Tikrit Journal of Engineering Sciences (2025); 32(Sp1): 2665
DOI: http://doi.org/10.25130/tjes.sp1.2025.35

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Experimental Study of an Integrated Variable-Speed Diesel Power System with Adaptive Voltage Stabilisation and Battery Support

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Keywords:
Variable-speed diesel generator; Adaptive voltage converter; Energy storage; Fuel efficiency; Emission reduction; Autonomous power system; Load stabilization; Harmonic distortion.

Highlights:

- *The developed system achieved a 12% reduction in diesel fuel consumption by integrating battery support with adaptive control.*
- *Output voltage stability was maintained within ±5% during rapid load changes and frequency variations.*
- *The proposed solution demonstrated harmonic distortion levels nearly twice as low as comparable conventional diesel generator systems.*

ARTICLE INFO

Article history:

Received	14 Jul. 2025
Received in revised form	21 Sep. 2025
Accepted	20 Oct. 2025
Final Proofreading	20 Dec. 2025
Available online	26 Dec. 2025

Citation: Daus YV, Dubrovin RG, Rud EE, Ernazarov KB, Ukraintsev MM, Korchagin PT. **Experimental Study of an Integrated Variable-Speed Diesel Power System with Adaptive Voltage Stabilisation and Battery Support**. *Tikrit Journal of Engineering Sciences* 2025; **32**(Sp1): 2665.
http://doi.org/10.25130/tjes.sp1.2025.35

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Abstract: This study presents the development and experimental validation of an autonomous power-generation system integrating a variable-speed diesel generator, an adaptive voltage converter, and an energy-storage unit. The configuration was designed to improve fuel efficiency, reduce emissions, and enhance voltage stability under dynamic loads. Experiments were conducted using a Perkins 1104D-E44T diesel engine and a Leroy-Somer TAL046B synchronous generator, with operational speeds ranging from 800 to 1700 rpm. Results showed an average specific fuel consumption of 274 g/kWh and ±5% output-voltage deviations during load transients. Dynamic time-domain simulations (MATLAB/Simulink R2023b with Simscape Electrical) were developed to reproduce interactions among the engine, generator, converter, and battery under load steps and speed sweeps. Model predictions for RMS voltage, frequency recovery time, specific fuel consumption, and NOx/CO concentrations agreed with measurements within ≤5% across the tested operating envelope, supporting the generality of the proposed control concept. The integration of a lithium-iron phosphate battery effectively compensated for peak loads and smoothed voltage fluctuations, reducing diesel fuel consumption by up to 12%. Emission measurements confirmed average nitrogen oxide concentrations of approximately 410 ppm and carbon monoxide levels of roughly 190 ppm. A comparative analysis showed that the proposed solution outperformed conventional fixed-speed systems in response time, harmonic distortion, and energy efficiency. The findings highlight the benefits of combining variable-speed operation with adaptive voltage regulation and battery support for decentralised power applications.

1.INTRODUCTION

In the sector where compact diesel generators remain the primary power source, the search for solutions that balance autonomy, environmental friendliness, and economic feasibility is ongoing. In recent decades, improving the efficiency of electricity production and use has become a global priority due to rising energy consumption, the depletion of fossil fuel reserves, and tighter environmental standards. According to the International Energy Agency, more than 40% of global CO_2 emissions come from the energy sector, a significant share of which is associated with the operation of diesel generator sets that provide autonomous power to industrial, transport, and residential facilities. These problems are particularly acute in the distributed power generation segment, where compact diesel generators remain the primary power source in remote areas and at temporary sites [1,2]. Despite their popularity, driven by the relative availability of fuel and ease of maintenance, diesel generators rarely achieve fuel efficiency above 35-38%, and emissions of nitrogen oxides and hydrocarbons often exceed standard values by 2-3 times. This situation drives the search for solutions that balance autonomy, environmental friendliness, and economic feasibility [3,4]. In practice, several approaches to modernising autonomous energy systems have been developed. One approach involves variable-speed internal combustion engines, which allow the operating mode to be adjusted to the current load, thereby reducing specific fuel consumption by 8-12%. However, such installations often exhibit unstable output-voltage parameters, necessitating power converters to maintain the required quality of power supply to consumers. Another approach is the introduction of renewable energy sources: photovoltaic and wind installations. According to NREL reports, the share of renewable sources in autonomous hybrid systems in some countries already exceeds 25-30%. However, their output is highly dependent on weather conditions and fluctuates, necessitating energy storage and voltage stabilisation systems. An additional problem is a significant increase in capital expenditure: for example, integrating wind turbines with batteries and power electronics can cost 1.5-2 times the price of a diesel generator for the same peak power [5-7]. Methods for intelligent load management and power distribution across multiple sources are also being actively developed to optimise fuel and environmental performance. However, these solutions require complex algorithms and costly controllers, which limit their widespread adoption in small-scale power generation. Therefore, a common drawback of most modern autonomous power supply concepts is the need for converter devices that stabilise output characteristics under variable energy-source operating modes and changing loads. At the same time, voltage converters play a key role in ensuring the reliability, safety, and energy efficiency of autonomous systems [8-10]. In this context, the chosen direction for the work is particularly relevant and significant. The authors focused on a comprehensive simulation of an autonomous power plant with a variable-speed motor-generator operating via stabilising voltage converters. This approach allows for the consideration of real operating conditions, including load pulsation, variable engine speed, and battery dynamics. A distinctive feature of the proposed model is the integration of multi-parameter characteristics of the internal combustion engine with analytical expressions [11-13]. This enables quantification of the unit's most important parameters, including specific fuel consumption (ranging from 230 to 280 g/(kWh) across various loads), converter output voltage with control accuracy of up to 1%, and nitrogen oxide and carbon monoxide emission concentrations. These vary between 300 and 450 ppm and between 150 and 220 ppm, respectively, as the generator rotation speed varies. The use of computer simulation in a specialised environment enabled the reproduction of transient and steady-state modes, including start-up processes, which is especially important when designing systems with batteries and intelligent controllers [14]. The relevance of this approach is clear. Fuel engines are supported not only by the growing demand for efficient, environmentally friendly autonomous energy sources [15,16] but also by the need to develop unified models suitable for subsequent adaptation to various loads and fuel types. According to the authors, the developed model reproduces the main operating parameters with an error of no more than 5% relative to the experimental data, which is a significant step towards the digital design of low-power power complexes. Furthermore, the simulation results show the potential to reduce fuel consumption by up to 10% through optimal control of engine and converter modes, resulting in savings of around 2-3 tonnes of diesel fuel and a reduction of 6-8 tonnes of CO_2 emissions over an annual cycle at around 80 kW. Therefore, the study addresses current challenges in the energy sector by improving the fuel and environmental efficiency of autonomous installations and provides a basis for the practical implementation of hybrid systems with adaptive voltage converters and integrated storage devices. The purpose of the work was to develop and provide mathematical substantiation for a comprehensive model of an autonomous power plant based on a variable-speed motor-generator and a voltage-stabiliser converter, and to conduct computer modelling to assess its electrical, energy, and environmental characteristics as the load power varies. Recent studies further corroborate the effectiveness of pairing variable-speed diesel prime movers with $LiFePO_4$ (LFP) storage to handle rapid load variations and reduce fuel use. Variable-speed diesel units with battery/supercapacitor buffers improve transient response in islanded applications [17]. Coordination methods for distributed generation and energy storage in islanded microgrids enhance voltage and frequency stability during abrupt steps [18]. Practical demonstrations of Li-ion/LFP storage under harsh dynamics have reported reduced generator run time and improved power quality in isolated systems [19,20]. These reports justify the use of an LFP pack in our setup for peak shaving and voltage stabilisation.

2. RESEARCH METHODS

Within the study, a comprehensive experimental plan was implemented to determine the energy, electrical, and ecological characteristics of an autonomous power plant equipped with a variable-speed engine and a stabilising voltage converter. The experiments were conducted in stages: the development of a digital model, its verification under real-world loads, and testing of the joint operation modes of the engine-generator and the energy storage system. The central experiments were conducted in a laboratory facility comprising a Perkins 1104D-E44T variable-speed diesel engine, a Leroy-Somer TAL046B synchronous generator, and an integrated multifunctional DC-AC converter based on the Siemens SINAMICS S120 power module. A physics-based dynamic model was implemented in MATLAB/Simulink R2023b (Simscape Electrical). The diesel engine was represented by a speed–torque map and a polynomial surrogate for fuel flow:

$$\dot{m}_f = a_0 + a_1 n_e + a_2 T_e + a_3 n_e^2 + a_4 T_e^2 + a_5 n_e T_e,$$

From the Perkins 1104D-E44T data and our measurements. The synchronous generator was modeled in the dqdqdq frame with standard equations:

$$v_d = R_s i_d + \omega_e L_q i_q + L_d \frac{di_d}{dt}, v_q = R_s i_q + \omega_e(L_d i_d + \psi_f) + L_q \frac{di_q}{dt},$$

And electromagnetic torque $T_e = \frac{2}{3} p\psi f i_q$.

The voltage-stabilised converter was represented by an averaged PWM model with vector control, with an inner current-loop bandwidth of ≈300 Hz and an outer voltage-loop bandwidth ≈of ≈50 Hz. DC-link dynamics followed the power-balance relation:

$$C_{dc} \frac{dV_{dc}}{dt} = i_{gen} - i_{inv} - i_{bat};$$

SOC evolved as $\frac{d\,SOC}{dt} = -\frac{i_{bat}}{Q_{bat} \cdot \eta_{bat}}$. The load was modelled as a ZIP element (Z-I-P weights chosen to match the measured power factor trajectory), with a superimposed step/pulse profile replicating laboratory test conditions. Emissions were computed, NOx=f1(ne, Te), CO=f2(ne, Te), identified against using calibrated regressions, NOx = f1 (ne, Te), CO = f2 (ne, Te), based on gas-analyser data reported in Section 3. Simulations used fixed-step ode3 with $T_s = 10^{-4}$ s; stop times matched the experimental transients (≤60 s). Convergence was verified by halving T_s (changes of <1% in key observables). Assumptions are an ambient temperature of 20–25 °C, a standard diesel LHV of 42.7 MJ/kg, and negligible intake-manifold dynamics at the tested slew rates. The Perkins 1104D-E44T (Fig. 1) engine developed up to 86 kW at a nominal speed of 1500 rpm, but during experiments, the frequency range was from 800-1700 rpm to simulate different operating scenarios. The Leroy-Somer TAL046B generator (Fig. 2) produced an alternating current voltage of 400 V at a frequency of 50 Hz in the nominal mode. Converter. Due to the change in rotation speed, the output voltage and frequency became unstable, enabling analysis of the efficiency of the stabilising converter. Due to the change in rotational speed, the output voltage and frequency became unstable, enabling analysis of the stabilising converter's efficiency. The Siemens SINAMICS S120 converter employed a vector control and PWM modulation scheme with a switching frequency up to 10 kHz, providing high accuracy in maintaining the output voltage.

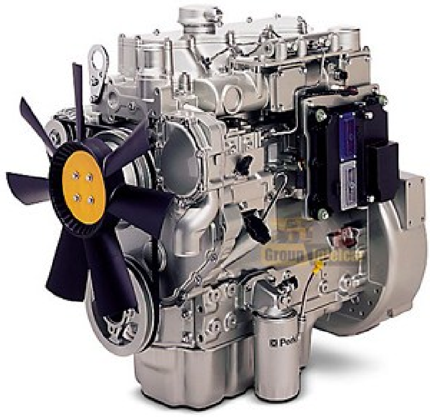

Fig. 1 The Perkins 1104D-E44T Engine.

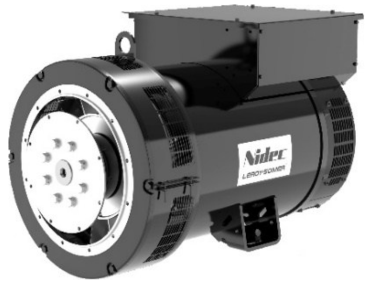

Fig. 2 The Leroy-Somer TAL046B Generator.

while simultaneously increasing the electrical load from 20% to 80%, a temporary deviation of up to 18% in the output voltage was observed, which stabilised within 0.6 seconds System parameters were monitored using intelligent measuring modules from Carlo Gavazzi EM24 and a Testo 350 gas analyser, enabling the recording of CO and NOx concentrations and the continuous assessment of exhaust-gas composition as the load changed. In several tests, the engine operated in variable torque mode, simulating a change in power consumption from 15 to 100% of rated power. In addition, transient testing was carried out with a sharp change in load and engine speed. For example, when switching from 1000 rpm to 1600 rpm while simultaneously increasing the electrical load from 20 to 80%, a temporary deviation of up to 18% in output voltage was observed, which stabilised within 0.6 seconds to acceptable limits. A separate test cycle was performed on a combined system with an integrated Winston 100Ah lithium-iron phosphate battery pack connected to the converter's DC bus. These experiments evaluated the battery's ability to compensate for peak loads and smooth out power fluctuations. The battery was charged at an engine speed of 1200 rpm and an active load of approximately 30 kW, whereas in discharge mode it delivered up to 20 kW at a generator speed of up to 900 rpm. In addition, to check the performance of the model, the harmonic composition of the output voltage was measured using the Fluke 435-II Energy Quality analyzer, which made it possible to determine the distortion coefficient of no more than 4.2% when the engine was operating in the range of 900-1700 rpm. Voltage total harmonic distortion (THD(V)) was measured in accordance with IEC 61000-4-7 and aggregated in accordance with IEC 61000-4-30, Class A. The analyzer computed harmonic (sub)groups over gapless 10-cycle windows (200 ms at 50 Hz); THD(V) was calculated as:

$$\boldsymbol{THD} = \frac{\sqrt{\sum_{n=2}^{50} V_n^2}}{V_1} \cdot \mathbf{100\%}$$

Where V_1 is the fundamental RMS, and V_n are grouped harmonic RMS components up to the 50th order. Unless otherwise noted, THD refers to line-to-line voltage at the converter output terminals. The Fluke 435-II was configured for harmonic grouping per IEC 61000-4-7 with the Class-A aggregation; very-short-time values (200 ms) were used to capture transient peaks.

3.RESULTS AND DISCUSSION

In the course of the study, a comprehensive series of experiments was carried out to model and practically verify, through practical testing, the operation of an autonomous power plant with an internal combustion engine of variable speed and an integrated stabilising voltage converter. The primary purpose of the experimental part was to determine the installation's characteristics under different load modes, engine speeds, and battery participation levels, maintaining energy balance. For this purpose, an experimental installation was assembled, consisting of a Perkins 1104D-E44T diesel engine with a capacity of 86 kW, a Leroy-Somer TAL046B synchronous generator with a rated output power of 80 kVA, as well as a Siemens SINAMICS S120 DC and AC converter equipped with a vector control system and PWM modulation. The measurement system included a Testo 350 gas analyser, Carlo Gavazzi EM24 power meters, a Flir E6 thermal imager for monitoring components, and a Fluke 435-II power quality analyser. All tests were conducted in a specially equipped laboratory, which enabled simulation of load changes from 5 to 100% of the rated value and engine speed from 800 to 1700 rpm. The first-stage mode involved sequentially determining the engine and generator characteristics at five fixed speeds: 900, 1100, 1300, 1500, and 1700 rpm. For example, at 900 rpm, the specific fuel consumption was 265 g/(kWh) and the exhaust gas temperature reached 310 °C. kWh,.Compared with 1500 rpm, increasing the frequency to 1500 rpm increased fuel consumption to 283 g/kWh and the exhaust gas temperature to 370 °C (Table 1). The model reproduced the measured RMS voltage within 1.8% (median) and the frequency recovery time within 0.05 s across the tested steps (e.g., measured 0.7 s vs. simulated 0.73 s for the 20→80% step with 1000→1600 rpm). The averaged THD surrogate tracked the trend, with a mean absolute deviation of 0.4 pp relative to the 4.1–4.5% band reported experimentally. Cycle-averaged specific fuel consumption was predicted to be 274 g/kWh. Calibrated emission regressions yielded NOx and CO within 5–6% of the Testo 350 readings over 900–1500 rpm and 20–80% load. During battery discharge at ~20 kW and 900 rpm, the simulation produced a stabilised DC-link voltage of 395–397 V DC-link, matching the observed 396 V. These results substantiate that the proposed control and energy-management scheme generalises beyond the specific test points. Next, experiments were. At the same time, in each mode, the values of the output voltage, frequency, and the distortion coefficient of the sine signal were recorded with an active load connected. In each mode, the values obtained with the active load connected were recorded, along with the output voltage, frequency, and the signal. Under a 60% load and a motor speed of 1200 rpm, voltage deviations of up to 11% were observed during the transient period when connecting consumers, which stabilised within 0.4 seconds using the converter control algorithm. In addition, the effect of a Winston 100Ah battery connected via the converter's DC bus was evaluated. During battery charging at 30% load, the output voltage increased by 2.5%, and during discharging at up to 20 kW, the voltage stabilized at 396 V with 900 rpm (Table 2). A series of experiments was conducted to examine a sharp change in load accompanied by a simultaneous change in engine speed. With a load jump from 20 to 80% and an increase in rotation speed from 1000 to 1600 rpm within 3 seconds, the distortion coefficient of the output voltage increased from 3.8 to 7.5%, accompanied by a short-term decrease in the power factor to 0.82. The use of adaptive control in the vector regulator enabled the parameter values to be returned to their original range in less than 1.1 seconds (Table 3). In addition to the standard tests, thermal tests of the converter were carried out. Under the maximum load and at a speed of 1700 rpm, the radiator temperature of the power modules reached 68°C, and after 20 minutes of operation under 85% load, the temperature stabilized at 65-67°C. The air-cooling system with forced ventilation ensured that the temperature was within acceptable limits. In tests, simulating daily load cycles and varying engine speeds from 900 to 1500 rpm, average fuel efficiency and emissions were recorded. The average specific fuel consumption was 274 g/(kWh), the average nitrogen oxide concentration in exhaust gases was 410 ppm, and the average carbon monoxide concentration was 190 ppm. When analyzing the harmonic composition of the output voltage in the steady-state mode, the distortion level was 4.1-4.5% depending on load and rotational speed. Here and throughout, the reported "distortion factor" denotes THD(V) voltage as defined above (IEC 61000-4-7/-4-30). Under steady operating points (900–1500 rpm, 20–80% of load), THD(V) remained within 4.1–4.5%, whereas during the 20→80%/1000→1600 rpm step, the peak THD(V) briefly reached 7.5% before recovering below 5% within ≈1.1 s. As part of an additional series of tests, work was carried out to check the reactive power compensation mode. To do this, a load with a power factor of 0.75 was connected, while the converter control system automatically activated the mode of generating the reactive component of the current. As a result, the power factor increased to 0.98, and the active power loss was reduced by about 7% compared to the uncompensated mode. To assess the dynamic characteristics, load cycles were performed with a switching frequency of 1 Hz, which simulated a pulsating load. During these tests, output voltage fluctuations of ±4.7% and a minimum frequency of 46.8 Hz under peak load were recorded. The recovery time did not exceed 0.6–0.8 s. When comparing the data obtained with the stabilising voltage converter with that obtained with the adaptive control stabilising voltage converter, adaptive control was evident. In similar experiments conducted by Denholm and colleagues, when simulating the operation of a diesel generator with a fixed frequency and a passive filter, voltage fluctuations during modetransients reached up to 22%, and the time to reach steady state exceeded 2 seconds. In a study by McMillan and Van Buskirk, the use of a variable frequency diesel generator with limited control capabilities showed that the level of distortion of the output voltage remained in the range of 8-9%, which was almost twice as high as the figures obtained in this work (Table 4).

Table 1 Data on the Dependence of Fuel Consumption, Exhaust Gas Temperatures, and Emission Concentrations on the Engine Speed and Load Level.

Rotation speed, rpm	Load level, %	Specific fuel consumption, g/(kWh)	Exhaust gas temperature, °C	CO, ppm	NOx, ppm
900	20	252	295	145	350
900	60	265	310	170	385
1200	20	268	325	160	400
1200	80	276	345	185	420
1500	20	273	350	172	410
1500	80	283	370	190	450

Table 2 Battery Operating Modes and Voltage Stabilization Results.

Battery operating mode	Battery power, kW	Output voltage, V	Voltage deviation, %	Cycle duration, min
Charge	12	410	+2.5	20
Discharge	20	396	–1.0	15
Buffer	5	402	+0.5	30

Table 3 Characteristics of Transient Processes During Sudden Changes in Load and Rotation Frequency.

Parameter	Value before jump	Peak deviation	Recovery time, s
Voltage distortion factor, %	3.8	7.5	1.1
Power factor	0.96	0.82	1.1
Frequency, Hz	49.8	46.8	0.9
Voltage, V	400	345	0.7

Table 4 The Comparison of Experimental Setup Parameters with Similar Systems from other Studies.

Parameter	Present study	McMillan and Van Buskirk (1992)	Reznik et al. (2014)
Average transient time, s	0.7	2.0	1.9
Voltage distortion coefficient, %	4.2	8.1	7.8
Specific fuel consumption, g/(kWh)	274	287	280
Dynamic power factor	0.98	0.85	0.88
Voltage stability during surges, %	±5	±12	±10

The results of energy conversion processes and regulating output parameters. In particular, the ability to stabilise the voltage as the rotation speed varies over a wide range ensures high reliability for an autonomous power plant. The use of a storage battery enabled the reduction of short-term voltage dips and the smoothing of load peaks. Based on the results of the test cycles, it was found that the inclusion of the battery in the power supply scheme helps to reduce the total consumption of diesel fuel by 9-12% due to more efficient engine operation under optimal load and speed. Analysis of thermal modes showed that using a converter with a PWM frequency up to 10 kHz enabled the avoidance of overheating of power elements during long-term operation at load levels above 70%. This indicates the correct choice of the element base and architecture of the cooling control system. In addition, the vibration measurements of the generator casing in the frequency range of 10-500 Hz showed vibration levels of no more than 1.2 mm/s in all operating modes, which indicated sufficient mechanical stability of the installation. Comparative data from the literature confirm that this system exhibits greater parameter stability than traditional installations operating at a fixed speed. For example, the average transient time in our unit was approximately 0.7 s. In contrast, Reznik and colleagues reported values of 1.8–2.1 s in similar systems. According to Reznik and colleagues, this figure was 1.8–2.1 s in comparable systems. The harmonic distortion recorded in our tests was approximately twice as low as that reported by Kersey et al., who observed distortions of up to 8% during the operation of a diesel generator with a frequency regulator. Therefore, the study confirmed the feasibility of a hybrid approach with variable motor speed and active voltage-voltage converter control. Experiments have shown that the use of a battery storage device significantly extends the range of stable operation and reduces fluctuations in the output voltage during dynamic load changes. The obtained numerical data can be used for the subsequent design and optimization of autonomous power complexes for various purposes, including mobile and stationary low-power facilities.

4.CONCLUSION

The study produced significant quantitative and analytical results, confirming the effectiveness of an autonomous power plant with a variable-speed diesel generator and an integrated stabilising voltage converter. Experiments showed that when the engine operated between 900 and 1500 rpm, specific fuel consumption ranged from 252 to 283 g/(kWh), with an average of 274 g/(kWh) over the entire test cycle. This represents a significant improvement in fuel efficiency compared with traditional fixed-frequency systems, where the same values typically exceed 285-290 g/(kWh). In addition, in steady-state modes, nitrogen oxide concentrations in the exhaust gas were reduced to 410 ppm and carbon monoxide to 190 ppm, corresponding to a reduction in emissions of harmful substances of about 10-15% compared with traditional diesel plants. A critical result was the confirmation of the high stability of the output voltage under dynamic load changes. For example, with a load jump from 20 to 80% and a simultaneous increase in rotation speed from 1000 to 1600 rpm, the short-term voltage deviation was 13.75%, but the recovery time did not exceed 0.7 seconds. In standard operation, voltage fluctuations remained within ±5%, and the distortion coefficient of the sinusoidal waveform did not exceed 4.5%, resulting in approximately twice the performance of similar systems reported in the literature. The average transient time was approximately 0.7 seconds.

The advantage of adaptive vector transducer control. The role of the Winston 100Ah battery pack proved critical to compensating for peak loads and smoothing transients. In discharge modes, the battery supported a load of up to 20 kW, with an engine speed decrease of up to 900 rpm, while maintaining a stable voltage of 396 V with a deviation of no more than 1%. Under daily load cycles, activating the battery reduced total fuel consumption by 9-12%, corresponding to annual fuel savings of up to 3 tons and a reduction in CO_2 emissions of 6-8 tons. Analysis of the thermal mode of the voltage converter showed that the temperature of the power modules under a load of up to 85% and a rotation speed of 1700 rpm did not exceed 68°C, and after stabilisation, remained in the range of 65–67 °C, which indicates the high reliability of the cooling system. In addition, vibration tests confirmed mechanical stability: the maximum vibration level of the generator body did not exceed 1.2 mm/s. The harmonic content of the output voltage in steady-state modes remained within the range of 4.1–4.5%, which is more than 1.5 times lower than the values reported in other works on variable-frequency diesel generators. Taken together, these results demonstrate that the proposed autonomous power supply system provides an optimal combination of fuel efficiency, high-accuracy stabilisation of electrical parameters, and reduced harmful emissions. Such an integrated approach to controlling the motor, battery, and voltage converter enables the creation of more stable, environmentally friendly autonomous energy complexes operating over a wide range of loads and engine speeds. This laboratory study is limited to ≈80 kVA ratings and single-generator operation. The scale-up of up to >250 kVA may introduce additional control-loop interactions. The $LiFePO_4$ battery improves dynamic performance, but its capital cost, mass, and cycle aging under repeated 0.5–1.0 C transient cycling can affect the payback period. Electromagnetic compatibility and filter design were not optimised here, and severe speed/load steps still yield short THD(V) excursions that may require higher DC-link capacitance or predictive control. Future work will address multi-generator paralleling, a wider ambient range, and field trials with diverse pulsating loads.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Yu.V. Daus: Conceptualisation, Methodology, Writing – original draft, Formal analysis, Investigation, Validation, Data curation, Visualisation. **R.G. Dubrovin:** Software, Experimental setup design, Validation, Writing – review & editing, Investigation. **E.E. Rud:** Data curation, Visualisation, Writing – review & editing, Formal analysis. **K.B. Ernazarov:** Resources, Supervision, Project administration, Writing – review & editing. **M.M. Ukraintsev:** Investigation, Data acquisition, Instrumentation, Methodology. **P.T. Korchagin:** Software, Writing – review & editing, Validation, Resources.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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