Journal of
Engineering Sciences
Faculty of Engineering
Assiut University
JES
مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط
journal homepage: http://jesaun.journals.ekb.eg

Design and Implementation of a PLC-Based SCADA System for Real-Time Monitoring and Control of ` Energy Conversion

Received 16 June 2025; Revised 5 July 2025; Accepted 7 July 2025

Majeed I. Mohammed[1]
Ahmed M. T. I. Al-Naib[2]

Keywords
Photovoltaic (PV) System,
SCADA System,
Industrial Automation,
Programmable Logic Controller,
Siemens S7-1200, and
DC-DC Converter.

Abstract: This study presents the development and experimental evaluation of a photovoltaic (PV) monitoring and control system utilizing a Siemens S7-1200 Programmable Logic Controller (PLC). The proposed system was integrated with a DC-DC boost converter and SCADA (Supervisory Control and Data Acquisition) supervision. The system was designed to stabilize the fluctuating output of PV panels by employing a closed-loop control strategy using a Proportional-Integral-Derivative (PID) controller in conjunction with Pulse Width Modulation (PWM) techniques, maintaining a stable output voltage despite variations in solar input. The PLC, programmed via TIA Portal V17, serves as the central processing unit, acquiring analog signals from PV modules and facilitating data logging, processing, and visualization. Field testing was conducted in Kirkuk City over a 10-hour operational window to monitor key PV parameters including terminal voltage, load current, output power, temperature, and solar irradiance. Experimental results confirm the system's effectiveness in real-time data acquisition, robust voltage regulation, and user-centric monitoring. The architecture demonstrates high scalability, accuracy, and reliability, with a cost-effective and modular design suitable for industrial deployment. Moreover, the system's flexible structure supports adaptation for broader industrial monitoring applications following minimal calibration. This approach offers a promising solution for enhancing operational efficiency, reducing maintenance demands, and maximizing the performance of renewable energy systems.

1. Introduction

The DC-DC converters are essential components in various electrical systems, enabling efficient power transfer and voltage regulation. Therefore, achieving precise voltage regulation is crucial in applications ranging from electric vehicles to industrial systems, communication devices, and renewable energy systems [1, 2]. Industrial automation requires precise control of processes, particularly in maintaining specific parameters like

[1] Department of Electrical Engineering Techniques, Technical Engineering College/Mosul, Northern Technical University, Mosul, Iraq. ahmed_alnaib2018@ntu.edu.iq
[2] Department of Electrical Engineering Techniques, Technical Engineering College/ Mosul, Northern Technical University , Mosul, Iraq. majeed.ismail@ntu.edu.iq

https://doi.org/10.21608/jesaun.2025.392688.1553

voltage regulation in DC-DC converters, speed control, temperature, pressure, or flow rate. PID control was used to achieve this. Siemens' TIA Portal simplifies the implementation of PID control by offering a ready-to-use PID function, allowing for efficient setup and configuration of PID controllers for various applications [3].

1.1. Literature Review

There are several studies related to the design, tuning, and implementation of the PID controller, especially via PLC, and so on. In [3], the authors presented a fine-tuning approach for the PID controller's parameters using a fuzzy-PD controller in a thermal plant. The system was built and tested using MATLAB/Simulink on a specific plant, and then the design was converted into a structured control language (SCL) code to be used in Siemens S7-1200 PLC programs. In [4], the authors present an auto-tuning method for the PID controller for the temperature control module based on the Siemens S7-1200 PLC. Thus, the system became stable more quickly. The system exhibits excellent suitability, optimal speed adjustment, and timely error correction. In [5, 6], the validation of the PID digital controller-based cascade control system using Micrologix-1200 PLC and RSVIEW-32 SCADA, along with RSLinx communication software that controls the flow rate system. It shows real-time data analysis, setpoint adjustments, automatic report generation, and data integration with MS Excel and MS Access. In [7], propose implementation of Siemens S7-1200 PID control on the water level controller for plants (Festo Labvolt 3531) with SCADA using Modbus communication protocol. [8] Describes the design, parameter tuning, and experimental evaluation of a fractional-order PID temperature control in a pipeline with induced air-flow on a laboratory test stand. The controller was implemented on a standard PLC Siemens S7-1200.

In [9, 10], stabilizing the motor speed according to a preset value using a PID algorithm integrated in Siemens S7–1200 PLC was implemented. A SCADA interface was designed for monitoring many parameters on a PC or HMI monitor, such as turning on/off the system, selecting the motor direction of rotation, entering the setpoint, PID parameters in the system, the actual motor speed, the error ratio, and showing the motor's current direction of rotation. In [11], the control of an asynchronous motor was realized experimentally using a PLC with a VFD driver using a PID controller algorithm. Different control PID values were experimented with constant speed trials to achieve the best results. Monitoring and controlling the PV system can be implemented based on various technologies, such as Arduino [12, 13], Field Programmable Gate Array (FPGA) [14], and Raspberry Pi [15]. Despite being low-cost, open-source, and extendable, these solutions should not be regarded as substitutes for PLC technology [16-19].

The authors previously published a research article [20], where it was focused solely on designing and implementing a SCADA monitoring system for solar panel data (five parameters: terminal voltage, load current, consumption power, irradiance, and temperature). It functions solely as a monitoring system without any controlling capabilities. While the current manuscript presents a design for a boost converter that is controlled via the PLC based on a PID controller and PWM for stabilizing the output voltage value of the PV panel at the desired level (at a setpoint equal to 42 volts or any required voltage level). The work also included designing an extended SCADA system interface for real-time data monitoring of the irradiance, temperature, terminal voltage, load current, and consumption power at both sides of the designed boost converter. Also, it displayed all the parameters of the PID controller and the value of the duty cycle and switching frequency.

2. Proposed PV System

As shown in Fig. 1, the proposed PV system was made up of a PV module, a DC-DC boost converter, current and voltage sensors for both sides (PV and load), an automation PLC for closed loop controller and also for monitoring the proposed PV system via SCADA, and a DC load. Fig. 2 shows the circuit diagram of the proposed PV system.

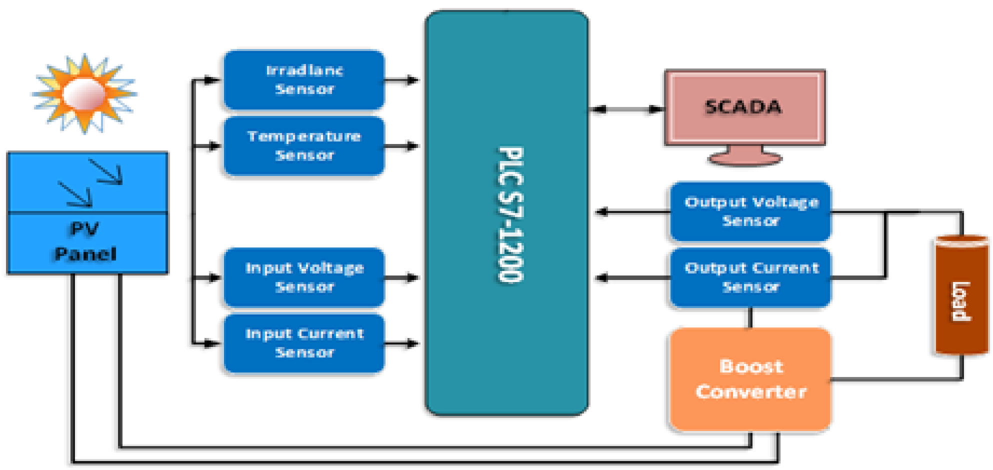

Fig. 1: Functional block layout diagram of the proposed PV System based on PLC

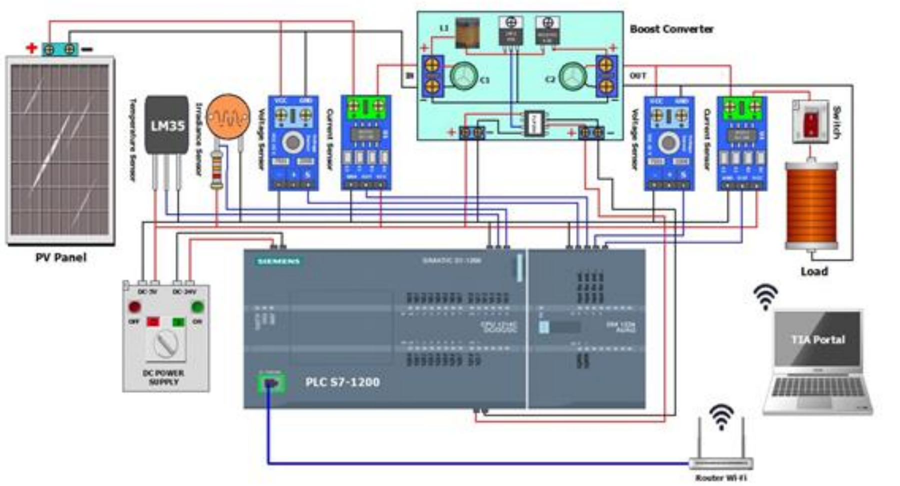

Fig. 2: Experimental scheme of the proposed PV monitoring system

The hardware for the proposed system will consist of the following components:

2.1. PV Panel

Table 1 presents the specification (under standard test conditions) of the PV panel that is used experimentally for this work [21].

Table 1. Parameter of the employed PV panel

TYPE	**M-100W** polycrystalline
Max. Power (P_{max})	100 W
Open Circuit Voltage (V_{oc})	22.0 V
Short Circuit Current (I_{sc})	6.5 A.
Max. Power Voltage (V_{mp})	18.0 V
Max. Power Current (I_{mp})	5.70 A
Max. System Voltage	1000 V
Power Tolerance	± 3 %
Dimension (mm)	1200*540*30

2.2. DC-DC Boost Converter

A DC-DC converter elevates the input PV voltage to the necessary output voltage without employing a transformer. The primary components of a DC-DC boost converter include an inductor (L), a high-frequency switch (Q), a diode (D1), and an output capacitor (C_o). [22], as shown in Fig. 3. Table 2 lists the component specifications of the designed converter. These systematically provide power to the load at a voltage above the input voltage magnitude. The control approach involves the modulation of the duty cycle (K) of the switch, resulting in voltage variation. The boost converter functions by intermittently applying the input voltage to the inductor, thereby storing energy in its magnetic field. This stored energy is subsequently released to the output load through the diode and capacitor, resulting in an increased output voltage. Fig. 4 illustrates the practical circuit of the proposed system's boost converter.

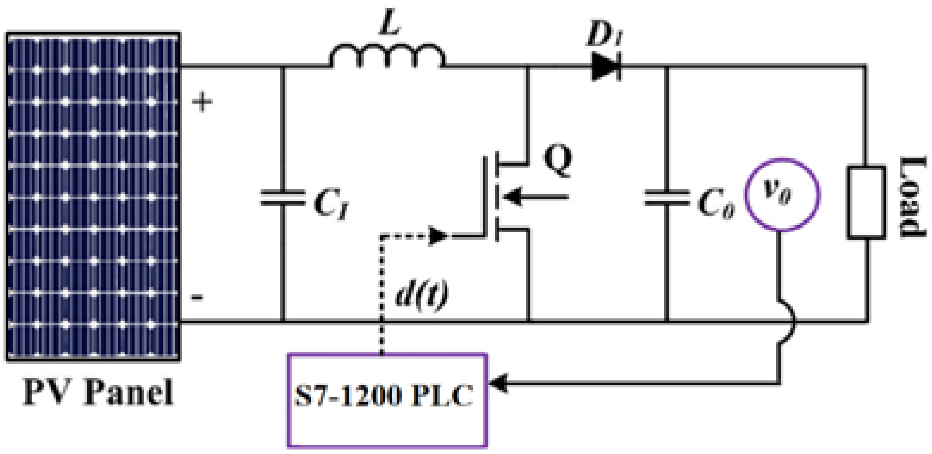

Fig. 3: Circuit diagram of the boost converter

Table 2. Component specifications

Component	**Value**
inductor (L)	1mH
Capacitance (C)	2200 μF
Switching frequency	5 KHz
Power switch	IRFP450
Optocoupler	TLP250

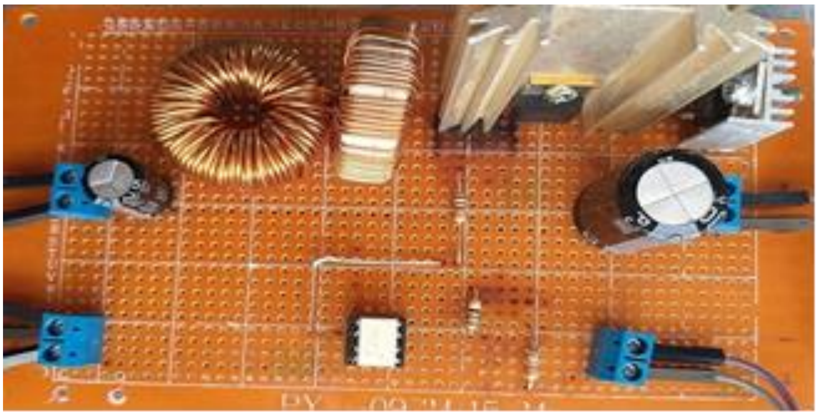

Fig. 4: Practical circuit of the proposed system's boost converter

2.3. Voltage Sensor

A voltage divider was employed with the PLC as a PV voltage sensor. It consists of two resistors (R_1 equal to 30 kΩ and R_2 equal to 7.5 kΩ). It operates between 0 and 50V. According to the following equation, its output voltage (V_{out}) can be defined.

$$V_{out} = V_{in} * \frac{R_2}{R_1 + R_2} \tag{1}$$

Where V_{in} is the input voltage to the sensor (PV terminal voltage).

2.4. Current Sensor

The ACS712 Current Sensor was utilized due to its excellent precision and ease of use for load current measurement [23], [24]. The "Hall Effect" underpins the operational principle of this device. This sensor was used to normalize the requisite hall voltage value derived from the load current, which is subsequently provided to the PLC. The PLC calibrates the Hall voltage to the actual load current (I) according to equation (2).

$$I = \frac{sensor\ value - 2.5}{scale\ factor} \tag{2}$$

The scale factor is contingent upon the group of the ACS-712 current sensor concerning its current load capacity; for the ACS-712 ELCT-5A utilized in this study, it is 185 mV/A.

2.5. Temperature Sensor (LM35)

This work utilizes the LM35 temperature sensor. This temperature sensor from Texas Instruments is well regarded; it produces a voltage that linearly correlates with temperature variations at a scale factor of 10.0 mV/°C. It exhibits minimal power consumption (60 µA), is economically priced, and provides exceptional accuracy. Due to its robust design, it can endure many environmental conditions. Furthermore, it required no further components for calibration and consistently demonstrates an accuracy of 0.5°C at ambient temperature and 1°C across the temperature range of -55°C to +155°C [20].

2.6. Irradiance Sensor

This study employed a simple and cost-effective method using LDR to quantify solar irradiance. It is widely employed as an automatic streetlight, light meter, light sensor, and in several applications necessitating light sensitivity. The light-dependent resistor (LDR) is a specialized resistor that operates on the principle of photoconductivity, wherein resistance varies with light intensity.

2.7. S7-1200 PLC

The Siemens S7-1200 is a programmable logic controller employed in industrial automation applications. It is a small, modular PLC capable of managing diverse automation tasks and processing data from several inputs and outputs. In this work, it is employed for controlling the duty cycle of the Boost converter based on the feedback voltage signal of the output terminal voltage, and thereby, the voltage is regulated. It is also used for processing and monitoring the PV terminal voltage, the boost converter's current, the output terminal voltage, and the load current via the proposed SCADA system.

3. Software Implementation

TIA Portal V17 is a software environment utilized for programming Siemens SIMATIC S7-1200 PLCs. Initially, for the assessment of the terminal output voltage of the PV panel and the boost converter, the lowest and max. Values of the voltage sensor signal (%IW64) were designated from 0 to 13824, and the value was defined in "NORM_X." The real voltage value (0–50 volts) was subsequently scaled using "SCALE_X" function blocks. The error rate during the calibration of the voltage sensor was determined to be 5%. To rectify this issue, a "CALCULATE" block was employed to adjust for the error % and ascertain the accurate voltage (see to Fig. 5).

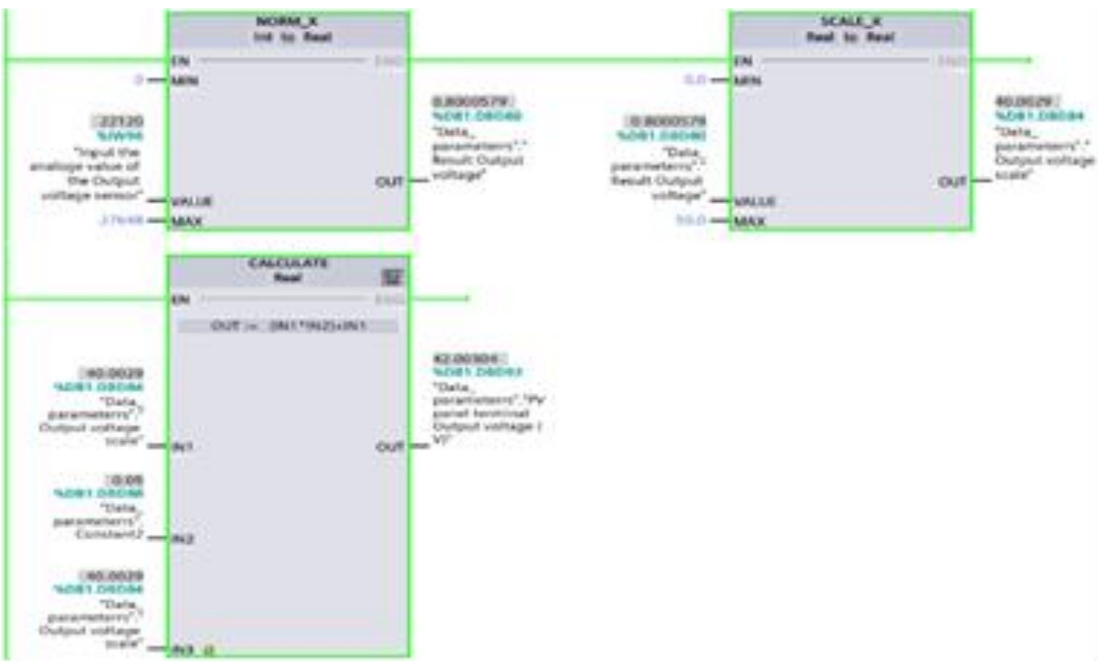

Fig. 5: PV Voltage measurement network

The load current was measured by normalizing the min. and max. Values of the load current sensor signal (IW66%) from a range of 0 to 27468 using the "NORM_X" block function. The scaling was established with min. and max. Values of 0-10 A, as defined by the "SCALE_X" block. A "CALCULATE" block function is employed to execute the necessary calibration equation for this sensor, as delineated in eq. (2) and illustrated in Fig. 6.

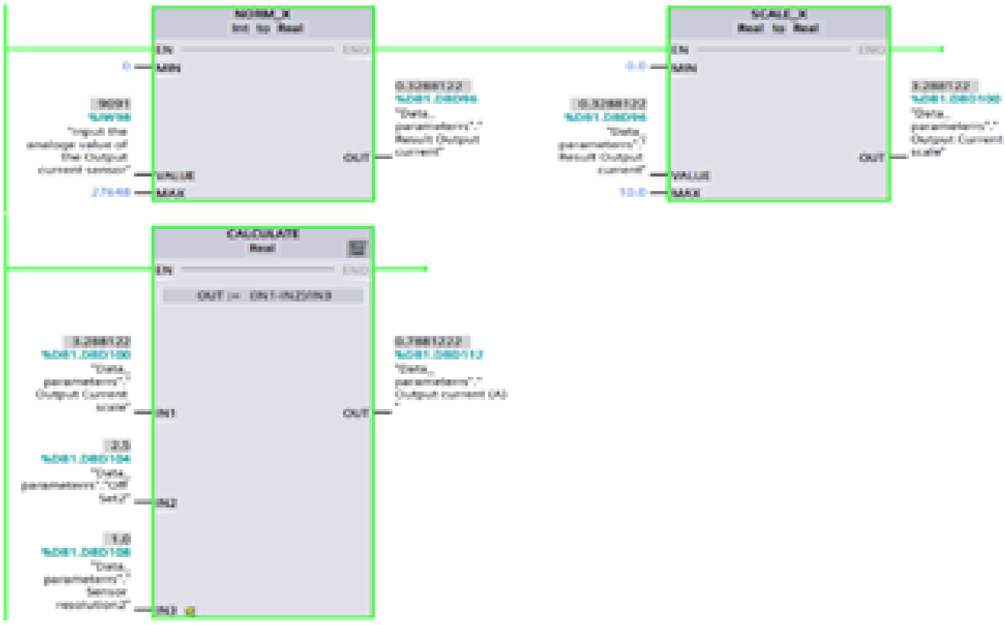

Fig. 6: Load current calculation network

The consumption power (in Watts) was calculated by multiplying the terminal voltage by the load current using the multiplication function block "MUL", as illustrated in Fig. 7.

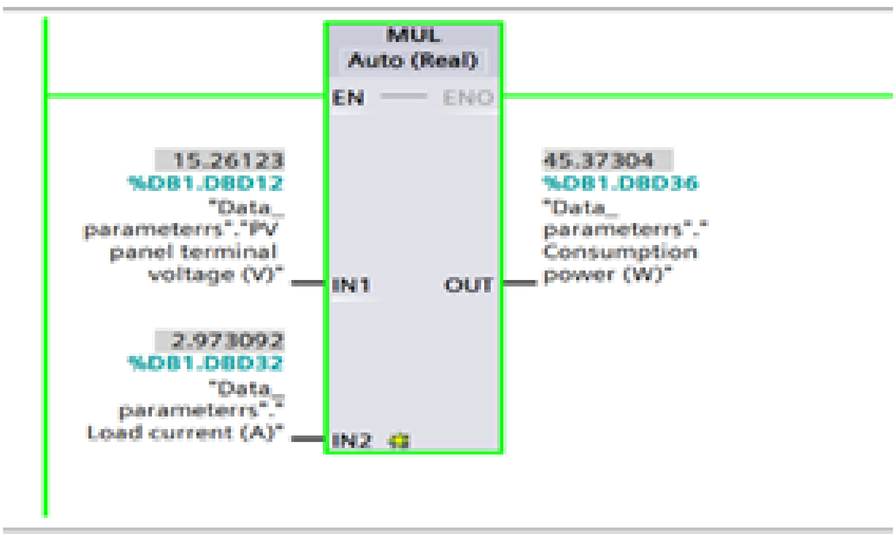

Fig. 7: Consumption power calculation network

3.1. PID Compact Controller

PID control is a widely used algorithm in industrial automation for regulating process variables. The S7-1200 PLC provides support for PID control via the "PID Compact" function block. In this work, this block performs the necessary calculations for PID control and generates an "output" signal that represents the duty cycle percentage ratio of a boost converter based on the deviation between the desired "setpoint" which represents the required output voltage of the boost converter (42 volts), and the actual process variable "input" value, which represents the feedback signal of the terminal voltage of the boost converter (see Fig. 8). Fig. 9 displays a block diagram illustrating the PID compact function block.

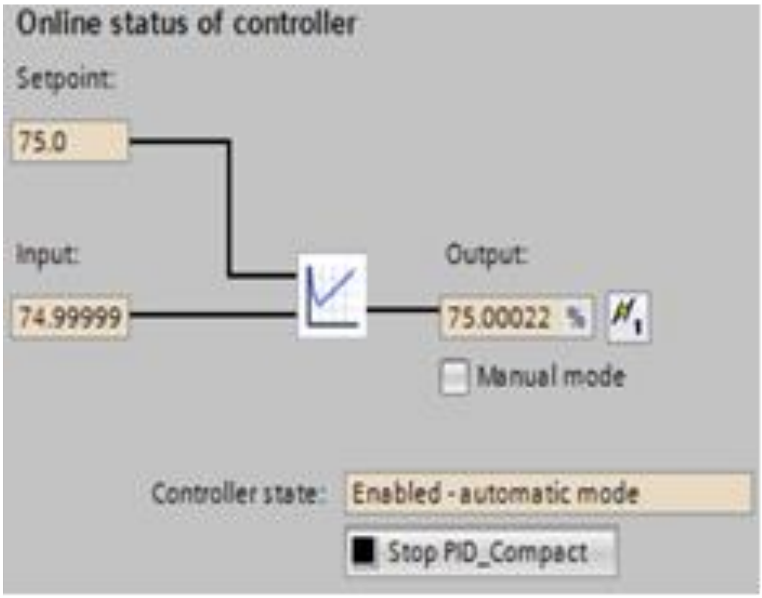

Fig. 8: Operation of PID Compact Block

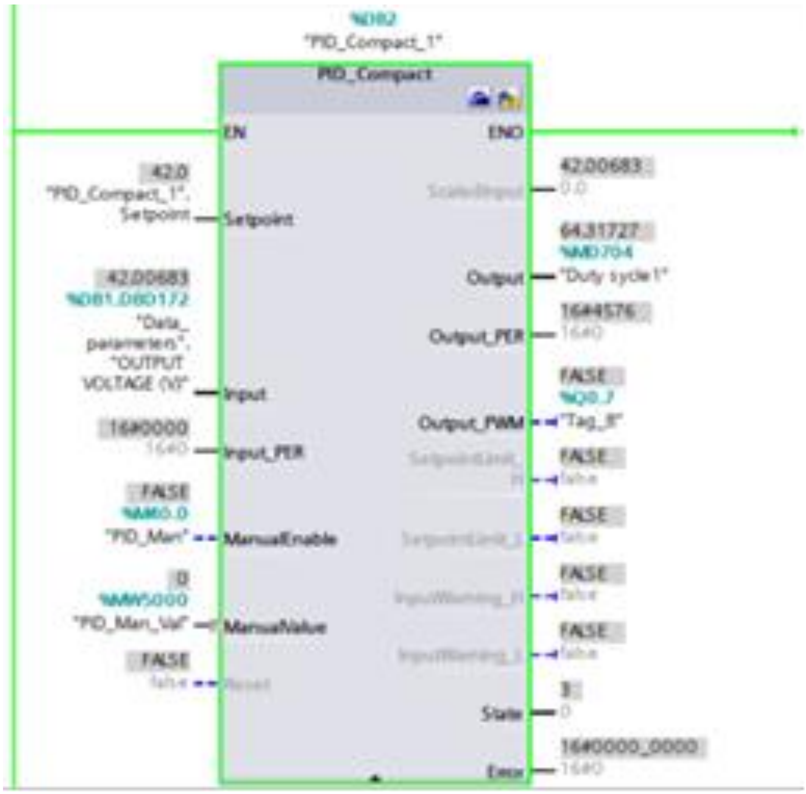

Fig. 9: Block diagram of PID compact

The PID compact function block is composed of three components, which are combined using tuning parameters to achieve the desired control response (i.e., It continuously adjusts the output signal to minimize the error and maintain the process variable at the setpoint). These components are:

Proportional control (P): Generates an output signal proportional to the error between the Set-Point (S_{point}) and the Process Variable (P_{var}). The proportional gain (K_p) determines the error amplification:

$$P = K_p * (S_{point} - P_{var.}) \qquad (3)$$

Integral control (I): Integrates the error over time and adds it to the output signal. This reduces steady-state errors and improves system response. The integral gain (K_i) determines the amplification of the integrated error:

$$I = K_i * \int (S_{point} - P_{var.})\, dt \qquad (4)$$

Derivative control (D): Calculates the error's rate of change and adjusts the output signal accordingly. This dampens the response and minimizes overshoot or undershoot. The derivative gain (K_d) determines the amplification of the rate of change:

$$D = K_d * \frac{d}{dt}(S_{point} - P_{var.}) \qquad (5)$$

Fig. 10 shows the relationship between the setpoint and the output voltage of the boost converter and the value of the duty cycle. The black line represents the setpoint value, the green line represents the output voltage value, and the red line represents the duty cycle value.

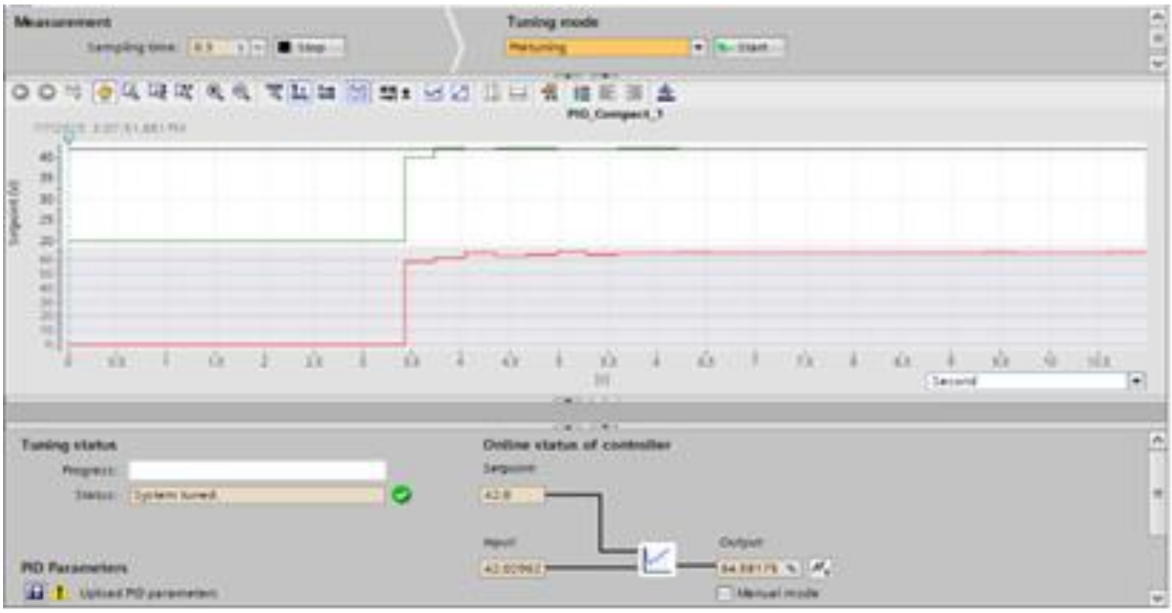

Fig. 10: Measurement view of the PID compact controller block

Siemens S7-1200 provides an auto-tuning feature built into the PID_Compact block (in TIA Portal). This feature automatically calculates the optimal values of the PID coefficients [3, 4].

3.2. Pulse Width Modulation

The "CTRL_PWM" instruction facilitates the activation and deactivation of a pulse output through software, utilizing the CPU. The input "PWM" instructions are responsible for inputting the device identifier of the controlled pulse generator. When the "ENABLE" bit in the instruction's input is set, the pulse output is activated. If the ENABLE bit is TRUE, the pulse generator generates a pulse according to the specified properties in the device configuration. Conversely, when the ENABLE bit is reset or the CPU transitions to the STOP state, the pulse output is deactivated, and pulse generation ceases. In the S7-1200 system, "BUSY" is always FALSE, as the execution of the "CTRL_PWM" instruction triggers the activation of the pulse generator. The enable output ENO is set when the EN enable input signal state is "1" and no errors have occurred during instruction execution. Fig. 11 depicts the configuration of a PWM block.

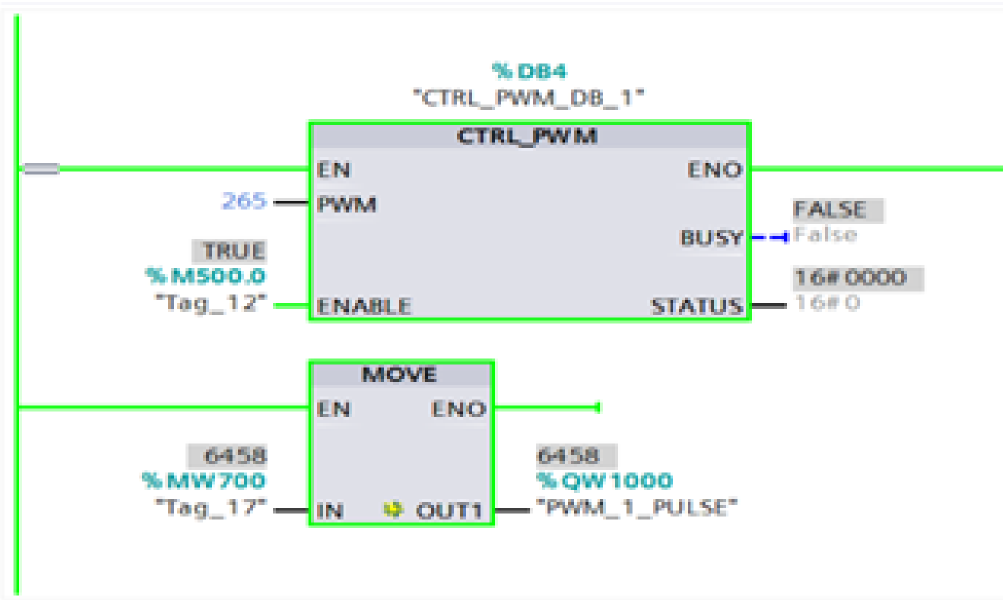

Fig. 11: PWM configuration network

The PWM block was configured with a frequency of 5 kHz, and the system was subjected to testing across various duty cycles. And it was evident that the signal maintained ideal characteristics without any distortions.

3.3. SCADA Interface

A SCADA system provides a scheme for remote control and monitoring of many systems, it widely used in various industrial applications, and they have helped improve the efficiency of such systems. A new working of PV systems is proposed in this paper that aims to design solar monitoring and control through SCADA. The TIA Portal program facilitated the creation of a display screen within the SCADA system, enabling the monitoring of the system's performance and its capacity to regulate the output voltage of the solar panel. This was achieved through data analysis and the generation of curves for the setpoint, duty cycle, and output voltage, as well as input and output values for each parameter, as shown in Fig. 12.

As shown in the figure, the system was subjected to a 9-hour test and operation phase, during which it was continuously observed via the SCADA display screen, which also provides a comprehensive overview of the PID control and PWM operations, illustrating their functionality and highlighting their regulation by the system. In the chart shown in the SCADA system, the black line represents the setpoint value, the green line represents the output voltage value, and the red line represents the duty cycle value.

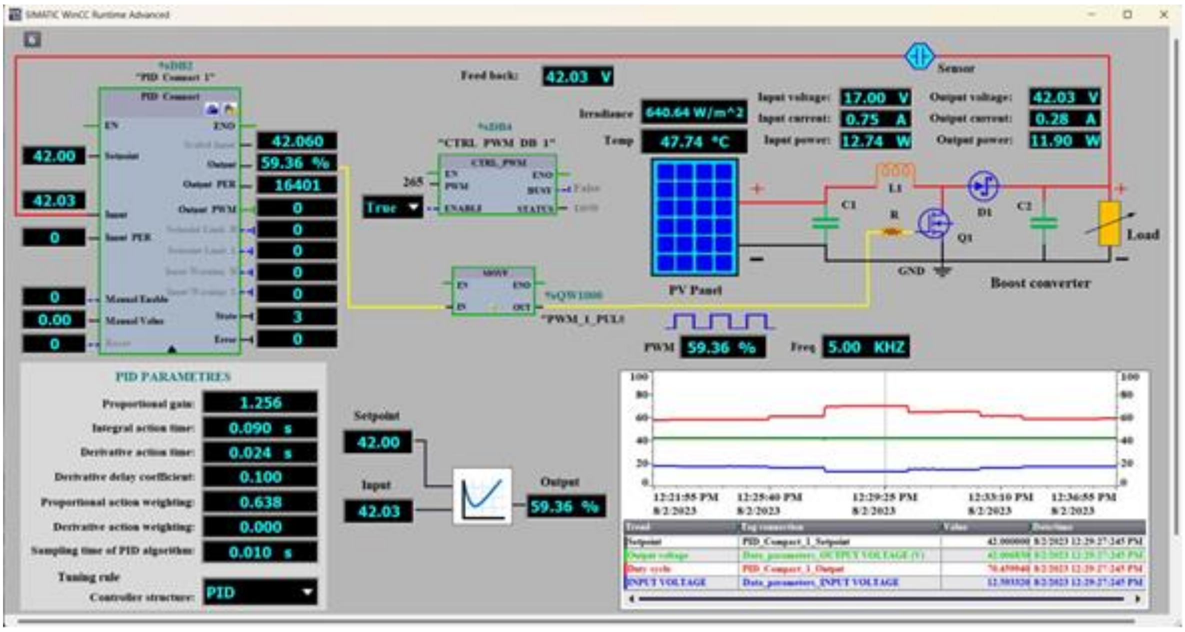

Fig. 12: Proposed SCADA System

4. Experimental Results

The left side of the SCADA screen in Fig. 13 shows instantaneous values and the curves of the PV terminal voltage (blue colored), source current (brown colored), and PV power (green colored), while the right side of this Fig. also shows the instantaneous values and the curves of regulated output voltage of the boost converter, load current, and the output consumption power with the same mentioned colors.

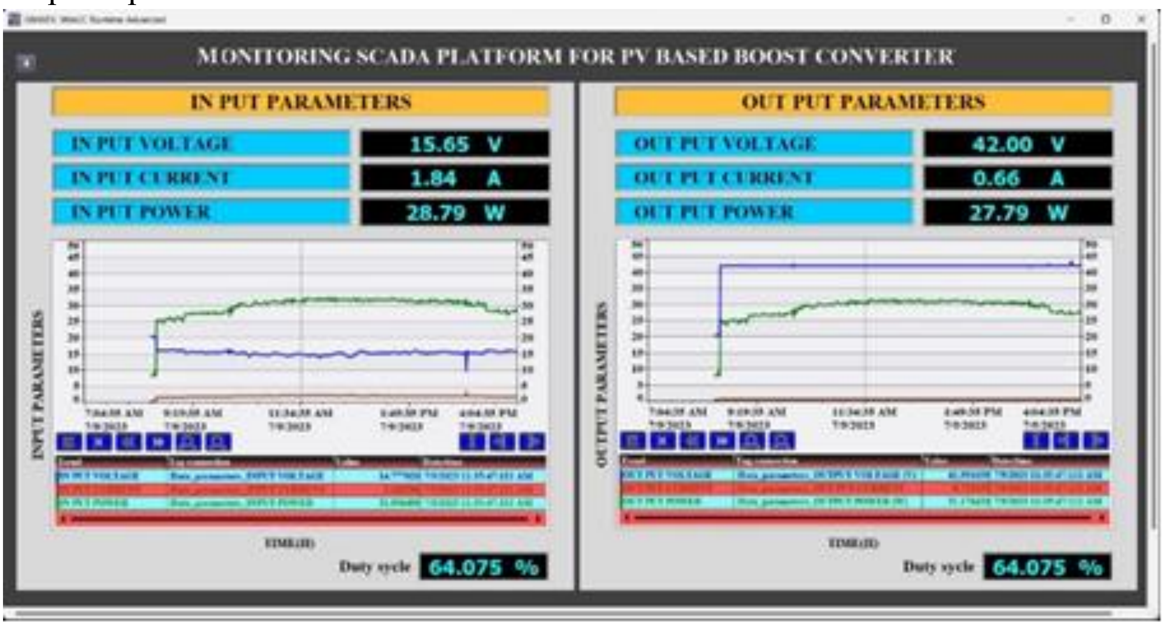

Fig. 13: SCADA screen presenting the input and output values of voltage, current, and power

Furthermore, Fig. 14 presents an additional SCADA screen that shows the instantaneous values and the curves of the PV terminal voltage (blue colored), source current (brown colored), and PV power (green colored), as well as the percentage ratio of the duty cycle (red colored) while the right side of this figure also shows the instantaneous values and the curves of the regulated output voltage of the boost converter, load current, and the output consumption power with the same mentioned colors. Each parameter is depicted in an individual graph, facilitating clear visualization, analysis, and demonstration of system stability during operation.

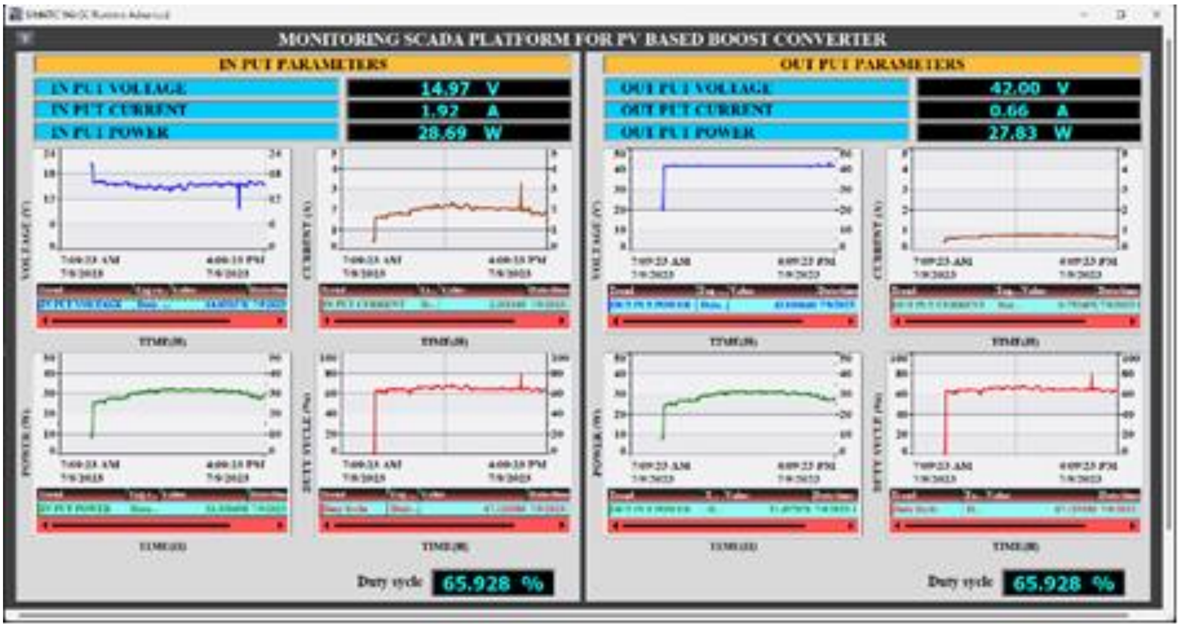

Fig. 14: A SCADA screen that presents the input and output values for voltage, current, power, and duty cycle

The system successfully demonstrated its proficiency and accuracy in controlling the output voltage of the solar panel, effectively adapting to variations in the input voltage. It effectively stabilized the output voltage at the desired level (at a setpoint equal to 42 volts), ensuring consistency despite fluctuations in the input voltage and preventing any instances of overshooting or undershooting that could arise during operation. Furthermore, it has been determined that both transient and steady-state performance are enhanced with the utilization of a PID controller. Fig. 15 shows the waveform of the terminal voltage of the PV panel and Duty cycle, and Fig. 16 shows the waveform of the load current of the boost converter and Duty cycle.

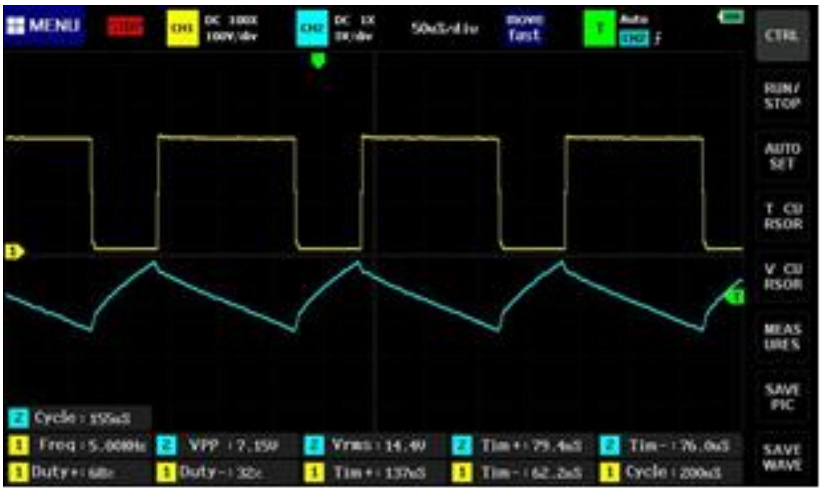

Fig. 15: Waveform of the of the terminal voltage of the PV panel & Duty cycle

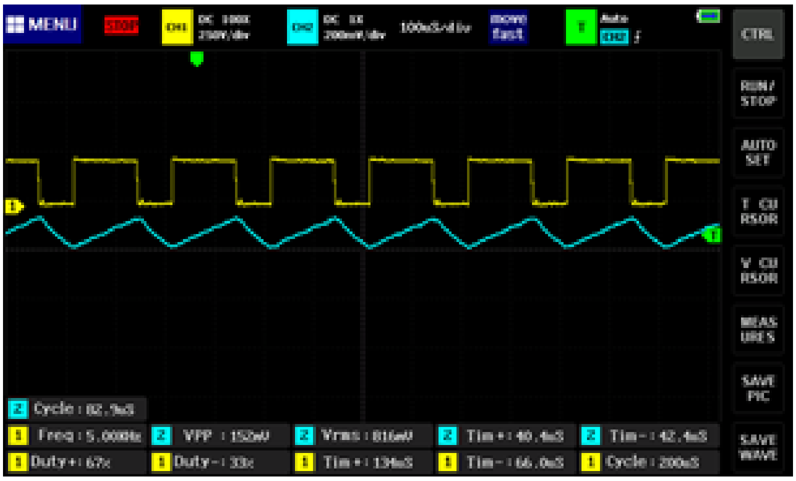

Fig. 16: Waveform of the of the load current of the PV panel & Duty cycle

5. Conclusions

The main conclusions of the present study could be summarized as follows:

- The proposed design based on PLC S71200 can be considered as a good choice for a DC-DC power converter for PV applications. It is a modular, flexible, and it has reliability features.
- The implementation of the PID-PWM control scheme leads to the converter's output voltage can be effectively regulated, ensuring stability and compensating with input voltage variations.
- The study concludes that the SCADA-based data acquisition system for PV panel parameters is a valuable and efficient key for monitoring electrical and meteorological data from PV power plants. In addition, it facilitates in supervisory management, and communicate system faults to minimize downtime.
- Future work has multiple opportunities for enhancement that can be executed, such as implementing the MPPT algorithms techniques for controlling the DC-DC power converter., Also, the machine learning algorithms can be integrated in this work for analyzing the collected data and providing predictive analytics to optimize the performance of the PV system.
- The results validate the system's effectiveness in real-time data acquisition, centralized monitoring and control, and closed-loop control of the boost converter's duty cycle. The system's scalability, flexibility, and user-friendly interfaces make it suitable for various solar panel installations, ranging from small residential systems to large-scale commercial arrays.

6. Acknowledgments

This research was supported by Northern Technical University/ Technical Engineering College Mosul/ Department of Electrical Engineering Techniques via using some of the laboratory instruments.

References

[1] Abolghasemi, Mahdi, et al. "Recent advances of step-up multi-stage DC-DC converters: A review on classifications, structures and grid applications." *Energy Reports, Vol.* 13 (2025), pp. 3050-3081 https://doi.org/10.1016/j.egyr.2025.02.025

[2] Ahmed M. T. Ibraheem Alnaib, Nashwan S. Sultan, Omar T. Mahmood, "Design a Fuel Cell Based Drive DC Motor for an Electric Vehicle Applications", International Journal of Engineering & Technology, Vol. 7, No. 4, 2018, pp. 2081-2087. https://doi.org/10.14419/ijet.v7i4.16308

[3] Nguyen, V. K., Tran, V. K., Pham, H., Nguyen, H. D., & Nguyen, C. N. (2024). Design and Implementation of Fuzzy-based Fine-tuning PID Controller for Programmable Logic Controller. *International Journal of Integrated Engineering*, Vol. *16, No.* 5, pp. 359-372. https://doi.org/10.30880/ijie.2024.16.05.027

[4] Y. Li, C. Tang and K. Liu, "PID parameter self-setting method base on S7–1200 PLC," *2011 International Conference on Electrical and Control Engineering*, Yichang, China, 2011, pp. 274-277, https://doi.org/10.1109/ICECENG.2011.6057410

[5] A. Lakshmi Sangeetha, B. Naveenkumar, A. Balaji Ganesh, N. Bharathi, "Experimental validation of PID based cascade control system through SCADA–PLC–OPC and internet architectures", Measurement,Vol. 45, Issue 4, 2012, pp. 643-649, https://doi.org/10.1016/j.measurement.2012.01.005

[6] A. Lakshmi, B. Sangeetha, A. Naveenkumar, B. Ganesh and N. Bharathi, "Experimental validation of PID based cascade control system through SCADA-PLC-OPC interface," *2012 International Conference on Computer Communication and Informatics*, Coimbatore, India, 2012, pp. 1-4, https://doi.org/10.10.1109/ICCCI.2012.6158893

[7] Hadi Supriyanto, Muhammad Nursyam Rizal, Sugeng Wibowo, "Implementation of Siemens S7-1200 PID Control on Festo Labvolt 3531 Plant Level Controller with Topkapi SCADA Using Modbus Communication Protocol", Journal La Multiapp , Vol. 05, Issue 02, pp. 131-144, 2024, https://doi.org/10.37899/journallamultiapp.v5i2.1356

[8] Możaryn, J., Petryszyn, J. & Ozana, S. PLC based fractional-order PID temperature control in pipeline: design procedure and experimental evaluation. *Meccanica, Vol.* 56, pp. 855–871, 2021. https://doi.org/10.1007/s11012-020-01215-0

[9] Almedin Salkić, Haris Muhović, Dejan Jokić,"Siemens S7-1200 PLC DC Motor control capabilities", IFAC-PapersOnLine,Vol. 55, Issue 4, 2022,pp. 103-108, https://doi.org/10.1016/j.ifacol.2022.06.017.

[10] Doan, N. T., & Thanh, P. H. (2021). "DC Motor Speed Stabilizer System uses PID algorithm" Thu Dau Mot University Journal of Science, 2021, Vol. 3, issue 2, pp. 177-188, https://doi.org/10.37550/tdmu.EJS/2021.02.198

[11] Harun Ozbay, "PLC based PID control for induction motor drive using VFD", Aintelia Science Notes, 2023, Vol. 2, Issue 1.

[12] Kutaiba K. Khaleel, Ahmed M. T. Ibraheem Al-Naib, Thamir H. Atyia "An efficient wireless monitoring system for photovoltaic panels using bluetooth technology", 2nd International Conference on Renewable Energy (ICRE2022), AIP Conference Proceedings. Vol. 2885. No. 1. AIP Publishing, 2024, https://doi.org/10.1063/5.0182370

[13] Thungsuk, N.; Tanaram, T.; Chaithanakulwat, A.; Savangboon, T.; Songruk, A.; Mungkung, N.; Maneepen, T.; Arunrungrusmi, S.; Poonthong, W.; Kasayapanand, N.; et al. "Performance Analysis of Solar Tracking Systems by Five-Position Angles with a Single Axis and Dual Axis", *Energies* 2023, Vol. *16*, 5869. https://doi.org/10.3390/en16165869

[14] H. Radwan, M. Mousa, M. Ahmed and M. Orabi, "Implementation of FPGA Control for Multilevel Boost Converter used for PV Applications," The 2nd International Symposium on Power Electronics for Distributed Generation Systems, Hefei, China, 2010, pp. 70-75, https://doi.org/10.1109/PEDG.2010.5545748

[15] Paredes-Parra, et al., " PV Module Monitoring System based on Low-cost Solutions: Wireless Raspberry Application and Assessment", Energies 2018, Vol. 11, 3051.

[16] Ahmed M. T. Ibraheem, "Design an Industrial Robot Arm Controller Based on PLC" PRZEGLĄD ELEKTROTECHNICZNY, Vol. 2022, No 7, PP 105-109. https://doi.org/10.15199/48.2022.07.18

[17] Bešić, J., Ajkunić, E., Hivziefendić, J., Jokić, D., & Šarić, M., "Stand-alone solar lighting system with Programmable Logic Controller", *IFAC-PapersOnLine*, Vol. *58, No.* 9, pp. 287-292, 2024, https://doi.org/10.1016/j.ifacol.2024.07.411

[18] A. M. T. I. Alnaib, O. T. Mahmood, N. Abed-Al-Bary, "PLC Controlled Multiple Stepper Motors Using Various Excitation Methods", IEEE International Conference on Engineering Technologies and their Applications, Islamic University, ALNajaf, Iraq, pp. 54-59, 2018. https://doi.org/10.1109/IICETA.2018.8458097

[19] A. M. T. I. Al-Naib, K. M. Z. Othman "Design and Implementation of a Real-Time Monitoring Platform for Solar PV Panels Using PLC", Przegląd Elektrotechniczny Journal, Vol. 99, Issue 6, 2023. https://doi.org/10.15199/48.2023.06.04

[20] Majeed Ismail Mohammed, Ahmed M. T. Ibrahim Al-Naib, "Design of a SCADA System for a Solar Photovoltaic Power Plant", NTU Journal of Engineering and Technology, 2023, Vol. 2, No. 2, pp. 55-62, https://doi.org/10.56286/ntujet.v2i2.598

[21] Ahmed M. T. Ibraheem Al-Naib, Majeed Ismail Mohammed," IoT-Based Real Time Data Acquisition of PV Panel", International Conference on Engineering, Science and Advanced Technology (ICESAT2023), Mosul, Iraq. https://doi.org/10.1109/ICESAT58213.2023.10347321

[22] S. Manna, D. Singh, et.al., "Design and implementation of a new adaptive MPPT controller for solar PV systems" Energy Reports, Vol. 9, 2023, pp. 1818-1829. https://doi.org/10.1016/j.egyr.2022.12.152

[23] Hossain, Mohammad Shahadat, and Imtiaz Akber Chowdhury. "DATAEMS: design and development of a data analysis-based energy monitoring system." *e-Prime-Advances in Electrical Engineering, Electronics and Energy, Vol.* 6, 2023, https://doi.org/10.1016/j.prime.2023.100387

[24] Ahmed J. Ali, Ahmed M. T. Ibraheem Alnaib, and Omar Talal Mahmood, " Design of a Smart Control and Protection System for Three-Phase Generator Using Arduino", IOP Conference Series: Materials Science and Engineering, Vol. 745, The Fourth Scientific Conference for Engineering and Postgraduate Research 16-17 Dec. 2019, Baghdad, Iraq. https://doi.org/10.1088/1757-899X/745/1/012027