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Design and Control for a Grid-Connected PV Generation System to Reduce Distortion

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ABSTRACT

This paper investigates the operation and optimization of photovoltaic (PV) power plants, focusing on the implementation of Proportional-Integral-Derivative (PID) controller to minimize waveform distortion and achieve a pure sinusoidal output. PV power plants consist of crucial components such as photovoltaic cells that convert solar radiation into direct current (DC) electricity, inverters that transform DC into alternating current (AC) for grid use, mounting systems for optimal panel orientation, charge controllers to manage power flow, battery storage systems for energy conservation, transformers for voltage regulation, and protective devices to ensure system safety. Despite these sophisticated components, fluctuations in solar radiation and grid disturbances can lead to harmonic distortion, affecting power quality. This study explores how PID controller can be employed to stabilize the output voltage, thereby reducing harmonic distortion and enhancing waveform quality. By continuously monitoring system parameters and adjusting control settings, the PID controller ensures the maintenance of a clean sinusoidal waveform, improving both the performance and reliability of PV power plants.

KEYWORDS: *DC; Distortion; MPPT; PV; PID.*

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INTRODUCTION

Alternative energy sources are being investigated for energy generation as a result of the growing energy demand brought on by population growth, industrial expansion, and technological advancement. Most research on renewable energy technologies is primarily motivated by environmental problems such as greenhouse gas emissions, global warming, and the gradual depletion of finite natural resources including coal, natural gas, and fossil fuels[1]. Renewable energy has been defined as the power harnessed from resources that are replenished by nature, such as wind, solar radiation, precipitation, geothermal heat, and ocean tides[1]. Photovoltaic generation of electricity plays a very important role in the global movement towards renewable sources of energy. These systems use photovoltaic cells to directly convert sunlight into electrical power. The PV system generates electricity without any emission of greenhouse gases or other harmful pollutants, hence environmental-friendly and sustainable. Besides all the ecological benefits, PV power plants have a number of advantages[2]. Inherently decentralized and modular, their applications range from a small residential installation to utility-scale power plants. Additionally, PV systems can be quickly deployed and scaled up as needed, making them highly adaptable to changing energy demands. Despite these advantages, PV power plants face challenges such as intermittent due to variations in sunlight intensity, limited efficiency of photovoltaic cells, and initial investment costs. Overcoming these challenges requires ongoing research and innovation in areas such as materials science, system design, and energy storage technologies. In this context, this paper aims to contribute to the understanding and improvement of PV power plant systems[3,4]. By exploring topics such as system modeling, design optimization, and control strategies, this paper seeks to enhance the efficiency, reliability, and sustainability of PV power generation, furthering the transition towards a cleaner and more resilient energy future[5]. In the quest for efficient and stable operation of PV power plants, the utilization of advanced control strategies has become imperative. Among these strategies, the PID controller stands out as a widely used and versatile option for regulating various aspects of the plant's operation. In this context, the integration of MATLAB Simulink models plays a crucial role in simulating and analyzing the behavior of PV power plant processes under different operating conditions[5,6]. Combining PID control with other advanced control methods, such as Fractional Order PID (FOPID) or Adaptive FOPID (A-FOPID), can improve robustness and reference tracking accuracy in PV system. Long Short-Term Memory (LSTM) networks can be used to compensate for time delays in PV systems. This approach can significantly improve the frequency performance of PV ancillary services. MIMO PID controllers can be designed to handle multiple inputs and outputs simultaneously, making them more suitable for complex PV systems. Also, by implementing Self-Adaptive Virtual Synchronous Generator (SDVSG) Control or Advanced Optimization Techniques, the limitations of traditional PID controllers in complex PV power plants can be overcome, leading to improved system performance, stability, and efficiency. To address the critical issue of energy storage in overcoming the intermittency of solar power[7]:

1. Implementing battery storage solutions, such as lithium-ion batteries, can capture excess solar energy during peak production times for use during low or no sunlight periods. This helps maintain a consistent energy supply and prevents sudden power shortages.
2. Solar energy storage systems play a pivotal role in load balancing by storing excess energy and making it available for later use. This reduces the burden on the grid and helps avoid voltage fluctuations or blackouts.
3. Increased Self-Consumption: Energy storage allows homeowners and businesses to maximize their use of solar-generated electricity, reducing reliance on the grid and potentially lowering electricity costs.
4. During power outages, stored solar energy can provide backup power, enhancing energy security and reducing dependence on external power sources.

The primary objective of employing PID controller in PV power plant systems is to minimize distortion and ensure the stability of the system while converting the generated current. By continuously monitoring and adjusting control parameters, this controller aims to mitigate fluctuations in solar irradiance, grid disturbances, and other external factors that may affect the quality of electricity output. Additionally, they play a crucial role in optimizing energy conversion efficiency, maximizing power output, and ensuring the reliability of the entire PV power plant infrastructure [8,9].

PHOTOVOLTAIC SYSTEM

As seen in Figure 1, PV power plants are made up of a number of essential parts that work together to efficiently generate electricity. At the center of the system are photovoltaic cells, which are usually composed of semiconductor materials like silicon and absorb sunlight to produce an electric current through the photovoltaic effect. To optimize exposure to sunlight, these cells are grouped into modules and panels, which are frequently installed on buildings like rooftops or ground-mounted arrays. In order to be compatible with the electrical grid and the majority of household appliances, the direct current (DC) electricity produced by the solar cells must be changed into alternating current (AC). Inverters, which also control the electricity's voltage and frequency to meet grid standards, are used to accomplish this conversion. To guaraee optimum performance and safety, PV power plants have other crucial pntarts in addition to solar modules and inverters8. These could be mounting structures to hold the solar panels in place, tracking systems to align the panels for optimal exposure to sunlight, monitoring and control systems to regulate power output and identify issues, and energy storage devices like batteries to store extra electricity for use when demand is high or sunlight is scarce. Figure 2 illustrates the varieties of solar cell systems.

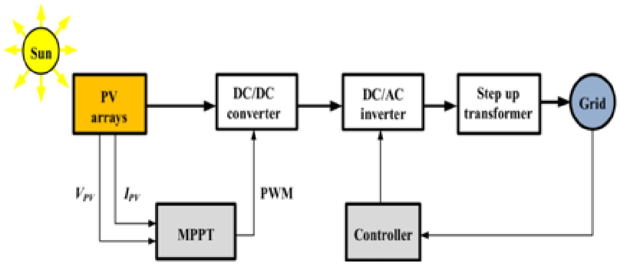


Figure 1. Schematic diagram of solar power generation system

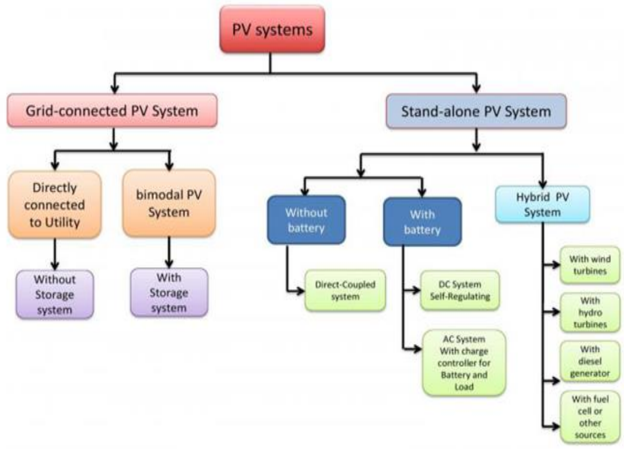


Figure 2. Photovoltaic system types

Inverters, which also control the electricity's voltage and frequency to meet grid standards, are used to accomplish this conversion. To guaraee optimum performance and safety, PV power plants have other crucial pElectric drives and industrial automation applications frequently use inverters, which are devices that can convert direct current into alternating current. Even while the fundamental function of all inverter types is the same (DC to AC conversion), as shown in Figure 3, their architecture and design vary depending on the particular application[9]. Most of the inverters have basic protection features such as anti-islanding protection and ground fault circuit interruption, and all of them have conversion efficiency of 90% or better. Most of the systems featuring these ensure that the PV system turns itself off during a power outage for safety reasons [10]. In addition to carrying out this conversion, the inverters also control the voltage and frequency of the electricity to meet grid standards. Besides, PV power plants have several other protection functions that are very important for optimal performance and safety. PWM regulates how the power electronic components of a three-phase inverter switch in order to produce a three-phase AC output from a DC input. PWM's primary goals in inverters are to control the output voltage, reduce switching losses, minimize harmonic content in the output waveform, and increase efficiency[11,12].

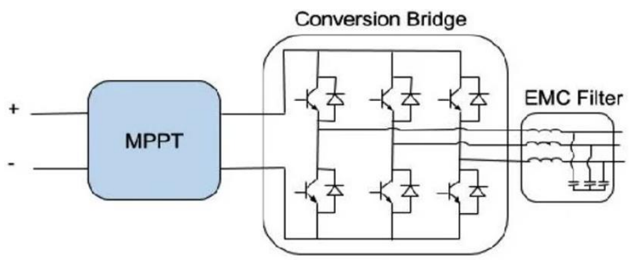


Figure 3. inverter

The implementation of PWM in three-phase inverters involves several key components working together to convert DC power into a stable, three-phase AC output. The DC input source provides the necessary DC power to the inverter. The power switches, typically six IGBTs or MOSFETs, are arranged in a three-phase bridge configuration to handle the switching required for the conversion process. A PWM controller is employed to generate the PWM signals based on the chosen PWM technique, such as Sinusoidal PWM (SPWM) or Space Vector PWM (SVPWM)[9]. The PWM controller generates PWM signals by comparing sinusoidal reference signals with a triangular carrier signal. These PWM signals are then amplified by gate drivers to drive the power switches. The power switches turn on and off according to the PWM signals, creating a modulated output that approximates a sine wave. Filters are used to smooth the PWM output, producing clean three-phase AC[3]. Inverters, which also control the electricity's voltage and frequency to meet grid standards, are used to accomplish this conversion. The maximum power point tracking (MPPT) converter is the first crucial component of the inverter to be observed, following the input side. MPPT converters are DC/DC converters designed to optimize the PV generator's single power output. It should be noted that this particular device maintains the direct current mode while converting the electrical parameters' characteristics at the input into the required ones (usually increasing or decreasing the input voltage). In actuality, the site's climate primarily its temperature and irradiance have a significant impact on the PV module's output [5,8]. An I-V curve, such as that shown in Figure 4, representing the relationship between current and voltage across the solar cells of any PV module or string may be used to characterize it for maximum power point conditions (I_{mp}, V_{mp}).

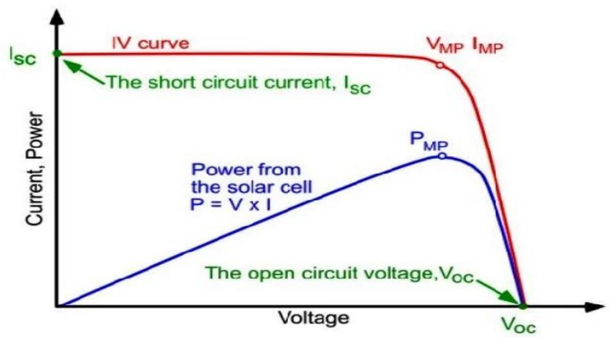


Figure 4. I-V curve

This curve typically appears on the datasheet of the PV module. The data is determined under STC: that is, irradiance of 1000 W/m², temperature of 25°C, and an air mass of 1.5. When the actual temperature and irradiance deviate from the STC values, the voltage and current also change, leading to I-V curves that differ from those obtained under STC. The PV modules generate only DC electricity; hence, all the grid-connected PV generation systems are interfaced with the electrical grid through an appropriate inverter. Figure 5 shows the configuration of a grid-connected PV system. Here, the PV array is connected to the DC bus through a DC/DC boost converter, which in turn is connected to the AC grid through a DC/AC inverter. It plays a very important role in the operation of the system: one boost converter for maintaining the operation of the PV system at the maximum power point, and another grid inverter that controls both the active and reactive power to operate stably at the AC bus[13,14].

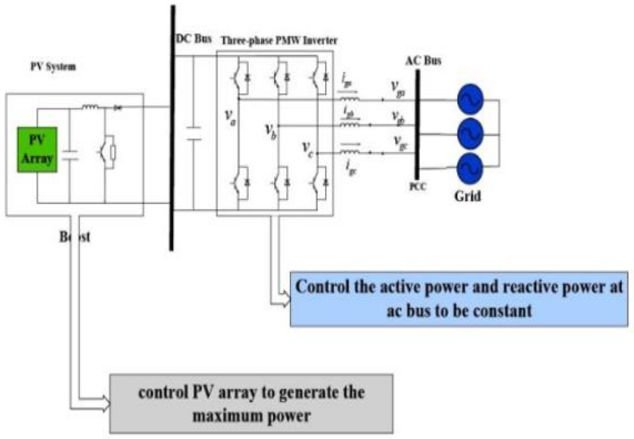


Figure 5. Configuration of the grid-connected PV generation system

The system will suggest a PV generation system of 20 solar modules connected in series and 200 strings in parallel, as shown in Figure 5. Since all the PV arrays produce direct current power, it is necessary to make use of power electronics to convert it into alternating current for grid integration. The PV array should operate at the maximum power output for the efficiency of the system. It is achieved through a Maximum Power Point Tracking algorithm. This ensures that the system draws the maximum available power from the solar panels, even when sunlight conditions change. In the case of a two-stage PV configuration, MPPT—using the Perturbation and Observation algorithm—controls the DC/DC boost converter. Meanwhile, the primary task of the DC/AC inverter will be to feed the current into the utility grid, keeping the DC bus voltage stable at 400 V. In general, the power management strategy includes the regulation of active and reactive power to provide appropriate energy flow control in the grid. To enhance performance across diverse climates, several techniques can be utilized, including temperature-sensitive coatings, automated adjustments to panel tilt, and hybrid systems that integrate solar with other renewable energy sources. Ensuring proper installation, optimal tilt, and correct orientation of solar panels, along with consistent maintenance and cleaning, is crucial for maximizing energy production under varying climatic conditions[11,12].

CONTROL SYSTEM DESIGN

The principle of the PID controller is described as the feedback control system for maintaining output through the manipulation of control inputs using the error-the difference between desired setpoint and measured variable-as illustrated in Figure 6. A basic PID controller contains three components :

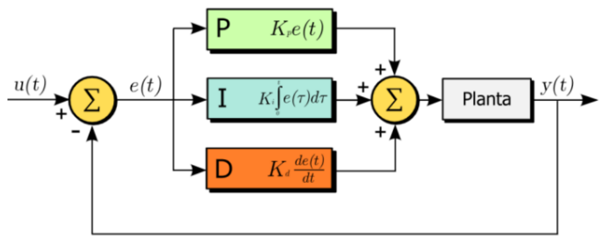
Proportionate (P): An output proportionate to the current error value is produced by the proportional term. It aids in lowering the error magnitude and rising time.

Integral (I): The accumulation of previous mistakes is the focus of the integral word. By modifying the control input to bring the error sum to zero, it removes steady-state error.

Derivative (D): The derivative term uses its rate of change to forecast future mistake. It enhances system stability and lessens overshoot.

PID controller can be used to control the PWM (Pulse Width Modulation) signals in a three-phase inverter. This approach is commonly used to improve the performance and accuracy of the inverter's output, particularly in applications requiring precise control, such as motor drives and renewable energy systems[15-18].

Figure 6. block diagram of PID controller



PID controllers play a crucial role in enhancing the performance and reliability of PV systems. By effectively regulating the operating conditions, they ensure maximum power output and stable operation under diverse environmental conditions.

Implementation Steps [19-21]

1. Measurement: Measure the actual output parameter (voltage, current) using appropriate sensors.
2. Error Calculation: Calculate the error as the difference between the desired setpoint and the measured value.
3. PID Computation: Use the PID algorithm to compute the correction needed based on the error.
4. PWM Adjustment: Adjust the duty cycle of the PWM signals based on the PID output to correct the error. The Benefits of Using PID Control for PWM: -

- Improved Stability: Reduces oscillations and provides smoother control.
- Reduced Steady-State Error: Integral action eliminates long-term deviations from the setpoint.

- Faster Response: Derivative action improves the speed of response to changes.
- Versatility: Can be tuned for various applications, from voltage regulation to motor speed control.

A PID controller can be employed to adjust the operating voltage and current precisely, aiming to optimize power output. The Perturb and Observe (P&O) method, illustrated in Figure 7, is an iterative approach widely used for achieving the Maximum Power Point (MPP) and is a popular MPPT algorithm. The algorithm begins by measuring the initial operating voltage, $V_{pv}(t_1)$, and current, $I_{pv}(t_1)$. Subsequently, a second measurement of the operating voltage, $V_{pv}(t_2)$, and current, $I_{pv}(t_2)$, is taken. Using these voltage and current measurements, ΔP_{pv} is computed[22,23]. If ΔP_{pv} is positive, the operating voltage should be adjusted in the same direction as the perturbation. Conversely, if ΔP_{pv} is negative, it indicates that the system's operating point has shifted away from the MPP, and the operating voltage should be adjusted in the opposite direction of the perturbation, as outlined in Table 1. The operating voltage is perturbed by a constant value, C. A perturbation step value of 0.1 V for C is often deemed suitable for the iteration process[24-26].

Implement adaptive algorithms that use variable step sizes proportional to the distance from the maximum power point (MPP). This allows for faster tracking when far from the MPP and finer adjustments when close. Combine traditional methods with artificial intelligence or machine learning techniques to improve tracking speed and accuracy under dynamic conditions.

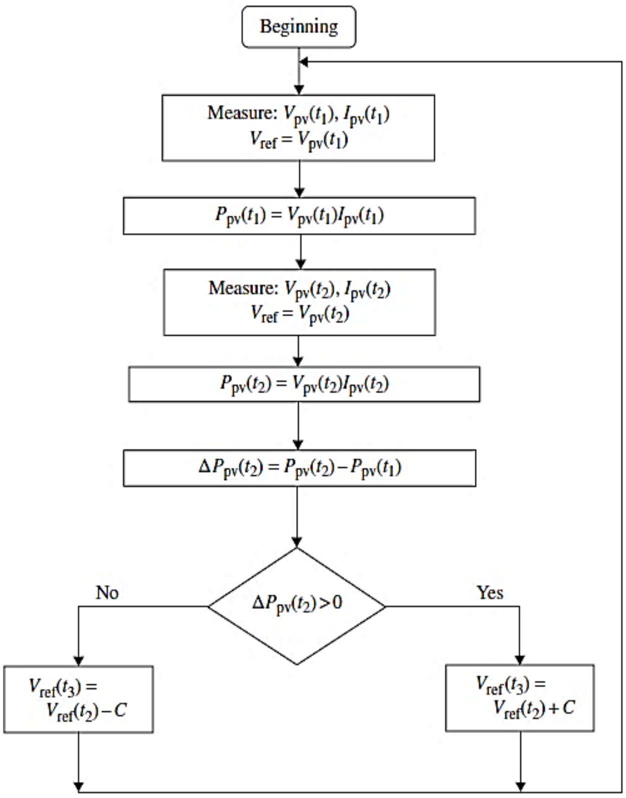


Figure 7. P&O-based MPPT method.

Table 1 Control Actions for Various Operating Points in the P&O Method

Case	**ΔV**	**ΔP**	**$\frac{\Delta P}{\Delta V}$**	**Tracking direction**	**Voltage control action**
1	+	+	+	Good direction	Increase V by ΔV
2	-	-	+	Bad direction	Increase V byΔV
3	-	+	-	Good direction	Decrease V by ΔV
4	+	-	-	Bad direction	Decrease V byΔV

SIMULATION RESULT AND DISCUSSION

Maximum power point tracking (MPPT)

This section shows the simulation of DC-DC (boost converter) by using MATLAB Simulink[27-35] as given in Figure 8, and the parameters used in this simulation are shown in table 2. Figure 9 shows how the I-V changes according to temperature[27-30] and irradiance (1000 w/m2) values. Obviously, the maximum power point will also change, so the MPPT algorithm always looks for this point in order to maximize the power output. Figure 10 and table 3 show simulation results and values of the solar cell with irradiation of 1000 W/m2 and temperature of 25°C.

Table 4 and figure 11 demonstrate how the boost converter efficiently increases the input voltage to the desired output voltage level, ensuring that the PV system can deliver maximum power to the load. The performance of the boost converter is critical in maintaining the efficiency and stability of the PV system [31-33].

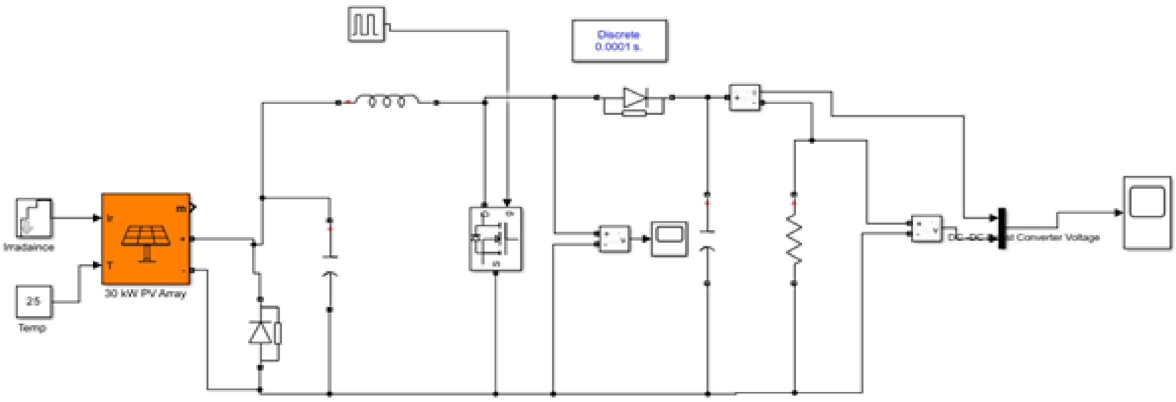


Figure 8. Block diagram of DC – DC (boost converter)

Table 2 The parameters of PV array and boost converter

Parameters of PV array		Input parameters for boost converter	
Parameters	**Value**	**Parameters**	**Value**
Maximum power (w)	213.1	Light - generated current I_L (A)	7.86
Parallel strings	15		
Series-connected modules per string	10	Diode saturation current I_O (A)	2.92e-10
Cells per module (Ncell)	60		
Open circuit voltage V_{oc} (V)	36.3	Diode ideality factor	0.981
Short-circuit current I_{SC} (A)	7.84		
Voltage at maximum power point VMP(v)	29	Shunt resistance R_{sh} (ohms)	313.05
Current at maximum power point IMP (A)	7.35		
Temperature coefficient of VOC (%/deg.C)	-0.360	Series resistance R_s (ohms)	393.81
Temperature coefficient of I_{SC} (%/deg.C)	0.102		

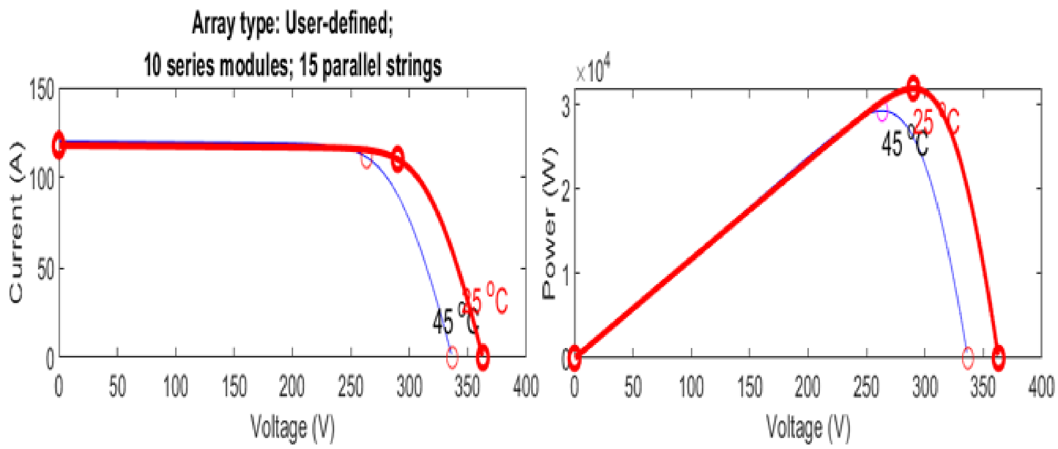


Figure 9. I-V and P-V curve of a PV module

Table 3. output of solar cell

Parameters	Value
PV Power array	30 KW
V_{PV}	340.6 V
I_{PV}	-45.26 A
Irradiance	1000 W/m^2
Temperature	25 deg.c

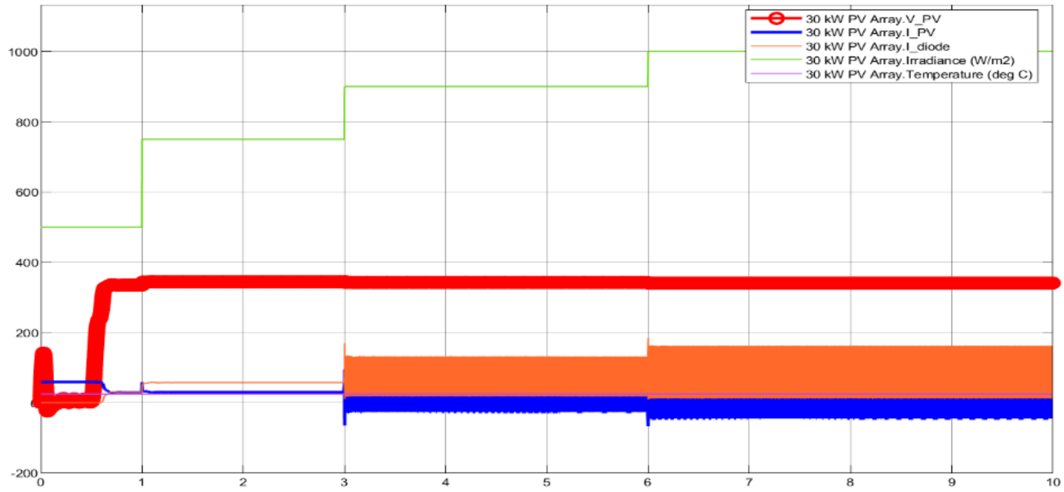


Figure 10. Output simulation of solar cell array

Table 4 shows the output results of boost converter

Parameter	V_{out}	I_{out}	P_{out}
value	325.1 V	29.56 A	9607 w

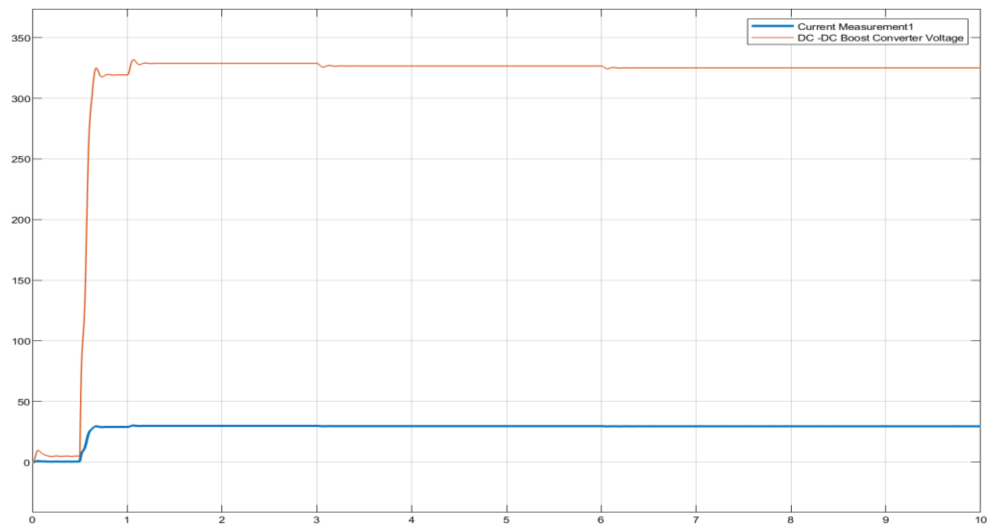


Figure 11. Output of the Boost Converter

Simulation results of PV power system without PID controller

A complete Matlab/Simulink simulation[34-38] of the grid-connected PV system, incorporating the MPPT algorithm and active and reactive power control of the grid-side inverter without the PID controller, has been performed.

Table 5, present the fundamental parameters of the solar cell, as well as the input and output values after the converter and MPPT. These values include the maximum power, voltage, and current at the maximum power point (MPP), as well as the open circuit voltage (Voc), short circuit current (Isc), irradiance, and temperature. The results of the simulation give the electrical performance of the PV generator when an irradiation level of 1000 W/m² and a temperature of 25°C, applying MPPT control voltage versus current characteristics. There is just one unique point where maximum output power is provided under specified atmospheric conditions. Figure 14 illustrates the simulation of active power and reactive power control inside the PV system. By observing the error values of P and Q, the performance and stability of the system can be analyzed in different operating scenarios [39-41].

Table 5. The parameters of solar cell panel

Parameters of PV array		Input parameters for boost converter	
Parameters	Value	Parameters	Value
Maximum power (w)	250.2	Light - generated current I_L (A)	8.706
Cells per module (Ncell)	60		
Open circuit voltage Voc (V)	37.3	Diode saturation current I_O (A)	$4.157e^{-10}$
Short-circuit current Isc (A)	8.66		
Voltage at maximum power point V_{MP}(v)	30.7	Diode ideality factor	1.01
Current at maximum power point I_{MP} (A)	8.15		
Temperature coefficient of Voc (%/deg.C)	-0.369	Shunt resistance R_{sh} (ohms)	240.60
Temperature coefficient of Isc (%/deg.C)	0.0869		
Irradiances W/m²	[1000 500 250]	Series resistance R_s (ohms)	0.2373
Temperature(deg.C)	25		

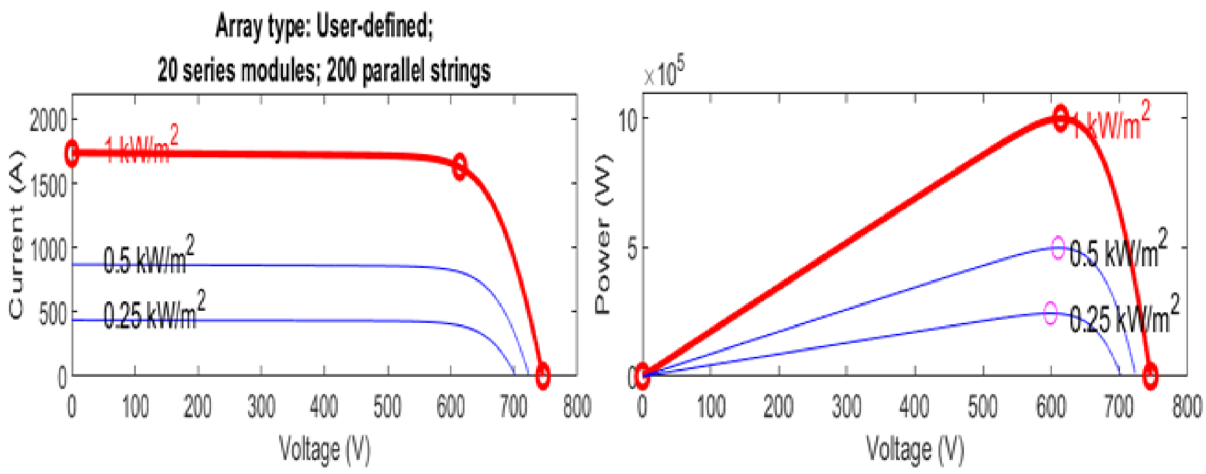


Figure 12. I-V and P-V curve of a PV module with constant temperature

Figure 12 presents the family of characteristics curves of the PV array at different levels of solar irradiation while keeping the temperature constant at 25°C. Similarly, the characteristic curves in Figure 13 are for various cell temperatures whereby the solar irradiation is fixed at 1000 W/m². Figure 12 also shows that a PV array shows nonlinear

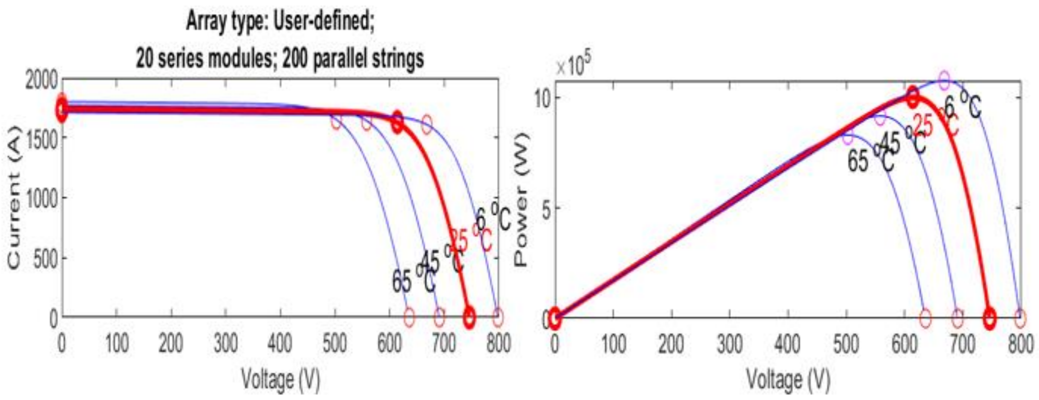


Figure 13. I-V and P-V curve of a PV module with irradiation solar constant

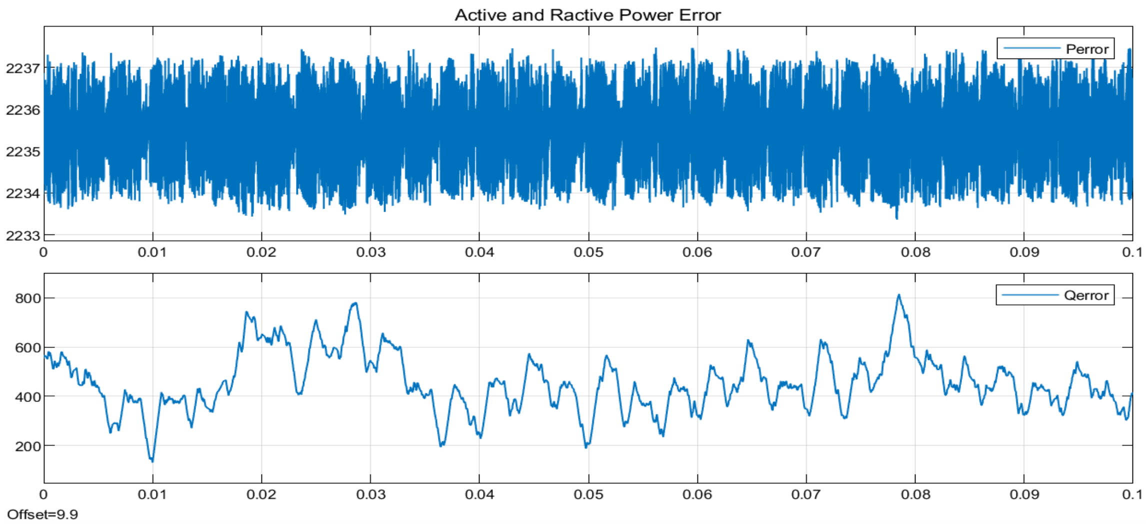


Figure 14. the error of active power (P) and reactive power (Q) over the simulation period

This configuration significantly impacts the performance of the photovoltaic system. Series connection increases the total voltage of the system, allowing it to achieve higher levels of power output. The results obtained, including the voltage and current generated by the station, are illustrated in table 6. The simulation results for the station are illustrated in Figures 15 and 16. In Figure 15 the results before 0.02, where the power has not yet reached its peak. Subsequently, we notice a stabilization in the wave, and after some time, once a stable wave is achieved, we observe that the wave has a slight break and that there is noise and energy loss. This is what we aim to improve after adding the controller in the second part

Table 6. Output voltage and current of PV cell

Parameter	V_{PV}	I_{PV}
Value	739.6 V	-8564 A

SIMULATION OF PV SYSTEM WITH PID CONTROLLER

Figure 17 shows the full Matlab/Simulink simulation [42-45] of the grid-connected PV system, including MPPT algorithm and active and reactive power control for the grid-side inverter. The first simulation was done without any controller, and it was possible to observe some energy losses in the system. The controller was thereby implemented into the solar station model in order to address the problem, as illustrated in updated simulation results below, in Figures 18 and 19. Immediately after reaching the MPP at approximately 0.02 seconds, the waveform began to stabilize and became much noisier to indicate appropriate action of the control strategy at work Total Harmonic Distortion (THD) analysis illustrates the differences in system performance with and without the PID controller as presented in table 7. The results with the PID controller show an improvement in the system, as the THD was less whereas it was greater than 1% without it.

Figure 15. Responses of the output before 0.02s

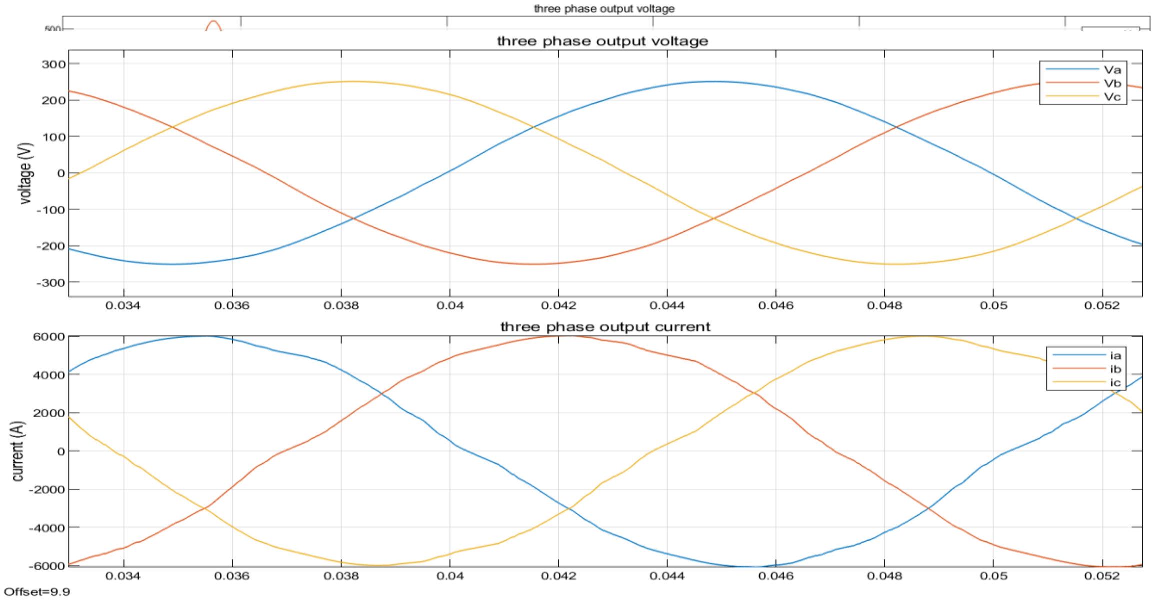


Figure 16. PV output three phase current and voltage

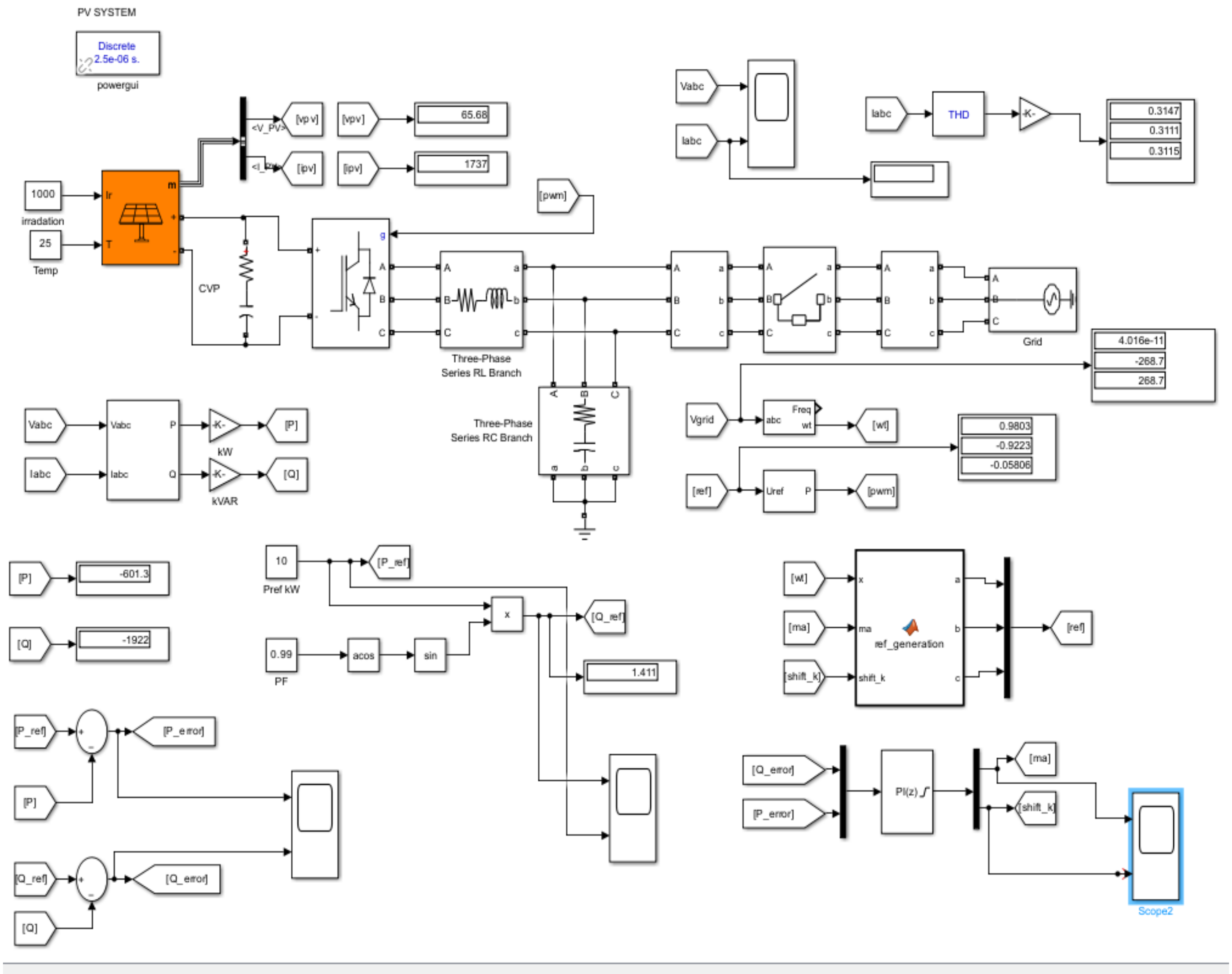


Figure 17. Modeling and simulation of grid-connected photovoltaic generation

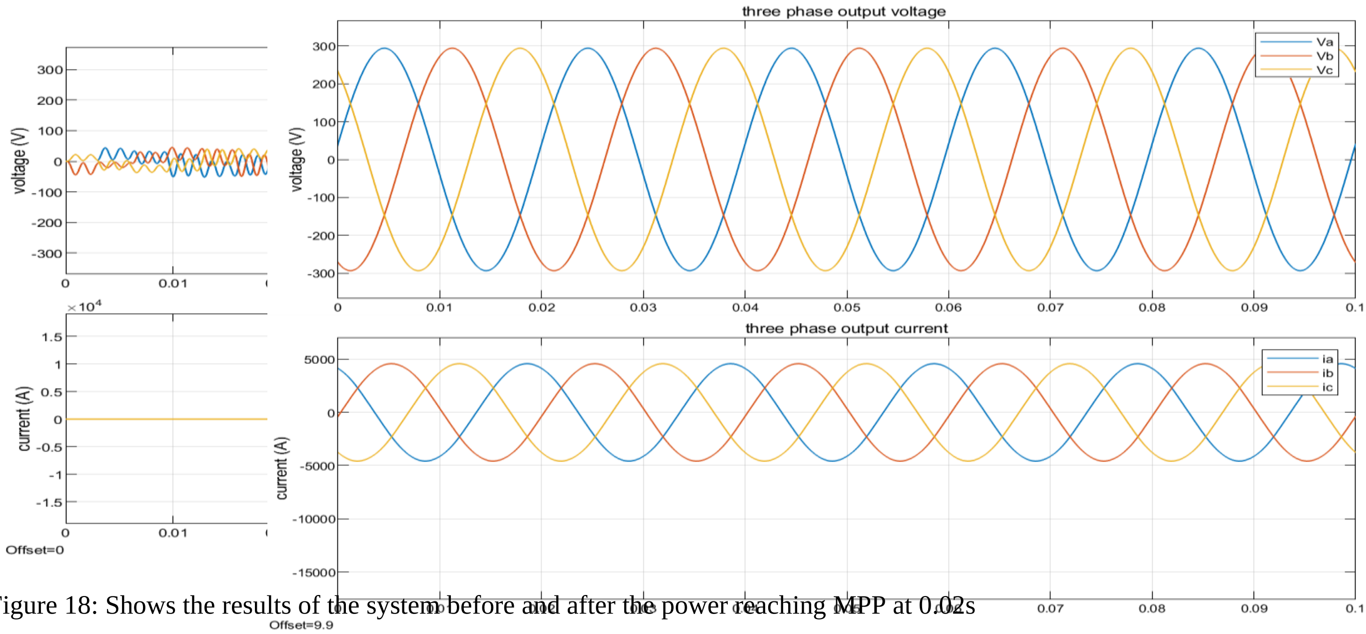


Figure 18: Shows the results of the system before and after the power reaching MPP at 0.02s

Figure 19. PV System voltage and current Output

Table 7. Total Harmonic Distortion (THD) results

Parameter	With PID controller	Without PID controller
I_a	0.3147	2.581
I_b	0.3111	1.919
I_c	0.3115	2.127

The results obtained from the simulation of the solar power plant are presented as shown in Table 8, with a comparison between the first phase, where the system operated without any controllers, and the second phase, where a controller was introduced to improve performance. The results clearly show a significant improvement in system efficiency and an increase in the energy produced after the controller was applied. The analysis also reflects that the system became more stable and efficient, leading to substantial improvements in overall performance and increased productivity compared to the first phase.

CONCLUSION

The work hereby describes a structured approach to designing and managing the grid-connected PV generation system, outlining its components and operational framework. A Maximum Power Point Tracking algorithm has been implemented, using the Perturb and Observe technique, so as to ensure the optimum conversion of the available solar energy. The method will keep the PV array at the maximum power deliverable to the utility grid at any given time. The paper further proceeds with the presentation of control strategies applied to a DC-AC inverter that are very essential in the control of both active and reactive power at the point of grid connection.

Table 8. Comparison of all Results with and without PID Controller in PV system.

Parameter		With PID	Without PID
P_{error}(W)		611.3	2235
Q_{error}(var)		1923	405.8
V_{pv} (V)		6.178	739.6
I_{pv} (A)		1739	8564
$V_{abc\ (output)}$	V_a	41.29	8.869
	V_b	-272.3	-221.6
	V_c	231	212.9
I_{abc}	I_a	4129	868.9
	I_b	-361.9	4713
	I_c	-3767	-5582

The results of the simulation, which are performed in a Matlab/Simulink environment, prove that the mechanisms are effective in managing the system to operate in stability and efficiency. The future extension of the MPPT might be done to this algorithm. Since it was structured in the traditional approach itself, the incorporation of an AI or ML-based algorithm would do a great amount of development and improvement in terms of tracking precision and efficiency, which would still be much good in dynamic conditions-for example, sudden changes within solar radiation and temperature that result in much adaptation in energy handling.

REFERENCE

1. Ammar, H., et al. (2019). Metaheuristic optimization of fractional order incremental conductance (FO-INC) maximum power point tracking (MPPT), Complexity, https://doi.org/10.1155/2019/7687891.
2. Ashreadi, M. (2024). Model Predictive Control for Optimizes Battery Charging Process, 2024 IEEE 4th International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA), Tripoli, Libya.
3. Emhemme, A. and et. al. (2022). Simulation Analysis and Control of Wireless Power Transfer for Implantable Medical Devices, IEEE 21st International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), Sousse – Tunisia.
4. Fu Q. and Cheng, L. (2012). Improvement of P&O MPPT method for photovoltaic system based on adaptive prediction algorithm, Applied Mechanics and Materials, pp. 263–266, 2131–2137, https://doi.org/10.4028/www.scientific.net/AMM.263-266.2131, 2-s2.0-84872469549.
5. Alshaybani, Q. and et al. (2022). Loads Instability Study of the Gas Turbine Blades for Al-Khums Power Station, In 2022 Second International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT), pp. 1-6.

6. Abosdeal, A. , et al. (2012). Design and Simulation of PFC Circuit for AC/DC Converter Based on PWM Boost Regulator International Journal of Automation and Power Engineering, vol. 1, Issue 5, pp. 124-128.
7. Mirza, F. and Ling, Q. (2021). High-efficiency swarm intelligent maximum power point tracking control techniques for varying temperature and irradiance, Energy. 228, 120602, https://doi.org/10.1016/j.energy.2021.120602.
8. Abougarair, A. (2022). Integrated Controller Design for Underactuated Nonlinear System, IEEE, Second International Conference on Power, Control and Computer Technologies (ICPC2T-2022), 1-3 March 2022.
9. Mokhtar M. and Attia, A. (2021). Hybrid SCA and adaptive controller to enhance the performance of grid-connected PV system, Ain Shams Engineering Journal. 12, no. 4, 3775–3781, https://doi.org/10.1016/j.asej.2021.03.019.
10. Phommixay S. and Doumbia, L. (2022). Review on the cost optimization of microgrids via particle swarm optimization, International Journal of Energy and Environmental Engineering. 11, no. 1, 73–89, https://doi.org/10.1007/s40095-019-00332-1.
11. Alkaber, I., et al. (2024). Comparative evaluation of PID controller tuning through conventional and genetic algorithm, IEEE 4th International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA), PP. 176-181.
12. Gupta A. and Singh, O. (2021). Grid connected PV system with MPPT scheme using particle swarm optimization technique, International Journal of Intelligent Networks, no. 02, https://doi.org/10.51735/ijiccn/001/32.
13. Popa L. and Popescu, M. (2016). Design and simulation of a 10 MW photovoltaic power plant using MATLAB and Simulink, Proceedings of the 2016 IEEE International Power Electronics and Motion Control Conference (PEMC), Varna, Bulgaria, 378–383, https://doi.org/10.1109/EPEPEMC.2016.7752027, 2-s2.0-85008253790.
14. Ramirez, A. (2019). Harmonic modeling and simulation of a stand-alone photovoltaic-battery-supercapacitor hybrid system Int. J. Electr. Power Energy Syst., 105, pp. 70-78.
15. Zaghba L. and Borni, A. (2024). Enhancing grid-connected photovoltaic system performance with novel hybrid MPPT technique in variable atmospheric conditions Sci. Rep., 14 (1), pp. 8205.
16. Alfian E. and et al. (2023). Optimizing Light Intensity with PID Control, Control Systems and Optimization Letters, vol. 1, Issue 3, pp 124-131.
17. Akbar, A and et al. (2020). Implementing PID Control on Arduino Uno for Air Temperature Optimization, Buletin Ilmiah Sarjana Teknik Elektro 6 (1), 1-13
18. Abougarair, A. (2020) Robust Control and Optimized Parallel Control Double Loop Design for Mobile Robot ", IAES International Journal of Robotics and Automation (IJRA), vol. 9, no. 3.
19. Zrigan, A., et. al. (2023) Optimized PID Controller and Generalized Inverted Decoupling Design for MIMO System, IEEE International Conference on Advanced Systems and Emergent Technologies (IC_ASET'2023).
20. Sheikholeslami M. and Khalili, Z. (2024). Simulation for impact of nanofluid spectral splitter on efficiency of concentrated solar photovoltaic thermal system Sustain. Cities Soc., 101, Article 105139.
21. Buzkhar, I. (2023). Modeling and Control of a Two-Wheeled Robot Machine with a Handling Mechanism, 2023 IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA2023).
22. Cabrane Z. and Kim, J. (2021). HESS-based photovoltaic/batteries/supercapacitors: energy management strategy and DC bus voltage stabilization Sol. Energy, 216, pp. 551-563.
23. Nadweh, S., and Hayek, G. (2022). Maximum power point tracking techniques for renewable energy generation Deregulated Electricity Market, Apple Academic Press, pp. 155-176.
24. Alkhzaimi, H, et. al. (2024). Securing Smart Homes: A Cloud-Based IoT Approach to Intelligent Home Security, International Conference on Artificial Intelligence and its Applications in the Age of Digital Transformation. Pages 244-263, Publisher Springer Nature Switzerland.
25. M. Kopicka and M. Ptacek, Analysis of the power quality and the impact of photovoltaic power plant operation on low-voltage distribution network Proc. 2014 Electric Power Quality and Supply Reliability Conference (PQ), Rakvere, Estonia, pp. 99-102
26. Argyrou, M. and Christodoulides, P. (2014). A grid-connected photovoltaic system: mathematical modeling using MATLAB/Simulink, 52nd Int. Univ. Power, Eng. Conf.
27. Zrigan, A. and Abougarair, A. (2025). Integration of MPC and SOLADRC to Optimize PWR Performance, Sebha University Conference Proceedings, VOL.04 NO. 1 2025, DOI: 10.51984/SUCP.V4I1.3870.
28. Ioannou, S. and Darwish, M. (2019). Efficiency investigation of a grid connected PV system with power smoothing 2019 54th International Universities Power Engineering Conference (UPEC), pp. 1-6
29. Abougarair, A. (2023). Adaptive Neural Networks Based Optimal Control for Stabilizing Nonlinear System , IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA2023).
30. Aboud, M. and et al. (2023). Robust H-Infinity Controller Synthesis Approach for Uncertainties System, 11th International Conference on Systems and Control (ICSC'2023), Sousse, Tunisia.
31. I. Attawil, I. (2024). Model Predictive Control for Achieving Lane, International Conference on

Artificial Intelligence and its Applications in the Age of Digital Transformation, Springer conference, Nouakchott, Mauritania.

32. W. Saheri, W., et al. (2021). Recursive Least Squares Algorithm for MISO CARAMA Systems Utilizing Data Filtering, 2021 IEEE 1st International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering MI-STA.
33. I. Attawil, et al., (2024). Lateral Control of Autonomous Vehicles through Adaptive Model Predictive Control, IEEE 4th International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA), 19-21 May 2024.
34. Alduraywish, A., et al. (2024). Optimizing cancer treatment using optimal control theory, AIMS Mathematics, Volume 9, Issue 11: 31740-31769. doi: 10.3934/math.20241526
35. Guma, W., et al. (2024). Implementation and Performance Evaluation of Intelligent Techniques for Controlling a Pressurized Water Reactor, Journal of Automation, Mobile Robotics and Intelligent Systems, pp. 71-85, issue 4.
36. Shashoa, N., et al. (2021). Fault Detection Based on Validated Model of Data Filtering Based Recursive Least Squares Algorithm for Box-Jenkins Systems, 2021 Global Congress on Electrical Engineering (GC-Elec. Eng), pp. 92-96.
37. Djurović, Ž, et al. (2013). Sensor fault detection and isolation in a thermal power plant steam separator, Control Engineering Practice 21, no. 7, pp. 908-916.
38. Arebi, W., et al. (2022). Smart Glove for Sign Language Translation International Robotics & Automation Journal, Volume 8, Issue 3.
39. Jleta, I., et al. (2022). Four-Stage Recursive Least Squares Algorithm for CARARMA Systems, In 2022 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), pp. 1-5.
40. Elmezughi, M., et al. (2023). ADRC Robustness for Boiler Turbine Unit at Equilibrium Operation Point, IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering MI-STA, Libya
41. Setiawan, M. et al. (2024). Enhancing Speed Estimation in DC Motors using the Kalman Filter Method: A Comprehensive Analysis, Jurnal Ilmiah Teknik Elektro Komputer dan Informatika, vol. 10 , issue 1,pp. 30-38.
42. Sawan, S., et al. (2024). Cancer Treatment Precision Strategies Through Optimal Control Theory, Journal of Robotics and Control (JRC), Vol. 5, Issue 5, pp. 1261-1290.
43. Elwefati, S. and et al. (2023) Identification and Control of Epidemic Disease Based Neural Networks and Optimization Technique, International Journal of Robotics and Control Systems 3 (4),780-803.
44. Swedan, M., et. al. (2023). Stabilizing of Quadcopter Flight Model, 2023 IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA2023), Libya.
45. Abougarair, A. (2022). “Tracking Control of a Continuous Stirred Tank Reactor Using Advanced Control Algorithms “, IJEIT International Journal on Engineering and Information Technology, vol.8, no. 2, Libya.