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High-Performance Analysis of Smart Grid Based on Intelligent Controller

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Keywords:
High Performance; Intelligent Controller; Photovoltaic System; Smart Grid.

Highlights:

- *The protection mechanisms were further validated using scaled network experiments and simulations on the MATLAB platform.*
- *Discuss and analyze the effects of current and voltage distortion resulting from harmonics on the electricity distribution system.*
- *Use the main characteristics of technical data in MATLAB/SIMULINK to analyze the entire model.*
- *Examining the model's performance under different weather conditions and partial shade conditions.*

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Abstract: Photovoltaic power from the sun's rays is becoming increasingly common in modern distribution networks due to environmental concerns. Regarding the outside environment, the photovoltaic modules' output power is not linear. This work evaluates the ideal performance for energy from renewable sources injection into distribution networks using an intelligent controller based on the Adaptive Neuro-Fuzzy Inference Systems (ANFIS) technique in safety employed through communication with every Protective Devices (PDs) within the grid, as well as an alternative approach that employs communication across the PDs in the same line to maximize the performance of photovoltaic systems (PVS). The protection mechanisms were further validated utilizing scaled-grid experiments and simulations on the MATLAB platform. Additionally, the current and voltage distortion effects brought on by harmonics on the electricity distribution system's feeder network are discussed in the comparison of the characteristics of the distribution system with different levels of solar PV system penetration. The simulation results demonstrated that a large harmonic dispersal level was injected as the solar electricity system's penetrating capacity increased, implying that the solar power array should only be connected to the network's optimum carrying capacity. The main characteristics of the technical data are employed in MATLAB/SIMULINK to analyze the whole model. The model's performance was examined under various weather and partial shade conditions. The gratifying results demonstrated the great performance of the system based on an intelligent controller. The expanded grid was created for smart grids to promote the experimental behavior of protection measures for traditional and AI-based defenses.

تحليل عالي الأداء للشبكة الذكية بناءً على وحدة التحكم الذكية

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الخلاصة

أصبحت الطاقة الكهروضوئية الناتجة عن أشعة الشمس شائعة بشكل متزايد في شبكات التوزيع الحديثة نتيجة للمكون البيئي. فيما يتعلق بالبيئة الخارجية، فإن طاقة خرج الوحدات الكهروضوئية ليست خطية. يقترح هذا العمل تقييم الأداء المثالي للطاقة من المصادر المتجددة التي يتم حقنها في شبكات التوزيع باستخدام وحدة التحكم الذكية تعتمد على تقنية أنظمة الاستدلال العصبي الضبابي التكيفية (ANFIS) في مجال السلامة المستخدمة من خلال الاتصال مع كل أجهزة الحماية (PDs) داخل الشبكة. فضلاً عن نهج بديل يستخدم الاتصال عبر وحدات التوزيع في نفس الخط، من أجل تعظيم أداء الأنظمة الكهروضوئية (PVS). يتم التحقق من صحة آليات الحماية بشكل أكبر في هذا العمل باستخدام تجارب الشبكة المتدرجة وعمليات المحاكاة على منصة MATLAB. فضلاً عن ذلك تمت مناقشة تأثيرات تشويه التيار والجهد الناتج عن التوافقيات على شبكة تغذية نظام توزيع الكهرباء في مقارنة خصائص نظام التوزيع مع مستويات مختلفة من اختراق نظام الطاقة الشمسية الكهروضوئية. توضح نتائج المحاكاة أنه يتم حقن مستوى تشتت توافقي كبير مع ارتفاع قدرة اختراق نظام الكهرباء الشمسي، مما يعني أن مجموعة الطاقة الشمسية يجب أن تكون متصلة فقط بالقدرة الاستيعابية المثلى للشبكة. يتم استخدام الخصائص الرئيسية للبيانات الفنية في MATLAB/SIMULINK لتحليل النموذج بأكمله. يتم فحص أداء النموذج في ظل الظروف الجوية المختلفة وظروف الظل الجزئي. وقد تم إثبات الأداء الرائع للنظام المعتمد على وحدة التحكم الذكية من خلال النتائج المرضية. تم إنشاء الشبكة الموسعة لغرض الشبكات الذكية لتعزيز السلوك التجريبي لتدابير الحماية لكل من الدفاعات التقليدية والقائمة على الذكاء الاصطناعي.

الكلمات الدالة: الأداء العالي، وحدة التحكم الذكية، النظام الكهروضوئي، الشبكة الذكية.

1.INTRODUCTION

The world's energy consumption is rapidly increasing due to industrialization and population growth. Between 2018 and 2050, it is predicted that the world's electricity consumption will rise by nearly 50%. Fossil fuels, known to be bad for the natural world, have historically been the most popular source of energy to meet the massive demand for it. [1, 2]. Utilizing petroleum and coal causes a large amount of harmful substances to be released into the surrounding environment as CO_2 emissions and leads to the greenhouse effect, which is bad for human health and contributes to climate change [3]. The primary causes of this issue are a shortage of resources and the harmful environmental impacts of conventional. In the future, there will not be much access to these energy sources [4]. Many academics are drawn to studying renewable energy for the reasons listed above. To reduce atmospheric carbon dioxide ($CO2$) levels and hence slow global warming, it is vital to convert to renewable energy sources [5]. The move to renewable energy has become one of the most significant trends in the 21st century. Photovoltaic, hydroelectricity, geothermal energy, wind, as well as biofuel are examples of rechargeable energy storage systems (RESs) that might offer everyone, wherever they may be, reasonably priced and environmentally friendly power options [6, 7]. 2021 had the largest annual rise in more than 40 years, with RES-generated energy increasing by nearly 8% to 8300 TWh. It was anticipated that by 2020, 30% of power will come from renewable sources as energy output across all RES rose [8, 9]. According to Fig. 1, by the final year of 2021, the capacity of renewable energy plants to produce electricity rose by 257 GW (+9.1%), bringing the total amount of capacity to 3,064 GW. Wind energy gained 93 GW (+13%), and solar energy increased 133 GW (+19%), respectively, to continue to dominate this energy development [10]. Compared to all other potential renewable energy sources, photovoltaic technology is expected to become the largest contributor to power generation by 2040.

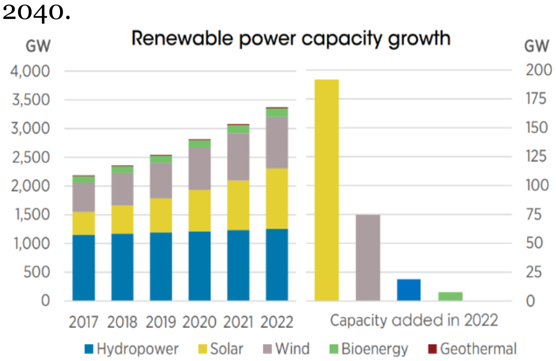


Fig. 1 Growth of Renewable Power Capacity Influence [10].

Solar energy is a key competitor among all renewable energy options available due to its plentiful in the environment. Solar photovoltaic (PV) systems have various benefits, including the possibility of delivering sustainable electricity to remote locations and clean energy [11]. They can be placed in residential or business complexes to satisfy partial or full load demand. If the photovoltaic system produces more energy than is required to fulfill demand, The additional electricity may be sent into the electrical system. The growing demand for PV systems necessitates a rise in R&D activities in various sectors. In response to the concerns expressed by those creating PV systems, utilities, and customers, more effective and affordable PV modules had been designed. The quantity of sunlight generated and the surface temperatures of the array influenced its output

[12]. Combining mechanical solar tracking devices may generate the most electrical energy from the arrays and optimize the quantity of light collected. Under fluctuating atmospheric conditions, to operate the PV array close to its maximum output tracing over a given demand, an MPPT method is utilized besides power electronic interface, stability and dependability, power quality, anti-islanding protection, and photovoltaic arrays for further details [13]. For more information on solar power systems, island defense, stability and reliability, power quality, power technical interface, and MPPT algorithms in general, the main goal of using MPPT for fixed loads is the same as the goal of impedance comparison, and this is done using a DC/DC power electronics converter to match the load impedance to the current and voltage ratio in the array at (MPP) [14]. To maximize the performance of photovoltaic systems (PVS), this study proposes an evaluation of the ideal performance for energy from renewable sources injection into distribution networks using an intelligent controller in safety employed through communication with every Protective Device (PD) within the grid, as well as an alternative approach that employs communication across the PDs in the same line. The inverter is a critical component in solar energy conversion into electrical power [15]. The inverter also includes a direct current (DC)-DC converter to improve average conversion efficiency and extract the maximum power out of the panels [16-19]. The three-phase Voltage Source Inverters (VSI) use They use the voltage at the DC link as a starting point and control the current flowing across the grid in the synchronously revolving frame of recommendation. They use voltage-oriented management (VOC) and a decoupled controller [20]. The fundamental purpose of this research is to use a sophisticated MPPT algorithm to maximize the amount of power produced by a solar photovoltaic (PV) system, performed by continuously evaluating the MPPT method's efficacy and, as a result, its effectiveness, as well as the quality of the injected AC to assure compliance with IEEE standards [21-24]. The essay's remaining sections are organized as follows: The related work is shown in Section 2, the problem statement present is presented in Section 3, the smart grid design is presented in Section 4, the intelligent controller design is presented in Section 5, including the inverter controller design, examples of the simulation's results are provided in Section 6, and the developed conclusions are presented in the last section.

2.RELATED WORK

Solar energy production has become more popular due to its vast availability and low maintenance needs. Power-switch technology allows the solar PV system to run at MPP under different weather conditions [25]. A method of producing electricity powered by the sun's heat, concentrated solar power (CSP) is a limitless supply of clean, free energy. This form of solar technology frequently functions as a big, centralized source of energy for companies [26]; However, it demands lots of bright sunlight. MPPT techniques applied by the solar PV array to manage these power-switching components included P&O, Incremental Conductance (IC), Fuzzy logic controller [27]. The P and O approach selects an alternative location of operation based on the gradient of the (P-V) curve [19]. A DC-DC boost conversion represents a single one of the internal steps detailed in the investigation. It promptly adapts by measuring the quantity of solar output power and the required duty cycles of the drive-switch signal [28-31]. Apart from a redesigned unipolar Sinusoidal Pulse Width Modulation (PWM) inverter, the technique provides a modified SPWM inverter that features an enhanced benchmark wave than the regular SPWM and an inverter containing a Zero Crossing Detector circuit [32]. Compared to an AC power source, such as a three-phase grid, which is indefinitely capable, the DC voltage generated by a PV array is far less valuable. As a result, several attempts at DC for convert AC have already been attempted [33]. There are both double-stage and one-stage conversion processes available [34, 35]. Among all all the currently available strategies, the P & O MPPT technique is probably the most commonly utilized [36]. Incremental conductance method surpasses P&O in terms of speed; however, It continues to be fairly sluggish for grid-connected operations since they require conducting calculations to keep track of its movement towards the maximum power point [37]. (PSO), (fuzzy logic), and (GA) These represent a few of the tools for subsequent-generation techniques. In contrast, stringent methodologies are used for traditional techniques that include linear programming (LP). The investigators suggested that a converter employs a suitable voltage-regulated oscillator (VCO) to give changeable carrier frequencies that are regulated by regard the grid voltage supplied by a completely rectifier pulse [38, 39]. After thorough adjustment, fuzzy logic-based algorithms provide a speedy response; nevertheless, they come with difficulties in execution and require previous data to determine the algorithm's fuzzing settings. A summary of P&O approaches is in [40]. According to this technique, energy is wasted due to the operating point's oscillation about the (maximum power point). Decreasing the fixed perturbation step size can reduce these oscillations and increase the time it takes to attain MPP. To address this issue, a modified P&O MPPT algorithm with a customizable step size is presented. A DC-AC inverter is required since the output of a PV module is DC and must be converted to AC electricity for grid interaction [28]. A better voltage controller for independent PV inverters by employing MultiStart optimization (MS) algorithm-based PI (MS-PI) to adjust the modulation index under varying load conditions is proposed in [34]. According to the research, It is hard to predict which among these dispatching mechanisms will considerably boost the system's effectiveness over another. This study looks at the viability of using a solar power plant connected to the grid to provide an Iraqi home's energy requirements [35]. A modified dispatching approach is developed utilizing MATLAB Link software and predictions regarding potential solar output and load demand. Based on the predicted data, the system is in full, most efficient operation. For the HES, a techno-economic and ecological assessment is performed to compare the created plan with the default techniques of load following (LF) and cycle charging (CC) [36].

3.PROBLEM STATEMENT

A voltage or current waveform distortion is mathematically described by harmonics. An element of a waveform that appears at an integer number over the fundamental frequency is referred to as a harmonic. Additionally, the goal of the electric utility is to distribute sinusoidal voltage across the whole system at a reasonably consistent amplitude. The presence of nonlinear loads that cause harmonic currents on the equipment makes this goal more challenging. These nonlinear components produce voltages on the system at a frequency other than the network frequency or absorb currents at the non-sinusoidal waveform. Because these loads are becoming more prevalent, the flow of harmonic currents on facilities distribution networks has significantly increased. Since 1980, there has been a significant surge in interest in challenges involving nonlinear components and their impact on systems. New power semiconductor devices have been developed, creating new converters that significantly impact the electrical signals' linearity. The increased use of electronic devices altered the sinusoidal character of electrical impulses. As a result, the equipment's increased current waveform distortion and the voltage waveform distortion.

4.SMART GRID DESIGN

Energy systems that incorporate ICT (information and communication technology) are known as smart grids in a smart fashion from sites of generation to consumers, as an inherent component of the SG due to the possibility that they will help maintain the automated equilibrium of production, use, and distribution. Modifying how power is delivered from generators to consumers makes grids more adaptable and reliable and enables the integration of various elements, including RES, scattered microprocessor rooms, and electrical storage units [37]. Figure 2 depicts the SG's many constituents.

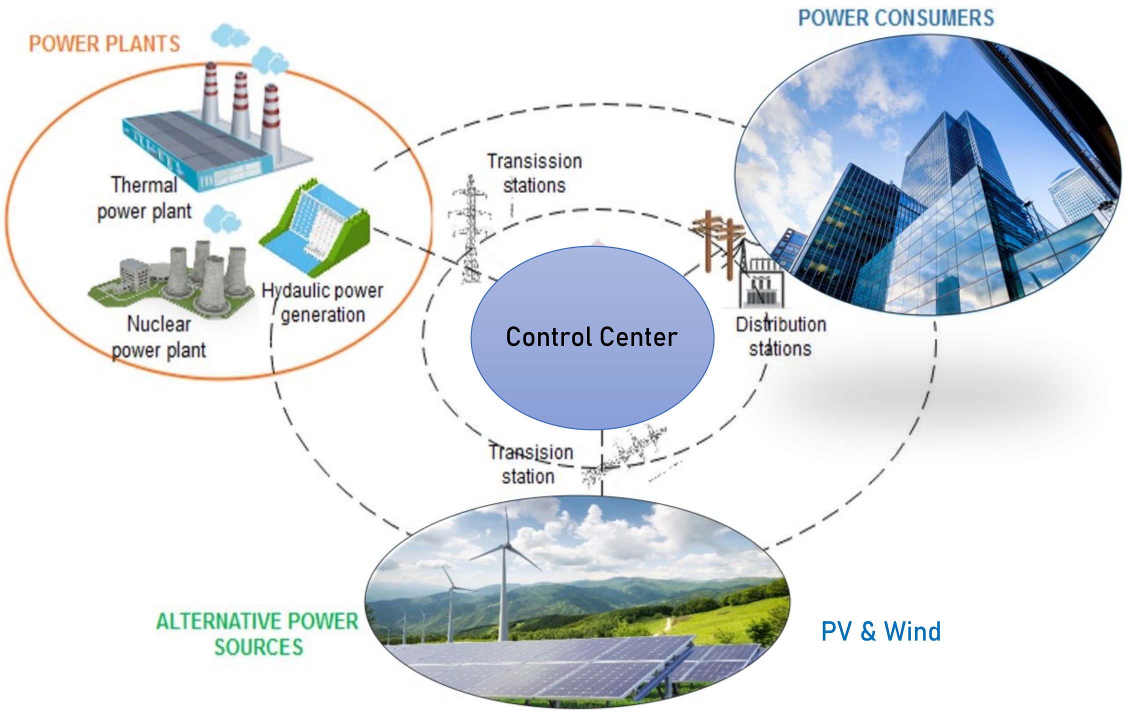


Fig. 2 Depicts the Many Constituents of the SG.

Real-time, two-way interaction is SG the technology's second key benefit allows for speedier restoration of electricity service following an outage. Rotating outages of electricity may have a devastating domino effect on banking, interactions, manufacturing, transportation, and security [38]. Green energy construction has increased substantially in the last decade, and the power levels of grid-connected converters are approaching MW [39-41]. Usually, they are made to serve as active power injection devices for AC grids [42]. Bi-directional grid-connected converters having a power factor (PF) ranging from 0.9 offer power injection capabilities for applications involving the smart grid 0.9 lagging, as well as rectification, are produced, which may be utilized for charging a battery bank for storage of electricity and delivering reactive power to AC grids. On the other hand, the bi-directional conversions allow the battery bank to drain to adjust the AC grid. As a result, a DC grid may be controlled to a certain voltage level that can power DC machinery and utilities [43, 44]. Figure 3 illustrates this form of system arrangement, whereby the power flow across the AC and DC grids is managed by an energy management system (EMS). Figure 3 shows the primary schematic of a grid-connected PV system. A PV panel, a DC-DC converter, and a grid is an element of a power-connected PV installation. In the suggested arrangement, a boost converter was used for DC-DC conversion, and an integrated MPPT controller was used to extract the greatest power from each PV unit.

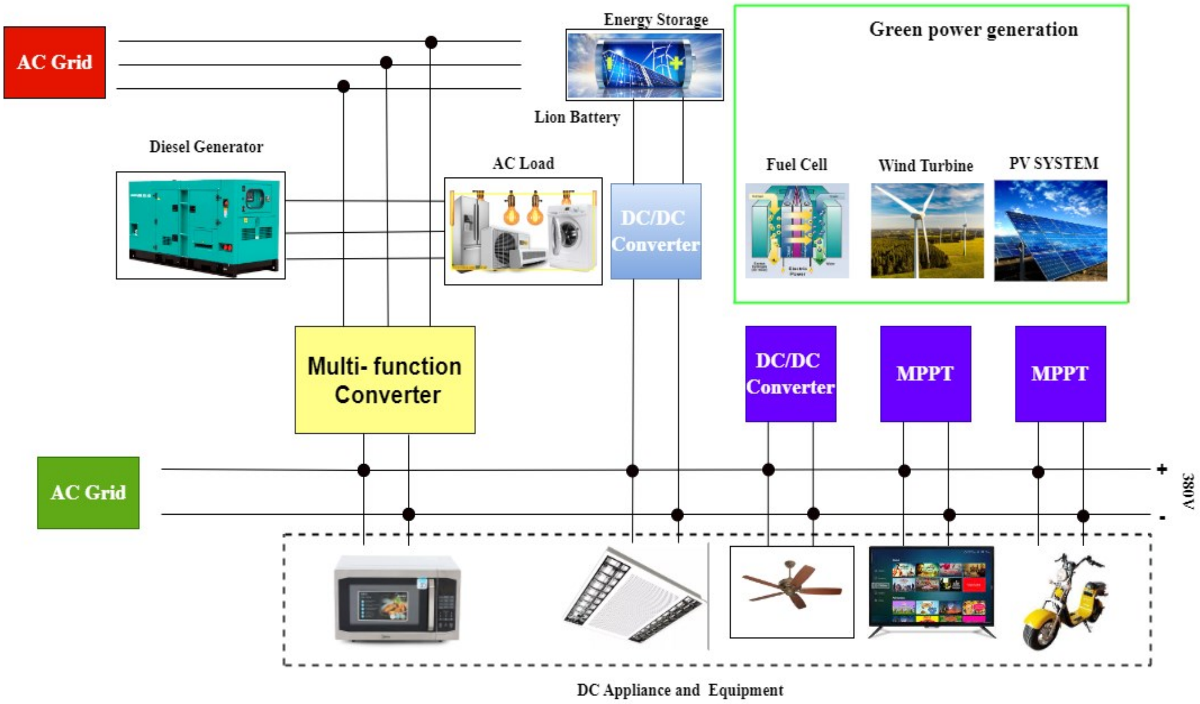


Fig. 3 Implementation of a Smart-Grid Green Energy System.

On the AC grid sides, there may also be diesel-powered generators and AC demands. Consequently, the converters can balance the diesel engine's power [45] and conduct active power filtering (APF) for the loads. By acting as uninterruptible power systems (UPS), the converters can provide both DC and AC loads in the case of a grid breakdown [46].

5.INTELLIGENT CONTROLLER DESIGN

Various techniques have been used to handle the MG uncertainties. Fuzzy-based techniques and scenario-based robust optimization approaches [47] have recently been developed. To address the idea of incomplete truth, FL was introduced. Unlike ES's use of Boolean logic, FL bases its computations on values ranging from 0 to 1. FL developed from fuzzy set theory, assigning a degree of membership, often a number between 0 and 1. By grading the truth of a statement, the FL, for instance, can utilize 0 to represent wholly false, 1 to represent totally truthful, and the values between 0 and 1 to indicate either partial truth or partial falsehood. It is frequently taken in a broad meaning that incorporates various degrees of formality. For the island MG, Rezaei et al. [48] provided a robust energy management strategy to address frequency variance brought on by RES generation and load shifting. The information lacked decision theory (ILDT), used to control the MGs uncertainty, was combined with the MILP methodology. To represent uncertainty in an EMS, the researchers also suggested a wide range of additional types of methods, incorporating scenario-based, resilient, fuzzy, linearization, i.e., unstructured modification, probabilistic, and Monte Carlo approaches as well as Gaussian mixture models, estimate distributions, and stochastic inventories theory [49]. Various temperatures, levels of irradiance, and grid configurations are used to represent the system's general structure. The findings were examined and analyzed in light of several possibilities. Figure 4 shows the complete mechanism. The fundamental concept relates to the photovoltaic panel comprises single lines. The MPPT control employed the Perturb and Observe (P&O) technique to determine the electrical power converter's output frequencies. To optimize the quantity of power generated by PV array, this controller continuously modified the duty cycle of the Boost converter. To create the needed currents, voltages, and power, the IGBTs inside the converter need gated impulses from the (VSI) controllers. IGBTs inside inverter require the appropriate gate impulses from the VSI Controller. Figure 4 shows the smart grid-connected PV inverter's control diagram.

6.SIMULATION RESULTS

The smart grid system based on an intelligent controller was implemented to maximize the photovoltaic systems (PVS) performance. The present study recommends evaluating the ideal performance for energy from renewable sources injection into distribution networks using an intelligent controller in safety employed through communication with every Protective Device (PD) within the grid, as well as an alternative approach that employs communication across the PDs in the same line. Figure 5 (A) shows the PV system evaluation simulation according to temperature effects with differences measured in PV Voltage, DC-DC Boost, and Irradiance. However, Figure 5. (B) shows the excess PV power with a max value of 2.194×104 and a min of 8.57×102. The peak-to-peak value was 2.108×104, and the RMS value was 1.403×104. While preserving STC-compliant temperatures and irradiance levels, the PV system's modeling was conducted with a linear load. Figure 6 shows the simulation's results, leading to the following Findings: The voltage and current waveforms are generally symmetrical, with soft edges. With maintaining STC circumstances for temperature and irradiance, a simulation is run with a nonlinear energy demand over the whole solar system. Figure 6 (A, B, C) reveals the following: The current was not proportional to the voltage; instead, it changed according to the impedance of the alternating line. It draws strength in abrupt, fleeting bursts. Due to the current waveform distortion these pulses generate, the distribution system's load and its internal equipment may be affected by harmonics.

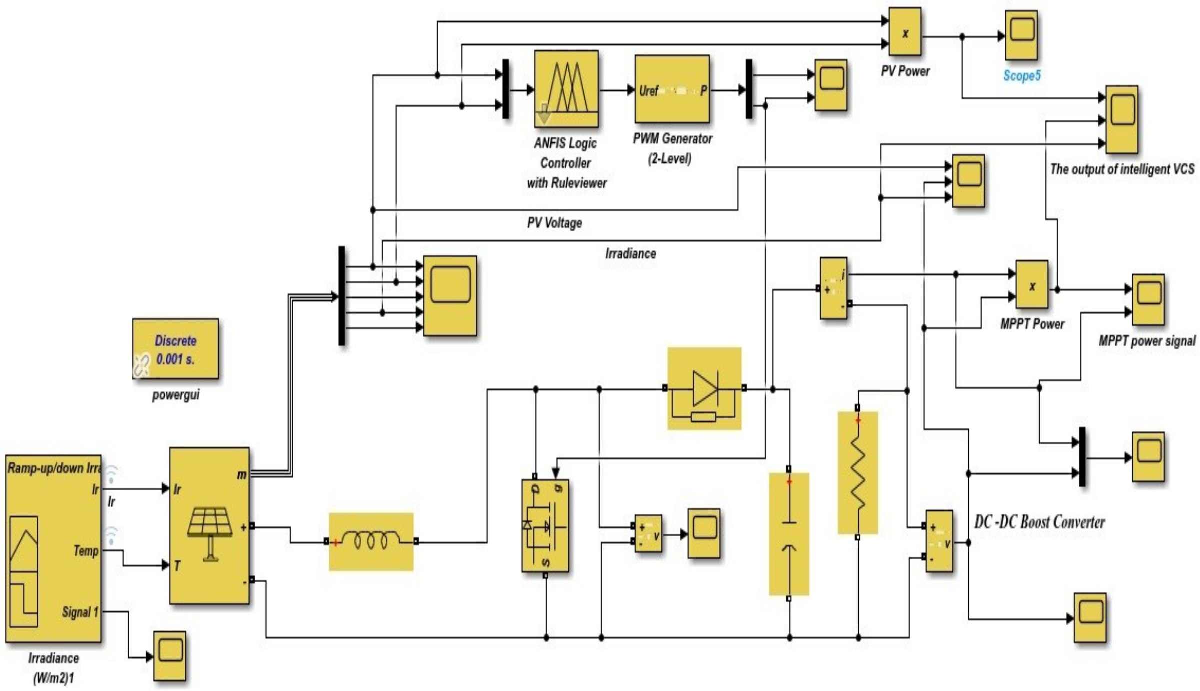
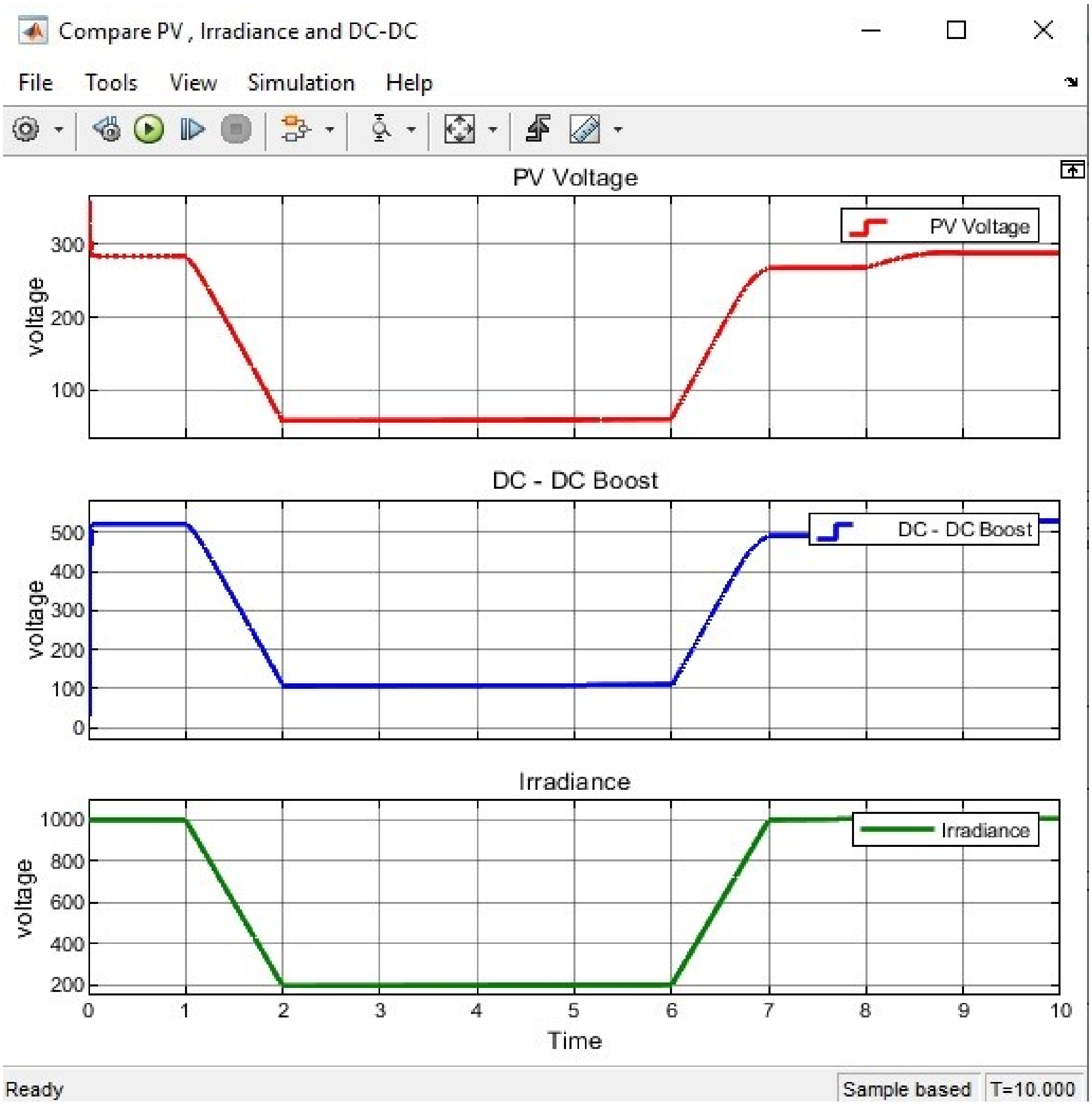
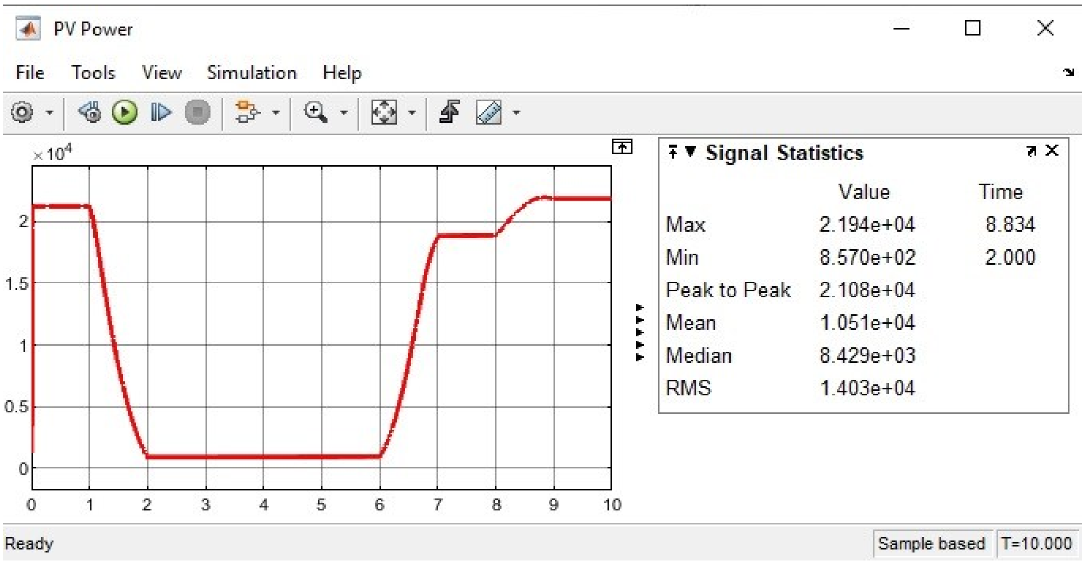


Fig. 4 The Control Diagram of a Smart Grid-Connected PV Inverter.

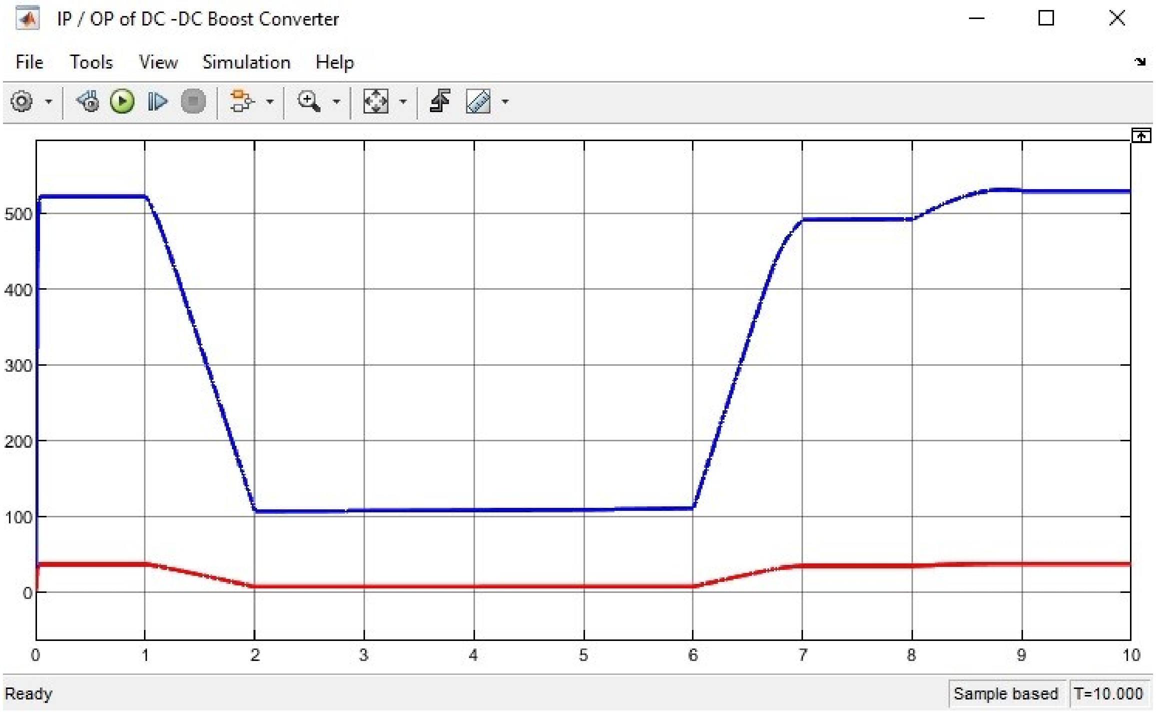


(A)



(B)

Fig. 5 PV System Evaluation Simulation According to Temperature Effects.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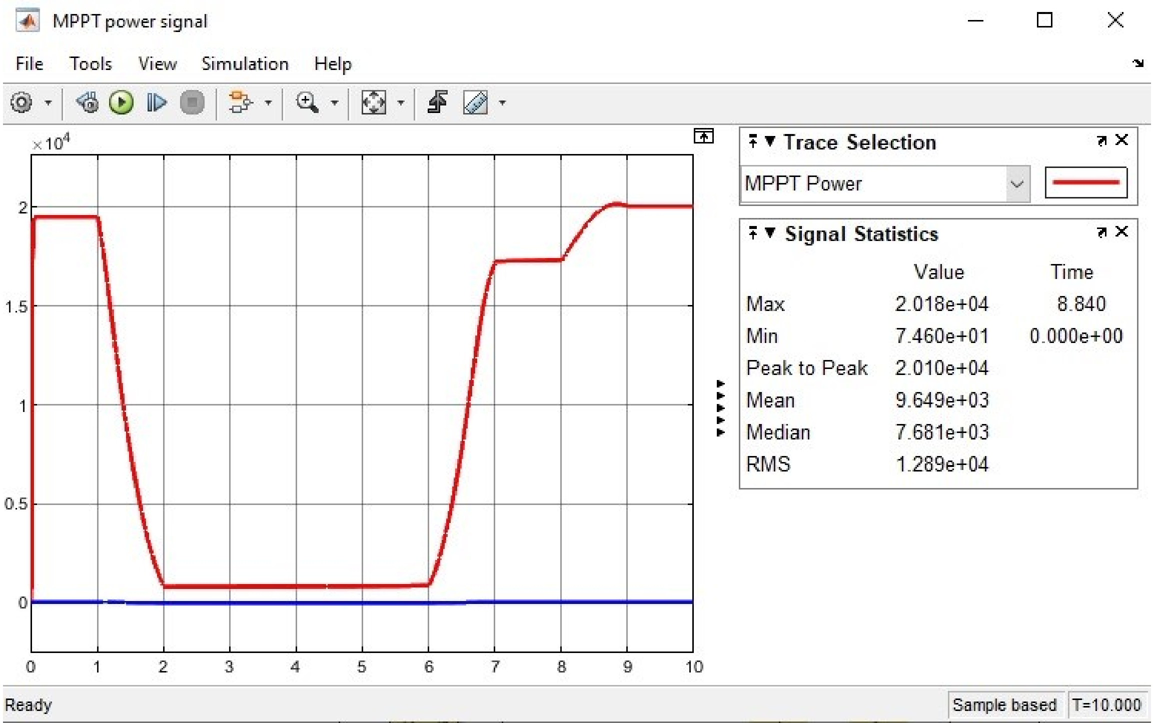
(A)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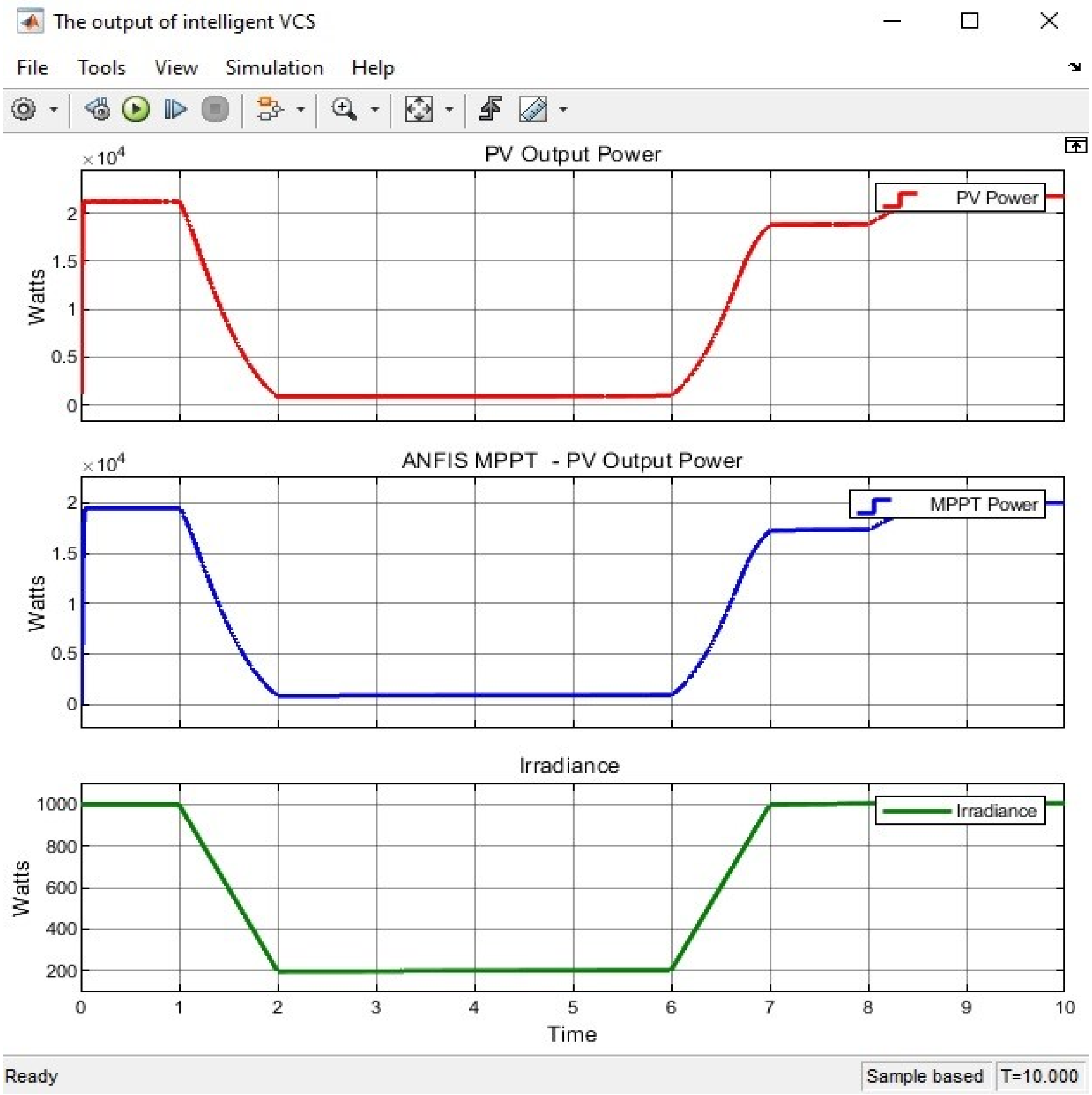
(B)



(C)

Fig. 6 Simulation of the Whole Proposed System Architecture.

7.CONCLUSION

The full Grid-Connected Photovoltaic (PV) system was thoroughly modeled in the present work and implemented using the MATLAB/Simulink platform. The designs were easy, highly precisely and accurately simulated an actual grid-connected photovoltaic system. In order to align the current of the three phases electric power transformer with the grid, the model employed a voltage-oriented control architecture with a decoupled controller and a central controller that operated on top of a direct injection of reactive and active power to the grid. In the present work, the issue of an assault on a smart distribution grid's physical layer was discussed. The three key findings found are as follows: The worst attack position in either a line grid was at the node with the greatest electrical connection to the substation. The maximum-case finite-time attack indication was provided by a step function that reversed its sign at the final time of the attack. Furthermore, detecting the worst-case attack was quite challenging if all known about the grid was its voltage levels. As a result, it can be concluded that grid construction and grid reconfiguration algorithms must be considered to lessen the impact of power injection assaults. More study is required to add attack tolerance against energy injection operations into grid reconfiguration algorithms. The modeling results demonstrated that the system effectively worked under various radiation and temperature circumstances. Additionally, the results illustrated how nonlinear and linear loads affect a photovoltaic system.

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NOMENCLATURE

PD	Protective Device
PVS	Photovoltaic Systems
RESS	Rechargeable energy storage system
MPPT	Maximum Power Point Tracking
IC	Incremental Conductance
CSP	Concentrated Solar Power
FLC	Fuzzy Logic Controller
VCO	Voltage-Regulated Oscillator
LF	Load Following
CC	Cycle Charging
PF	Power Factor
APF	Active Power Filtering
UPS	Uninterruptible Power Systems
EMS	Energy Management System
ILDT	Information Lack Decision Theory
I	Current, A

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