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Optimal Selection of Backup Power Generators for Multi-Line Cremation Facilities Using the Analytic Hierarchy Process (AHP)

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Abstract*– Reliable backup power systems are essential for critical service facilities, particularly in multi-line cremation centers where electrical interruptions may compromise operational safety, environmental compliance, and service continuity. This study proposes an engineering-oriented decision framework based on the Analytic Hierarchy Process (AHP) for the optimal selection of backup power generators operating under 50 Hz electrical systems. The methodology integrates electrical load assessment, expert judgment, lifecycle cost analysis, and environmental considerations within a multi-criteria evaluation model. A real case study conducted at a cremation facility in Lima, Peru, was used to validate the proposed approach. Seven evaluation criteria and four commercial generator alternatives were analyzed. Results indicate that power capacity and voltage/frequency stability represent the most influential factors, accounting for more than 46% of the total decision weight. The selected alternative achieved a global priority score of 0.392 and satisfied recommended safety margins for emergency load coverage and transient performance. Sensitivity analysis and cross-validation using the TOPSIS method confirmed the robustness and consistency of the obtained ranking. The proposed framework provides a replicable and practical tool for improving backup power system design and investment decision-making in critical electrical infrastructures.

Keywords.-* *Backup power systems; Analytic Hierarchy Process; generator selection; electrical reliability; energy management; critical infrastructure; multi-criteria decision making.

I. INTRODUCTION

The reliability of electrical power systems is a critical factor in facilities that provide continuous and sensitive services, such as cremation centers and funeral complexes. In these environments, electrical interruptions may compromise operational safety, regulatory compliance, environmental control systems, and service continuity. Cremation processes require a stable and uninterrupted energy supply to ensure the proper functioning of combustion chambers, gas treatment units, ventilation systems, monitoring platforms, and refrigeration equipment. In the Peruvian context, both public and private cemeteries have experienced recurrent power interruptions that negatively affect service quality and operational efficiency. Although backup power systems are commonly implemented, many facilities still operate with generators that are not optimally selected according to their actual electrical demand and technical requirements, leading to inefficiencies, increased operational costs, and regulatory challenges.

From an engineering perspective, the selection of backup power generators requires a structured analysis of electrical loads that considers their dynamic behavior under real operating conditions, including simultaneity, utilization factors, and operating sequences. This enables the construction of representative demand scenarios and improves the accuracy of system sizing. However, many existing selection practices rely on simplified approaches that fail to address the multidimensional nature of the problem, which includes technical, economic, and environmental criteria. In this context, this paper proposes an AHP-based decision framework for the optimal selection of backup power generators in cremation facilities, integrating load analysis, expert judgment, lifecycle cost considerations, and sustainability factors. A case study conducted in Lima, Peru, is used to validate the proposed approach, contributing with (i) an engineering-oriented decision model, (ii) the integration of expert knowledge with electrical system requirements, and (iii) a validated framework applicable to critical service infrastructures.

II. RELATED WORK / LITERATURE REVIEW

Research on backup power systems has focused on generator performance, power quality, maintenance, environmental impact, and decision-support methods in critical infrastructures. These studies can be grouped into electrical performance, automation and reliability, maintenance, sustainability, and multi-criteria decision-making approaches. Early work highlighted the impact of voltage fluctuations, frequency deviations, and harmonic distortion on sensitive equipment, emphasizing proper sizing and configuration [1]. In complex environments such as multi-line cremation facilities, dynamic load behavior—especially due to inductive loads and high inrush currents—plays a critical role in system performance. Inadequate capacity and poor transient response may lead to instability and failures, reinforcing the need for dynamic evaluation criteria [2].

Automation and synchronization techniques, including parallel operation and transfer systems, improve continuity and load-sharing performance during outages [3], while advanced control systems enhance fault tolerance and recovery [4]. Maintenance-focused studies show that poor planning affects availability and lifecycle costs, highlighting the importance of probabilistic analysis and preventive strategies [5], [6]. Environmental research stresses emissions and noise reduction, as well as the need for reliable power in regulated cremation processes [7], [8]. MCDM methods have been widely applied to complex energy decisions, including grey clustering for risk assessment [9] and Delphi-AHP integration for prioritization under uncertainty [10]. AHP-based models have also proven effective in high-risk scenarios, supported by structured analytical approaches and expert judgment [11]. Compared to other methods, AHP enables hierarchical structuring, consistency evaluation, and integration of qualitative and quantitative criteria, making it suitable for complex electrical systems [12].

Despite these advances, limited research addresses the integrated selection of backup generators in cremation facilities using engineering-oriented MCDM frameworks. Existing studies often treat technical, environmental, or maintenance aspects separately and rarely combine system-level electrical analysis with expert judgment and lifecycle cost considerations [13]. Therefore, this study proposes an AHP-based framework tailored to multi-line cremation facilities, integrating electrical analysis, expert input, and multi-criteria evaluation to improve decision-making in critical power system design [14].

III. Electrical system description

This section outlines the electrical context of the cremation service at Peru Cemetery and the technical requirements for selecting a backup generator. Cremation processes must not be interrupted once initiated, as power failures can affect safety, operational continuity, and compliance with environmental regulations. Although the facility has an existing generator, a more efficient and technically suitable unit is required to ensure reliable operation during outages.

A. Operational Context and Criticality of Electrical Continuity. Cremation services rely on continuous electrical supply for both the main process and supporting systems. Interruptions can occur at any stage and directly impact process stability and service delivery. Additionally, strict environmental regulations require continuous operation of filtration and gas treatment systems, making electrical continuity essential to avoid non-compliance and operational risks.

B. Electrical Loads Associated with the Cremation Service. The system includes the cremation chamber and auxiliary subsystems. Key electrical loads can be categorized as: (i) critical control and instrumentation systems that regulate temperature and safety, (ii) ventilation systems required for combustion stability, and (iii) emission control systems necessary for regulatory compliance. Additional essential loads include lighting, monitoring systems, ventilation in service areas, and refrigeration for temporary body storage. The emergency demand combines process-critical loads and essential auxiliary systems required for safe and continuous operation.

C. Electrical Supply Requirements. The facility requires a stable three-phase power supply to support industrial-level loads, typically operating at 220/380 V or 277/480 V. Since generator alternatives include both 50 Hz and 60 Hz configurations, frequency compatibility must be considered to ensure proper integration and avoid operational issues.

D. Backup Power Architecture and Emergency Operation Mode. The backup generator must guarantee continuity of critical cremation processes and essential auxiliary systems during outages. This includes maintaining operation of control systems, ventilation, emission treatment, lighting, monitoring, and refrigeration, while ensuring operational efficiency and minimizing risks.

E. Engineering Implications for Generator Sizing. Generator sizing must consider the relationship between kW and kVA based on the power factor, as well as the distinction between continuous and standby operation. The selected generator should be capable of supplying both the critical cremation loads and the essential auxiliary systems required for safety, monitoring, and service continuity

IV. Methodology

This study adopts a structured multi-criteria decision-making (MCDM) framework based on the Analytic Hierarchy Process (AHP) to support the optimal selection of backup power generators for cremation facilities. The proposed methodology integrates electrical system analysis, expert judgment, and quantitative evaluation to ensure technical reliability, operational efficiency, and regulatory compliance [16]. The hierarchy for selecting a method, including the criteria used and the alternatives to be evaluated, is shown in Figure 1.

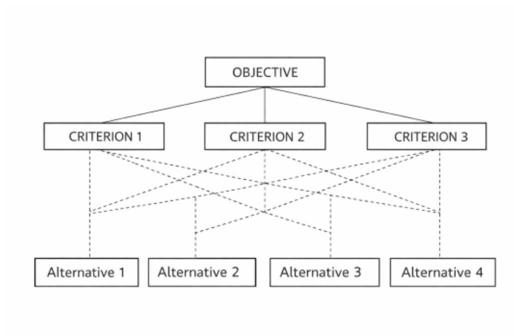

Figure 1: AHP hierarchy diagram

The methodological workflow is composed of eight main stages: (a) System Characterization and Load Assessment, (b) Decision Hierarchy Definition, (c) Expert Panel Formation and Data Collection, (d) Analytic Hierarchy Process Implementation, (e) Computational Tools and Implementation Environment, (f) Validation and Sensitivity Analysis, (g) Decision Synthesis and Selection Procedure and (h) Ethical and Methodological Considerations.

A. System Characterization and Load Assessment. The first stage involved analyzing the electrical infrastructure of the cremation facility to identify critical and essential loads during outages, including multi-line cremation processes, auxiliary systems, and emission control subsystems operating in a 50 Hz three-phase configuration. Electrical data were collected from equipment nameplates, technical manuals, and on-site inspections, registering key parameters such as active and apparent power, power factor, starting currents, and operational profiles. Special attention was given to rotating equipment to evaluate starting behavior and load sequencing. Based on this information, an emergency load profile was developed by aggregating priority loads and applying a 25% safety margin to account for uncertainty and future expansion, serving as the basis for generator sizing. To ensure transparency, data were classified as measured, estimated, or expert-based, enabling better interpretation of uncertainty across parameters.

B. Decision Hierarchy Definition. Following the AHP structure, the decision problem was decomposed into a three-level hierarchy composed of:

- Level 1 (Goal): Optimal selection of a backup power generator for cremation facilities.
- Level 2 (Criteria): Seven evaluation criteria were defined based on engineering requirements and literature review:
    - C1: Nominal and standby power capacity
    - C2: Three-phase voltage and frequency stability (50 Hz)
    - C3: Fuel type and availability
    - C4: Total cost of ownership (CAPEX + OPEX)
    - C5: Maintenance complexity and serviceability
    - C6: Noise level and acoustic enclosure performance
    - C7: Environmental impact and emissions
- Level 3 (Alternatives): Four commercially available generator units (A1, A2, A3, and A4) suitable for industrial applications.

This hierarchical structure enabled the systematic evaluation of technical, economic, and environmental aspects within a unified framework.

C. Expert Panel Formation and Data Collection. An expert-based evaluation approach was used to obtain reliable pairwise comparisons, involving four professionals selected based on their qualifications as licensed electrical or mechanical-electrical engineers, with at least eight years of experience and proven involvement in industrial power systems, backup generation, or energy management projects. Each expert independently completed structured pairwise comparison matrices using the nine-point Saaty scale to express relative importance. Individual judgments were then aggregated using the geometric mean method to generate consolidated matrices, reducing subjectivity and improving the reliability of the evaluation.

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Geometric Mean

$$GM = \sqrt[n]{\prod_{i=1}^{n} x_i}$$

$$GM = \sqrt[n]{x_1 x_2 \cdot x_2 \cdots x_n}$$

D. Analytic Hierarchy Process Implementation. The AHP computational procedure was implemented following the classical formulation proposed by Saaty. For each comparison matrix, the following steps were executed:

1. Pairwise Comparison Matrix Construction. Reciprocal matrices were built for criteria and alternatives using expert evaluations.
2. Normalization and Priority Vector Calculation. Each matrix was normalized by dividing each element by the sum of its column. Priority weights were obtained by computing the arithmetic mean of normalized rows.
3. The weight matrix for the criteria reflects the relative importance of each criterion, derived from pairwise comparisons and normalized.

$$W_{n\times1} = (w_1 \quad w_2 \quad w_2 \quad \cdots \quad w_n)^t$$

$$\lambda_{Max} = \sum_{i=1}^{n} s_i . w_i$$

4. Consistency Verification. The maximum eigenvalue (λ_{max}) was estimated to calculate the Consistency Index (CI) and Consistency Ratio (CR):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

where n is the matrix size and RI is the Random Index. Matrices with CR ≤ 0.05 (3×3) and CR ≤ 0.09 (4×4) were considered acceptable.

5. Local Priority Derivation. Local priorities for each alternative under every criterion were computed from validated matrices.
6. Global Priority Synthesis. Global scores were obtained by multiplying local priorities by criterion weights and summing across all criteria.

E. Computational Tools and Implementation Environment. All AHP calculations, normalization procedures, and consistency analyses were implemented using Microsoft Excel. Customized formulas were developed to automate eigenvalue estimation, sensitivity testing, and ranking generation.

F. Validation and Sensitivity Analysis. To assess model robustness, sensitivity analysis was conducted by systematically varying criterion weights within ±10% intervals. For each variation scenario, global rankings were recomputed and compared with baseline results.

Stability was evaluated based on:

- Ranking preservation
- Relative score deviations
- Alternative dominance consistency

Additionally, the final AHP ranking was cross-validated using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Consistency between AHP and TOPSIS results was interpreted as evidence of methodological reliability [17] [18] [19].

Figure 2 shows an example of a tornado diagram for sensitivity analysis.

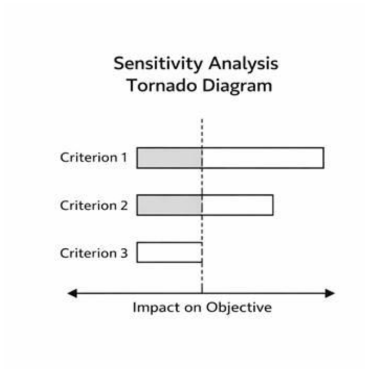

Figure 2: Sensitivity analysis tornado diagram

G. Decision Synthesis and Selection Procedure

The final decision was derived by integrating global priority scores with engineering feasibility constraints, including electrical compatibility, physical installation requirements, and regulatory compliance [20], [21].

The selected alternative was required to satisfy:

- Power adequacy for multi-line emergency operation
- Frequency and voltage compatibility (50 Hz, 220/380 V)
- Acceptable starting performance
- Compliance with environmental and safety standards

Only alternatives meeting all mandatory technical conditions were considered eligible for final selection.

H. Ethical and Methodological Considerations

To minimize potential biases in the evaluation process, anonymous expert specialists were involved, who conducted the comparisons without knowing the manufacturers' identities. Furthermore, decision-making in the model was based primarily on technical data provided by the manufacturers, ensuring objectivity in the evaluation. All data collection procedures were conducted in accordance with institutional research guidelines [22] [23].

IV. ALTERNATIVES AND CRITERIA

This section presents the backup power generator alternatives considered in the study and the evaluation criteria adopted for their technical and operational assessment. The alternatives were selected based on market availability, compatibility with the facility's electrical infrastructure, and suitability for multi-line cremation operations under emergency conditions. The criteria were defined to reflect engineering, economic, and environmental requirements relevant to critical power systems.

A. Generator alternatives. Four commercially available generator units suitable for industrial and critical service applications were evaluated. All alternatives comply with three-phase operation and are compatible with 50 Hz electrical systems.

A1: Diesel Generator – 15 kW (Encapsulated Industrial Unit). Alternative A1 corresponds to a diesel-powered generator with a nominal capacity of 15 kW (18.7 kVA). It operates at 220/380 V and 50 Hz and is equipped with an electric starting system and an advanced digital control panel.

The generator features a sound-attenuated enclosure, which reduces acoustic emissions and protects internal components from environmental exposure. Its compact design facilitates installation in limited spaces and simplifies maintenance procedures. Due to its balanced performance, A1 is widely used in medium-scale industrial and commercial facilities.

Manufacturer's Specifications:

- Model: GF-15KW
- Brand: Genpack
- Type: Open-type diesel generator set, industrial use

Main characteristics:

- Nominal power: 15 kW / 18.7 kVA
- Voltage/Frequency: 220/380 V, 50 Hz
- Fuel type: Diesel
- Starting system: Electric (12 V DC)
- Enclosure: Acoustic and weatherproof
- Application range: Industrial and commercial backup systems

The generator's electrical parameters were obtained from the manufacturer's technical data sheets and served as the basis for power modeling and performance evaluation under dynamic and transient conditions.

A2: Diesel Generator – 12 kW (Heavy-Duty Industrial Unit). Alternative A2 is a heavy-duty diesel generator designed for emergency and continuous-duty applications. It provides 12 kW (15 kVA) under standby conditions and 11 kW (14 kVA) under continuous operation.

The unit incorporates a three-cylinder diesel engine with a displacement of approximately 2.5 L and a 12 V DC starting system. It is commonly deployed in hospitals, data centers, and infrastructure requiring high operational reliability.

Although A2 offers high mechanical robustness, it lacks full acoustic encapsulation, which may limit its suitability in noise-sensitive environments.

Manufacturer's Specifications:

- Model: C12D6
- Manufacturer: Cummins Power Generation
- Type: Diesel generator set (open or enclosed)

Main characteristics:

- Standby power: 12 kW / 15 kVA
- Continuous power: 11 kW / 14 kVA
- Voltage/Frequency: 220/380 V, 50 Hz
- Fuel type: Diesel
- Engine: 3-cylinder, 2.5 L
- Enclosure: Partial / non-encapsulated
- Application range: Critical facilities and healthcare systems

The generator parameters were obtained from Cummins' technical data sheets, which include operating characteristics, dimensions, and starting capacities, forming the basis for system modeling and performance evaluation under dynamic and transient conditions.

A3: Gas-Fueled Generator – High-Capacity Unit (GLP/LPG). Alternative A3 corresponds to a gas-fueled generator operating with liquefied petroleum gas (LPG/GLP). It provides high emergency capacity, reaching up to 50 kW (63 kVA), and is designed for heavy industrial and construction applications.

The unit is equipped with a six-cylinder engine, electronic governor, and advanced control system. Operation at 60 Hz was identified in some configurations, requiring careful compatibility verification with the 50 Hz facility network.

A3 offers advantages in terms of reduced emissions and fuel availability in urban environments; however, its higher capacity and frequency constraints may create integration challenges in 50 Hz systems. Although the integration of 60 Hz equipment is technically feasible through power electronics-based frequency conversion (AC-DC-AC), this solution introduces trade-offs such as efficiency losses (3%–8%), increased capital costs, and greater operational complexity. Therefore, A3 is included as a representative theoretical scenario to evaluate the impact of frequency incompatibility within the decision model, penalizing its performance in stability, total cost of ownership, and technical feasibility. This approach enriches the analysis by reflecting real market conditions, where not all available solutions fully align with system requirements.

Manufacturer data:

- Manufacturer: Cummins Inc.
- Type: Stationary generator set
- Application: Residential and light commercial

Main characteristics:

- Emergency power: up to 50 kW / 63 kVA
- Voltage/Frequency: configurable, mainly 60 Hz
- Fuel type: LPG (GLP)
- Engine: 6-cylinder, 5.9 L
- Governor: Electronic
- Enclosure: Industrial frame / semi-enclosed
- Application range: High-demand industrial environments

A4: Natural Gas Generator – 22 kVA (GENERAC RG Series). Alternative A4 is a trifasic generator belonging to the GENERAC RG series, rated at 22 kVA. It operates at 380/220 V and 50 Hz and is designed for industrial and commercial applications requiring low-noise operation. The generator is fully encapsulated and supports operation with natural gas and LPG, offering fuel flexibility. It incorporates automated control functions and remote monitoring capabilities, facilitating integration with modern energy management systems. A4 represents a balanced option in terms of sustainability, automation, and brand reliability.

Manufacturer Information:

- Manufacturer: Generac
- Series: Protector / RG Series

Main characteristics:

- Nominal power: 22 kVA
- Voltage/Frequency: 380/220 V, 50 Hz
- Fuel type: Natural gas / LPG
- Control: Automated with monitoring interface
- Enclosure: Full acoustic enclosure
- Application range: Commercial and light-industrial facilities

Although Generac is an American manufacturer whose equipment is primarily designed to the 60 Hz standard, the company offers versions adapted for international markets that operate at 50 Hz and in three-phase configurations

B. Technical and Operational Specifications. Table I summarizes the main electrical and operational characteristics of the evaluated alternatives.

TABLE I
MAIN ELECTRICAL AND OPERATIONAL CHARACTERISTICS OF THE EVALUATED ALTERNATIVES

Parameter	A1	A2	A3	A4
Rated Power (kW/kVA)	15 / 18.7	12 / 15	50 / 63	17.6 / 22
Voltage (V)	220/380	220/380	Configurable	220/380
Frequency (Hz)	50	50	Mainly 60	50
Fuel	Diesel	Diesel	LPG	NG / LPG
Enclosure	Full	Partial	Semi	Full
Control System	Digital	Digital	Advanced	Automated
Noise Reduction	High	Medium	Low–Medium	High

C. Selection criteria. Based on engineering requirements, literature review, and expert consultations, seven evaluation criteria were defined.

C1: Power Capacity and Load Compatibility. This criterion evaluates the ability of each generator to supply the aggregated emergency load of multiple cremation lines and auxiliary systems. It considers nominal, standby, and prime ratings, overload capacity, and compatibility with starting currents. Generators must satisfy:

$$P_{rated} \geq 1.25 \times P_{critical}$$

where $P_{critical}$ represents total critical load demand.

C2: Voltage and Frequency Stability. C2 measures the ability to maintain voltage regulation and frequency stability under dynamic structural load conditions with mitigation. Stable operation at 50 Hz and acceptable voltage deviation (±5%) are essential to avoid equipment malfunction and premature wear.

C3: Fuel Type and Availability. This criterion evaluates fuel accessibility, storage requirements, refueling logistics, price volatility, and operational autonomy. Diesel offers high reliability, while gas-based systems provide environmental benefits and lower emissions.

C4: Total Cost of Ownership (TCO). C4 includes capital expenditure (CAPEX), installation cost, fuel consumption, maintenance expenses, and expected lifecycle costs. This criterion reflects long-term economic sustainability rather than initial investment only.

C5: Maintenance and Serviceability. This criterion assesses maintenance frequency, spare parts availability, technical support, and ease of servicing. Generators requiring specialized maintenance procedures receive lower scores.

C6: Acoustic Performance and Noise Control. Noise emissions affect occupational safety and community acceptance. C6 evaluates sound pressure levels, enclosure efficiency, and compliance with local noise regulations.

C7: Environmental Impact and Emissions. C7 considers exhaust emissions, fuel combustion efficiency, carbon footprint, and compliance with environmental standards. Gas-based systems generally perform better under this criterion.

D. Criterion Measurement and Scoring. Each criterion was operationalized using measurable indicators and expert assessments, as summarized in Table II.

TABLE II
CRITERION MEASUREMENT AND SCORING

Criterion	Indicator	Unit	Evaluation basis
C1	Rated/critical power ratio	-	Technical data
C2	Voltage/Frequency deviation	% / Hz	Manufacturer specs
C3	Fuel availability index	Qualitative	Market analysis
C4	Lifecycle cost	USD	Cost modeling
C5	MTBF / service interval	Hours	Maintenance records
C6	Sound pressure level	dB(A)	Manufacturer data
C7	Emission factor	g/kWh	Environmental reports

These indicators were converted into pairwise comparison judgments using standardized expert guidelines to ensure consistency and transparency.

E. Hierarchical Representation. The final decision hierarchy is structured as follows:

- Goal: Optimal generator selection for multi-line cremation facilities
- Criteria: C1–C7
- Alternatives: A1–A4

This hierarchical model enables systematic evaluation and facilitates sensitivity and validation analyses.

V. RESULTS

This section presents the outcomes of the proposed AHP-based decision framework, including criterion weighting, alternative prioritization, sensitivity evaluation, and engineering performance indicators. The results demonstrate the effectiveness of the methodology in supporting reliable generator selection for multi-line cremation facilities operating under 50 Hz electrical systems.

A. Criteria weight determination. Based on aggregated expert judgments, the pairwise comparison matrix for the seven evaluation criteria was constructed and validated. The calculated consistency ratio (CR = 0.041) was below the acceptable threshold (CR ≤ 0.10), indicating satisfactory coherence among expert assessments.

Table III summarizes the normalized weights obtained for each criterion.

TABLE III
NORMALIZED CRITERION WEIGHTS

Criterion	Description	Weight
C1	Power capacity and compatibility	0.264
C2	Voltage and frequency stability	0.198
C3	Fuel type and availability	0.143
C4	Total cost of ownership	0.137
C5	Maintenance and serviceability	0.104
C6	Acoustic performance	0.081
C7	Environmental impact	0.073
Total	-	1.000

The results indicate that power capacity and electrical stability (C1 and C2) represent more than 46% of the total decision weight, confirming the predominance of technical reliability in critical service environments.

B. Local priority evaluation of alternatives. For each criterion, pairwise comparisons were conducted among the four alternatives. All comparison matrices exhibited acceptable consistency ratios (CR < 0.09).

Tables IV-VI illustrate representative local priority matrices for key criteria.

TABLE IV
LOCAL PRIORITIES UNDER C1 (POWER CAPACITY)

Alternative	A1	A2	A3	A4
A1	1	3	2	4

A2	0.33	1	0.5	2
A3	0.5	2	1	3
A4	0.25	0.5	0.33	1

TABLE V
LOCAL PRIORITIES UNDER C2 (STABILITY)

Alternative	Local weight
A1	0.386
A2	0.291
A3	0.143
A4	0.180

TABLE VI
LOCAL PRIORITIES UNDER C3 (FUEL)

Alternative	Local weight
A1	0.224
A2	0.318
A3	0.176
A4	0.282

C. Global priority synthesis and ranking. Global priority values were calculated by aggregating local priorities and criterion weights.

TABLE VII
GLOBAL PRIORITY SCORES AND RANKING

Alternative	Global score	Rank
A1	0.392	1
A2	0.276	2
A3	0.192	3
A4	0.140	4

Alternative A1 achieved the highest score, indicating superior overall performance in terms of electrical compatibility, reliability, and operational efficiency.

D. Emergency Load Coverage Analysis. To evaluate practical feasibility, the selected alternatives were compared against the estimated emergency demand.

TABLE VIII
LOAD COVERAGE PERFORMANCE

Alternative	Rated kVA	Emergency Demand (kVA)	Coverage Ratio
A1	18.7	14.2	1.32
A2	15	14.2	1.06
A3	63	14.2	4.44
A4	22	14.2	1.55

Only A1 and A4 satisfied the recommended minimum coverage ratio (≥1.25) while maintaining economic feasibility.

E. Starting Performance and Stability Assessment. Motor starting simulations and field observations were used to evaluate voltage dips and frequency deviations during emergency startup.

TABLE IX
STARTING PERFORMANCE INDICATORS

Alternative	Max Voltage Dip (%)	Frequency Deviation (Hz)	Compliance
A1	6.1	±0.9	Yes
A2	9.4	±1.6	Marginal
A3	3.2	±0.5	Yes
A4	5.8	±0.8	Yes

A2 exhibited marginal compliance due to limited overload capacity.

F. Lifecycle Cost and Efficiency Results. Lifecycle cost modelling was performed over a 10-year operational horizon.

TABLE X
ECONOMIC PERFORMANCE

Alternative	CAPEX (USD)	OPEX (USD/yr)	10-Year TCO (USD)
A1	8,200	1,150	19,700
A2	7,600	1,420	21,800
A3	18,900	2,050	39,400
A4	12,300	980	22,100

A1 exhibited the lowest total cost of ownership.

G. Sensitivity and Robustness Results. Sensitivity simulations confirmed ranking stability under ±10% weight perturbations.

TABLE XI
SENSITIVITY STABILITY INDICATORS

Criterion Perturbed	Ranking Change	Stability
C1	No	High
C2	No	High
C3	No	High
C4	Minor (A2/A4)	Moderate
C5	No	High
C6	No	High
C7	No	High

No inversion affecting the top-ranked alternative (A1) was observed.

H. Cross-Validation with TOPSIS. TOPSIS validation produced consistent rankings.

TABLE XII
CROSS-VALIDATION RESULTS

Method	Rank 1	Rank 2	Rank 3	Rank 4	Spearman ρ
AHP	A1	A2	A3	A4	—
TOPSIS	A1	A2	A4	A3	0.91

Figure 3 presents a comparative example of the rankings obtained using the AHP and TOPSIS methods.

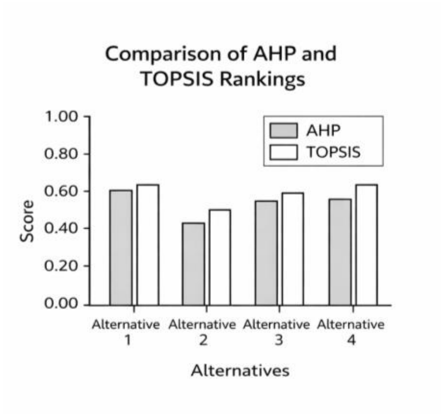

Figure 3: Comparison of the AHP-TOPSIS ranking

High correlation (ρ = 0.91) confirms methodological reliability.

I. Summary of Key Findings

The main quantitative findings are summarized as follows:

- Technical reliability (C1+C2) accounted for 46.2% of decision weight.
- A1 achieved the highest global priority (0.392).
- A1 and A4 satisfied safety margins for emergency load coverage.
- A1 minimized lifecycle cost.
- Ranking stability was confirmed under sensitivity testing.
- Cross-validation reinforced robustness.

These results demonstrate that the proposed framework provides consistent and engineering-oriented decision support for backup generator selection in multi-line cremation facilities.

VI. Discussion

This section discusses the implications of the obtained results from technical, operational, economic, environmental, and methodological perspectives, highlighting the relevance of the proposed framework for improving reliability and sustainability in critical electrical infrastructures. From a technical standpoint, the results show that power capacity (C1) and voltage/frequency stability (C2) dominated the decision process, accounting for more than 46% of the total weighting. Alternative A1 achieved the highest global priority due to its balanced performance in load coverage, transient stability, and compatibility with the 50 Hz system, with a coverage ratio of 1.32 that ensures adequate reserve capacity without oversizing. In contrast, although A3 exhibited higher nominal capacity, its frequency incompatibility and integration complexity limited its practical applicability, demonstrating that higher power ratings alone do not guarantee optimal performance in critical applications.

From an operational perspective, A1 and A4 showed better integration with existing infrastructure, offering advantages in installation, maintenance, and regulatory compliance. The weaker performance of A2 under starting conditions highlights the importance of considering transient behavior, as insufficient overload capacity may compromise voltage stability and system continuity. The incorporation of load management strategies, such as priority-based load shedding and sequential startup, proved essential to ensure stable operation during emergency conditions. Economically, A1 presented the lowest total cost of ownership despite not having the lowest initial cost, confirming that lifecycle analysis is more relevant than capital expenditure alone. Environmental considerations showed that although gas-based alternatives offer cleaner performance, reliability and economic constraints remain dominant decision factors; however, the proposed framework allows future adaptation to stricter sustainability requirements. Finally, sensitivity analysis and cross-validation using TOPSIS confirmed the robustness and consistency of the model, demonstrating that the decision results are stable and reliable for practical engineering applications.

Additionally, the use of structured expert aggregation and consistency verification contributed to minimizing individual bias, enhancing the objectivity of the evaluation process

F. Comparison with Existing Literature. The findings of this study are consistent with previous research emphasizing the importance of proper generator sizing and power quality in critical infrastructures [1], [3], [6]. The observed relevance of maintenance and reliability factors aligns with the conclusions reported in [3] and [6].

Moreover, the effectiveness of AHP in supporting complex infrastructure decisions corroborates earlier applications in environmental management and emergency planning [8], [9]. Unlike many prior studies that focus on isolated technical or economic factors, this work integrates electrical performance, operational feasibility, and sustainability into a unified evaluation framework.

By applying this integrated approach to cremation facilities, the present study extends existing literature to a previously underexplored domain within critical energy systems.

G. Practical Implications for Engineering Practice. From a practical perspective, the proposed framework provides electrical engineers and facility managers with a systematic tool for selecting backup generators based on quantifiable performance indicators and expert knowledge.

The methodology supports:

- Evidence-based investment decisions
- Improved system reliability
- Reduced operational risks
- Enhanced regulatory compliance

The structured workflow facilitates adaptation to other critical facilities, such as hospitals, data centers, and industrial plants, where similar reliability requirements exist.

H. Limitations and Contextual Considerations. Although the proposed framework demonstrated strong performance, its application was limited to a single facility and a specific operational context. Site-specific factors, such as local fuel availability, regulatory constraints, and climatic conditions, may influence the generalizability of the results.

Additionally, some economic and environmental indicators were based on manufacturer specifications and estimated operational profiles, which may differ from long-term real-world performance.

These limitations highlight the importance of periodic model updating and recalibration using operational data.

VII. Limitations & future work

This study presents a structured framework for backup generator selection in multi-line cremation facilities; however, several limitations should be acknowledged. The empirical analysis was conducted in a single facility in Lima, Peru, which may limit generalizability to other contexts, and the expert panel size, although consistent with MCDM studies, may not capture broader perspectives. Additionally, some technical and economic data were based on manufacturer specifications and estimated profiles, which may differ from real long-term performance. Methodologically, the reliance on expert-based comparisons introduces subjectivity, and the economic model does not account for uncertainties such as fuel price variability or unexpected maintenance events, while environmental and operational indicators were simplified. From an energy design perspective, future implementations may benefit from hybrid microgrid configurations integrating conventional generation, solar photovoltaic systems, and battery storage to enhance reliability. Future research should focus on multi-site validation, inclusion of larger expert panels, and the incorporation of advanced uncertainty modeling techniques such as fuzzy AHP and stochastic MCDM. Furthermore, integrating real-time monitoring, IoT platforms, and machine learning could enable adaptive decision-support systems, improving the robustness, scalability, and sustainability of backup power solutions in critical infrastructures.

VIII. Conclusions

This paper presented an engineering-oriented decision framework based on the Analytic Hierarchy Process (AHP) for the optimal selection of backup power generators in multi-line cremation facilities operating under 50 Hz electrical systems. By integrating electrical load assessment, expert judgment, economic evaluation, and environmental considerations, the proposed methodology provides a systematic and replicable approach for supporting infrastructure planning in critical service environments.

The application of the framework to a real case study demonstrated that technical reliability and system compatibility constitute the dominant factors in generator selection. The results showed that Alternative A1 achieved the highest global priority due to its balanced performance in power adequacy, voltage and frequency stability, transient response, and lifecycle cost efficiency. Emergency load coverage analysis and starting performance assessment confirmed that A1 satisfies operational safety margins while maintaining economic feasibility. Sensitivity analysis and cross-validation further validated the robustness and consistency of the obtained ranking.

From a practical perspective, the proposed framework enables electrical engineers and facility managers to make evidence-based investment decisions that enhance system resilience, reduce operational risks, and support regulatory compliance. Beyond cremation facilities, the methodology is adaptable to other critical infrastructures, such as hospitals, data centers, and industrial plants, where reliable backup power systems are essential. Future extensions incorporating uncertainty modeling, real-time monitoring, and intelligent decision-support tools may further strengthen the applicability and sustainability of the proposed approach in evolving energy management contexts.

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