Received: 8 September 2023 | *Revised: 29 March 2024* | *Accepted: 5 July 2024*
DOI: 10.37917/ijeee.22.1.27 *Vol. 22 | Issue 1 | June 2026*

Open Access

Iraqi Journal for Electrical and Electronic Engineering
Original Article

Simulation and Analysis of High Performance of On-Grid Solar Panel System Based on Intelligent Controller

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Abstract
Engineers are searching for alternatives to conventional energy sources to address the energy crisis as a result of the sharp increase in energy usage. This work describes developing, simulating, and evaluating a three-phase, 13.25 kW solar power system. PV analysis is also performed. An inverter featuring a dual Electricity flow is connected to a solar system consisting of six consecutive strings of four solar power cells connected in series. The output of the phase lock loop (PLL) feedback in the linearization system is used to generate a signal, and the power conversion voltage is synchronized with the signal by using its output as a voltage reference. This hybrid technology, which has two phases that are optimal for the rechargeable recharging process of the batteries, is used to replenish a battery bank in capacity or float arrangement for eight sequences of 12V - 200-Ah rechargeable batteries. Ultimately, a MATLAB computational model has been created for a grid-connected photovoltaic system that uses sinusoidal modulation of pulse width and an inverter as voltage sources.

Keywords
Hybrid Technology, Intelligent Controller, On-Grid Solar, Matlab Simulation

I. Introduction

Due to industrialization and rising population, the world's energy consumption is rising quickly. Between 2018 and 2050, it is predicted that worldwide consumption of energy will rise by almost 50 percent. The greatest source of energy to meet the high demand has always been fossil fuels, which is bad for the environment [1]. When fossil fuels are burned, there is a significant discharge of contaminants into the atmosphere as CO2 emissions, causing harm to human health as well as creating climate change owing to the greenhouse emission effect. The primary causes of this are the scarcity of natural resources and the damaging impact traditional methods have on the environment. Additionally, there won't be a great deal of these energy sources available in the future [2,3]. These are the motivations that drive many academics to work in the field of renewable energy. It is necessary to switch to renewable energy sources that can lessen atmospheric carbon dioxide (CO2) levels and, thus, curb global warming [4,5]. One of the most significant trends of the twenty-first century is the switch to renewable energy. RESs include solar photovoltaic (PV), solar thermal, hydropower, and geothermal energy, wind, as well as biomass, which might provide everyone, irrespective of geographical location, with inexpensive options as well as environmentally friendly power [6,7]. Energy produced from RES climbed by over 8 percent to 8300 TWh in 2021, marking the largest annual increase in over forty years. Due to rising energy output from all RES, it is projected that by 2020, the percentage of power produced through renewable energy sources will reach 30 percent in 2021 [8]. As seen in Fig. 1, by the end of 2021, the global capacity for producing renewable

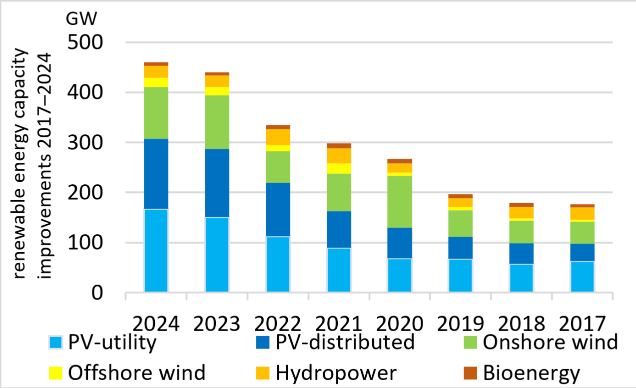

Fig. 1. Growth of renewable power capacity Influence [10].

energy was expected to surpass 3,064 GW; in that same year, the amount of electricity generated by renewable power plants increased by 257 GW (+9.1 percent). However, solar energy is still the main driver of this energy surge, adding 133 GW (+19 percent), followed by wind energy with 93 GW (+13 percent). The use of photovoltaic cells is predicted to be the most important contributor to power production amongst all renewable energy choices by 2040 [9] Growth is dominated by solar PV, while onshore wind installations return to surpass the record set in 2020. 2023 will see the largest increase in renewable capacity worldwide coming from solar photovoltaics, nearly half of the increase in PV worldwide is accounted for by dispersed applications, which include residential and commercial systems, and account for 65 percent of the increase. To surpass the record set in 2020, annual worldwide onshore wind power additions are predicted to increase by 70 percent in 2023. The production of renewable energies has declined, This decline is being driven by most of the Chinese projects that were halted for a few years because of COVID-related restrictions. Although an over 50 percent rise in offshore additions is anticipated in 2023, this growth will not be enough to equal the record-breaking expansion that occurred last year prior. The expedited scenario suggests that this year's renewable capacity increases might surpass 500 GW, which is over 15 percent more than in the main scenario [10, 11].

Because solar energy is abundant in nature, it seems to be a serious contender among the available all-renewable energy sources. Solar photovoltaic (PV) systems offer several advantages, such as the capacity to provide clean energy and environmentally friendly power to remote areas [12, 13]. They can be installed in commercial or residential complexes to meet either partial or full load demand. The excess energy generated by the photovoltaic system can be fed back into the grid if it produces more than is needed to meet demand [14]. Under fluctuating atmospheric conditions, a (MPPT) technique is utilized to run the photovoltaic system near its maximum power generation for a given load, for additional information see Photovoltaic arrays, anti-islanding protection, stability, power quality, and power electronic interfaces are all examples of power electronic interfaces [15]. MPPT for fixed loads has the same goal as impedance comparison, where the load impedance is matched to the ratio by a power electronics converter that converts DC to DC of the array's current and voltage at the maximum power point (MPP). This study shows a comprehensive simulation of a 13.25 KW solar photovoltaic (PV) panels running below conditions of continuous illumination and connected to a three-phase grid with a power factor of one. (DC-DC) boost as well as (DC-AC) conversion in two stages of conversion has been modeled. The duty cycle of the boost converter between DC and DC is watched carefully to ensure that the DC link voltage remains consistent [16]. The inverter [17]. constitutes one of the key elements in the conversion of solar energy into electrical power. A direct current (DC)-DC converter is also included in the inverter to boost average conversion efficiency with the goal to get the most power possible from the panels [18]. The three-phase Voltage source inverters (VSI) employ the DC link power as a source of input. which uses Voltage oriented control (VOC)and a decoupling controller to regulate the current through the grid in the frame of reference that rotates synchronously. The primary goal of this study is to maximize the amount of power generated by a solar PV system using a powerful MPPT algorithm. This is done by monitoring the MPPT method's effectiveness and, consequently, its effectiveness, as well as the quality of the injected AC current to ensure that it complies with IEEE standards [19, 20]. The remainder of the essay is structured as follows: The Background is presented in Section II. , and Section III. presents the Proposal System Design, and methodology, which includes the Design of the Inverter Controller and Design of DC-DC Converter assessments of electricity consumption, resource availability, controlling and modifying formulas. Section IV. provides examples of the Simulation's outcomes. In the last Section, the conclusion is further developed.

II. Background

Due to its widespread availability, low maintenance requirements, etc., the generation of solar energy has gained ground [15]. The mathematical modelling of the photovoltaic (PV) system for solar power has been comprehensively addressed in [21] . Power-switching devices enable solar PV systems to operate at maximum power points (MPP) under diverse climatic conditions [22]. Concentrated solar power, or CSP, is an additional form of solar energy that uses the sun's heat—an endless source of unadulterated, free energy—to create electricity. This type of solar technology is typically used as a massive, centralized source of power for utilities, but it does require a lot of direct sunshine. These power-switching devices are regulated by the solar PV array using a range of MPPT algorithms, such as P and O, the fuzz-logic controller (FLC), and others [23]. The approach also provides a modified SPWM inverter with a modified, more potent reference wave than the standard SPWM, inverter featuring a Zero Crossing Detector circuit, in addition to a revised unipolar Sinusoidal Pulse Width Modulation inverter (PWM) [24]. The DC voltage produced by a PV array is far less valuable than an infinitely capable AC power source like a three-phase grid. As a result, several efforts, were previously accomplished for DC - AC conversions. There are two types of conversion strategies available: single-stage and two-stage. The Pand O MPPT method is the extreme extensively utilized MPPT sketch out of all the strategies that are currently available [25]. Even though the incremental conductance approach outperforms P and O in terms of speed, it is still comparatively sluggish for applications that are linked to the grid since it must execute calculations to maintain its a sensation of movement toward the (maximum power point) [26] . The tools for the new generation methodologies include fuzzy logic, genetic algorithms, and particle swarm optimization. Conversely, rigid procedures, such as linear programming, are put into place for conventional methodologies. The researchers suggested inverter employs a suitable Voltage regulated Oscillator (VCO) to generate variable carrier frequency regulated by full rectified wave reference grid voltage [27]. Although fuzzy logic-based algorithms provide a speedy response after careful tuning, they experience implementation challenges as well as demand prior knowledge to correctly define the fuzzification settings for the algorithm. P and O approaches have been reviewed In [28]. According to this technique, energy is wasted due to the operating point's oscillation about the (maximum power point). Decrease the fixed perturbation step size can reduce these oscillations, but also increases the time it takes to attain MPP. A modified Pand O MPPT algorithm with configurable step size is used suggested to resolve this problematic circumstance. A DC-AC inverter is needed since the output of a PV module is a DC, which needs to be converted into AC power for grid interface [29]. To regulate the coefficient of modulation under various load circumstances, this study provides a better voltage control system for a standalone PV power inverter that employs the MultiStart (MS) optimizing algorithm-based PI (MS-PI) [30].

ANFIS and ANN were compared by researchers in [31] for solar energy projection in various meteorological scenarios. The ANFIS and ANN approaches yielded good results, based on the experiment findings. It is thought that a PV system's nonlinear dynamics are its essential feature [32]. One may determine the variable impedance of a photovoltaic module at a particular working position by dividing the variations in voltage by the variations in current. It calculates the rate at which a change in current causes the voltage between each component to change [33]. Hence, the maximum power point can be found more easily using the MPPT approach in these regions where the dynamic admittance is almost constant [34]. This phenomenon necessitates adjusting the MPPT controller in the power zone. Conventional MPPT techniques, including progressive conductivity and perturb observation, take advantage of both the power and voltage characteristics of the PV panel [35]. A solar module's voltage usually fluctuates from 70 percent to 80 percent of its open-circuit voltage (Voc) for any specific temperature and level of sunlight. This suggests that the maximum power point (MPP) of a PV module often lies within this range of values [36]. The efficiency of a DC-DC converter is determined by its duty cycle, which is a ratio of its ON time to its OFF time. Effectiveness is affected by the output as well as the input voltages. further significant factor involves the converter's setting time, which determines how soon it may reach its steady-state output voltage. The methods used in MPPT employ voltage and current samples to calculate power at every stage. For methods using MPPT such as the observe and perturb method as well as more advanced approaches, this energy then determines the course of tracking [37] . If the MPPT method's step duration is less compared to the converter's resting time, the measurements of current as well as voltage are going to be incorrect, leading to incorrect PV curve monitoring [38]. It is clear from the aforementioned research that it is unattainable to predict that one of these dispatch mechanisms would considerably improve system performance over the other. This study examines the viability of using a grid-connected PV system to provide an Iraqi home's electricity needs [39]. A modified dispatching technique is created using HOMER's MATLAB Link program as well as depending on the prediction of future solar production as well as load demand [40]. The system performs at its most effective and efficient level based on the projected data. For the HES, a techno-economic and ecological evaluation is done to compare the produced plan with the default approaches of Load following (LF) and, cycle charging (CC) [41]. Table I shows some of the techniques used, their advantages, and what scientists have concluded

III. Problem Formula For Grid-Connected Systems

The quantitative and topologies approaches are two widely used observability study techniques for energy grids. However, because of the drawbacks of numerical methods like the Jacobian matrix's singularity problem and processing expense, most researchers prefer to use topological methods based on graph theory. With negligible challenge, the topology tech-

TABLE I.
SOME OF THE TECHNIQUES USED, THEIR ADVANTAGES, AND WHAT SCIENTISTS HAVE CONCLUDED

No	Technical	efficiency	Benefit
[30]	ANFIS	the system to collect higher power, compared to the P and O technique by an average of 21 percent	higher accuracy, faster response and better tracking efficiency.
[36]	ANFIS-MPPT	The technical of ANFIS is higher than FLC by 0.35 w	the proposed ANFIS-MPPT controller furnishes a robust operation
[37]	ANN	partial shade that is more than 7000 W and is thought to be an effective technique	An ANN approach is used to generate a PV output with the greatest power
[38]	GWO-DE	the GMPP yielded results of 984.65 W at 0.08 sec, which was the maximum power when compared to other approaches.	the hybrid GWO-DE approach shows a greater performance as compared to other studied
[39]	ANFIS	increasing productivity by up to 19.96 percent.	The ANFIS controller operates more quickly and efficiently. and the electrical system can now provide the highest quality electricity.

niques can also yield the same result as their numerical counterparts. Concerning electrical system:

$$P(x_i) = \sum_{N=1}^{M_B} C_{x_q} \tag{1}$$

In Equation (1) Using the topological technique, the distribution system with MB number of nodes, It is commonly recognized that the topographical transparency principles can be used to analyze the topological transparency of electrical transmission grids. In this work, same rules will be applied to examine distribution grid observability.

IV. PROPOSAL SYSTEM DESIGN

The primary arrangement of blocks of a grid-connected photovoltaic system is shown in Fig. 2. There are two alternative topologies for grid-connected photovoltaic systems; the two-stage configuration is the most popular. Both the power conversion processes (DC-DC as well as DC-AC) are coupled between the grid and photovoltaic through the dual-stage setup method. A grid, a DC-DC conversion device, a DC-AC inverter, and a PV panel comprise a grid-connected PV construction. In this proposed system, the DC-DC conversion is handled by the boost converter, and the integrated MPPT controller maximizes the power output of each PV unit. DC-to-AC converters are used to connect a solar power (PV) plant to the electrical grid. A three-level inverter and converter are used for DC-AC conversion.

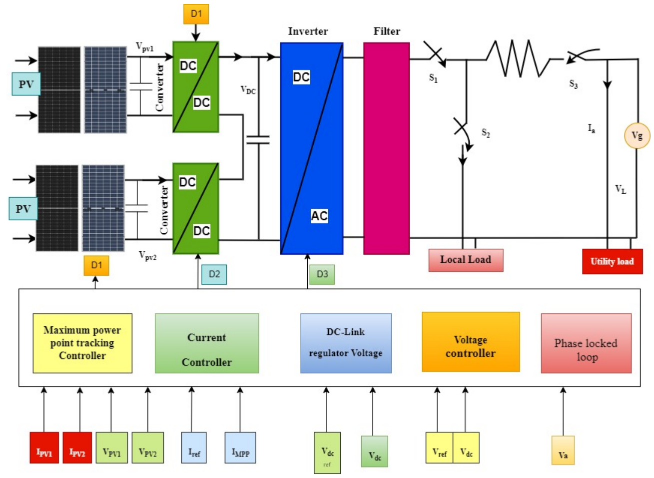

Fig. 2. Overall system design [41].

A. *Design of Inverter Controller*

A source of power inverter is used to link the PV system to the AC bus. The boost converter's result is a constant DC voltage that is fed into a three-phase inverter that is linked to the system. These inverters are utilized only in applications that demand them. considerable power and produce a three-phase voltage (va, vb, and vc).

Typically, voltage source inverters (VSI) are used to create three-phase alternating current voltages with adjustable frequency and amplitude from a constant direct current voltage (DC voltage). In the present work, utilized is a (Neutral-Point-Clamped) triple-level converter with triple bridge legs A, B, and C on every bridge leg might be in three different voltage levels, as shown in Fig. 1. which is referred to as being "three-level" in this context. Fig. 3 shows how a converter is designed. The semiconductor is turned ON and OFF to supply the necessary outputs, which is how the inverter generates its AC voltage output. Pulse Width Modulation (PWM) techniques are frequently used to accomplish this objective.

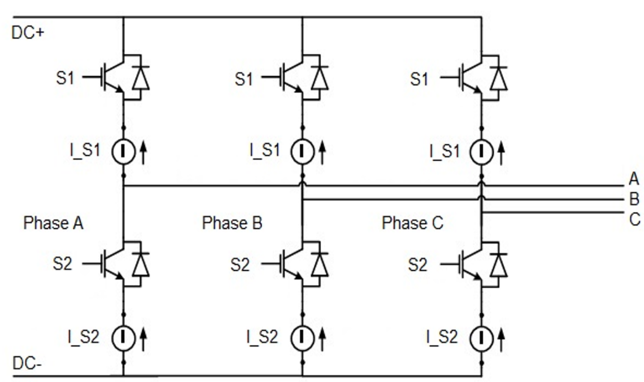

Fig. 3. Overall system design.

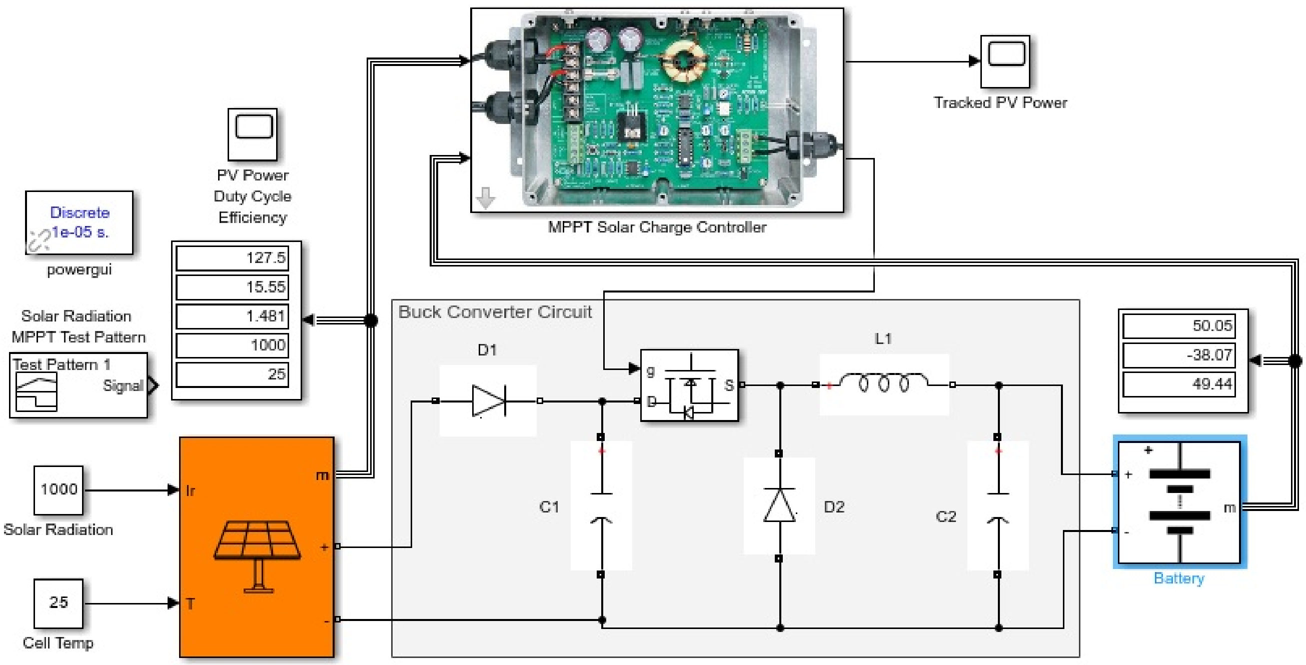

Fig. 4. Overall simulation diagram of on-grid solar panel system based on intelligent controller.

It should be noted that in order to prevent a DC supply from shorting out, the switches on each leg should be triggered alternately. Power MOSFETs and insulated gate bipolar transistors (IGBTs) can both be used to create the switches. Every device has a different power rating as well as switching speed. As seen in Fig. 4, IGBTs are ideally suited for applications requiring medium power as well as switching frequencies.

B. Design of DC - DC Converter

A switching mode DC to DC converter transforms an input voltage of unregulated direct current into a controlled direct power output power at a given voltage level. Comparing switching generators to linear power supplies reveals much higher efficiency and power density. Common components of basic conversions that increase or decrease the source voltage are inductive devices, diodes, transistors, capacitors, and diodes. The three main conversion configurations are boost (step-up), buck (step-down), and buck-boost (step-up or step-down). In our recommended design, the boost topology is utilized due to its free-wheeling diode's potential to be employed to avoid reverse current and effectively increase PV array output voltage to a higher level.

It is feasible to control converters with a Pulse Width Modulation (PWM) duty cycle since the state of a transistor switch dictates the converter's result. Thus, the ideal load impedance of the PV module is achieved by varying duty cycles. By temporarily storing energy inside a semiconductor and using

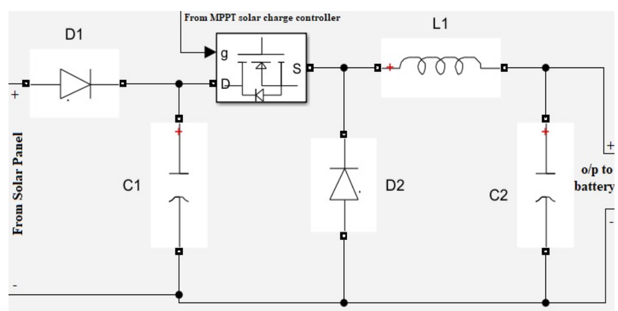

Fig. 5. Circuit diagram of DC-DC converter.

that power to raise the voltage being supplied to a higher level, the boost DC converter raises the voltage supplied. The boost converter circuit schematic is displayed in Fig. 5. The inductor charges up when switch G is closed, in order to generate isolation between the converter's The input as well as output of diode D are reverse-biased. Energy is kept in the inductor until the switch is flipped, at which point the load is provided with energy. Table II shows the grid and inverter parameters that were considered when designing the filter. The current ripple is used to determine the value of L. Lower switching and conduction losses come from smaller ripple.

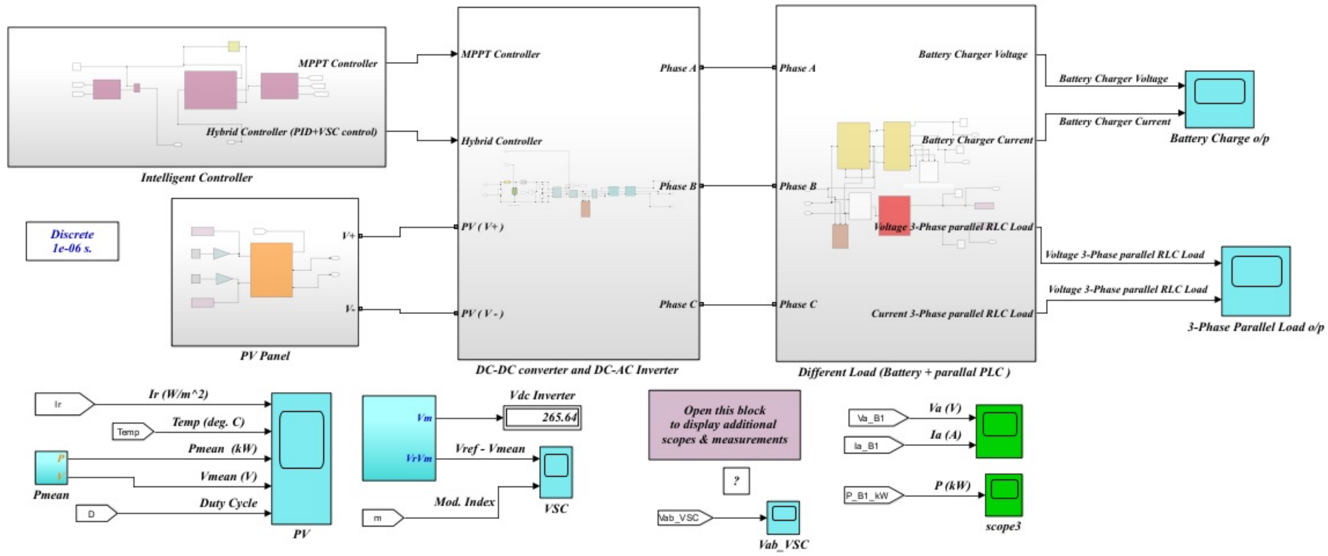

Fig. 6. Overall simulation diagram of on-grid solar panel system based on intelligent controller.

TABLE II.
PROPOSAL SYSTEM DESIGN SETTING PARAMETERS

Parameters	Value
Grid line voltage (V L-L)	430 Volt
Grid phase voltage (Vph)	220 V
DC source voltage (Vdc)	240V
Output power fed to grid (Pn)	1200 W
Grid Frequency (f)	50 Hz
Switching frequency (fs)	30 KHz

V. SIMULATION RESULTS

The system's overall design is simulated in a range of temperature, irradiance, as well as grid conditions. The findings were reviewed as well as evaluated in light of different hypotheses. The entire system is shown in Fig. 6.

The PV array is made up of two parallel lines, which sums up the premise. Each string has ten Tata Power solar System TP300LBZ solar panels connected in order. The photovoltaic system at STC (1400 W/m2 of sunshine and 30 °C of temp) may produce up to 8 kW at its maximum output. A DC-DC Booster Converter raises the solar system MPP power output from 389V at STC to 700V. The Power converter uses 10kHz as its changing frequency. The MPPT processor produces the duty cycle connected to the Boost converters. The MPPT Controller generates the power converter's output frequency by utilizing the Perturb and Observe function (P and O) method. To get the most electricity out of the PV array, this controller automatically changes the Boost converter's duty cycle. An inverter was used to change the 700V Voltage level into a 415V rms line-to-line voltage. PWM is used to regulate the inverter IGBTs. The inverter controller produces the PWM impulses. The IGBTs inside the inverter receive the proper gate impulses from the VSI Controller With the goal to generate the required (AC) voltages, currents, and energy. An LCR filter called the Grid Function is used to remove overtones from the inverter's output. The PV system has a connection to the grid, a 415V grid.

The starting point simulation is conducted by increasing radiation from 0 W/m2 to 1400 W/m2 at 30°C, as per the STC displayed in Fig. 7. The following inferences can be made from the image: The desired voltage level, 930V DC, is present. As the irradiance increases, the PV electrical voltage and current will grow as well, automatically raising the

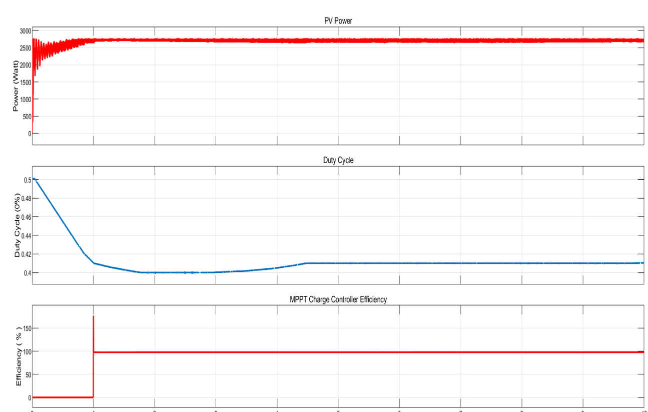

Fig. 7. Simulation of PV system analysis based on MPPT charge controller efficiency.

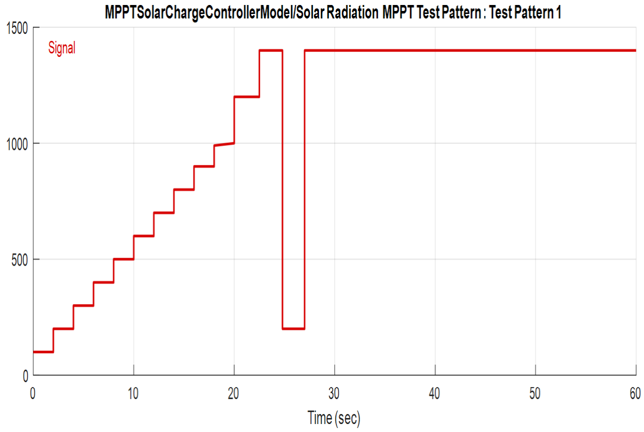

Fig. 8. Simulation of solar radiation MPPT test pattern.

output power. With an 8kW PV panel, the inverter's 5860W power output corresponds to 97.3 percent of its theoretically maximum efficacy

A second simulation is conducted by expanding the environmental temperature range from 0 to 25 degrees Celsius while keeping the radiation level constant at 1400 W/m2, by the STC displayed in Fig. 8. It is possible to infer the following from the figures: The desired number for the DC connection voltage is 930V DC. As a result of the PV the voltage and current decreasing as a result of rising temperatures, the power produced will decrease. The output power of the inverter is 5860W, indicating a decrease in inverter efficiency.

The PV system's modelling is run with a linear load while maintaining STC-compliant temperatures and irradiance levels, shows the results of the simulation. It is possible to infer the following from the figures: Both the voltage and the current have smooth, in-phase waveforms. Under STC parameters for temperature and irradiation, the simulation is done with a non-linear consumption in the solar system. The simulation results for the overall system architecture are shown in Fig. 9.

VI. Discussion

In this part, the research's findings will be explained and assessed. An effectiveness study of the planned solar system during real operating conditions is presented. The relationship between the energy produced and the operational parameters is examined to determine the links, to discuss and prove the results obtained in this work, and to prove the effectiveness of the mathematical model that was adopted in this study. The effects of the change in temperature can be discussed, as well as the period of exposure to sunlight, which will reveal to us the extent of the influence of these factors. On the performance of the proposed system, the most important of these factors are: Energy produced: The results demonstrated that the amount of energy produced by the solar system depends primarily on the extent of temperature changes and the period of exposure to the sun, and that the most important factor is temperature, but warmer temperatures may lead to reduced efficiency, although More exposure to sunlight often increases the amount of energy produced. Efficiency of the solar system: The efficiency of the solar system is directly proportional to the increase in temperature to a certain extent, and then the increase in temperature may cause a decrease in efficiency due to the increase in the resistance of the solar cells after this temperature limit, and this is proven by the simulation results shown in Figs. 8, 9. Optimal operation: The simulation results showed a roadmap for the optimal operating times of the solar system by calculating areas of high temperatures and periods of exposure to sunlight, which will provide the opportunity to produce maximum energy from the proposed system. Sensitivity analysis: The results might include an analysis of sensitivity to demonstrate how the system responds to variations in temperature and sun. This facilitates comprehension of the system's sensitivity to modifications in its external environment.

VII. Conclusion

This work includes and uses MATLAB/Simulink to implement detailed simulation of a grid-connected photovoltaic system. This model mimics an actual grid-connected photovoltaic system and is realistic and simple to use. A centrally positioned controller higher than the instantaneous connection of receptive and active electrical power to the grid, in addition to separate the controllers that serves as a technique for synchronizing the current three-phase transformer that supplies electricity with the grid, constitute a part of the voltage-directed control system that the model implements. This algorithm has a 99.4 percent tracking efficiency and reaches MPPT. When the results of the simulation are compared to the real Tata Power Solar System specification for a photovoltaic array, they match it quite well. PWM is used in the signals of the IGBTs in the inverter to minimize switching losses and boost the effectiveness of the Photovoltaics system. The simulation findings demonstrate that the modelled system performs well beneath a range of temperature and irradiance conditions. Additionally, it demonstrates how a Photovoltaic system is affected by linear and non-linear loads. Synced d-q transformation is used to control the inverter in order to supply active electricity to the grid. PLL are employed to secure grid phase and frequency. By utilizing d-q modification inside the three-phase system, the phase detection portion of PLL is correctly completed. The PV prototype, DC to DV converter model, and DC to DC converter control should all be present with the goal to simulate an actual grid-connected PV system.

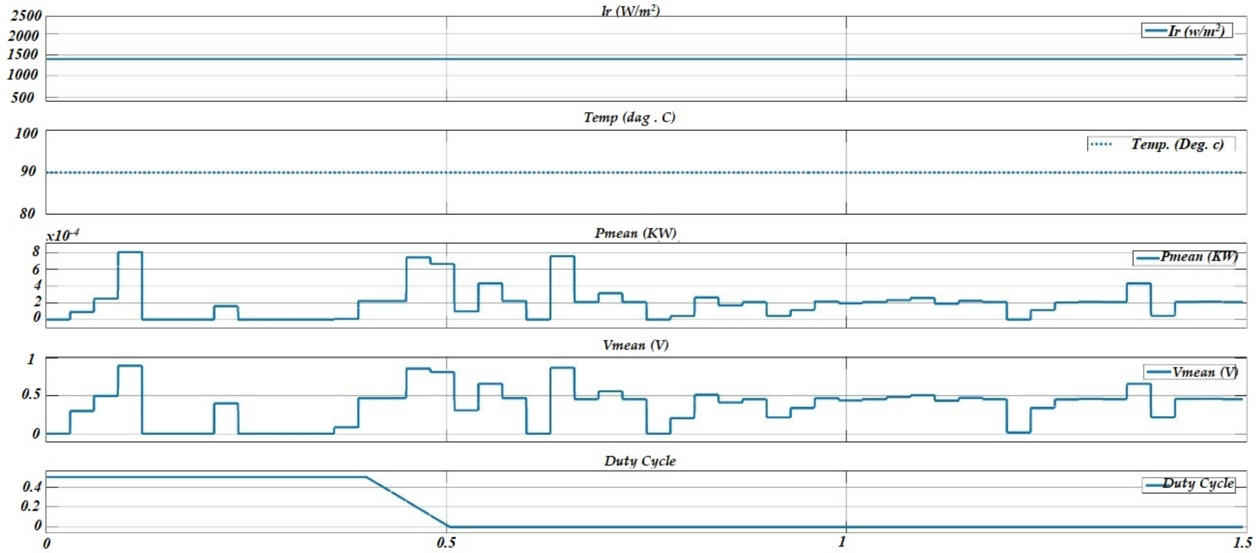

Fig. 9. Overall simulation of PV system investigation with temperature and insolation effects.

Studies in the future can expand on this by enhancing the attributes of power quality using current innovative optimization approaches or by changing the architecture of multi-level inverters.

ACKNOWLEDGMENT

The researchers are grateful to the Ministry of Higher Education and Scientific Research of Iraq, as well as the University of Anbar, for their support and application of this study.

CONFLICT OF INTEREST

The authors have no conflict of relevant interest to this article.

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