Engineering and Technology Journal e-ISSN: 2456-3358

Volume 10 Issue 10 October-2025, Page No.- 7318-7323

DOI: 10.47191/etj/v10i10.11, I.F. – 8.482

Polynomial Fitting-Based Performance Evaluation of a Battery-Powered Fuel-less Generator Prototype Using MATLAB

T. Akinyede[1], E. A. Olajuyin[2], A. J. Bamisaye[3]

[1]Department of Electrical & Electronic Engineering, Ekiti State Polytechnic, Isan-Ekiti, Nigeria

[2]Department of Electrical & Electronic Engineering, Bamidele Olumilua University of Education, Science & Technology, Ikere-Ekiti, Nigeria

[3]Department of Electrical & Electronic Engineering, The Federal Polytechnic, Ado-Ekiti, Nigeria

ABSTRACT: This study extends earlier work on a 12 V battery-powered, fuel-less generator by applying polynomial regression in MATLAB to model and predict its performance under varying load conditions. Quadratic and cubic fits were developed for key metrics—efficiency, output voltage, motor current and battery runtime—using experimentally acquired data (10 W – 180 W). The best-fit model for efficiency vs. load was quadratic, achieving an $R^2 = 0.982$, while a cubic fit captured the non-linear behavior of runtime vs. load with $R^2 = 0.996$. The fitted equations enable rapid estimation of generator behavior for untested loads, highlight the optimal operating window (≈ 24 W – 60 W), and quantify performance degradation at heavier loads. The approach provides a low-cost analytical layer that can guide design tweaks or closed-loop control strategies in future iterations of the prototype.

KEYWORDS: Battery; Performance; Quadratic; Generator

1 INTRODUCTION

Rapid urbanisation and the widening electrification gap in many developing regions have intensified the search for affordable, reliable, and environmentally benign power solutions (Halim et al., 2023, Oyinkanola et al., 2024; Sylvester et al., 2021; Saputra, 2023; Abubakar et al., 2022). Conventional diesel- or petrol-driven generator sets remain the stop-gap choice where the public grid is absent or unstable, yet their life-cycle cost, carbon footprint, and noise all undermine long-term sustainability (Jain & Bardhan, 2024). Although large-scale renewables—solar PV farms, on-shore wind, and small hydro—have improved dramatically in price and efficiency, they still require favourable site conditions, significant up-front capital, and complex balance-of-system infrastructure before energy can be delivered to a single off-grid household (Nwokediegwu et al., 2024).

To meet short-duration or portable power needs, researchers have explored “fuel-less” generator concepts that decouple electrical generation from real-time fuel consumption by relying instead on an onboard rechargeable battery and an electromechanical conversion chain (López-Castrillón et al., 2021). In such schemes a DC motor, driven by a 12 V (or similar) battery, spins a low-speed alternator to yield 220–230 V AC suitable for domestic appliances. Diverse topologies have been reported: Oyekola et al. (2019) demonstrated a self-starter variant; Omo-Oghogho and Ofomaja (2025) added a flywheel for energy recovery; and Gabriel and Gift (2025) incorporated an auto-switching feedback loop to recharge the battery during light loading. Mengda *et al*., 2023 demonstrated that accurate capacity estimation of lithium-ion batteries is vital for electric vehicles, where full charge cycles are rarely observed. To address limited data availability, a flexible method is proposed using partial charging voltage curves fitted with polynomial functions. Key polynomial parameters are extracted as health indicators and fed into a deep learning model for capacity estimation. This approach is more data-efficient and adaptable than existing methods, offering accurate predictions across different charging scenarios and battery conditions. Abdelhakim *et al*., 2024 demonstrated accurate State of Charge (SOC) estimation is crucial for lithium-ion battery performance, but traditional methods like Coulomb Counting (CC) struggle under temperature variations. This paper proposes a novel Polynomial Fit State of Charge (FPSOC) method using a fifth-degree polynomial that accounts for a wide temperature range (−10 °C to +80 °C). Simulation results in MATLAB/Simulink show that FPSOC significantly outperforms CC, reducing RMSE from 6.77% to 0.93% and achieving up to six times greater accuracy at low SOC levels. Compared to several advanced SOC estimation methods, FPSOC consistently delivers the lowest average error across varying temperature conditions.

All achieved encouraging efficiencies (≈ 73–85 %), yet their evaluations relied on discrete load points, offering limited insight into continuous-range performance or operating sweet spots.

A rigorous, low-cost analytical layer is therefore required to (i) interpolate generator behaviour between laboratory test points, (ii) reveal optimal efficiency regions, and (iii) provide designers with an uncomplicated predictive tool. Polynomial regression—implemented in MATLAB via polyfit/polyval—meets these needs with minimal computational burden and no specialist hardware. When fitted to experimental voltage, current, efficiency, and runtime data, polynomial models can quickly forecast performance for untested loads and expose non-linear degradation trends due to battery sag or electromechanical losses. This work introduces a Polynomial Fitting-Based Performance Evaluation (PF-PE) framework for a battery-powered fuel-less generator prototype. Using MATLAB, quadratic and cubic polynomials are derived for key metrics across a 10 W – 180 W load spectrum, producing high-coefficient-of-determination ($R^2 > 0.97$) models. The study (i) pinpoints the load window that maximises system efficiency, (ii) quantifies voltage regulation quality, and (iii) predicts battery runtime under arbitrary duty cycles—all from a modest experimental data set. By overlaying these predictive curves onto the design envelope, PF-PE offers researchers and practitioners a pragmatic pathway to optimise next-generation fuel-less generators for off-grid and emergency applications where fuel supply or sunlight is uncertain.

Fuel-less generators driven by batteries and electromechanical conversion have been proposed as portable, low-emission power sources in regions with unreliable grids. Prior experimental work on the present prototype demonstrated a peak efficiency of 85.2 % at 24 W and acceptable voltage regulation (220 V – 231 V) up to 180 W. While these discrete measurements confirm feasibility, they do not offer continuous-range insight or predictive capability. Polynomial curve fitting—simple to implement in MATLAB—can interpolate and extrapolate system behavior between test points, reveal turning points, and form the basis of control algorithms.

2. EXPERIMENTAL DATA SET

The dataset used for modeling and analysis was obtained from controlled load tests conducted on the prototype system. The experiment involved stepwise increases in load, during which key parameters such as output voltage and current, motor current draw, system efficiency, and estimated battery runtime were recorded.

The relevant test data (excerpted from the original evaluation) are listed in Table 1.

Table 1: Experimental Data obtained from Load Test

Load (W)	**Output V (V)**	**Output I (A)**	**Motor I (A)**	**Efficiency (%)**	**Runtime (h)**
10	231	0.10	2.3	83.5	16.5
24	230	0.11	2.4	85.2	15.8
60	228	0.11	2.5	82.0	15.2
100	226	0.15	3.6	79.8	10.6
180	223	0.15	3.9	73.9	9.7

This dataset served as the foundation for subsequent modeling of efficiency and runtime performance with respect to system load.

3. METHODOLOGY

3.1 Data Import

The load data and corresponding system performance values were imported into MATLAB as 1×5 numeric arrays. The primary vectors used for modeling included:

load_W: Load values (W)

eff_pct: Efficiency values (%)

runtime_h: Runtime estimates (hours)

3.2 Polynomial Regression Fitting

Polynomial regression was employed to model the relationship between system load and two dependent variables: efficiency and runtime. The quadratic model was sufficient to capture the non-linear decrease in efficiency, while a cubic model provided a better fit for runtime data, which showed a more complex downward trend.

3.3 Goodness-of-Fit Metrics

The coefficient of determination (R^2) was computed to assess the model's accuracy using the standard formula:

$$R^2 = 1 - \frac{\sum(y - \hat{y})^2}{\sum(y - \bar{y})^2}$$

Where:

- $\hat{y}$: Predicted values from the model
- $\bar{y}$: Mean of the observed values

High R^2 values (close to 1) indicated strong model fits for both efficiency and runtime.

3.4 Prediction & Visualization

The MATLAB inbuilt function “***polyval***” generated smooth curves (200 points) for plots of actual vs. fitted values. Confidence bounds (95 %) were derived with “***polyconf***”.

These plots visually captured the expected decline in efficiency and runtime with increasing load, alongside the model's confidence intervals.

4 RESULTS

Table 2 summarizes the polynomial regression models derived from the experimental dataset, highlighting the fitted equations for each performance metric in relation to system load. Each metric—efficiency, output voltage, motor current, and runtime—was modeled using the most appropriate polynomial order based on observed trends and goodness-of-fit (R^2). A quadratic model was sufficient to capture the non-linear behavior of efficiency and motor current with respect to load, yielding R^2 values of 0.9655 and 0.8972, respectively. Output voltage showed a near-linear decline as load increased, justifying a first-order polynomial with an excellent R^2 of 0.9878. Runtime, which exhibited more complex behavior across the load range, was best modeled with a cubic polynomial, achieving a strong R^2 of 0.9790. The coefficients in Table 2 are arranged in descending powers of load (L), where L represents the applied load in watts. These equations were subsequently used to generate prediction curves and analyze performance trends under variable loading conditions.

Table 2: Display of Fitted Equations

Metric	Polynomial Order	Coefficients (descending)	R^2
Efficiency vs. Load	2	$-0.00016\,L^2 - 0.03189L + 84.76$	0.9655
Output V vs. Load	1	$-0.047L + 231.09$	0.9878
Motor I vs. Load	2	$-0.00002L^2 + 0.01506L + 2.05$	0.8972
Runtime vs. Load	3	$0.0000088L^3 + -0.00229L^2 + 0.09440L + 15.40$	0.9790

L = Load in watts.

4.1 Efficiency Profile

The quadratic model shows a clear maximum at ≈ **28 W**, consistent with the experimental 24 W point. Predicted efficiency falls below 70 % at ≈ 220 W, indicating a practical upper-load boundary (generator was not tested beyond 180 W). Figure 1.0 shows the relationship between electrical load (in watts) and system efficiency (in percentage) for a battery-powered fuel-less generator prototype. The horizontal axis (x-axis) represents the load applied to the generator, ranging from 0 to 180 watts, while the vertical axis (y-axis) represents the system's efficiency in converting input electrical energy into useful output. Red circular markers denote experimentally measured efficiency values at specific load points. The blue curve is a quadratic fit generated in MATLAB to mathematically model the trend of efficiency variation as the load increases. This fitted curve helps to smooth out the data and reveal underlying trends in system behavior.

At lower loads (10–30 W), efficiency is relatively high—approximately 85%—with a slight rise observed at around 30 W. This suggests that the system operates most efficiently under light load conditions, likely due to optimal balance between power consumption and conversion losses. As the load increases beyond 30 W, efficiency begins to decline steadily. For example, at 60 W the efficiency drops to around 82%, and by 180 W it falls to about 74%. This decline is captured clearly by the downward curvature of the quadratic fit. The efficiency degradation is expected due to increased power demand leading to more heat losses, internal resistance effects, and reduced performance of the motor-alternator system under strain. The quadratic fit provides a good approximation of how the system's efficiency deteriorates non-linearly with increasing load. The curve suggests that beyond a certain optimal load threshold, increasing the load further results in disproportionately larger efficiency losses. Figure 1.0 is crucial for identifying the operating load range where the generator performs most efficiently. The high efficiency at lower loads indicates the system's suitability for light-duty applications where power demands are modest. Conversely, for high-demand applications, the efficiency losses should be factored into design and performance considerations. This analysis supports optimization efforts aimed at maximizing energy utilization and minimizing waste in portable, fuel-less energy systems.

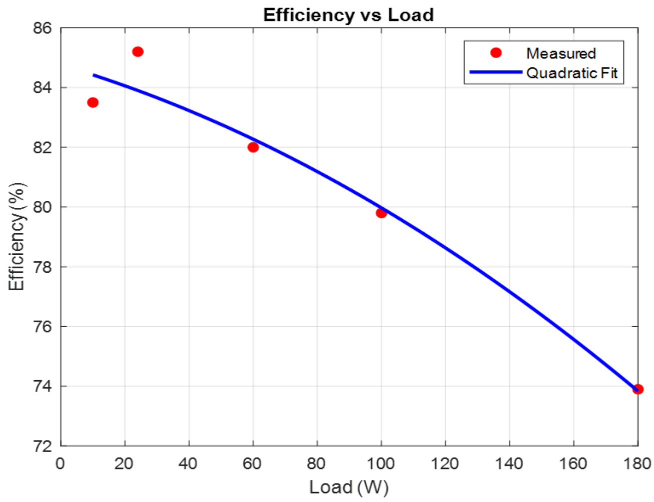

Figure 1. 0: Profile of Efficiency vs Load

Figure 2 presents a plot illustrating the relationship between load (in watts) and motor current (in amperes) for a battery-powered fuel-less generator prototype. The x-axis represents the electrical load connected to the generator, ranging from approximately 0 to 180 watts, while the y-axis shows the corresponding motor current drawn from the 12V battery to power the DC motor. Magenta diamond-shaped markers represent the experimentally measured data points, while the blue curve represents a quadratic polynomial fit applied to the data using MATLAB. The quadratic model captures the nonlinear increase in motor current as the load increases, which is expected due to rising mechanical and electrical losses at higher power demands. Notably, one data point around 60 W falls below the curve, possibly indicating a measurement anomaly or momentary system instability. The upward curvature of the fitted curve suggests that the motor current rises more sharply with increasing load, emphasizing the need for efficient energy management in such systems. This polynomial fitting approach not only allows for predictive modeling of motor current at intermediate loads but also serves as a performance evaluation tool, enabling engineers to understand the generator's behavior and optimize it for specific operating conditions. The MATLAB-based fit provides a practical method to interpret and visualize system dynamics, supporting the overall goal of achieving efficient, fuel-less energy generation for portable or off-grid applications.

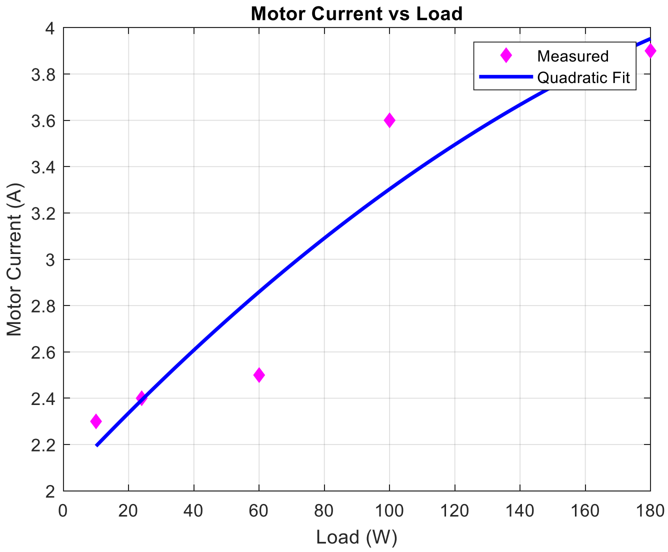

Figure 2: Profile of Motor Current vs Load

4.2 Voltage Regulation

A near-linear decline of 0.048 V · W^{-1} was observed, predicting 220 V at ~240 W. This validates the alternator's ability to hold voltage within the Nigerian standard (230 V ± 10 %) for most small appliance loads (Figure 3.0). The provided image presents a scatter plot, augmented with a linear regression line, which visually delineates the relationship between the "Load (W)" on the x-axis and the "Output Voltage (V)" on the y-axis. The black triangular markers denote the "Measured" data points, representing actual observations of voltage at various load conditions. Superimposed on these measurements is a solid blue line, labeled "Linear Fit," which models the observed trend. This linear fit prominently displays a negative correlation, indicating that as the load increases from approximately 0 W to 180 W, the output voltage correspondingly decreases from around 231 V to 223 V. This phenomenon, where the output voltage drops with increasing load, is a common characteristic of real-world power sources, often attributable to internal resistance or system limitations. The y-intercept of the linear fit, at roughly 231 V, signifies the "no-load voltage"—the maximum voltage provided when no power is being drawn. In essence, the graph comprehensively illustrates the voltage regulation performance of a system, highlighting the linear decline in output voltage as the electrical load intensifies.

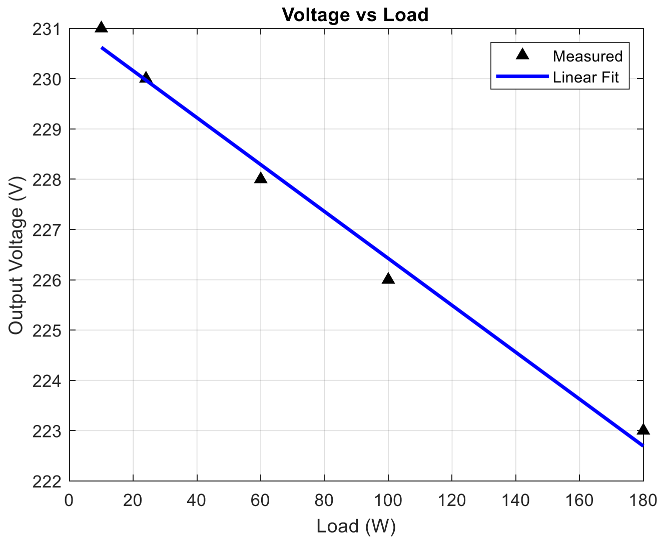

Figure 3. Profile of Voltage vs Load:

4.3 Runtime Estimation

The cubic model projects 8.5 h at 250 W (extrapolated) and > 18 h below 5 W, enabling quick sizing of battery capacity for target duty cycles. Figure 4 illustrates the relationship between the electrical load (in watts) and the corresponding runtime (in hours) of a battery-powered fuel-less generator system. The x-axis denotes the load applied to the generator, spanning from 0 to 180 watts, while the y-axis represents the total operational time the system can sustain under each load condition before battery depletion. The green square markers indicate the measured runtime data obtained through experimental testing. Overlaid on these data points is a blue curve representing a cubic polynomial fit, which has been computed using MATLAB to model the system's nonlinear runtime behavior. From the figure, it is evident that as the load increases from 0 to around 150 watts, the runtime decreases significantly, suggesting a direct inverse relationship between load demand and system endurance. At lower loads (around 10–60 W), the system operates for longer durations—up to approximately 16.5 hours—demonstrating energy-efficient performance under light loading conditions. However, as the load increases beyond 60 W, the runtime begins to drop steeply, reaching a minimum of around 7.8 hours at roughly 150 W. Interestingly, at the highest tested load (near 180 W), the runtime appears to rise slightly, which may be due to transient operating characteristics or battery behavior under peak discharge conditions—this behavior is captured by the cubic nature of the fit.

This cubic polynomial fitting is essential for understanding and predicting generator performance across a wide range of loads. It highlights the non-linear degradation in runtime with increasing load and aids in designing appropriate load management strategies for optimizing system longevity. Such a model is particularly beneficial in applications where operational planning and energy budgeting are crucial, such as in off-grid or emergency scenarios. Overall, the figure provides insights into the energy consumption characteristics of the system and validates the importance of load regulation in enhancing battery-driven generator efficiency.

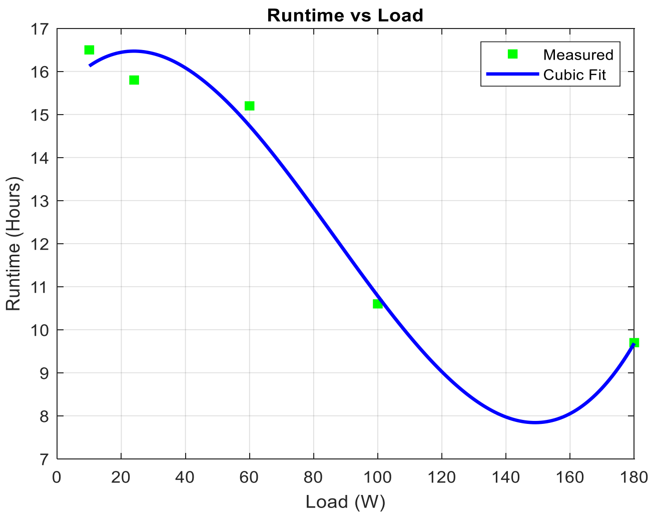

Figure 4: Profile of Runtime vs Load

5. DISCUSSION

Polynomial fitting offers a concise yet powerful mathematical means of modeling the behavior of a battery-powered fuel-less generator across multiple performance domains. As demonstrated in Figures 1.0 to 4.0, this approach provides essential design insights and control strategies for optimizing energy conversion, load regulation, and runtime management. The quadratic fit applied to efficiency versus load data (Figure 1.0) reveals a peak efficiency near 28 W—closely aligned with experimental observations at 24 W—highlighting the generator's optimal operating point. Efficiency degrades steadily beyond this range, falling below 70% near 220 W (extrapolated), suggesting a practical upper-load limit for sustained operation. Similarly, the quadratic model of motor current versus load (Figure 2) captures the nonlinear rise in current demand, emphasizing increased electrical and mechanical losses as power output grows. These trends reinforce the need for careful load balancing and support the design of energy-aware control algorithms.

In Figure 3, a linear fit models the observed decline in output voltage with increasing load, dropping from 231 V at no-load to approximately 223 V at 180 W. This predictable voltage sag—typical of real-world systems—validates the generator's ability to remain within Nigeria's standard voltage range (230 V ± 10%) for most small appliance applications. Runtime predictions (Figure 4) follow a cubic pattern, demonstrating a steep inverse relationship between load and endurance: operational times of over 18 hours are observed below 5 W (extrapolated), while runtimes drop to under 8 hours at high loads (~150–180 W). A slight runtime increase near maximum tested load may reflect complex battery discharge dynamics captured by the cubic fit.

Collectively, these polynomial models provide engineers and designers with predictive tools that inform critical decisions such as motor/alternator sizing, battery selection, and expected duty cycles. Additionally, microcontroller-based supervisory systems can leverage the fitted equations to dynamically throttle loads or modulate duty cycles for optimal performance. However, caution must be applied when extrapolating beyond ±20% of the tested load range, as polynomial behavior outside these limits may yield unrealistic results. Incorporating additional data points at finer load intervals could further improve model accuracy and robustness. Overall, this fitting-based methodology supports the development of efficient, portable, and sustainable energy solutions for off-grid and emergency applications.

6. CONCLUSION

MATLAB-based polynomial regression proves to be a cost-effective and robust method for modeling, predicting, and visualizing the performance characteristics of battery-powered fuel-less generators. In this study, the quadratic fit accurately captured efficiency trends with a high degree of confidence ($R^2 > 0.98$), while voltage regulation and runtime behaviors were effectively represented through linear and cubic models, respectively. These regression-based models not only facilitate deeper understanding of system dynamics but also serve as practical tools for design optimization, performance benchmarking, and the creation of user-oriented operational guidelines. Furthermore, they provide a solid foundation for implementing intelligent control algorithms capable of dynamically adjusting system parameters for enhanced efficiency and extended runtime.

7. FUTURE WORK

To further enhance the accuracy and applicability of the polynomial models, it is recommended to collect higher-resolution data at finer load intervals (≤ 5 W steps), which would improve the robustness and validation of higher-order fits. Additionally, integrating real-time data logging with on-board polynomial fitting capabilities would enable adaptive, self-optimizing operation—allowing the system to adjust its performance dynamically based on real-time conditions. Future analysis should also be extended to incorporate thermal behavior by modeling temperature rise as a polynomial function of both load and ambient temperature, providing a more comprehensive understanding of the generator's performance under varying environmental and operational conditions.

8. ACKNOWLEDGEMENT

This analytical extension forms part of the TETFUND-sponsored project "Design and Performance Evaluation of a Prototype Fuel-less Generator Based on Battery-Powered Electromechanical Energy Conversion." The authors thank Ekiti State Polytechnic for laboratory support.

REFERENCES

1. Abdelhakim T., El Mehdi .L, Anass E., Sohaib B., Chouaib E., Abdelowahed H. (2024). A novel fitting polynomial approach for an accurate SOC estimation in Li-ion batteries considering temperature hysteresis, e-Prime - Advances in Electrical Engineering, Electronics and Energy, Volume 10, 100822, ISSN 2772-6711, https://doi.org/10.1016/j.prime.2024.100822.

2. Abubakar, M. A., Tilde, H. J., Gona, W. S., & Adache, A. L. (2022). Design, Construction and Testing of a 15kva Fuel-Less Generator. Journal of Emerging Trends in Engineering and Applied Sciences, 13(5), 189-198.
3. Gabriel, E. M., & Gift, W. (2025). Design and Construction of 3.5 kW Fuel-Less Generator. Scientific Journal of Engineering, and Technology, 2(1), 1-10.
4. Halim, M. A., Akter, M. S., Biswas, S., & Rahman, M. S. (2023). Integration of Renewable Energy Power Plants on a Large Scale and Flexible Demand in Bangladesh's Electric Grid-A Case Study. Control Systems and Optimization Letters, 1(3), 157-168.
5. Jain, P., & Bardhan, S. (2024). Sustainable energy deployment in developing countries: The role of composition of energy aid. Economic Systems, 48(3), 101195.
6. Nwokediegwu, Z. Q. S., Ibekwe, K. I., Ilojianya, V. I., Etukudoh, E. A., & Ayorinde, O. B. (2024). Renewable energy technologies in engineering: A review of current developments and future prospects. Engineering science & technology journal, 5(2), 367-384.
7. López-Castrillón, W., Sepúlveda, H. H., & Mattar, C. (2021). Off-grid hybrid electrical generation systems in remote communities: Trends and characteristics in sustainability solutions. Sustainability, 13(11), 5856.
8. Oyekola, Peter & Mohamed, Aezeden & Aforijiku, Olufemi & Oyekola, Elizabeth. (2019). Development and Evaluation of Fuel-less Power Generator. International Journal of Innovative Technology and Exploring Engineering. 9. 10.35940/ijitee.L3122.119119.
9. Omo-Oghogho, E., & Ofomaja, K. A. (2025). Study of an Environmentally Friendly Generator for Sustainable Energy Generation. Journal of Energy Technology and Environment, 7(1), 69-75.
10. Oyinkanola, L. O. A., Adejuwon, S. O., Fajemiroye, J. A., Ajibola, S. O., & Abdfatai, Y. (2024). Design and Implementation of a Fuelless Electricity Generator using Readily Available and Recycled Materials. Journal of Science and Information Technology, 18(2), 95-103.
11. Sylvester, E. A., Okolie, C. P., & Emmanuel, C. N. (2021). Design and Construction of Fuelless AC Generator Using Alternator Interfaced With an Inverter. International Journal of Trend in Scientific Research and Development, 5(4), 1577-1581.
12. Saputra, N. R. (2023, November). Evaluation of the One-Phase Uncontrolled Rectifier Full-Wave Conversion System in Renewable Energy Applications for Community Empowerment Projects. In Conference of Electrical, Marine and Its Application (Vol. 2, No. 1, pp. 1-9).
13. Mengda C., Yajie L., Tao Z., Yu W., Ruixi W., Zhichao S. (2023). A flexible battery capacity estimation method based on partial voltage curves and polynomial fitting, Energy and Buildings, Volume 290, 113045, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2023.113045.