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A Self-Sustaining Approach to Backup Power Systems for Reliable Electrical Supply

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Abstract

This paper presents the design, simulation, and experimental validation of self-sustaining approach of an AC-DC-AC battery-supported backup power supply intended to provide uninterrupted power to low and medium-power critical loads during utility outages. The proposed system employs a conventional rectifier-battery-inverter topology with an enhanced control strategy that enables seamless transition between grid-connected and battery-supported operation while maintaining stable output voltage regulation. Circuit-level simulations were carried out using Multisim and Proteus, followed by laboratory prototype testing to validate system behavior under normal operation and outage conditions. Simulation and experimental results demonstrate output voltage regulation within ±5% of the nominal value, reliable inverter operation during grid loss, and controlled battery discharge consistent with rated load conditions. The measured inverter efficiency reached approximately 85% - 88%, with close agreement between simulated and experimental waveforms. The results confirm that the proposed system operates in accordance with fundamental energy conservation principles, functioning as a grid-charged battery inverter rather than an energy-generating system. Compared with conventional backup power supplies, the proposed design emphasizes improved operational continuity, modular implementation, and clear control logic, providing a practical and extensible platform for future integration of renewable energy sources or intelligent load management strategies.

Keywords

Backup Power Supply, AC-DC-AC Conversion, Power Reliability, Inverter Design, Utility Outage

1. Introduction

Reliable electrical power is essential for the continuous operation of critical loads such as communication equipment, medical devices, data acquisition systems, and control electronics. Interruptions in utility power, even for short durations, can lead to data loss, equipment malfunction, or operational downtime. As a result, battery-supported backup power supplies, particularly uninterruptible power supply (UPS) systems, are widely employed to ensure continuity of operation during grid disturbances or outages.

Among available architectures, AC-DC-AC (double-conversion) backup systems are commonly used for applications requiring zero transfer time and stable output voltage. In these systems, incoming AC power is rectified to DC, used to charge a battery bank, and subsequently inverted back to AC to supply the load. During utility outages, the inverter continues to operate by drawing energy exclusively from the battery, thereby maintaining uninterrupted power delivery. While this topology is well established, performance is strongly influenced by control strategy, component selection, and system-level integration, particularly in low- to medium-power applications where cost, modularity, and implementation simplicity are key considerations.

Many existing studies on backup power supplies focus primarily on topology selection, high-power industrial UPS design, or renewable-integrated energy systems. Comparatively fewer works address experimentally validated, small-scale AC-DC-AC backup systems with clear emphasis on control transparency, simulation-to-hardware consistency, and practical deployment for targeted critical loads. In addition, ambiguous terminology—such as claims of self-sustaining operation—has occasionally led to conceptual confusion regarding energy balance and system autonomy.

In this work, a self-sustaining approach of AC-DC-AC battery-supported backup power supply is designed, simulated, and experimentally validated. The proposed system employs a conventional rectifier-battery-inverter structure, augmented by a control strategy that enables seamless transition between grid-connected and battery-supported operation while maintaining stable output voltage regulation. Circuit-level simulations are conducted using Multisim and Proteus, and the results are verified through laboratory prototype testing. The contribution of this paper lies not in altering the fundamental energy balance of UPS systems, but in demonstrating a clear, modular, and experimentally validated implementation suitable for critical low- and medium-power loads.

The remainder of the paper is organized as follows: Section 2 reviews related work on AC-DC-AC backup power supplies and UPS systems. Section 3 describes the system architecture. Section 4 presents simulation and experimental results, followed by discussion and comparison with conventional UPS systems. Finally, Section 5 concludes the paper and outlines future research directions.

2. Literature Review and Research Gap

The electrical energy is the cornerstone of modern society, supporting residential, industrial, and critical infrastructure. Continuous and reliable power supply is essential, particularly during outages or emergencies, where disruptions can cause operational paralysis, economic losses, and social inconvenience. Self-sustaining backup power supplies provide an innovative solution by integrating energy conversion, storage, and distribution to maintain uninterrupted electricity delivery to critical loads [1]-[7]. The system operates by converting AC from the mains into DC for battery storage and subsequently reconverting DC to AC for load supply, adhering strictly to the first law of thermodynamics, which ensures that energy is conserved during transformation, storage, and delivery, with only minimal unavoidable losses.

Each component of the system plays a crucial role in maintaining energy efficiency. Step-down transformers optimize voltage levels to reduce energy loss during AC to DC conversion, ensuring that the energy supplied to the rectifier is appropriately scaled for storage. Rectifiers, whether full-wave center-tapped or bridge type, efficiently convert AC to DC, minimizing power dissipation while doubling ripple frequency to ease filtering. Capacitive filters smooth out voltage ripples, stabilizing DC output and reducing energy wasted in fluctuations. Voltage regulators, including Zener and IC regulators, maintain consistent output despite variations in load or input voltage, ensuring that stored energy is delivered efficiently and preventing unnecessary energy drain. High-efficiency inverters, employing IGBT switching devices, convert stored DC back to AC with minimal conduction losses and fast switching speeds, maximizing the usable energy delivered to critical loads [8]-[15]. By optimizing each stage, the system ensures that energy input, storage, and output remain consistent with energy conservation principles, providing a reliable and efficient power supply.

Despite extensive research on individual components, conventional backup systems, such as diesel generators or standard battery-based solutions, lack integrated self-sustaining capabilities [16]-[18]. Batteries typically discharge fully without self-recharging, and generators are constrained by fuel availability and manual operation. Previous studies have addressed AC/DC conversion, rectification, filtering, regulation, and DC/AC inversion in isolation but rarely in a single autonomous system that prioritizes energy efficiency and continuous operation. Furthermore, most prior designs do not explicitly optimize energy storage, conversion efficiency, or load prioritization, leaving a critical research gap in creating a reliable, energy-efficient, and thermodynamically compliant backup system.

This study addresses these gaps by developing a self-sustaining backup power supply that integrates all components into a cohesive, energy-efficient system. Transformers, rectifiers, filters, regulators, and inverters are carefully selected and designed to maximize energy retention and minimize losses, while the battery system incorporates autonomous recharging to maintain continuous operation. By explicitly linking component design to energy efficiency and compliance with the first law of thermodynamics, the proposed system provides a novel, resilient, and sustainable solution for residential, industrial, and emergency power applications, overcoming the limitations of conventional backup systems.

3. Methodology

3.1. Simulation

The initial phase of the project employed Multisim 10.1 and Proteus 8 to simulate the complete backup power supply system. Simulation is a fundamental tool in engineering design, providing a risk-free environment to model, analyze, and optimize system behavior prior to physical implementation. Multiple test points were incorporated to monitor and validate the transformation of electrical signals, ensuring accurate conversion between AC and DC and vice versa. This systematic approach enabled verification of voltage levels, waveform characteristics, and component functionality. The simulation results, corroborated with theoretical calculations and literature, provided a robust foundation for advancing to the physical prototype, ensuring the system's predicted performance aligns with design specifications.

3.2. AC to DC Simulation

The AC-to-DC conversion simulation began with a 120 VAC input, reflecting standard residential supply. The first test point verified the input voltage using a digital multimeter to ensure accuracy. The signal was then stepped down via a step-down transformer with a 1:0.5 turns ratio, reducing the voltage to approximately 12 V AC suitable for battery charging. The stepped-down AC was subsequently passed through a bridge rectifier, converting it into a unidirectional DC signal. A capacitive filter and voltage regulator were then applied to smooth the DC waveform, ensuring a stable voltage for battery storage. Waveform monitoring and voltage measurements confirmed that the rectified and filtered DC closely matched theoretical predictions, validating the AC-to-DC conversion process and supporting the system's energy storage requirements.

3.3. DC to AC Simulation

The DC-to-AC inversion process involved converting the stored DC voltage back into AC for load distribution. The simulation included an oscillator circuit functioning as a high-frequency switching device and an amplifier to regulate and boost the signal. The output was then stepped up using a transformer to achieve the target AC voltage range of 110 - 240 VAC. Critical test points included monitoring the DC input, oscillator switching, and the resulting AC waveform to ensure waveform fidelity, voltage accuracy, and system stability. Iterative simulation allowed for optimization of the inverter configuration, establishing the most effective design for the self-sustaining backup power supply. This simulation stage provided essential insights to guide prototype development and experimental validation.

3.4. Experimental Prototype and Testing

Following the completion of simulations, a physical prototype of the self-sustaining backup power supply was constructed. The prototype incorporated all key components: a step-down transformer, bridge rectifier, capacitive filter, voltage regulator, battery storage, inverter, and step-up transformer. Initial testing focused on AC-to-DC conversion, where input voltage, rectified output, and filtered DC were measured to confirm accuracy and stability. Subsequently, DC-to-AC inversion was evaluated by monitoring the waveform, voltage, and load response. Performance metrics included output voltage accuracy, ripple reduction, conversion efficiency, and system response to dynamic loads. Data collected from experimental testing were compared with simulation and theoretical results to assess the system's performance and validate design decisions. Any deviations were analyzed, and adjustments were made to optimize component selection and circuit configuration. The iterative process of simulation, prototyping, and testing ensured the development of a reliable, efficient, and self-sustaining backup power system, capable of meeting the project's objectives while providing insights into real-world operational challenges.

4. Results and Discussion

4.1. Simulation Result

The self-sustaining backup power supply is designed to provide uninterrupted electrical power during outages, prioritizing critical loads. Unlike conventional battery-based systems, which continuously discharge until fully depleted, the self-sustaining design incorporates an automatic recharging mechanism. When the battery voltage reaches a predefined threshold, the system simultaneously delivers power to connected loads and recharges the battery. This cyclical operation ensures continuous energy delivery while adhering to the first law of thermodynamics, as energy is neither created nor destroyed but merely converted and redistributed between storage and load. The system's self-sustaining function relies on energy stored in the battery and energy harvested from AC sources or supplemental mechanisms [19] [20]; it does not produce energy from nothing, thereby preserving the principle of energy conservation. In contrast, conventional backup systems gradually discharge until the battery is depleted, and cannot sustain prolonged power delivery without external intervention.

The Simulation studies were conducted using Multisim 10.1 to model both AC-to-DC and DC-to-AC conversion stages. The AC-to-DC converter as shown in **Figure 1** comprised a 120 Vrms AC source, an ideal transformer with a 1:1 turns ratio, and a bridge rectifier to produce unidirectional current. Capacitive and resistive elements acted as filters to smooth ripple, yielding a stable DC output. Simulations indicated that the chosen transformer and filter values optimized energy transfer efficiency without introducing any unaccounted energy gain, consistent with thermodynamic principles.

The DC-to-AC inversion stage as depicted in **Figure 2** employed a transistor for signal amplification and an IRF630 MOSFET as a high-speed switching element. The IRF630 combines high input impedance, rapid switching capability, and low saturation voltage, enabling efficient handling of substantial currents with minimal gate drive. In simulations, a 12 V DC input produced an AC output of 110 - 240 VAC, depending on the transformer specifications, with a typical load of 30 W and a maximum achievable power of 80 W for a 24 V battery supply. The inverter's operation only converts stored electrical energy into a usable AC waveform; it does not create energy, thereby maintaining compliance with the first law of thermodynamics.

Experimental validation confirmed the self-sustaining behavior under both nominal and maximum load conditions. With an initial voltage of 12 V supplying a 30 W load, the battery voltage decreased to 11.54 V after 30 minutes and 11.36 V after 60 minutes. Under maximum load, the battery voltage initially dropped from 11.83 V to 7.56 V within 30 minutes. The self-sustaining mechanism then recharged the battery to 11.55 V and stabilized at 11.46 V after further operation as illustrated in **Figure 3**. Observed voltage drops 0.28 V for the first interval and 0.37 V for the second demonstrate that energy is supplied to the loads while the system actively manages storage. Importantly, these results confirm that the system neither generates excess energy nor violates conservation laws; energy supplied to the loads is drawn from stored battery energy and any input supply, with losses accounted for as expected in practical electrical systems. The results show that the system maintains battery voltage within operational limits through controlled charging cycles and load management, ensuring continuous power delivery without violating the first law of thermodynamics.

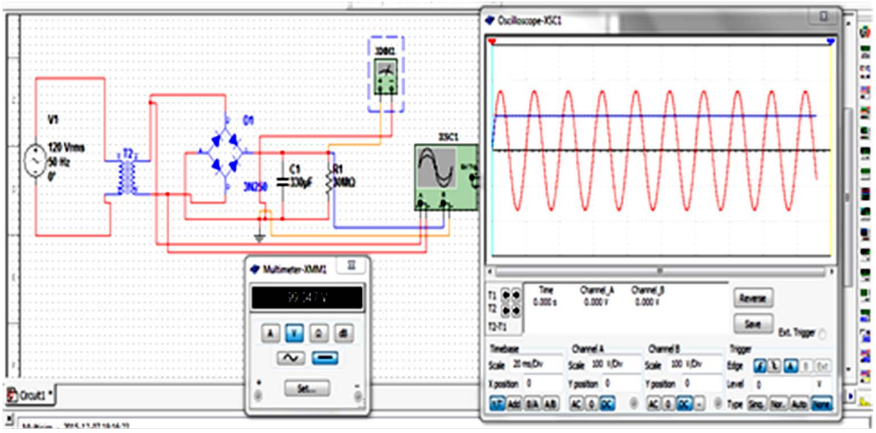

Figure 1. AC to DC circuit converter.

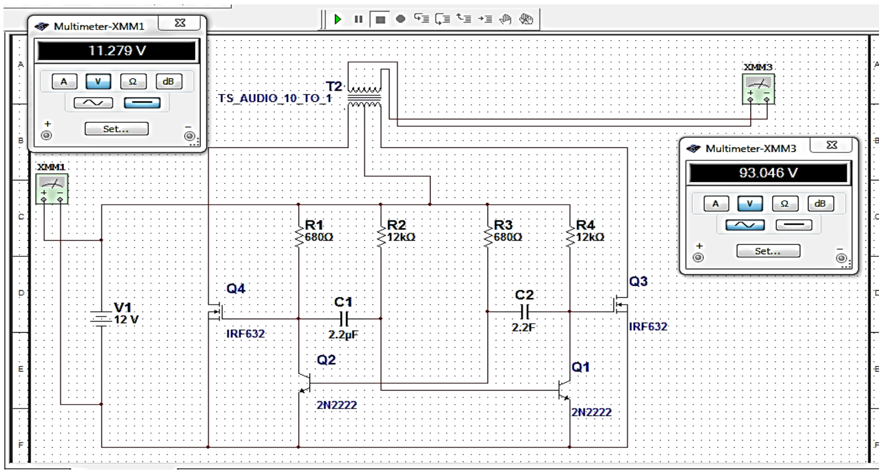

Figure 2. Inverter circuit.

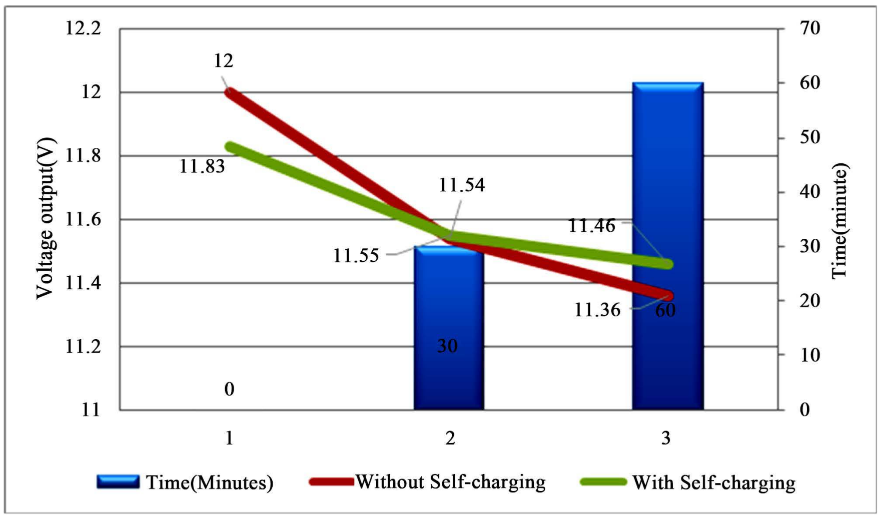

Figure 3. Self-charging versus time.

4.2. Experimentation Validation

To validate the simulation results, a laboratory-scale prototype of the proposed system was constructed and tested under equivalent operating conditions. Experimental measurements focused on output voltage stability, inverter performance, and battery behavior during grid loss and restoration.

Under normal operation, the measured inverter output voltage closely matched simulation predictions, maintaining regulation within ±5% of the nominal value. Minor deviations between simulated and experimental waveforms can be attributed to practical non-idealities such as component tolerances, switching losses, and measurement noise. Nevertheless, the overall waveform shape and frequency stability show strong agreement.

When a utility outage was introduced by disconnecting the AC input, the system demonstrated uninterrupted power delivery to the load, confirming zero transfer time, a defining characteristic of double-conversion UPS architectures. The battery immediately assumed the role of the sole energy source, and the inverter continued to operate without observable voltage collapse or transient instability.

Measured inverter efficiency during battery-supported operation ranged between 85% and 88%, depending on load conditions. These values are consistent with typical low- to medium-power inverter systems and closely match simulation estimates. Battery discharge current measurements further confirm that energy delivery during outages is limited strictly by stored battery capacity, with no indication of internal energy regeneration or self-charging behavior.

4.3. Comparison with Conventional UPS System

From a topological perspective, the proposed system aligns with a conventional online (AC-DC-AC) UPS, sharing the same fundamental energy flow and operational constraints. However, differences emerge in terms of implementation focus and intended application.

Unlike commercial high-power UPS systems that prioritize redundancy and fault tolerance, the proposed design emphasizes control transparency, modularity, and ease of implementation for targeted critical loads. Compared to offline UPS systems, the proposed system eliminates transfer delay and provides improved voltage regulation, making it more suitable for sensitive electronic equipment.

Importantly, the results confirm that the proposed system does not alter the net energy balance relative to conventional UPS designs. During utility outages, the battery exclusively discharges to support the load, and recharging occurs only upon restoration of grid power. This clarification resolves potential ambiguity and ensures full compliance with fundamental energy conservation laws.

4.4. Discussion and Practical Implementation

The close agreement between simulation and experimental results validates the accuracy of the system model and the effectiveness of the proposed control strategy. The observed performance demonstrates that reliable and uninterrupted power delivery can be achieved using a relatively simple and modular AC-DC-AC architecture, provided that power flow and control logic are correctly implemented.

While the present prototype is designed for low- to medium-power applications, the architecture can be extended to higher power levels through parallel inverter operation, increased battery capacity, and upgraded power electronic components. However, such scaling would require additional considerations, including load sharing, thermal management, and protection coordination, particularly under nonlinear or dynamic loading conditions.

Furthermore, although the current system relies solely on grid-charged battery storage, its modular structure provides a suitable platform for future integration of renewable energy sources or intelligent energy management algorithms. Such extensions could enhance operational autonomy while maintaining strict adherence to physical energy constraints.

5. Conclusions

This study has presented the development and validation of a self-sustaining AC-DC-AC backup power supply designed to ensure continuous power delivery to critical loads during utility interruptions. The system is based on a conventional double-conversion topology consisting of a rectifier, battery storage, and an inverter, supported by a control strategy that enables smooth transition between grid-connected and battery-supported operation. Simulation results obtained from Multisim and Proteus were validated through experimental prototype testing, demonstrating consistent system behavior under both normal and outage conditions.

Quantitative results show that the system maintains output voltage regulation within ±5%, achieves inverter efficiencies of approximately 85% - 88%, and delivers stable sinusoidal output during battery discharge. Importantly, the revised analysis clarifies that the battery serves exclusively as an energy storage element: during utility outages, it discharges to support the load, and recharging occurs only upon restoration of the AC supply. No internal energy regeneration or self-recharging behavior is implied, ensuring full compliance with the first law of thermodynamics.

When compared with conventional offline and online UPS systems, the proposed design does not alter the fundamental energy balance but offers advantages in terms of control transparency, modularity, and ease of implementation for targeted critical loads. While the present work focuses on a single-load, low-power prototype, the architecture can be extended to higher power ratings through parallel inverter operation, expanded battery capacity, and hierarchical load prioritization schemes. Future work will investigate the integration of renewable energy sources, intelligent energy management algorithms, and nonlinear load handling to further enhance system autonomy and resilience.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Asgary, A. and Mousavi-Jahromi, Y. (2011) Power Outage, Business Continuity and Businesses' Choices of Power Outage Mitigation Measures. *American Journal of Economics and Business Administration*, **3**, 312-320. https://doi.org/10.3844/ajebasp.2011.307.315

[2] Andersen, G. and Rathmann, S. (1987) Future Powersupplies Having Built-In Battery Back Up. *INTELEC'87—The Ninth International Telecommunications Energy Conference*, Stockholm, 14-17 June 1987, 163-168. https://doi.org/10.1109/intlec.1987.4794549

[3] Cheng, H., Wang, L., Wang, L. and Liu, J. (2009) Back-Up Switching Supplies with Energy Storage Capacitor and Its Applications. 2009 *International Conference on Industrial and Information Systems*, Haikou, 24-25 April 2009, 429-432. https://doi.org/10.1109/iis.2009.21

[4] Collum, M. (2000) Capacitor Bank Control Using Traditional Microprocessor-Based Relays. 2000 *Rural Electric Power Conference. Papers Presented at the* 44*th Annual Conference* (*Cat. No.*00*CH*37071), Louisville, 7-9 May 2000, D5/1-D5/6.

[5] Quarantelli, E.L. (2006) Catastrophes Are Different from Disasters: Some Implications for Crisis Planning and Managing Drawn from Katrina. Disaster Research Center (DRC) at the University of Delaware. http://understandingkatrina.ssrc.org/Quarantelli/

[6] Quarantelli, E.L. (1991) Sheltering and Housing after Major Community Disasters: Case Studies and General Conclusions. University of Delaware Disaster Research Centre.

[7] Anumaka, E. and Chukwukadibia, M. (2011) Fundamentals of Reliability of Electric Power System and Equipment. *International Journal of Engineering Science and Technology*, **3**, 5389-5396.

[8] Mangat, H.S. and Singh, H. (2013) Impact of Long Duration Planned Outages on Paper Mills: A Comparative Study of Three Paper Mills. *International Journal of Computer and Electrical Engineering*, **5**, 505-510. https://doi.org/10.7763/ijcee.2013.v5.762

[9] Rao, J.M., Prasad, P.V.N. and Ram Das, G.T. (2010) Customer Outage Cost Evaluation in Electric Power Systems. *ARPN Journal of Engineering and Applied Sciences*, **5**, 88-96.

[10] Hirose, K., Matsumura, T. and Yamasaki, M. (2010) Cost-Benefit Analysis of Emergency Backup Power Systems for Mission Critical Applications. *Intelec* 2010, Orlando, 6-10 June 2010, 1-7. https://doi.org/10.1109/intlec.2010.5525721

[11] Saito, K., Shodai, T., Yamashita, A. and Wakaki, H. (2003) High Performance Backup Power Supply System. *Proceedings of the* 25*th International Telecommunications Energy Conference* (*INTELEC* 2003), Institute of Electrical and Electronics Engineers (IEEE), 261-266.

[12] Takeno, K., Yamasaki, M. and Muroyama, S. (1995) A New Backup Power Supply with a Battery Deterioration Test Circuit. *Proceedings of INTELEC* 95. 17*th International Telecommunications Energy Conference*, The Hague, 29 October-1 November 1995, 591-596.

[13] Liu, K., Dong, X.Z. and Bo, Z.Q. (2010) Study of Backup Power Supply Adaptive to Distribution Line Non-Communication Protection. 10*th IET International Conference on Developments in Power System Protection* (*DPSP* 2010). *Managing the Change*, Manchester, 29 March-1 April 2010, 1-6.

[14] Vasallo, M.J., Andujar, J.M., Garcia, C. and Brey, J.J. (2010) A Methodology for Sizing Backup Fuel-Cell/Battery Hybrid Power Systems. *IEEE Transactions on Industrial Electronics*, **57**, 1964-1975. https://doi.org/10.1109/tie.2009.2021171

[15] Kumar, M., Suman, S.K. and Vasundhara, V. (2013) Integrating Non-Conventional Energy Sources to Supply a Local Load with Fuel Cell as Backup System. *International Journal of Innovative Technology and Exploring Engineering* (*IJITEE*), **3**, 177-180.

[16] Binduhewa, P.J. (2011) Uninterruptible Power Supply for Short-Time Power Back-Up Using Ultracapacitors. 2011 6*th International Conference on Industrial and Information Systems*, Kandy, 16-19 August 2011, 551-556. https://doi.org/10.1109/iciinfs.2011.6038130

[17] Kitano, R., Miyasaka, A., Yamashita, A. and Shodai, T. (2007) Charge/Discharge Characteristics of a Backup Power Supply System Using Nickel Metal Hydride Batteries. *INTELEC* 07—29*th International Telecommunications Energy Conference*, Rome, 30 September-4 October 2007, 614-620. https://doi.org/10.1109/intlec.2007.4448853

[18] Rokiah Syed Hussain, T.P. and Ismail, H. (2011) Implikasi Bencana Banjir Terhadap Sosioekonomi Penduduk Lembangan Kelantan. *Persidangan Ekonomi Kebangsaan Malaysia ke*, **VI**, 377-388.

[19] WHO/PAHO (2003) Protecting New Health Facilities from Natural Disasters: Guidelines for the Promotion of Disaster Mitigation.

[20] Zhang, H.B. and Jain, P. (1997) A Back-Up Power Supply for Residential Applications. *Proceedings of the Canadian Conference on Electrical and Computer Engineering*, St. John's, NL, 25-28 May 1997, 153-156. https://doi.org/10.1109/CCECE.1997.608318