} \tag{1}$$

$$Minimum\ No.\ of\ modules/string = \frac{(v_{mpp})_{inverter}}{(v_{mpp})(t_{m.max})} \tag{2}$$

$$No.\ of\ strings\ in\ parallel = \frac{(p_{output\ kw})\frac{inverter}{\eta_{max}}}{\left(no.\frac{modules}{string}\right)\times(p_{max})module} \tag{3}$$

2.1.2. Maximum power point tracking (MPPT)

PV array's maximum output is limited by the array's temperature and insulation due to the low efficiency of PV systems. The MPP point and temperature must be monitored often since insulation is dependent on the MPP point. To monitor MPP, the perturb and observation (P&O) approach was used. As the power from the PV array increases, the operational voltage is changed in a single direction by this MPPT method, shifting the operating point from one to the next [16]. The opposite of a step change, this cycle will continue indefinitely unless something drastic occurs. It is stated in P&O's flowchart that the MPP point in power required is zero. Figure 2 shows the MPPT (P&O) algorithm principle, while Figure 3 shows the P&O MPPT flowchart [17], [18].

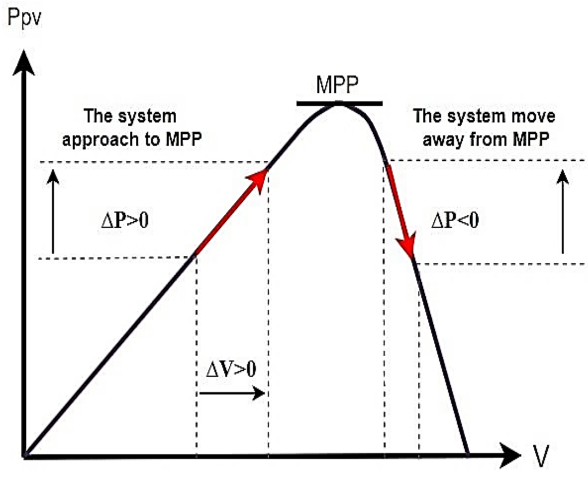

Figure 2. The MPPT (P&O) algorithm principle

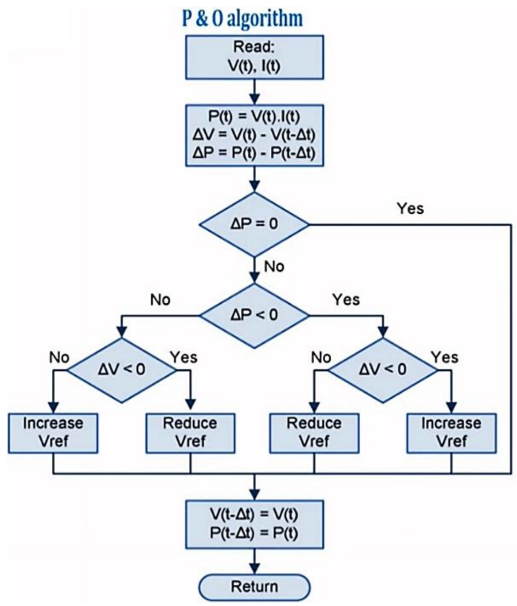

Figure 3. The P & O MPPT flowchart

2.2. DC-link

2.2.1. Calculation of capacitance value

Given the quantity of the maximum permissible ripple voltage, (4) can be used to determine the minimum capacitance of the DC-link capacitor [19]–[22]:

$$\boldsymbol{C_{dc}} = \frac{\boldsymbol{S_{rated}}}{\boldsymbol{4\pi f_o V_{dc} V_{max}}} \tag{4}$$

where: $\boldsymbol{S_{rated}}$: is the inverter output rated power, Cdc is the DC-link capacitor, and f0 is the utility frequency of 50 Hz. As demonstrated by (5), DC-link voltage must be greater than grid voltage to ensure power flow and impose forward current injection into the utility grid.

$$V_{\boldsymbol{dc}} = \frac{\sqrt{2V_g}}{m_a} \tag{5}$$

V_g :is the output voltage's RMS (root mean square) value at the inverter's fundamental frequency, and m a is the modulation index ($m_a \leq 1$) [23].

2.2.2. Voltage control for DC-links

The voltage of the DC-link in the suggested arrangement is equal to the PV output voltage fed into the inverter (725 V). Prior to changing the grid current injection, the MPP voltage can be established. A PI controller is used to correct the error and guarantee that the PV output voltage is exactly at the MPP voltage point. Figure 1 displays the PI controller's output to the generated i_d reference current, as well as a future-oriented statement. It is only need to push the active component of the current into the grid, which is now a simple task, in order to push reference current into the grid that is in phase with voltage. Reactive current is always generated through feed-forward power feedback. Figure 3 demonstrates unequivocally that the reactive power flow of this PV system into the grid is also zero [24].

2.3. Inverter construction

The DC-link voltage must be changed into a three-phase output voltage using a three-phase inverter. In this configuration, the DC-voltage source which is applied to the input side of the inverter is the PV panel and boost converter. A decoupling capacitor with a high value is used in this arrangement. The DC input current controls the power flow since the polarity of the input voltage is constant. In addition to managing reactive power and producing the required output voltage and frequency, the inverter completes the DC-AC conversion. The output voltage of the inverter is a regular waveform. The three-phase voltage source inverter circuit topology with six switching components is shown in Figure 4.

2.4. LCL filter

2.4.1. Design of LCL filter

Due to the inverter's production of substandard harmonics, its output cannot be directly linked to the electrical grid. Therefore, a three-phase LCL-filter can be employed to address this issue [20], [25]. Reactive power requirement = 5% of rated power (S).

$$Q = \frac{v2}{(\frac{1}{2*pi*f*c})} = 5\% \text{ of } S \quad (6)$$

$$v^2 * 2 * pi * f * c = 5\% \, s \quad (7)$$

$$c = \frac{0.05*s}{v^2*2*pi*f} \quad (8)$$

The value of inductance:

$$v_L = 20\% \, of \, V_{grid} \quad (9)$$

$$L = \frac{0.2*V_{grid}}{2*\pi*50*I} \quad (10)$$

2.4.2. The design of the current controller

Grid voltage must be transformed from ABC to dq by the current controller in order to communicate grid voltage and inverter output currents in a pure sinusoidal form (e_d, e_q, i_d, i_q). The (11) and (12) are the equations that describe the controller's current output. It is also possible to take into account the pace at which the voltage changes when inductance is included in the equation [26], [27]. Figure 5 shows the whole proposed control system.

$$V_d = e_d + L\frac{did}{dx} - WLi_q \quad (11)$$

$$V_d = e_d + L\frac{diq}{dx} - WLi_d \quad (12)$$

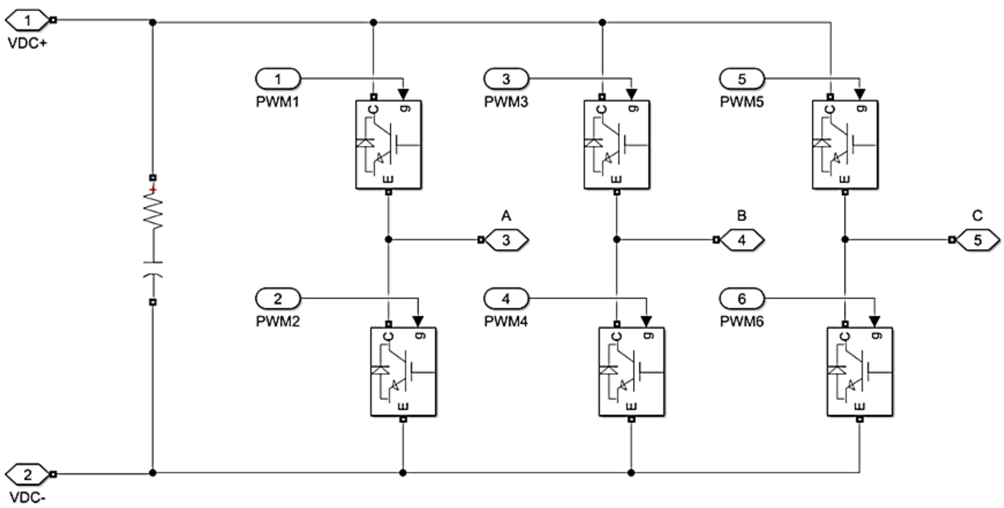

Figure 4. Inverter with a three-phase voltage source and six switches

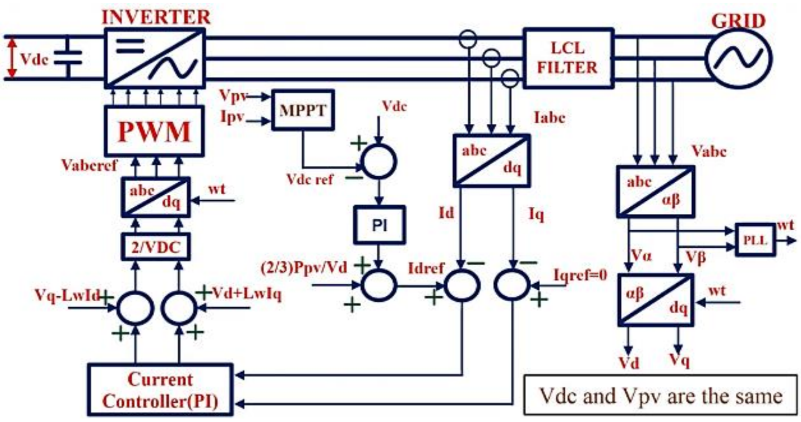

Figure 5. The system block diagram with the suggested controller

3. RESULTS AND DISCUSSION

For this work, the module has the specifications of the PV system is presented in Table 1. 18 strings are connected in parallel, 25 modules in each string are connected and 60 cell per module to get the specified power and voltage. So, mono plates were used because this type is a commonly used type of cell that contributes to about 80% of the market and remains leading up to extra efficient and cost-effective PV technologies. The MATLAB/Simulink simulation of the proposed model yields the simulated system parameters in Table 2.

Table 1. Parameters of PV Array

Parameter	Symbol	Value	Unit
Power at maximum power point	Pmax	213.15	W
Voltage on an open circuit	Voc	36.3	V
Current in a short circuit	Isc	7.84	A
Voltage at the point of maximum power	Vmax	29	V
The current at the point of maximum power	Imax	7.35	A

Table 2. System parameters

The parameter description	The calculated quantity	Unit
Power's worth	100	kW
Voltage of an open circuit	907	V
Voltage in a network.	400	V
The filters' inductances	500, 500	µH
Filter capacitance	100	µF
Dc capacitance	1000	µF
Grid frequency	50	HZ
Switching frequency	10	KHZ
Kp and Ki of current control loop	3.33 and 5000	-
Kp and Ki of DC-Link voltage control loop	0.25 and 0.001	-
Kp and Ki of PLL controller	10 and 50000	-

It's clear that the most powerful tool at your disposal is your own. Using 100-kW and the same extract at MPP voltage, the qualities of PV arrays, on the other hand, are somewhat different as shown in Figures 6, 7 and 8. Figure 6(a) shows I-V characteristics whereas Figure 6(b) displays the relationship between power and voltage. PV array output power is shown in Figure 7. Figure 8 illustrates DC-Link voltage. The results show that a constant voltage and harmonic reduction were obtained through the injection and control of the active and reactive power. The LCL filter is to blame shown in Figures 9 and 10. It appears that PV grid current has a very low total harmonic distortion (THD) (1.41 percent), it is less than 5 percent (According to the international standards IEC61727 and IEEE1547, the grid interactive inverter, total harmonics distortion of the inverter output current must be limited (THD < 5%)). Figure 11 illustrates the sinusoidal nature of the injected current into the grid. The electricity supply will be affected if there is any climatic change that results in insulation change. A constant voltage is obtained despite the change in the solar irradiation and the change in the value of the outgoing current shown in Figure 12.

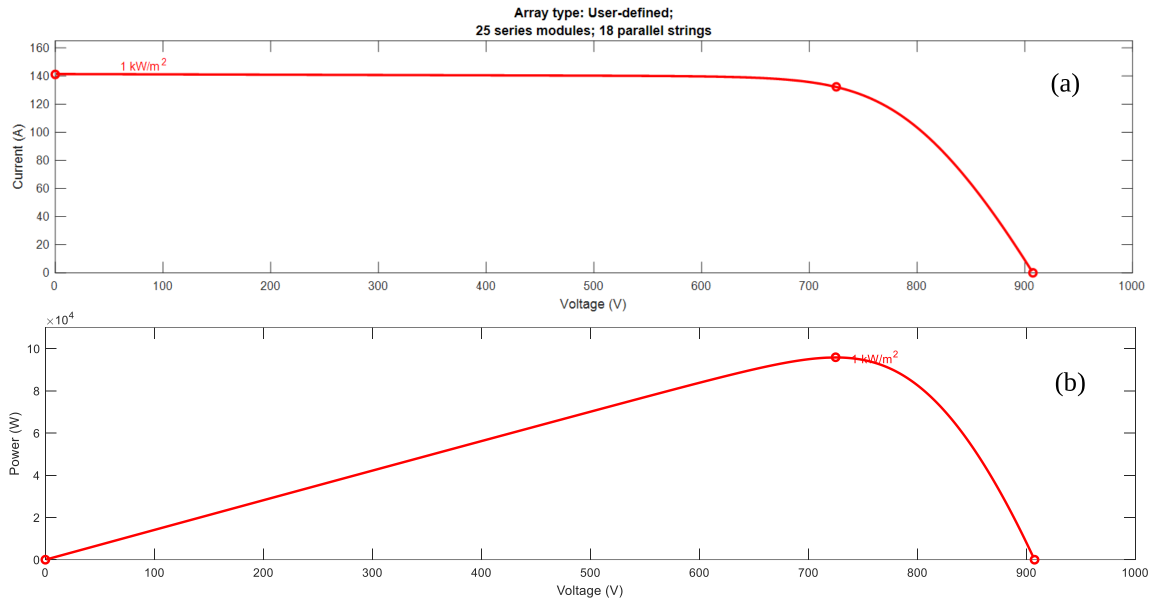

Figure 6. The PV array characteristics of different irradiation and constant temperature of 25 °C: (a) I-V characteristics, and (b) P-V characteristics

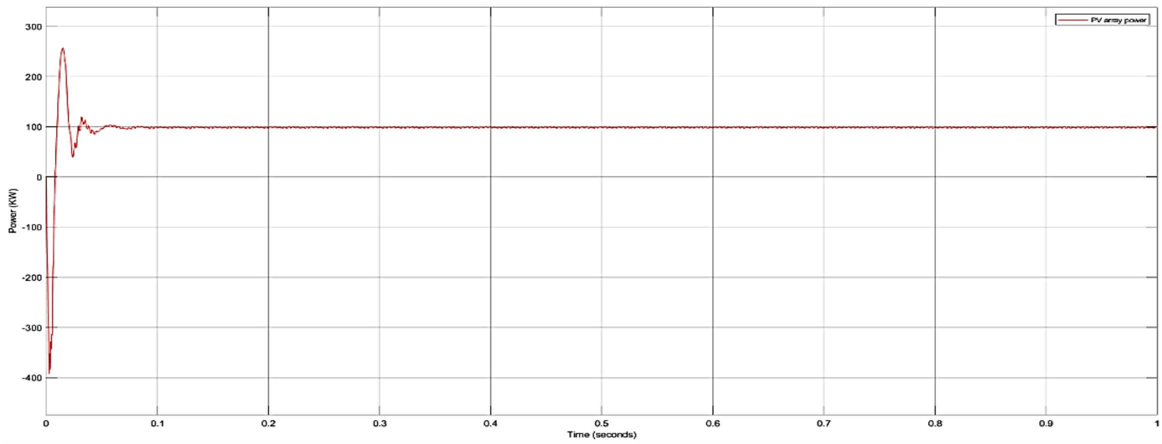

Figure 7. PV array output power versus time

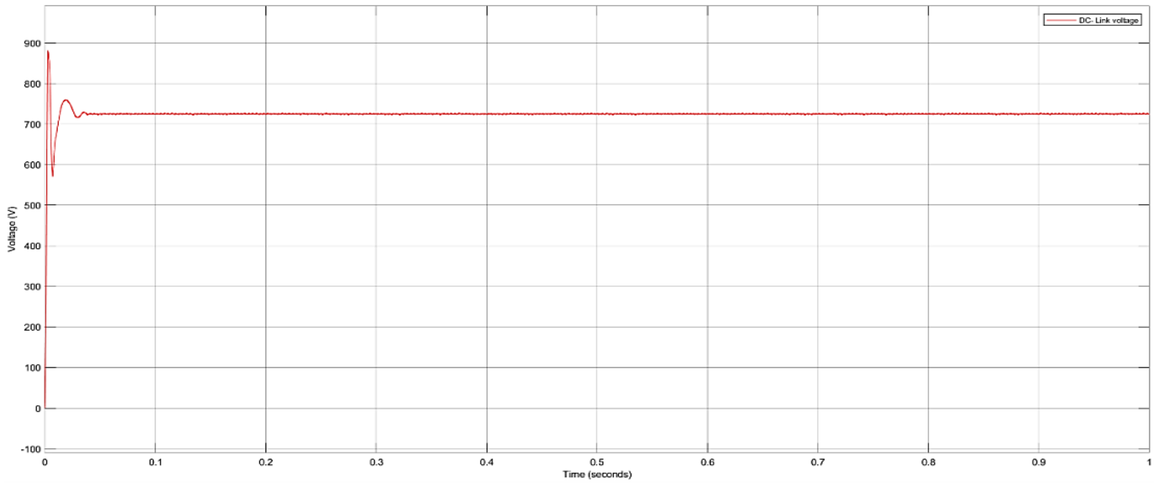

Figure 8. DC-Link voltage

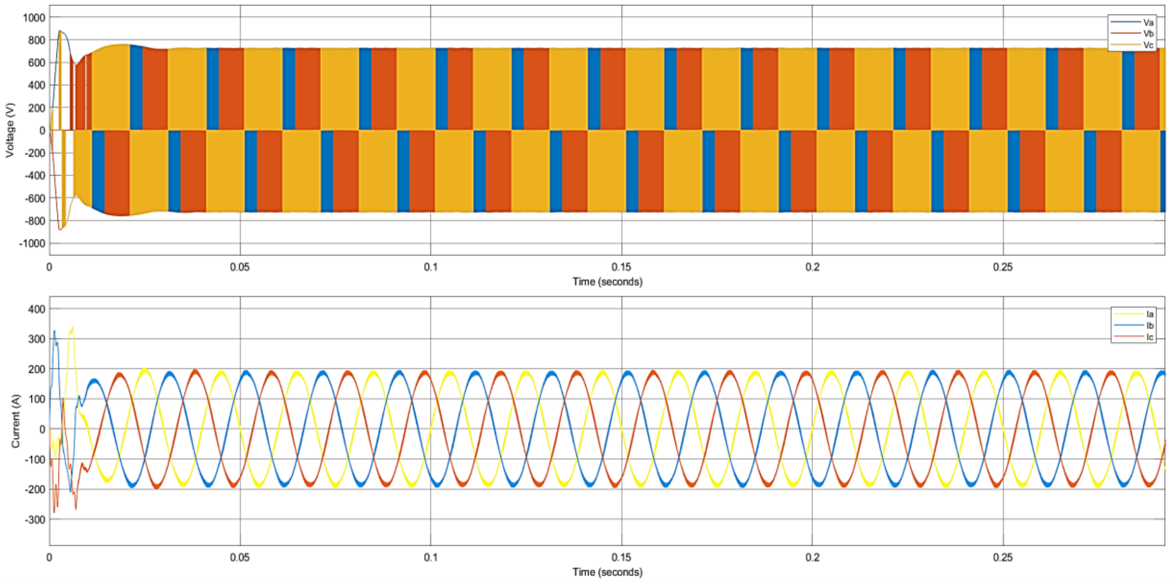

Figure 9. An inverter output voltage and current

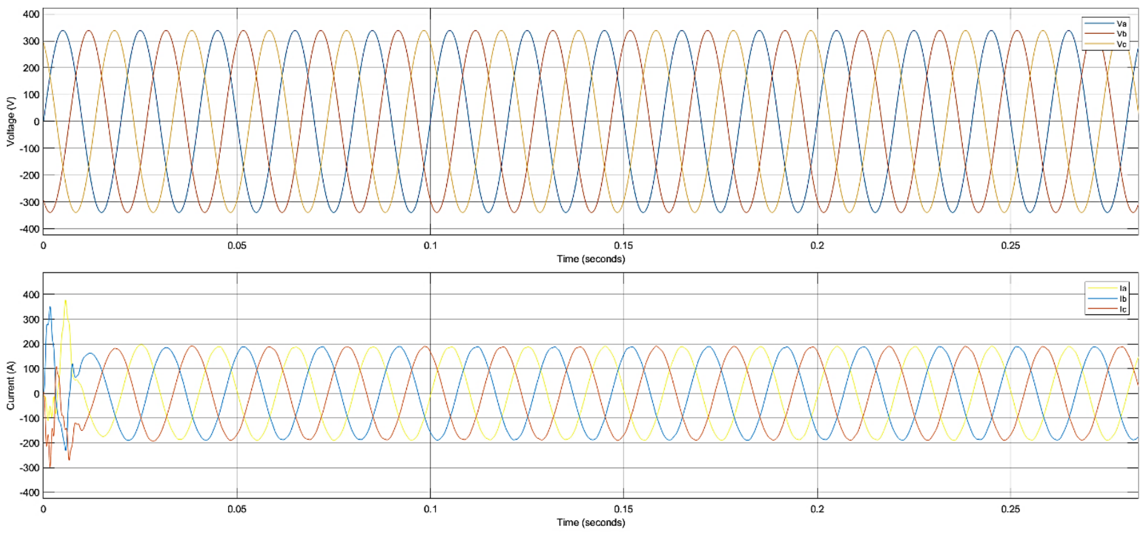

Figure 10. Output voltage and current in relation to time

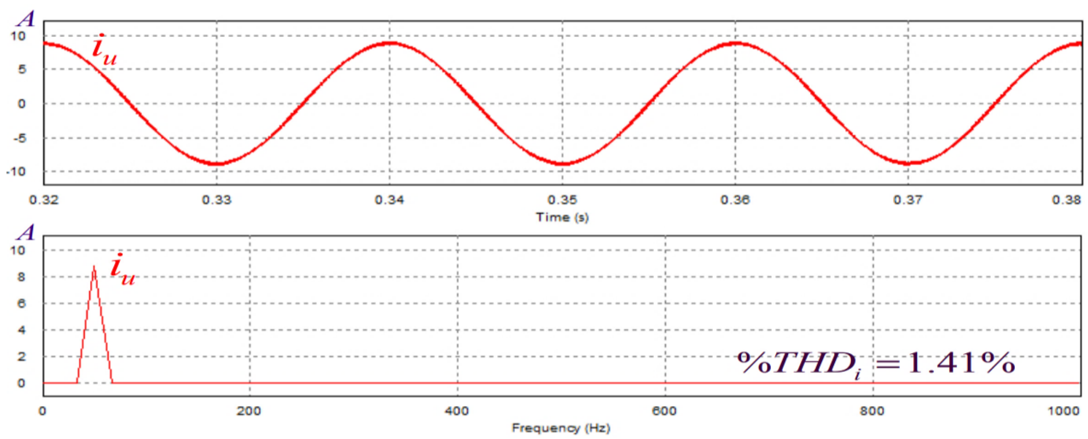

Figure 11. Current FFT analysis

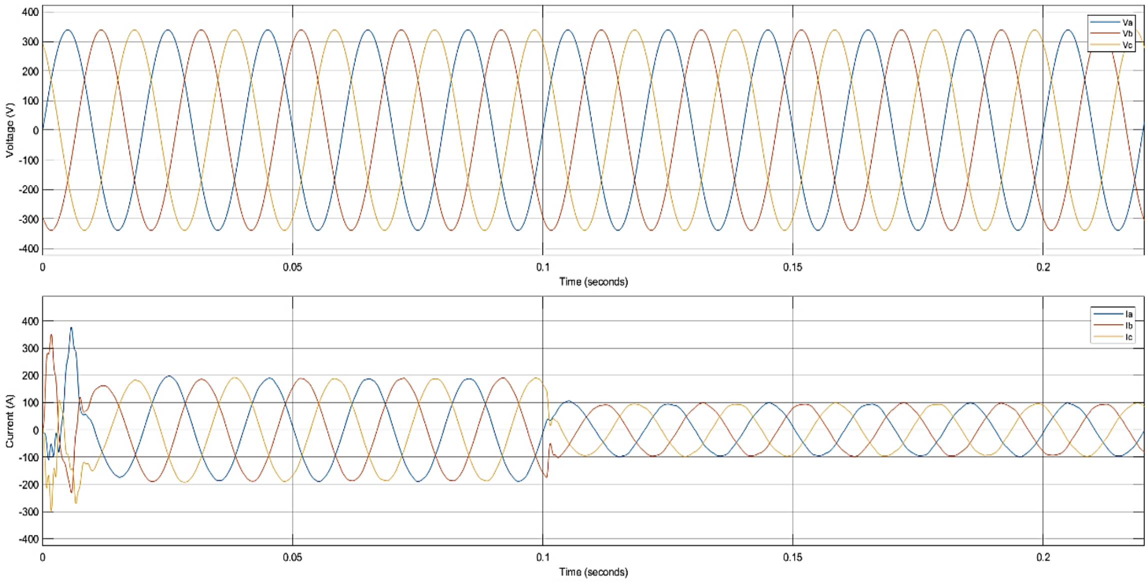

Figure 12. Output voltage and current with varying irradiance

4. CONCLUSION

This study investigates the design and modeling of an on grid 100-kW three-phase grid-connected solar system. The main objectives of this work are to inject and control active and reactive power into the grid by a three-phase, one-stage solar grid-connected 100-kW photovoltaic (PV) plant, ensure that a constant voltage is maintained regardless of changes in solar radiation, and maintain the current's THD below the level required by international standards. The obtained results show the efficiency of the proposed design and modelling.

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BIOGRAPHIES OF AUTHORS

Adnan Majeed Abed received the Engineer degree in electrical Engineering from University of Technology, Baghdad-Iraq, in 2008. He also has a BA in English from the College of Languages, University of Baghdad, Iraq in 2013. He has been working as an electrical engineer in the Iraqi Ministry of Electricity since 2008 until now. He can be contacted at email: eee.20.55@grad.uotechnology.edu.iq.

Afaneen Anwer Alkhazraji was born in Baghdad, lraq in January of 1967.she received her B. Sc in 1990 from Baghdad university. Her M. Sc and PhD degrees in 1998 and 2005 respectively from university of technology, Iraq. She is an assistant professor since 2006. Her field of interest is power system operation and control. She had more than 35 published papers. Supervised mor than 30 Doctor and master students. She can be contacted at email: 30237@uotechnology.edu.iq.

Shatha Suhbat Abdulla Al-Kubragyi received her B.Sc. and M.Sc. degree in Electrical and Electronic Engineering from University of Technology, Baghdad-Iraq, in 2000 and 2003 respectively. She was awarded a PhD degree from University of Cranefield, UK, in 2018. since 2005 she has been a Lecture in Electrical Engineering in the Department of Engineering at University of Technology, where she teaches Electrical Machines, Power System, Engineering Analysis and electric circuits. She can be contacted at email: 30070@uotechnology.edu.iq.