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Control and monitoring of 1 phase generator automatic voltage regulator internet of things

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ABSTRACT

This research focuses on the importance of maintaining generator output voltage stabilization using automatic voltage regulator (AVR), especially in dealing with load impacts and environmental changes. Through the implementation of internet of things (IoT), this system can be controlled and monitored remotely, enabling real-time monitoring without physical presence at the generator location. The main objective of this research is to increase energy efficiency by optimizing generator operation. System development methods include design, prototyping and testing stages. Test results show that the automatic voltage regulator is effective in maintaining a stable output voltage of around 220 V, even though the current varies according to the existing load. The power produced ranges from 23 to 670 W, with a power factor between 0.7 and 1. Despite a slight voltage drop to 217 V, the power factor increases to 0.93. The system uses NodeMCU to send data to Blynk and Google Spreadsheets servers, as well as servo motors and PZEM-004T sensors for control and monitoring. Overall, this research shows that the internet of things-based automatic voltage regulator system is effective in maintaining stability and increasing generator operational efficiency, with the ability to manage voltage, current, power, and power factor efficiently.

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1. INTRODUCTION

In the current era, the internet of things (IoT) has changed the paradigm of controlling and monitoring electronic devices [1], [2] including the automatic voltage regulator (AVR) control and monitoring system on single-phase generators [3], [4]. Generators are important industrial and commercial devices for providing backup power [5]. One of the key components in the generator is the AVR [6] which functions to maintain the stability of the output voltage [7]. However, the problems faced are generator output voltage instability [8], load fluctuations, environmental changes and reduced system efficiency which can cause damage to electrical equipment or even failure of the electric power supply [9]. Therefore [10], the development of an effective and efficient control and monitoring system is important in ensuring the smooth operation of electric generators [11], [12]

This research aims to develop an IoT-based AVR control and monitoring system for single-phase generators. Currently, AVR control is still done manually, which is not only inefficient but also prone to human error. A known solution is to adopt IoT technology for automation and remote monitoring, which has been proven effective in various fields but has not been widely implemented in AVR generator set systems. The main obstacles faced are the integration of IoT technology with existing AVR systems, as well as the reliability and security of data transmitted via the internet network. The main objective of this research is to design and implement an IoT-based AVR system that is capable of controlling and monitoring voltage in real-time [13], with the hope of increasing operational efficiency and reducing errors in operation. In the context of IoT [14], this research further contributes by combining traditional AVR [15], [16] control using microcontrollers with IoT technology to provide remote control and monitoring capabilities [17]. This IoT system allows voltage, current, and power data to be collected in real-time, processed, and analyzed to ensure optimal voltage stability [18]. The addition of IoT elements also enables operators to respond quickly to changing operational conditions and potential issues, reducing the risk of damage and increasing overall system efficiency [19].

Studies related to AVR control systems using the hill climbing method on microcontrollers provide a crucial foundation for this research. Previous research titled “automatic voltage regulator (AVR) generator with microcontroller using hill climbing method” has demonstrated how the hill climbing method can be used to efficiently regulate the generator's output voltage. This hill climbing method works by continuously iterating to find the optimal output voltage value, ensuring stable voltage despite load changes. Another study, “automatic voltage regulator control system for synchronous generator,” implemented a proportional-integral-derivative (PID) controller to control the AVR on three-phase synchronous generators [20]. This approach successfully improved terminal voltage stability and system response to load changes. A third study, “Performance and durability analysis of PID V-Tiger controllers for automatic voltage regulators,” evaluated the performance and durability of PID V-Tiger controllers on AVRs. The results showed that PID V-Tiger controllers provided better voltage stability and extended the operational life of the generator with more precise control [21]. The integration of IoT technology into AVR systems can not only increase energy efficiency [22] and electricity [23] supply availability, but also improve operational safety and security [24]. The proposed solution will involve the use of hardware such as a NodeMCU microcontroller connected to the internet, to ensure effective control and monitoring of the AVR system [25].

2. METHOD

The type of research used in this research is development research. This type of research aims to develop a new system or technology, in this case the development of an IoT-based AVR control and monitoring system [26]. This research includes the design, prototyping and system testing stages. The main research variable is the implementation of the AVR control and monitoring system on an IoT-based single-phase generator. The associated variables involve data on generator voltage, current, generator status, IoT connection status, and AVR Settings by controlling the magnetic field applied to the associated load.

2.1. AVR control and monitoring equipment working system

The flowchart of Figure 1 covers all the main steps in the IoT-based AVR control and monitoring system of a single-phase generator. To customize the details and add additional steps according to the specific implementation and configuration of the system being developed. Starting from sensors as input to AVR control with servo motors.

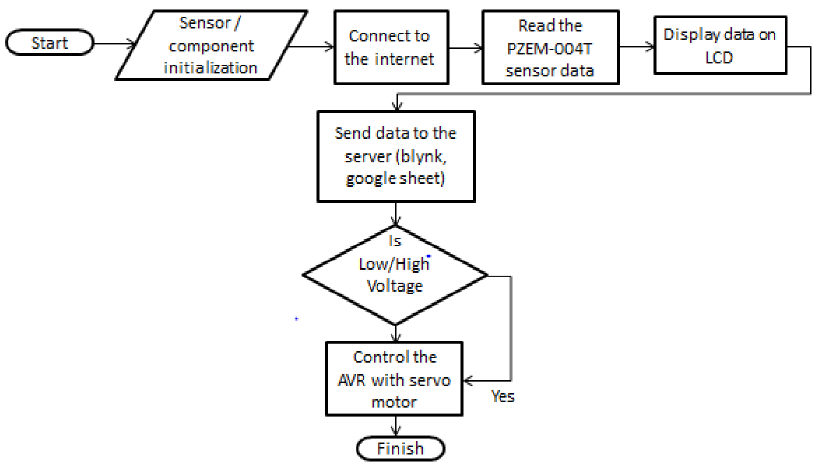


Figure 1. AVR control and monitoring device working system

2.1.1. Flowchart explained

Read sensor data (PZEM004T): The PZEM-004T sensor measures generator voltage and current periodically. Decisions are based on this data to determine voltage stability. If stable, adjust the AVR settings by controlling the servo motor to move the potentiometer or AVR part. If unstable, additional measures may be required. Adjust AVR settings: The servo motor adjusts the AVR components to keep the output voltage stable. Servo motor control: Servo drives AVR components per control signal. Display data: voltage, current and generator status are displayed on the LCD. Data updates: data and sensor status are updated in real-time to the Blynk app and stored in Google Sheets for analysis.

2.2. Hardware design

2.2.1. PZEM-004T sensor

The PZEM-004T sensor is used to measure [27] voltage, current, power and electrical power factor by pairing a current transformer (CT) connected to the PZEM-004T sensor at each phase. Parameters are measured using the current transformer coil and input source. The PZEM-004T [28] sensor connects to the ESP32 NodeMCU via serial communication [29].

2.2.2. nodeMCU ESP32

Acts as the main microcontroller that processes the data from the PZEM-004T sensor and transmits the data to the IoT platform. The ESP32 NodeMCU [30] is connected with a PZEM-004T sensor, servo motor, and I2C LCD. In addition, NodeMCU also connects to a Wi-Fi network to transmit data to Blynk and Google Spreadsheets servers [31], [32].

2.2.3. Liquid crystal display (LCD) I2C

The I2C LCD serves as a crucial display for showing voltage, current, power, and power factor values [33], essential for monitoring and controlling electrical systems. It utilizes 4 pins—serial clock line (SCL), serial data line (SDA), Ground (GND), and voltage common collector (VCC)—connected to the ESP32 NodeMCU to ensure stable communication and power supply [34]. SCL and SDA facilitate data exchange between the LCD and ESP32 NodeMCU, while GND and VCC provide necessary power. This integration enables real-time monitoring via a user-friendly display [35], enhancing efficiency and accuracy in monitoring electrical parameters.

2.2.4. Servo motors

A servo motor in smart industrial machines adjusts objects by varying its angle (0°, 90°, 180°) with precise control over position, acceleration, and speed [36], [37]. In this study, a servo motor acts as an AVR controller [38], regulating voltage by positioning AVR components. Feedback systems use servo motors to adjust AVR parts based on voltage sensor data. The motor signals move AVR components, regulating potentiometers or transformers for voltage output. Movements are precise, aligning with set voltage points. This loop maintains stable output voltage.

2.3. Software design

2.3.1. Arduino IDE

The Arduino IDE functions as a command center for all device system [39] components and the main platform for NodeMCU ESP32 programming. It is used to write, compile, and upload code for sensor data collection, servo motor control, and IoT platform communications, ensuring efficient integration [40]. Verification checks for errors in the code, ensuring proper functionality before real-world implementation. The Arduino IDE reads [41] data from the PZEM-004T sensor, controls the servo motor based on voltage measurements, and sends the data to the Blynk server and Google Spreadsheets for accurate, real-time monitoring and control.

2.3.2. Blynk

Blynk is used as a mobile application for real-time AVR control and monitoring [42], ensuring efficient and responsive system management. This IoT-based app allows users to quickly and easily control and read electrical parameters via the internet. Through the Blynk dashboard, users can monitor electrical parameters, control AVR output voltage [43], and receive notifications of system anomalies. Blynk was chosen for its ease of use [44], smartphone compatibility, and ability to provide critical real-time information, offering flexibility and convenience for remote system performance maintenance.

2.3.3. Google Sheets

NodeMCU ESP32 sends collected data to Google Spreadsheets via API, facilitating organized data storage and long-term access for analysis [45]. Generator measurement data includes current, voltage, power and power factor [46], controlled by AVR, collected by sensors, processed by NodeMCU ESP32, and then displayed on the smartphone application. Google Sheets serves as a data repository for recording AVR control and monitoring results, ensuring data is accessible for real-time monitoring and historical analysis to improve system efficiency [47].

2.4. Testing and calibration

The PZEM-004T sensor undergoes rigorous testing for accurate voltage, current and power measurements essential in AVR control and monitoring systems. Connected to NodeMCU ESP32, it ensures effective communication with proper pin configuration, supporting real-time system monitoring with high precision. Likewise, the servo motor underwent testing to precisely control the position according to the AVR voltage settings, demonstrating its ability to maintain voltage accuracy. Connected via PWM to the NodeMCU ESP32, it precisely adjusts the servo rotation angle, ensuring stable system operation. Integration with Blynk and Google Spreadsheets enables real-time transmission of electrical data for responsive IoT-based generator management.

2.5. Realization of automatic voltage regulator (AVR) control and monitoring system

This system aims to control and monitor AVR voltage and current both locally and remotely. Start by installing the control box to manage AVR operation. The PZEM-004T sensor measures voltage, current, power and power factor in real-time, processed by the NodeMCU ESP32 to assess electrical conditions. The LCD screen visually displays AVR data and settings. The servo motor regulates the AVR mechanism to stabilize the output voltage based on the control signal. Figure 2 shows the overall system circuit, providing an overview of how all components are connected and work together to achieve effective control and monitoring. This arrangement enables real-time monitoring and regulation of mains voltage, increasing control effectiveness and reducing power supply instability. Using the Arduino IDE simplifies program development for the NodeMCU ESP32, integrating sensor control, servo motor operation, and IoT communications through platforms such as Blynk and Google Spreadsheets. Thus, the system efficiently manages AVR control and monitoring, sending real-time data for remote analysis and monitoring.

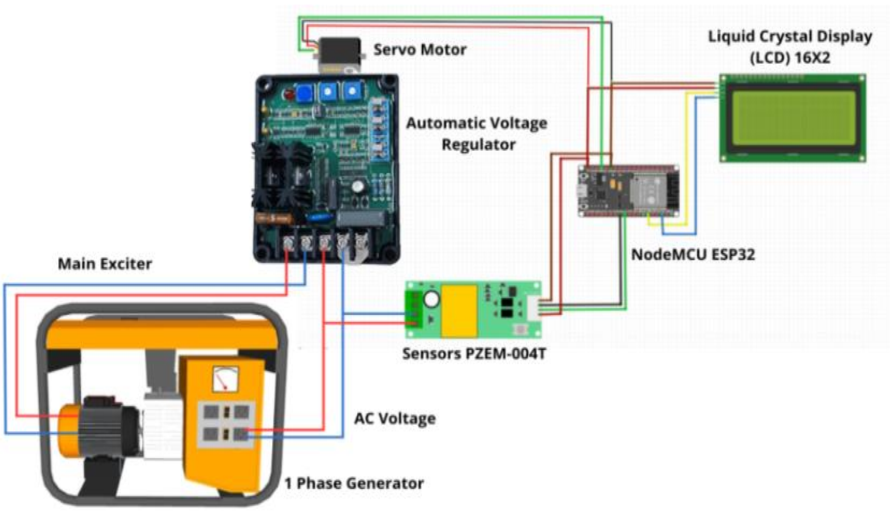


Figure 2. Realization of AVR control and monitoring system design

3. RESULTS AND DISCUSSION

3.1. PZEM-004T sensor test results at voltage

The PZEM-004T sensor consistently provides accurate voltage measurements, maintaining stable readings near expected levels across multiple tests, as shown in Table 1 Testing the PZEM-004T sensor on voltage, ensuring its reliability for real-time monitoring and control applications. Table 1 shows the results of the electrical voltage test of the PZEM-004T sensor which was carried out on February 6, 2024. The test results show that the voltage values measured by the measuring instrument and the PZEM-004T sensor are in the same condition. the distance is very close, with little difference between the two. This shows that the PZEM-004T sensor is capable of providing stable and accurate voltage measurements during operation on the electrical system being tested.

Table 1. PZEM-004T sensor testing at voltage

Date	Time	Measuring instrument (V)	PZEM-004T sensors (V)
2024-02-06	15:05:25	220.4	220.4
2024-02-06	15:05:44	220.7	220.7
2024-02-06	15:06:01	221.1	221.1
2024-02-06	15:06:39	220.6	220.6
2024-02-06	15:07:28	220.7	220.6

3.2. PZEM-004T sensor test results on current

The PZEM-004T sensor displays current measurements across various electrical loads, its reliable accuracy in detecting current variations to identify potential overloads or anomalies in the electrical system. The results of these measurements are summarized in Table 2 which shows the current variations. Table 2 summarizes the PZEM-004T sensor current measurements at various loads on February 6, 2024, showing stable and consistent readings in a variety of electrical settings. For example, it recorded 0.15 A at a 28 W fan load and 1.44 A at a 350 W Maspion iron load. These results demonstrate the reliable accuracy of the sensor in current monitoring, although there are slight deviations from other measuring instruments, possibly due to tolerances sensor or operational conditions during measurement.

Table 2. PZEM-004T sensor testing on current

Date	Time	Load type	Measuring instrument (A)	PZEM-004T sensors (V)
2024-02-06	00:18:17	28 W Fan	0.15	0.15
2024-02-06	00:41:48	HE lamp 23 W	0.13	0.14
2024-02-06	00:32:17	Soldering 40 W	0.14	0.14
2024-02-06	00:21:23	Maspion Iron 350 W	1.45	1.44
2024-02-06	01:32:39	Dispenser Genesys 450 W	2.01	2.01

3.3. PZEM-004T sensor test results on power

The recorded power measurement results show the accuracy of the PZEM-004T sensor in calculating electrical power consumption at various loads. The results of these measurements are summarized in Table 3, which shows the variations in electrical power. These measurements are important for optimizing energy efficiency in electrical systems.

Table 3. PZEM-004T sensor test on electrical power

Date	Time	Load type	Measuring instrument (W)	PZEM-004T sensors (W)
2024-02-06	00:18:17	28 W Fan	25	25
2024-02-06	00:41:48	HE lamp 23 W	20,9	21
2024-02-06	00:32:17	Soldering 40 W	30,9	31,2
2024-02-06	00:21:23	Maspion Iron 350 W	304,9	205
2024-02-06	01:32:39	Dispenser Genesys 450 W	417	417

Table 3 dated February 6, 2024, summarizes PZEM-004T sensor tests across different loads, focusing on electrical power. Measurements include 25 W at 00:18:17 for fans, 21 W at 00:41:48 matching 20.9 W for lamps, and 31.2 W at 00:32:17 compared to 30.9 W for soldering. At 00:21:23, a discrepancy showed 205 W on the sensor versus 304.9 W on another device, possibly due to load complexity. At 01:32:39, both sensors recorded 417 W for dispensers, indicating consistent measurement accuracy across varying loads.

3.4. Servo motor test results on automatic voltage regulator (AVR)

The servo motor confirmed the effectiveness of the AVR in regulating the generator output voltage. The results in Table 4 show the response of the servo motor to voltage adjustments, highlighting its role in maintaining stable voltage levels under various conditions. The servo motor is active at an angle of 170° (turn left) and an angle of 35° (turn right), under ideal conditions. When rotating to the right, the servo motor increases the system voltage, showing good controllability. Conversely, turning left produces a decrease in voltage. This test is very important in controlling the generator output voltage on the AVR. Integration of mini servo motors for AVR setup involves electronic mechanization and control. The rotational movement of the motor is converted into linear movement to regulate the voltage. The electronic control program receives signals from the IoT to drive the servo.

Table 4. servo motor angle test on AVR potentiometer

No	Servo motors	Servo angle	Condition		Information
			Rotate left	Rotate right	
1	Active	170°		Ideal	Voltage increases
2	Active	35°	Ideal		Voltage drop

3.5. Automatic voltage regulator (AVR) test results

The AVR test results show that the voltage regulation system on the generator has been evaluated well. During testing, the AVR was able to keep the generator output voltage stable within the desired limits, even when significant load fluctuations occurred. The results of these measurements are summarized in Table 5, which shows the variation in output voltage (VAC) for each type of load. The response to changes in load is very responsive, with a stable output voltage in a short time after the change occurs.

Table 5. Automatic voltage regulator (AVR) test on a 1-phase generator

No	Testing	Amount	Specification	Voltage (VAC)	Excitation voltage	Excitation current
1	No burden	0	0	220.7 VAC	15.3 VEx	0.84 IEx
2	Lighting	23 Watt	1	220.2 VAC	21.6 VEx	0.72 IEx
3	Soldering	40 Watt	1	220.9 VAC	16.9 Vex	0.91 IEx
4	Fan	50 Watt	1	220.2 VAC	24.3 Vex	1.25 IEx
5	Sanyo sharp	125 Watt	1	217.5 VAC	18.6 Vex	2.88 IEx
6	Coconut grating machine	200 Watt	1	219.3 VAC	20.2 Vex	2.21 IEx
7	Blender	300 Watt	1	218.1 VAC	25.6 Vex	2.31 IEx
8	Washing machine	320 Watt	1	218.9 VAC	20.9 Vex	2.30 IEx
9	Maspion iron	350 Watt	1	217.1 VAC	16.7 Vex	3.05 IEx
10	Genesy dispenser	450 Watt	1	217.5 VAC	15.4 Vex	4.03 IEx
11	Drill ryu	600 Watt	1	217.3 VAC	26.6 Vex	3.21 IEx
12	Bosch grinder	670 Watt	1	217.1 VAC	20.9 Vex	3.77 IEx

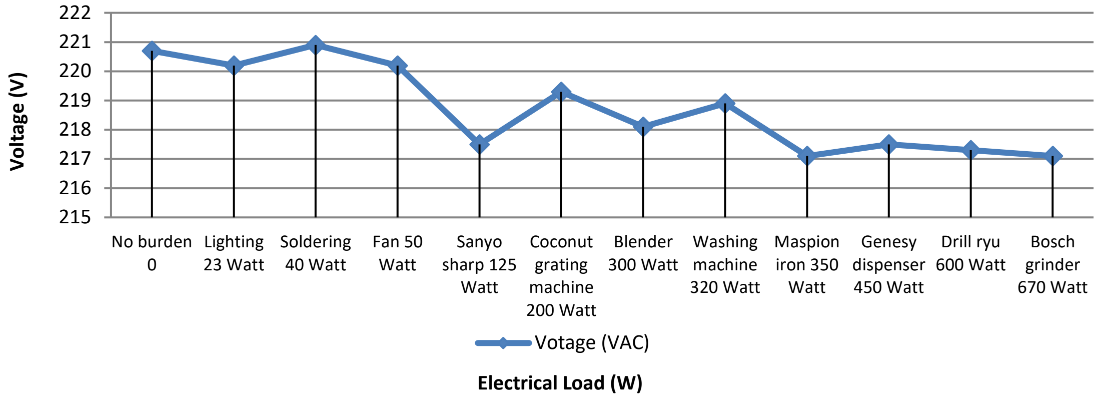
Generators with AVR keep the output voltage stable. Loads ranging from 40 to 670 W demonstrate the AVR's ability to adjust output voltages between 217.1 and 220.9 VAC. Figure 3 shows the performance simulation results of the automatic voltage regulator on Figure 3(a) voltage (VAC), Figure 3(b) excitation voltage (VEx), and Figure 3(c) excitation current (IEx) graphs, illustrating the voltage stability and adjustment of excitation parameters under various loads.

The graph displays voltage over time, highlighting fluctuations. Peak voltage reached 220.9 V, with variations at 220.5, 220.1, and 217.1 V. AVR excitation voltage ranged from 15.3 to 26.6 V, showing system response instability to diverse loads. Excitation current varied between 0.72 and 4.03 A unpredictably. AVR testing affirmed stable generator voltage control under varied loads, adjusting excitation voltage and current appropriately. Monitoring over three days tracked voltage around 220 V, varying current (23 to 670 W), and power factor (0.7 to 1). Voltage briefly dipped to 217.1 V, with a power factor peak at 0.93. This data outlines system performance, aiding effective monitoring.

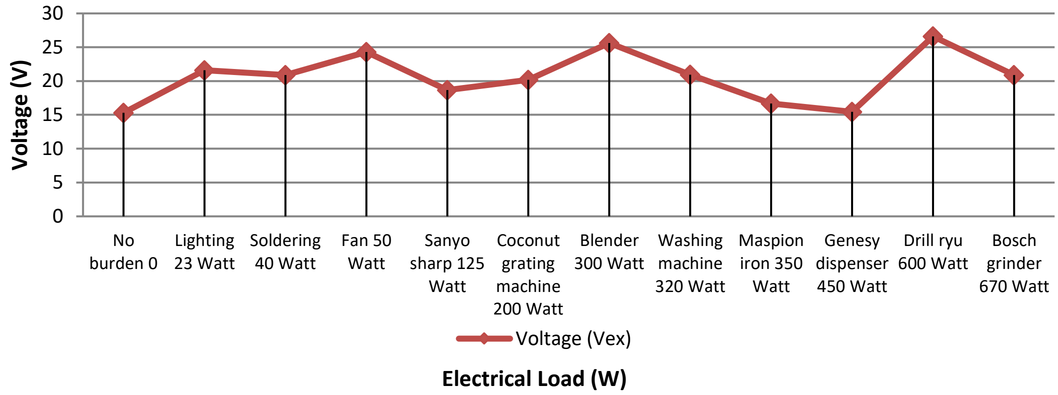
3.6. Realization of AVR control and monitoring system

During the process of installing the control box, make sure the generator is turned off first to maintain the safety of technicians and equipment. After the generator is turned off, install the controller on the AVR and connect the voltage to the PZEM-004T sensor. Figure 4 shows the integration of the tool and generator system, providing a visual guide to how the components are physically connected. Once completed, ensure circuit continuity for safe use of the equipment. After the generator restarts, monitor the LCD displays on the control box and Blynk server. Monitoring was carried out for 3 days by monitoring the output graph on Blynk which displays the results of monitoring voltage and current. from the generator. The Blynk platform includes widgets to control the AVR and display electrical parameter values and graphs. Voltage, current, power and power factor data can be stored and accessed via spreadsheets on a mobile phone, PC or laptop. The measurement results are summarized in Table 6 which shows variations in electrical parameters for each type of load.

Electrical system monitoring data on certain dates shows voltage variations between 217.1 to 220.8 V, and current flowing between 0.16 to 2.36 A. Electrical power consumption ranges from 25 to 670 W, with a power factor recorded efficiencies from 0.7 to 1. This information provides the monitor operator with an overview of the performance of the electrical system at various times.



(a)



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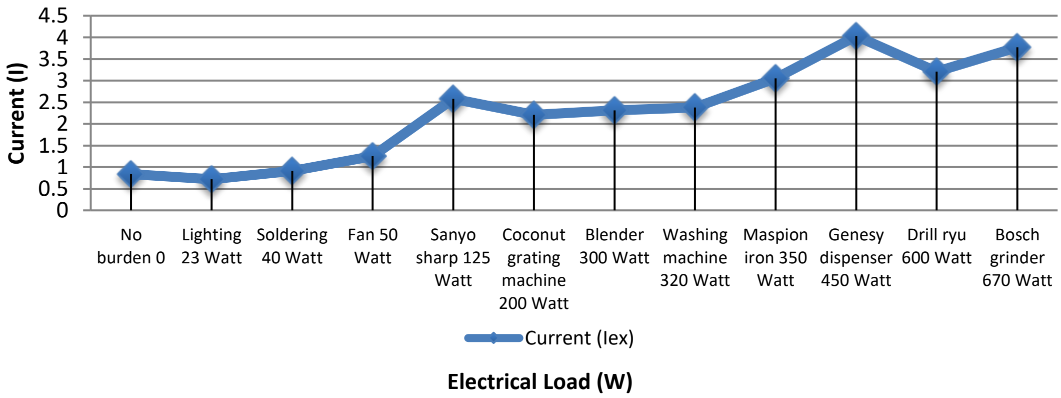

(c)

Figure 3. Simulation results of automatic voltage regulator performance on (a) voltage graph (VAC), (b) excitation voltage (VEx), and (c) excitation current (IEx)

Table 6. Monitoring spreadsheets on AVR

Date	Time	Voltage (V)	Current (A)	Power (W)	Power Factor (Pf)
06/02/2024	9:36:10	220.8	0.16	25	0.7
06/02/2024	9:51:23	220.2	0.2	33.4	0.76
07/02/2024	13:57:18	219.2	0.42	84.4	0.93
07/02/2024	14:12:09	219.4	0.43	86	0.92
08/02/2024	11:39:26	219.3	1.98	415.1	1
08/02/2024	11:55:04	218.9	1.98	413	1
09/02/2024	8:20:08	217.1	2.36	670	1
09/02/2024	8:36:16	217.4	2.34	658	0.97

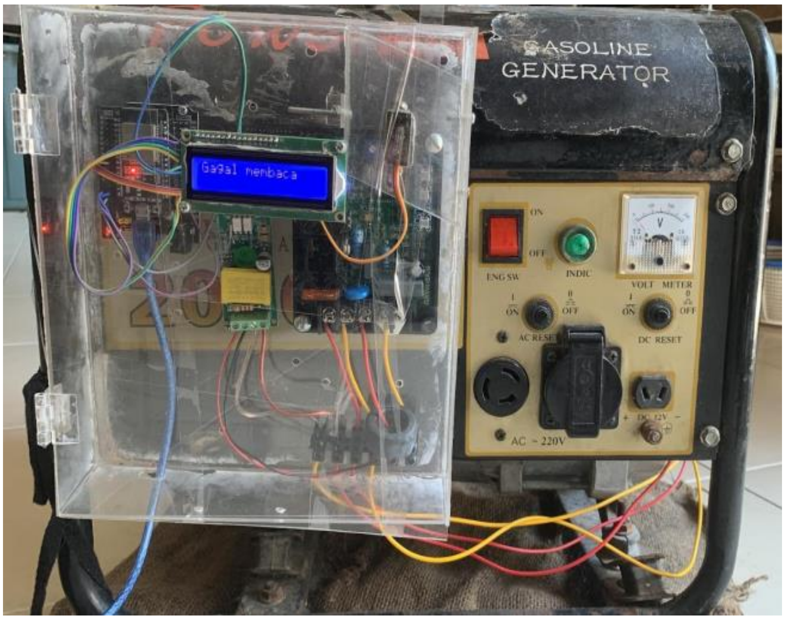

Figure 4. Overall design of the tools on the system

4. CONCLUSION

This research successfully designed and implemented an IoT-based AVR control system for single-phase generators, enabling remote monitoring and control via platforms such as NodeMCU, Blynk, and Google Spreadsheets. Testing confirmed accurate voltage, current and power measurements of the PZEM-004T sensor, maintaining a stable output voltage of approximately 220 V despite load changes. Utilizing servo motors for AVR voltage control ensures precise and stable response, improving operational efficiency and equipment safety. Data collection supports further analysis, provides insight into electrical system performance and suggests broad industrial applications. Future research could optimize IoT integration in AVR systems and assess economic and environmental impacts.

REFERENCES

[1] N. H. Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of things (IoT) and the energy sector," *Energies*, vol. 13, no. 2, Jan. 2020, doi: 10.3390/en13020494.

[2] V. P. Kour and S. Arora, "Recent developments of the internet of things in agriculture: a survey," *IEEE Access*, vol. 8, pp. 129924–129957, 2020, doi: 10.1109/ACCESS.2020.3009298.

[3] P. M. Patil and D. S. K. Patil, "Automatic voltage regulator," in *International Conference on Emerging Trends in Information Technology and Engineering, ic-ETITE 2020*, 2020, pp. 1–5, doi: 10.1109/ic-ETITE47903.2020.476.

[4] D. Izci, R. M. Rizk-Allah, V. Snášel, S. Ekinci, F. A. Hashim, and L. Abualigah, "A novel control scheme for automatic voltage regulator using novel modified artificial rabbits optimizer," *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 6, no. August, 2023, doi: 10.1016/j.prime.2023.100325.

[5] P. Marchi, P. G. Estevez, F. Messina, and C. G. Galarza, "Loss of excitation detection in synchronous generators based on dynamic state estimation," *IEEE Transactions on Energy Conversion*, vol. 35, no. 3, pp. 1606–1616, 2020, doi: 10.1109/TEC.2020.2985529.

[6] M. Micev, M. Ćalasan, and M. Radulović, "Optimal tuning of the novel voltage regulation controller considering the real model of the automatic voltage regulation system," *Heliyon*, vol. 9, no. 8, 2023, doi: 10.1016/j.heliyon.2023.e18707.

[7] R. Syawali and S. Meliala, "IoT-based three-phase induction motor monitoring system," *Journal of Renewable Energy, Electrical, and Computer Engineering*, vol. 3, no. 1, 2023, doi: 10.29103/jreece.v3i1.9811.

[8] A. Hasibuan, M. Isa, M. I. Yusoff, S. R. Abdul Rahim, and I. M. A. Nrartha, "Effect of installation of distributed generation at different points in the distribution system on voltage drops and power losses," in *AIP Conference Proceedings*, 2021, vol. 2339, no. December 2022, doi: 10.1063/5.0044192.

[9] X. Zhang, L. Gong, X. Zhao, R. Li, L. Yang, and B. Wang, "Voltage and frequency stabilization control strategy of virtual synchronous generator based on small signal model," *Energy Reports*, vol. 9, no. 221, pp. 583–590, 2023, doi: 10.1016/j.egyr.2023.03.071.

[10] A. A. Mahal and A. R. S. Hadi, "Analysis of performance for the various types of controllers used in the automatic voltage regulator system (AVR)," *Passer Journal of Basic and Applied Sciences*, vol. 6, no. 25, pp. 382–393, 2024, doi: 10.24271/PSR.2024.189657.

[11] C. P. Ohanu, K. C. Odo, L. U. Omeje, and T. Sutikno, "Output performance evaluation of the automatic voltage regulator system on pre-filter control technique," *International Journal of Power Electronics and Drive Systems*, vol. 14, no. 2, pp. 789–798, 2023, doi: 10.11591/ijpeds.v14.i2.pp789-798.

[12] D. E. Ochoa, F. Galarza-Jimenez, F. Wilches-Bernal, D. A. Schoenwald, and J. I. Poveda, "Control systems for low-inertia power grids: a survey on virtual power plants," *IEEE Access*, vol. 11, no. February, pp. 20560–20581, 2023, doi:

10.1109/ACCESS.2023.3249151.

[13] S. Ur Rehman, H. Mustafa, and A. R. Larik, "IoT based substation monitoring control system using arduino with data logging," in *2021 4th International Conference on Computing & Information Sciences (ICCIS)*, Nov. 2021, pp. 1–6, doi: 10.1109/ICCIS54243.2021.9676384.

[14] M. Mina and K. Kartika, "Monitoring system for levels of voltage, current, temperature, methane, and hydrogen in IoT-based distribution transformers," *International Journal of Engineering, Science and Information Technology*, vol. 3, no. 1, pp. 22–27, 2023, doi: 10.52088/ijesty.v3i1.414.

[15] Ö. Türksoy and A. Türksoy, "A fast and robust sliding mode controller for automatic voltage regulators in electrical power systems," *Engineering Science and Technology, an International Journal*, vol. 53, no. April, 2024, doi: 10.1016/j.jestch.2024.101697.

[16] A. K. Sahin, B. Cavdar, and M. S. Ayas, "An adaptive fractional controller design for automatic voltage regulator system: sigmoid-based fractional-order PID controller," *Neural Computing and Applications*, vol. 6, 2024, doi: 10.1007/s00521-024-09816-6.

[17] Wahyu Sejati and Vivi Melinda, "Education on the use of IoT technology for energy audit and management within the context of conservation and efficiency," *International Transactions on Education Technology (ITEE)*, vol. 1, no. 2, pp. 138–143, 2023, doi: 10.34306/itee.v1i2.324.

[18] A. Hasibuan, M. Isa, I. M. A. Nrartha, and S. Hardi, "Improving voltage profile of 150 KV transmission line in Aceh subsystem with capacitor bank installation," in *2019 3rd International Conference on Electrical, Telecommunication and Computer Engineering, ELTICOM 2019 - Proceedings*, 2019, no. September 2020, pp. 140–144, doi: 10.1109/ELTICOM47379.2019.8943910.

[19] A. Hasibuan, W. V. Siregar, M. Isa, E. Warman, R. Finata, and M. Mursalin, "The use of regression method on simple e for estimating electrical energy consumption," *HighTech and Innovation Journal*, vol. 3, no. 3, pp. 306–318, 2022, doi: 10.28991/HIJ-SP2022-03-06.

[20] I. A. Ezenugu and C. S. Nwokonko, "Automatic voltage regulator control system for synchronous generator," *Saudi Journal of Engineering and Technology*, vol. 9, no. 06, pp. 265–273, Jun. 2024, doi: 10.36348/sjet.2024.v09i06.004.

[21] P. Gopi, S. V. Reddy, M. Bajaj, I. Zaitsev, and L. Prokop, "Performance and robustness analysis of V-Tiger PID controller for automatic voltage regulator," *Scientific Reports*, vol. 14, no. 1, pp. 1–15, 2024, doi: 10.1038/s41598-024-58481-1.

[22] P. Mishra and G. Singh, "Energy management systems in sustainable smart cities based on the internet of energy: a technical review," *Energies*, vol. 16, no. 19, 2023, doi: 10.3390/en16196903.

[23] Rohana, S. Hardi, J. D. A. Tambunan, and A. Hasibuan, "Influence of static VAR compensator application for improving power quality in distribution lines supplied industry," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 1003, no. 1, doi: 10.1088/1757-899X/1003/1/012136.

[24] S. El Himer, M. Ouaissa, M. Ouaissa, M. Krichen, M. Alswailim, and M. Almutiq, "Energy consumption monitoring system based on IoT for residential rooftops," *Computation*, vol. 11, no. 4, 2023, doi: 10.3390/computation11040078.

[25] M. Bošković, T. B. Šekara, D. M. Stojić, and M. R. Rapaić, "Novel tuning rules for PIDC controllers in automatic voltage regulation systems under constraints on robustness and sensitivity to measurement noise," *International Journal of Electrical Power and Energy Systems*, vol. 157, no. January, 2024, doi: 10.1016/j.ijepes.2024.109791.

[26] G. Guerrero-Ulloa, C. Rodríguez-Domínguez, and M. J. Hornos, "Agile methodologies applied to the development of internet of things (IoT)-based systems: a review," *Sensors*, vol. 23, no. 2, 2023, doi: 10.3390/s23020790.

[27] A. Multi, M. Mujiburohman, and K. Wardana, "Application design of a multiple power source monitoring system based on the internet of things (IoT)," *International Journal of Advanced Multidisciplinary*, vol. 2, no. 4, pp. 998–1010, 2024.

[28] Suprianto, H. T. Frianto, A. F. Bin Abidin, M. F. bin M. Idros, and A. H. A. Razak, "Electrical load control using PIR sensor for IoT-based electrical power saving," *International Journal of Research in Vocational Studies (IJRVOCAS)*, vol. 3, no. 4, pp. 198–203, 2024, doi: 10.53893/ijrvocas.v3i4.252.

[29] S. A. Ajagbe, O. A. Adeaga, O. O. Alabi, A. B. Ikotun, M. A. Akintunde, and M. O. Adigun, "Design and development of arduino-based automation home system using the internet of things," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 33, no. 2, pp. 767–776, 2024, doi: 10.11591/ijeecs.v33.i2.pp767-776.

[30] M. Ghafoor, A. A. Amin, and M. S. Khalid, "Design of IoT-based solar array cleaning system with enhanced performance and efficiency," *Measurement and Control (United Kingdom)*, 2024, doi: 10.1177/00202940241233383.

[31] I. G. M. N. Desnanjaya and I. M. A. Nugraha, "Real-time monitoring system for blood pressure monitoring based on internet of things," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 35, no. 1, pp. 62–69, 2024, doi: 10.11591/ijeecs.v35.i1.pp62-69.

[32] I. D. Pranowo and D. Artanto, "Smart monitoring system using NodeMCU for maintenance of production machines," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 25, no. 2, pp. 788–795, 2022, doi: 10.11591/ijeecs.v25.i2.pp788-795.

[33] T. B. Nguyen and T. C. Nguyen, "Design and fabrication of an IoT-based smart electrical meter for residential energy management," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 30, no. 3, pp. 1259–1268, 2023, doi: 10.11591/ijeecs.v30.i3.pp1259-1268.

[34] P. Y. Aisyah, I. P. E. W. Pratama, F. Rahmadhana, and M. G. Al Ghifari, "Internet of things-based rice field irrigation evaporation monitoring system," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 4, pp. 2331–2339, Aug. 2024, doi: 10.11591/eei.v13i4.5803.

[35] M. Anisah *et al.*, "Implementation of smart grid system for alternative energy power plants sources," in *Proceedings of the 5th FIRST T1 T2 2021 International Conference (FIRST-T1-T2 2021)*, 2022, vol. 9, pp. 227–231, doi: 10.2991/ahe.k.220205.040.

[36] M. A. Fkirin and M. A. E. Khira, "Enhanced antenna positioning control system using adapted DC Servo motor and Fuzzy-PI controller," *IEEE Access*, vol. 11, no. August, pp. 102661–102668, 2023, doi: 10.1109/ACCESS.2023.3313976.

[37] C. Chen, Z. Lv, S. Wu, K. Li, Z. Chen, and Z. Huang, "Design of control system for six-degree-of-freedom robotic arm," *Journal of Physics: Conference Series*, vol. 2724, no. 1, 2024, doi: 10.1088/1742-6596/2724/1/012006.

[38] Z. Huang, S. Qiu, B. Wang, and Q. Liu, "A real-time field bus architecture for multi-smart-motor servo system," *Scientific Reports*, vol. 14, no. 1, pp. 1–14, 2024, doi: 10.1038/s41598-024-53022-2.

[39] N. Okomba, A. Esan, B. Omodunbi, A. Sobowale, and O. Adanigbo, "Development of an android based home automation system," *ABUAD Journal of Engineering Research and Development (AJERD)*, vol. 6, no. 1, pp. 51–58, 2023, doi: 10.53982/ajerd.2023.0601.07-j.

[40] D. Hercog, T. Lerher, M. Truntič, and O. Težak, "Design and implementation of ESP32-based IoT devices," *Sensors*, vol. 23, no. 15, 2023, doi: 10.3390/s23156739.

[41] R. Siskandar, W. Wiyoto, S. H. Santosa, A. P. Hidayat, B. R. Kusumah, and M. D. M. Darmawan, "Prediction of freshwater fish

disease severity based on fuzzy logic approach, Arduino IDE and proteus ISIS," *Universal Journal of Agricultural Research*, vol. 11, no. 6, pp. 1089–1101, 2023, doi: 10.13189/ujar.2023.110616.
[42] D. Singh, K. Rajpurohit, and M. Sevak, "IoT-based food tracking and management system employing NodeMCU and the Blynk App," *International Research Journal of Engineering and Technology*, vol. 10, no. 4, pp. 56–2395, 2023.
[43] A. M. Salvan, M. Fadly, and A. Razak, "Real time monitoring small scale off grid solar system with Blynk App," *Progress in Engineering Application and Technology*, vol. 4, no. 2, pp. 385–393, 2023.
[44] M. A. Hailan, B. M. Albaker, and M. S. Alwan, "Transformation to a smart factory using NodeMCU with Blynk platform," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 30, no. 1, pp. 237–245, 2023, doi: 10.11591/ijeecs.v30.i1.pp237-245.
[45] M. Ismail Mohammed and A. M. T. Ibraheem Al-Naib, "Web server based data monitoring system of PV panels using S7-1200 PLC," *NTU Journal of Renewable Energy*, vol. 5, no. 1, pp. 103–111, 2023, doi: 10.56286/ntujre.v5i1.653.
[46] E. Garabitos Lara, A. Vallejo Díaz, and C. N. Pereyra Mariñez, "Electrical dataset of household appliances in operation in an apartment," *Data in Brief*, vol. 51, Dec. 2023, doi: 10.1016/j.dib.2023.109742.
[47] I. B. Sperstad, O. B. Fosso, S. H. Jakobsen, A. O. Eggen, J. H. Evenstuen, and G. Kjølle, "Reference data set for a Norwegian medium voltage power distribution system," *Data in Brief*, vol. 47, 2023, doi: 10.1016/j.dib.2023.109025.

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