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Analysis Of A Hybrid Micro Grid With Photovoltaic System, Battery And A Geerator

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Abstract: *The study assesses a hybrid microgrid system that provides power for rural and off-grid areas, consisting of a photovoltaic (PV) array, a battery storage system, and a diesel generator. Various operating conditions, including with or without the generator and varying solar radiation, were used to test performance in MATLAB/Simulink. First tests were conducted with the PV only and the battery; the system was able to satisfy the load demands effectively, with the PV providing about 5 kW and the battery providing additional support. The hybrid system was used to feed a 35-kW load when a PV-battery system and a 40 kVA generator at a power factor of 0.8 was introduced. The results showed successful load coverage, a stable rise in battery state of charge, and stable values of system parameters: voltage V=565.6 V, current I=14 A, and frequency f=50.15 Hz, which confirmed the seamless integration of the generator. Resilience testing with intermittent solar radiation, when the solar radiation power is reduced to 500 W/m^2, showed that the battery discharges to compensate for the reduced PV output. Even though the PV output was reduced, the system maintained the load voltage at 415V and frequency within standard limits of ±5%. Overall, the hybrid micro-grid is found to be robust, stable, and can support an uninterrupted power supply during different input renewable energy and load conditions, showing the possibility of the micro-grid system to power off-grid buildings.*

Keywords: Hybrid micro-grid system; Photovoltaic (PV) array; Battery storage system; Diesel generator

Introduction

Electricity in rural areas is the process of providing electrical power to isolated villages and places without access to a consistent supply of electricity. (Javadi et al., 2013) (Akbas et al, 2022). This is a critical aspect for the socio-economic development, quality of life, and, conversely, poverty alleviation in rural communities. The significance of rural electrification can hardly be overemphasized, because it has a bearing on many aspects of human development and national progress. Rural electrification is a key component in the process of making rural areas vibrant, productive and sustainable. It is a major component in the quest for equitable development, economic growth, provision of social services, and overall rural well-being.

Investing in rural electrification will unlock the full potential of rural regions, enhancing the nation's overall prosperity and sustainability. One way of rural electrification is by adopting a micro-grid strategy. Hybrid micro-grids are small-scale energy systems that combine different energy generation technologies, including renewable and non-conventional energy sources such as wind, solar, and bioenergy, with traditional power generation technologies like diesel generators (Canale et al, 2021). These systems are designed to operate as stand-alone systems or as an alternative power source to the main electric grid, providing rural communities and towns with a more reliable and sustainable power supply when the main grid infrastructure is unreliable or unavailable. The idea of hybrid microgrids emerged as a solution to help reduce the challenges from the intermittency of renewable energy sources (Naeem & Hassan, 2020). While renewables like solar and wind are environmentally friendly, their variability due to weather conditions, with respect to time of day can lead to instability in power supply. To address this, hybrid microgrids are designed with energy storage systems, such as batteries, and in some cases with conventional generators to maintain an uninterrupted and stable electrical grid. The rollout of hybrid micro-grids in rural settings, especially in developing areas, is an attractive option to grid extension which is challenging and costly in such areas. These micro-grid systems provide power, improve living standards, promote economic growth and reduce dependence on fossil fuels, all of which help to sustain the environment. (Parag & Ainspan, 2019).

The technology and design of hybrid micro-grids have undergone tremendous development over the years, including the improvements of power electronics, energy management strategy, and control systems (Kumar et al, 2020; Elmouatamid et al, 2020). Advanced control technologies are integrated into modern hybrid micro-grids to ensure optimal utilization of multiple energy sources, cost minimization, and efficient operation of the micro-grid. The adaptability makes them especially well-suited for electrification in rural areas., where energy demand is often lower and more variable compared to urban areas (Dimovski et al, 2023).

The Inclusion of sustainable energy sources into hybrid micro-grids is in line with the worldwide efforts to reduce emissions of carbon and to combat global warming. These local solutions ensure energy security and, above all, empower communities to access sustainable energy solutions, using their local resources. Hybrid micro-grids are gaining traction due to their ability to deliver clean, reliable, and cost-effective electricity in areas where access to energy has been a significant challenge. Hybrid micro-grids are a revolutionary solution for rural electrification that takes advantage of the benefits of different energy sources to build resilient, efficient, and sustainable micro-grid power systems. The world is evolving into an independent and renewable energy landscape and hybrid micro-grids will be a key element in meeting the energy needs of rural and marginalized populations.

Hybrid Micro-Grid

Hybrid micro-grid configurations use multiple energy generation technologies, typically a mix of energy storage, traditional power generation, and renewable energy technologies (Canale, L., et al, 2021). These configurations offer flexibility, reliability, and efficiency in meeting the energy demands of rural and distant locations where access to a reliable supply of power is often limited. The knowledge of various hybrid micro-grid options is crucial to making sure that the micro-grid operates at its best and to ensure that the communities in which it is deployed have their needs addressed. The setup of a hybrid microgrid is depicted in Figure 1. The micro-grid consists of a Wind Turbine, a Photovoltaic System, Energy Storage System (ESS), etc. The common hybrid micro-grid configurations are Wind-Diesel-Battery Hybrid Micro-Grid, Solar PV-Diesel Micro-Grid, Solar PV-Wind-Biomass Hybrid Micro-grid, Solar PV-Natural Gas-Battery Hybrid Micro-grid, and Solar PV-Hydro-Battery Hybrid Micro-grid.

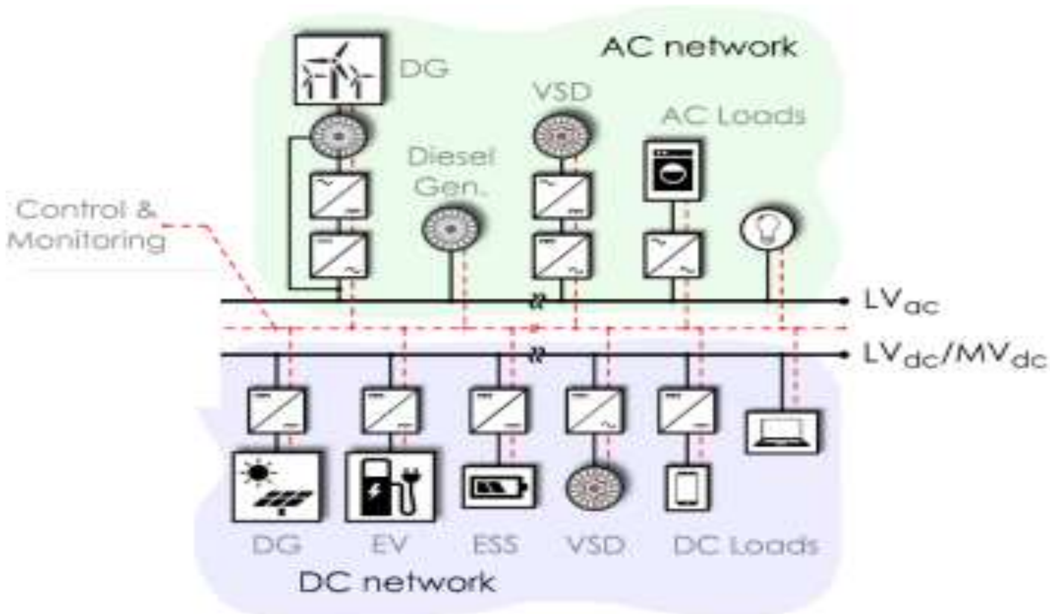

Figure 1: A Typical Hybrid Micro-Grid Configuration

Methodology

The research was conducted using the MATLAB/Simulink software environment

System Description

The studied microgrid consists of a variety of different energy sources, designed to ensure a reliable and sustainable energy supply. This microgrid system consists of a 5.6 kW PV farm, a battery energy storage system (200 AH) to meet a load of 5.6 kW without generator, and the integration of a generator rate at 40 kVA (power factor of 0.8) and the same PV array and battery to meet a load demand when change to 35 kW. The microgrid distribution network impedance is line impedance of 1.652+j1.2 ohm/km. The use of renewable energy in this hybrid system complements the usage of conventional diesel generation, with all the benefits of both sustainable and dispatchable power sources.

Method of analysis

The micro-grid system in the study is shown in Figure 2; it shows the overall layout and interconnection of the various energy sources and the load. The structure shown in Figure 2 is also modeled in the MATLAB/Simulink environment as shown in Figure 3. This micro-grid configuration is a foreshadowing of the future of energy use, where multiple generation sources will be combined to form a strong, flexible, and sustainable energy supply. These various sources are also being connected in a single grid, which not only helps ensure energy security but also aids in the shift towards a cleaner, more resilient energy infrastructure.

The following approaches were used to analyze the performance of the system;

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1. Evaluate the PV performance of the microgrid system without and with a generator.
2. Analyze the impact of the battery system on the microgrid with and without a generator.
3. Impact and analysis of the battery energy system under intermittency

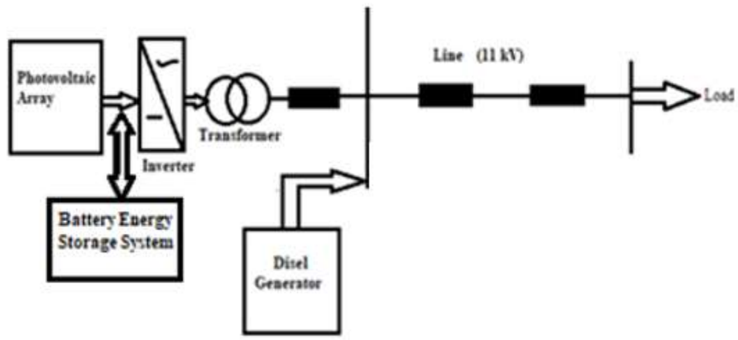

Figure 2: Hybrid Micro-grid System

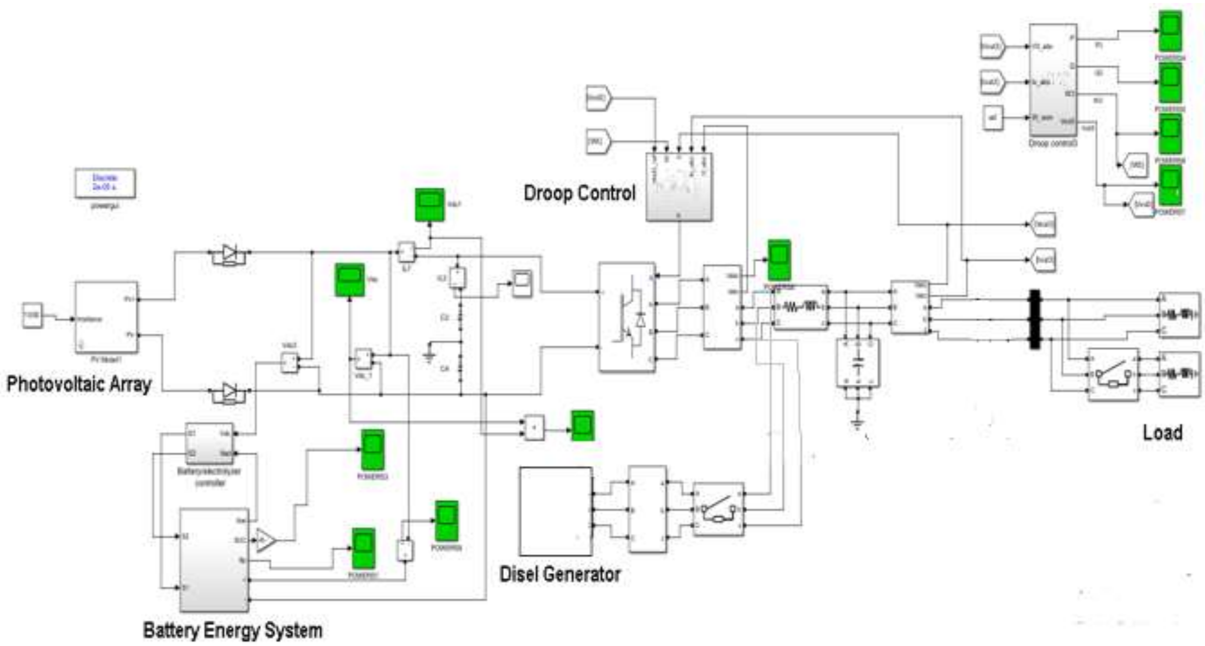

Figure 3 Modelled Micro-grid System in Simulink

Results And Discussion

Analyses of the Modelled PV performance without the Generator system

The assessment of the micro-grid performance was done without the diesel generator; only the PV array and battery storage were used to demonstrate their ability to meet energy demands without the diesel generator. The line-to-line load voltage was a major concern, with the line-to-line load voltage recorded as 565.6 V (≈ 400 V RMS), as shown in Figure 4, which meets design criteria and is safe for the operation of connected equipment. The load current was measured at 14A as shown in Figure 5, which translates to 5.6 kW, as shown in Figure 6, showing that the renewable-storage system can satisfy the anticipated energy demand without variation. The PV-battery system was found to be effective in providing power supply stability in terms of both voltage and frequency, and it also showed good performance in load balancing, making it a suitable system for off-the-grid rural electrification applications where load balancing and power supply stability are required. The frequency was measured to be 49.96 Hz as shown in figure 7. This frequency is very near the standard frequency of 50 Hz and within the acceptable error of ±5% of the standard. This frequency stability shows that the microgrid can be operated within the industry standards even without the diesel generator, to provide a stable power supply to the microgrid.

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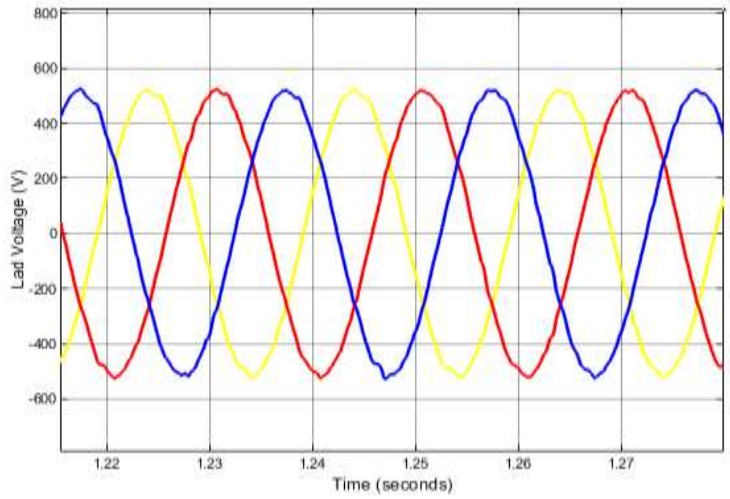

Figure 4: Load Voltage

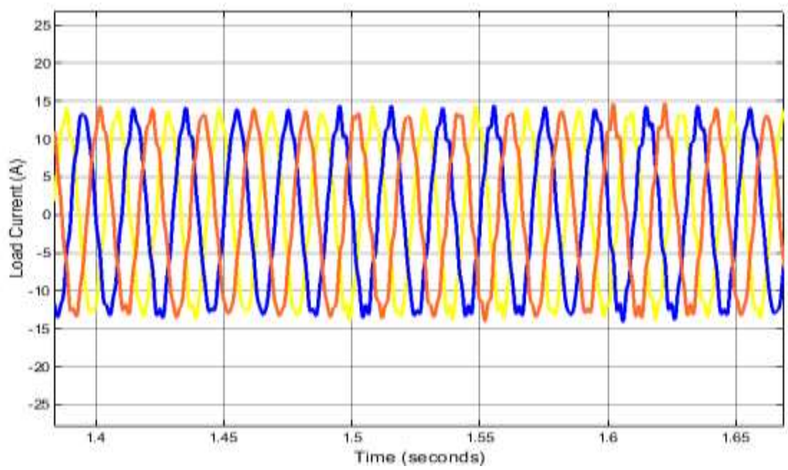

Figure 5: Load Current

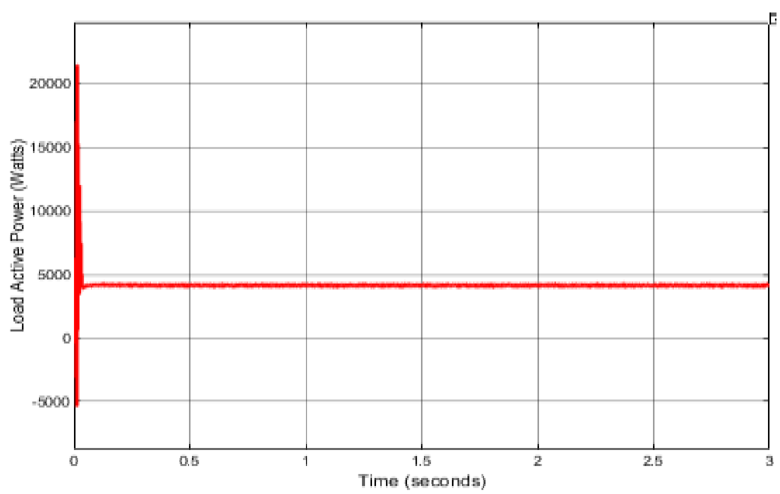

Figure 6: Load Power

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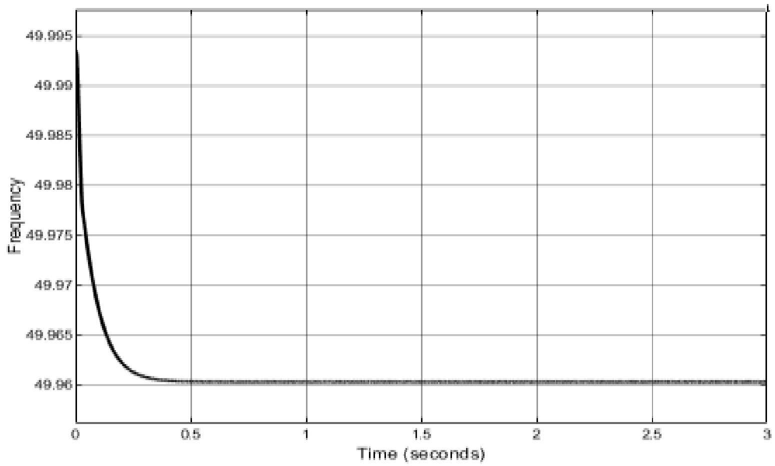

Figure 7: Micro-grid frequency

Analysis of the Energy Storage System performance without and with a generator

The microgrid's energy storage system is expected to have a capacity of 200 ampere-hours (AH) with an initial state of charge (SOC) of 60%. When the operation starts, the battery is in a state of 60% of its full charging state, so that it can deliver backup power or store more than enough energy generated by the PV system. The battery system also has a response time of about 30 seconds (time to start delivering power when it is needed. The battery system is rated at 5 kW, which means that when fully charged, it can deliver up to 5 kW of electrical power. In the simulation, it was observed that the battery was discharging because the load is increase from 5 kW to 35 kW, as shown in Figure 8 without generator was integrated.

When a 40 kVA diesel generator was integrated into the PV-based microgrid to form a hybrid system. This integration was initiated to assess the synergy between the combined power sources and their ability to meet the load requirements. When the 40 KVA generator was introduced, the load was increased to 35 KW. The corresponding load voltage of 420 V and current of 80 Amps were measured as shown in Figures 9 and 10 respectively given a load power of 33.6 kW. The generator successfully met the increased load demand of 35 kW, and the system frequency was monitored to evaluate the generator's impact on the overall frequency of the microgrid. As shown in Figure 11, system frequency remained within the standard limit of ±5% of the nominal 50 Hz frequency, indicating stable operation with the generator integrated into the microgrid.

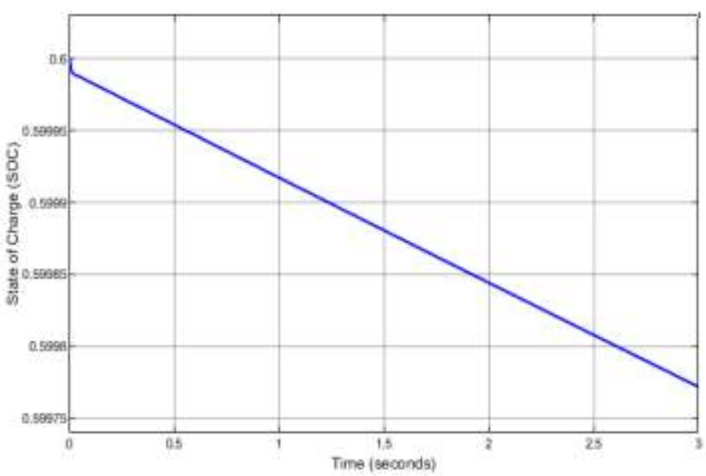

Figure 8: Battery Discharging without Generator

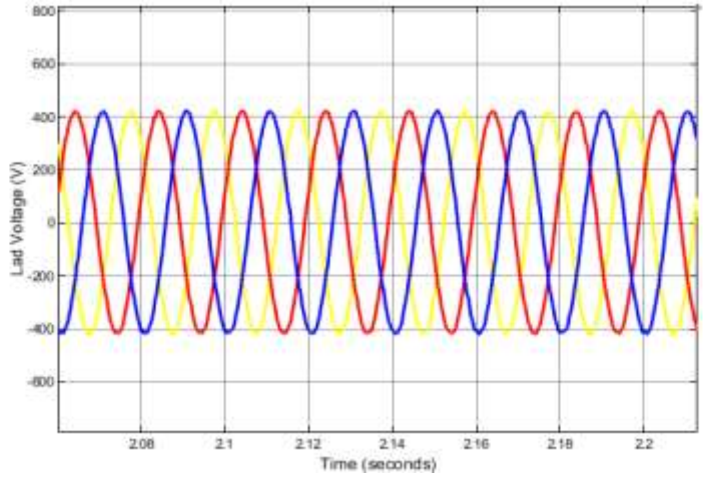

Figure 9: Load Voltage (V) with generator

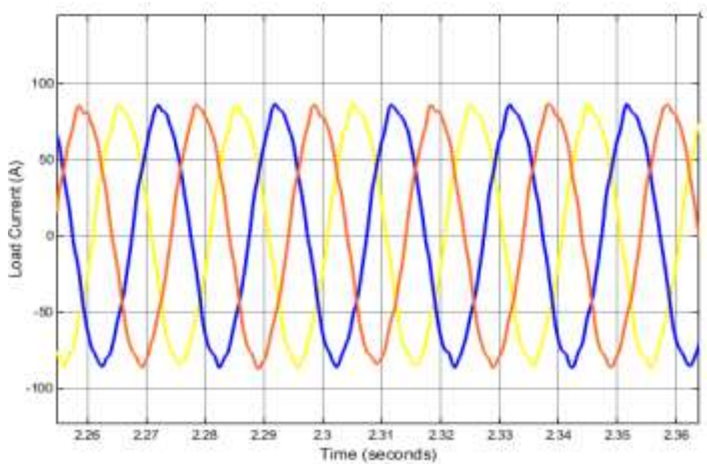

Figure 10: Load Current with generator

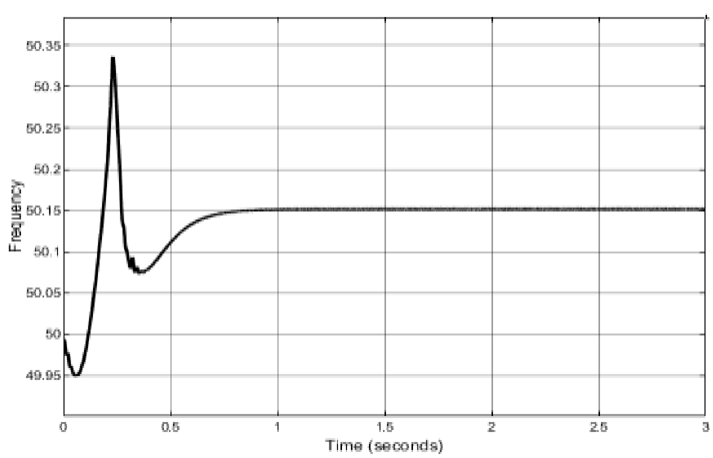

Figure 11: Microgrid frequency with 40 KVA diesel generator

In the hybrid micro-grid system, the diesel generator played a very important role for power to the load consistently. It was generating approximately 34 kW, which precisely matched the load demand. This indicates that the generator was operating efficiently and was capable of meeting the energy needs of the system. With the diesel generator effectively managing the load requirements, the photovoltaic (PV) array could focus on charging the battery storage system. This transition is shown in Figure 12, where the PV array's energy output is directed towards replenishing the battery's stored energy.

Figure 13 shows that the battery power and indicates that it was indeed being charged (the negative graph indicates that the battery is charging) during this period, reflecting the effectiveness of the PV array in supplying energy to the storage system. This indicates that the hybrid microgrid system was not only meeting the immediate load requirements with the diesel generator but also utilizing the renewable energy from the PV array to enhance the overall energy efficiency and sustainability of the system.

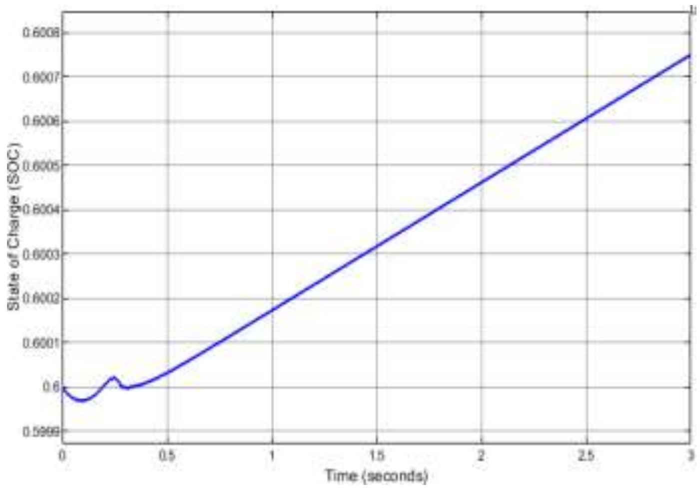

Figure 12: Battery state of charge (SOC) with Generator

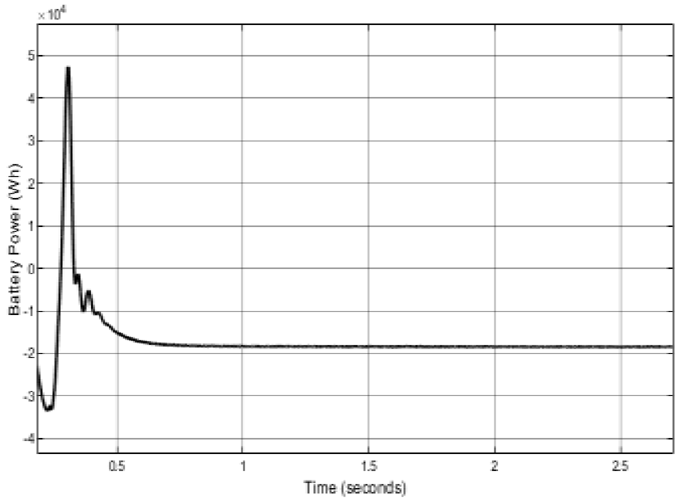

Figure 13: Battery Power has been charged with a PV array

Impact of Battery energy system on micro-grid frequency, load voltage, and current, and state of SOC under intermittency

The performance of the microgrid was further assessed under conditions of intermittency, specifically simulating the impact of reduced solar radiation. In this scenario, the solar radiation level was decreased from the typical baseline of 1000 W/m² to 500 W/m², which was attributed to cloud cover. This reduction in solar radiation directly affected the power output of the photovoltaic (PV) array, causing it to produce less energy than usual. As a result of this diminished output, the battery system was called upon to compensate for the energy shortfall. The findings from the evaluation reveal that, with solar radiation reduced to 500 W/m², the battery began to discharge its stored energy, as illustrated in Figure 14. This discharge was crucial in meeting the load power requirement of 4 kW, as shown in Figure 15.

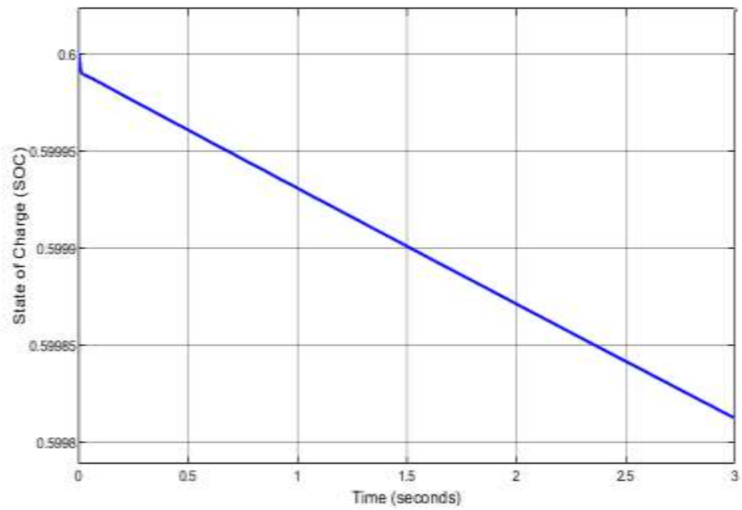

Figure 14: Battery discharge during intermittency

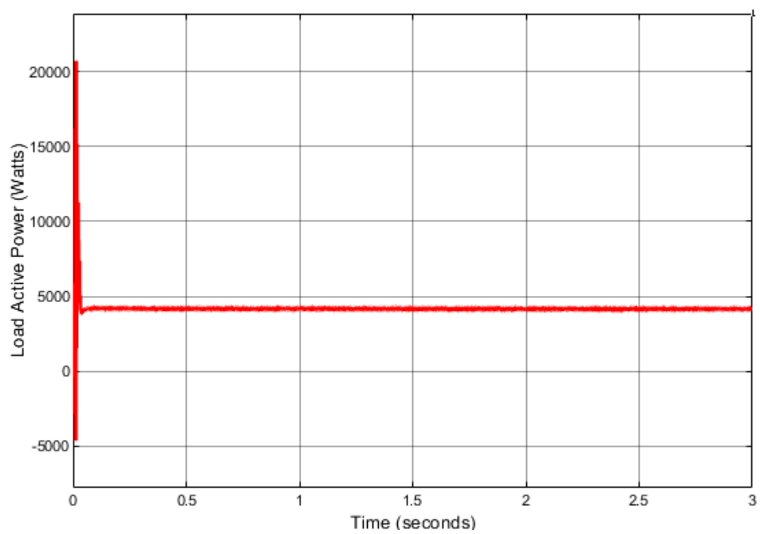

Figure 15: Load power under intermittency

This additional power was available from the battery, ensuring that load demands were satisfied even if less solar power was available. The PV array produced less power, but the microgrid maintained stable operation. The load voltage was constant at 565 V (400 RMS) and the current was constant at 12 Amps as shown in Figures 16 and 17 respectively. These steady voltages and currents are necessary to ensure that the electrical loads connected to the microgrid operate reliably and within their specified limits.

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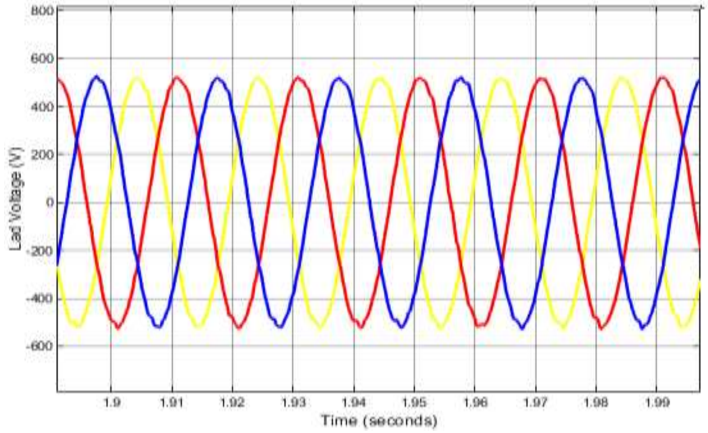

Figure 16: Load Voltage Under intermittency

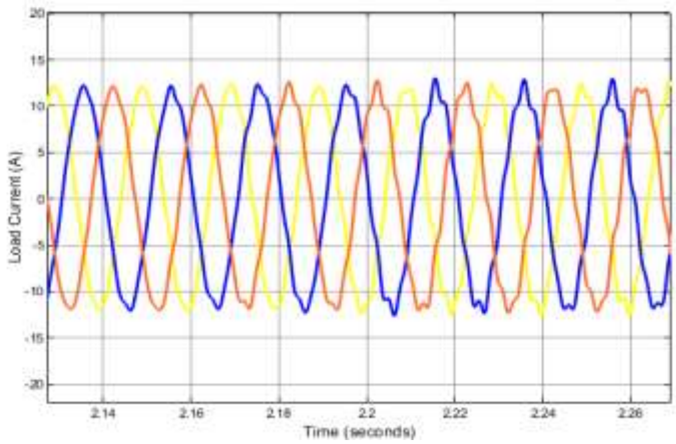

Figure 17: Load Current Under Intermittency

Also, the system frequency was monitored and was kept inside the normal frequency limits as shown in Figure 18. This frequency stability demonstrates the effectiveness of the battery system to maintain the overall system performance and reliability even when the solar radiation is greatly reduced. The capability of the power grid to maintain voltage, current and frequency within standard limits, is an indication of the robustness of the hybrid system and its capacity to manage instabilities in the solar energy generation, providing a reliable power supply under various conditions.

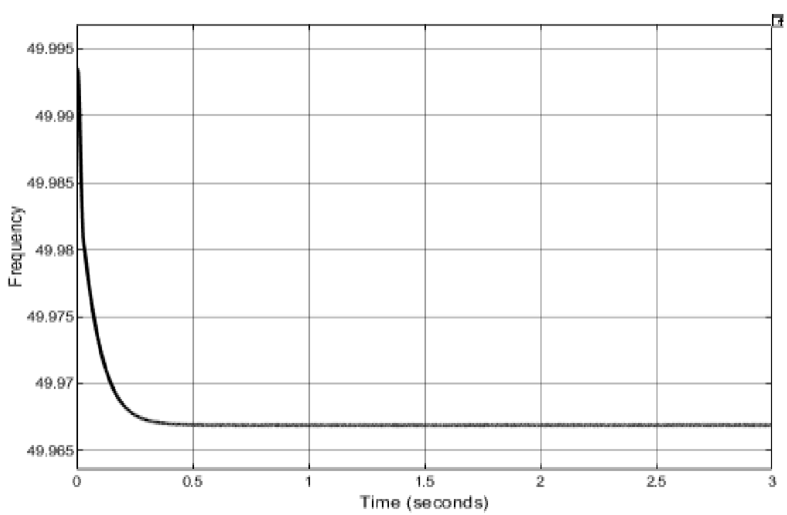

Figure 18: System frequency under intermittency

Conclusion

The study of the performance of hybrid micro-grid systems in remote areas reveals their significant potential to meet the energy needs of off-grid and underserved rural communities. Hybrid micro-grids, that combine renewable energy sources such as solar and wind with conventional backup systems such as diesel generators and battery storage, offer a reliable, cost-effective and environmentally conscious alternative to conventional power generation. The study demonstrates the potential of using locally available renewable resources for improving rural energy access, reducing dependency on fossil fuels, decreasing greenhouse gases and promoting sustainable development. Properly designed and optimized, these systems provide a high degree of energy reliability and efficiency, adequately responding to different load demands over the year.

Hybrid micro-grids are attractive for rural electrification because of the long-term operational cost savings and the reduced maintenance, albeit the substantial initial capital investment. Their case is further strengthened by environmental benefits, such as reduced emissions and ecological impact, which serve as a key driver of rural sustainability. But there are many hurdles to overcome. It is also constrained by technical limitations such as energy storage and the intermittent nature of renewables, as well as socio-economic and policy barriers that may inhibit its widespread deployment. Overall, the hybrid micro-grid systems present a promising, sustainable, reliable, and affordable solution for electrifying off-grid communities while contributing to broader environmental and economic goals.

Reference

Akbas, B., Kocaman, A. S., Nock, D., & Trotter, P. A. (2022). Rural electrification: An overview of optimization methods. Renewable and Sustainable Energy Reviews, 156, 111935.

Canale, L., Di Fazio, A. R., Russo, M., Frattolillo, A., & Dell'Isola, M. (2021). An overview on functional integration of hybrid renewable energy systems in multi-energy buildings. Energies, 14(4), 1078.

Dimovski, A., Corigliano, S., Edeme, D., & Merlo, M. (2023). Holistic MILP-based approach for rural electrification planning. Energy Strategy Reviews, 49, 101171.

Elmouatamid, A., Ouladsine, R., Bakhouya, M., El Kamoun, N., Khaidar, M., & Zine-Dine, K. (2020). Review of control and energy management approaches in micro-grid systems. Energies, 14(1), 168.

Javadi, F. S., Rismanchi, B., Sarraf, M., Afshar, O., Saidur, R., Ping, H. W., & Rahim, N. A. (2013). Global policy of rural electrification. Renewable and Sustainable Energy Reviews, 19, 402-416.

Kumar, G. R., Sattianadan, D., & Vijayakumar, K. J. I. J. O. E. (2020). A survey on power management strategies of hybrid energy systems in microgrid. International Journal of Electrical & Computer Engineering (2088-8708), 10(2).

Naeem, A., & Hassan, N. U. (2020, March). Renewable energy intermittency mitigation in microgrids: State-of-the-art and future prospects. In 2020 4th International Conference on Green Energy and Applications (ICGEA) (pp. 158-164). IEEE.

Parag, Y., & Ainspan, M. (2019). Sustainable microgrids: Economic, environmental and social costs and benefits of microgrid deployment. Energy for Sustainable Development, 52, 72-81.