

Installation Practice of 3.5KVA Hybrid Inverter System with Appropriate Protection Mechanisms

ADEOGO J. O.¹, OLALUYI O. J.², OFODU P. C.³, BELLO F.⁴, HARUNA A. O.⁵

^{1, 2, 3, 5}*Department of Electrical and Electronic Engineering, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Nigeria.*

⁴*Department of Electrical and Electronic Engineering Technology, Rufus Giwa Polytechnic Owo, Ondo State, Nigeria.*

Abstract- *This study presents the design, installation, and evaluation of a 3.5 kVA hybrid inverter system as a sustainable and reliable solution to Nigeria's persistent energy challenges. The hybrid inverter integrates solar photovoltaic (PV) modules, battery storage, and grid power to provide continuous electricity for small-scale residential and office applications. The system was designed using three 450 W monocrystalline solar panels, a 60 A PWM charge controller, two 200 Ah deep-cycle batteries, and a 3.5 kVA pure sine wave inverter. Methodologically, the project combined theoretical design calculations, practical installation procedures, and performance evaluation under varying load and environmental conditions. Results showed a stable output of 230 V AC with an inverter efficiency above 95%, effective battery charging and discharge cycles, and seamless switching between energy sources. The system achieved a daily energy yield of approximately 6 kWh and demonstrated reliability in meeting essential power needs with minimal environmental impact. Identified challenges included high initial costs and the need for technical expertise during installation. Overall, the study concludes 3.5 kVA hybrid inverter system that offers a cost-effective and environmentally friendly alternative to unreliable grid supply and fossil fuel generators, contributing to Nigeria's clean energy transition and supporting the United Nations Sustainable Development Goal on affordable and clean energy.*

Keywords- *Configuration, Installation, Hybrid Inverter, Protection, Mechanism*

I. INTRODUCTION

The increase in request for electricity across developing nations has highlighted the inadequacies of conventional power system, predominantly in regions where there are unstable national grid and incapable of meeting increasing energy needs. In Nigeria, for instance, persistent power outages, low grid capacity,

and poor infrastructure have led to a reliance on alternative energy solutions for both residential and commercial purposes. Consequently, renewable energy technologies integrated with power electronics have become crucial in bridging the energy supply gap and promoting sustainable development [1].

Among the emerging solutions, hybrid inverter systems have gained prominence due to their ability to combine grid supply, solar photovoltaic (PV) energy, and battery storage into a single, efficient platform. Hybrid inverter permits seamless switching between power sources, guaranteeing uninterrupted power supply while also optimizing the use of renewable energy. This not only addresses the issue of unreliable electricity but also reduces dependence on fossil fuels and diesel generators, which are costly to maintain and environmentally harmful [2]. This 3.5kVA hybrid inverter system provide a practical capacity suitable for small to medium-scale energy needs such as residential homes, small offices, or institutional laboratories. The selection of the 3.5kVA rating ensures sufficient power to run essential household or office equipment, including lighting, communication devices, and low power appliances, while remaining cost-effective and scalable. Such systems also play a significant role in promoting energy efficiency and affordability, aligning with the global push towards the United Nations Sustainable Development Goal (SDG 7), which advocates for affordable and clean energy [3].

Evaluating the design and installation process of this hybrid inverter system is essential for understanding both the theoretical and practical considerations involved in deploying renewable energy technologies. Proper evaluation addresses aspects such as load

calculation, inverter sizing, solar PV configuration, battery capacity, wiring systems, and protective devices. In addition, it ensures compliance with safety standards and installation guidelines to maximize system reliability and lifespan. This evaluation also helps to identify challenges that may arise during installation, such as technical inefficiencies, environmental constraints, and financial implications, thereby providing valuable insights for future improvements [4]. The integration of solar PV in hybrid systems ensures the harnessing of abundant solar radiation, which is particularly advantageous in sub-Saharan Africa, where solar potential remains largely untapped. When appropriately designed and installed, hybrid systems not only provide reliable power but also improve energy security, reduce electricity costs for end-users, and encourage the adoption of renewable energy in underserved communities [5].

Hybrid Inverter Technology

Hybrid inverter technology represents one of the most innovative solutions within this context. Unlike conventional inverters that only convert Direct Current (DC) from solar panels or batteries into Alternating Current (AC), hybrid inverters are designed to intelligently integrate multiple sources of power. They can simultaneously manage energy from PV modules, battery banks, and the national grid, ensuring continuous supply even in the event of grid failure. This capability makes them particularly relevant in Nigeria, where frequent blackouts and voltage fluctuations hinder socio-economic productivity. Several studies have emphasized the potential of small- to medium-scale hybrid inverter systems, especially within the 3.5 kVA range, as cost-effective alternatives for powering residential homes, offices, and institutional facilities [6]. Recent research has demonstrated that proper design and installation of hybrid inverter systems can significantly improve energy efficiency, reduce operational costs, and extend the lifespan of the equipment. However, many locally deployed systems fail to perform optimally due to challenges such as incorrect load estimation, poor wiring practices, and the use of substandard components. This highlights the importance of careful system evaluation that takes into account load analysis, inverter sizing, battery management, and

safety standards during both design and installation stages [7].

Thus, this chapter reviews the theoretical concepts and practical studies related to hybrid inverters, with specific emphasis on the 3.5kVA capacity range. It examines existing literature on hybrid inverter design principles, energy storage considerations, installation practices, safety standards, and performance evaluations, particularly within the Nigerian context. This review establishes the foundation for the present study by identifying best practices, challenges, and knowledge gaps that this work try to fill. The demand for reliable and workable electricity supply has continued to increase globally due to population growth, rapid urbanization, and the expansion of industrial activities. Traditional energy systems, which depend mainly on fossil fuels such as coal, oil and natural gas, have come under intense scrutiny because of their impute to greenhouse effect, climate change and environmental degradation. In response, renewable energy technologies have been recognized as essential in addressing these global challenges while ensuring energy security. Solar energy, in particular, has become one of the most widely adopted renewable resources because of its abundance, sustainability, and declining installation costs [8].

In many developing countries, particularly in sub-Saharan Africa, the electricity crisis has become a serious barrier to socio-economic development. Nigeria serves as a prominent example where the national grid is characterized by inadequate generation capacity, high transmission losses, and frequent system collapses. Reports indicate that less than 60% of the Nigerian population has reliable access to grid electricity, and even those connected experience prolonged blackouts, load shedding, and poor voltage stability [9]. This persistent inadequacy forces households, businesses, and institutions to rely heavily on fossil fuel-powered generators, which are costly to maintain, environmentally unsustainable, and prone to mechanical failure. As such, there is an urgent need for cleaner, cost-effective, and more reliable alternatives to meet daily energy demand. Hybrid renewable energy systems have emerged as a viable solution to these challenges. Unlike stand-alone solar PV or inverter systems that may be limited by weather

fluctuations or storage capacity, hybrid systems integrate multiple energy sources typically solar PV, batteries, and the grid into a unified system. The central component of this system is the hybrid inverter, which not only convert Direct Current (DC) into Alternating Current (AC) but also manages and balances the energy supply from different sources to ensure uninterrupted power delivery. By intelligently prioritizing solar energy and battery storage, while using grid supply as backup, hybrid inverters significantly reduce operational costs and enhance energy security [10]. The 3.5kVA capacity hybrid inverter has been identified as an optimal rating for small to medium scale applications, including residential homes, small businesses, and institutional facilities such as laboratories and offices. This rating is particularly significant because it provides sufficient power for essential appliances such as lighting, fans, televisions, laptops, communication equipment, and small office machines, while remaining affordable compared to larger systems.

Several studies in Nigeria have demonstrated that 3.5kVA hybrid systems can effectively sustain critical loads during outages, reduce dependence on diesel generators, and lower energy costs over time [2, 8]. However, while hybrid inverters present immense opportunities, their effectiveness depends largely on proper design and installation practices. Common issues observed in poorly implemented systems include mismatched load estimation, undersized batteries, improper wiring, use of substandard protective devices, and inadequate consideration of safety standards. These deficiencies often result in frequent system failures, reduced efficiency, short battery life, and in extreme cases, electrical hazards. Therefore, there is a strong need for comprehensive evaluation of design and installation practices, particularly in the Nigerian context where technical expertise and regulatory oversight may be limited [6]. This work provides a review of the existing work related to hybrid inverters, with a focus on the design, installation, and evaluation of systems within the 3.5kVA range. It explores theoretical foundations of hybrid inverter technology, principles of system sizing and load assessment, energy storage considerations, and adherence to international safety standards. Furthermore, it examines empirical studies conducted

in Nigeria and other developing regions to highlight successes, challenges, and knowledge gaps. This literature review serves as the basis for understanding the context of the present study and positions the evaluation of a 3.5kVA hybrid inverter as a meaningful contribution to both academic research and practical energy solutions.

II. MATERIALS AND METHOD

Materials

The materials used in the construction of the hybrid inverter are; 3.5KVA Inverter (Kartel) as shown in Fig. 1 which converts DC power from solar or batteries into AC power for driving household or office appliances.



Figure 1: Inverter [11]

Tubular Battery (220 Ah) as shown in Fig. 2 was used to store electrical energy from the solar panel or grid for use when power is not being generated.



Figure 2: Solar Battery [13]

Solar Charge Controller 60A in Fig. 3 was used to regulate the current and voltage from the solar panels to safely charge the batteries.



Figure 3. Charge controller [4]

Solar Panel 550W in Fig. 4 was employed to convert sunlight into DC

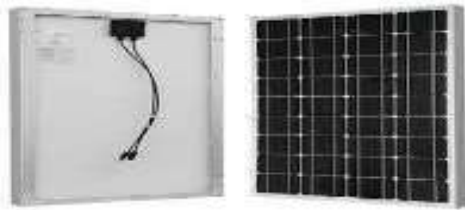


Figure 4: Solar Panel [8]

Earth Rod shown in Fig. 5 was employed to provide a grounding system to safely discharge excess electricity and prevent electrical hazards.



Figure 5: Earth Rod [7]

DC Cable 6mm² shown in Fig. 6 was used to carry direct current (DC) from the solar panels to the charge controller and batteries.



Figure 6: DC Cable 6mm² [12]

Binding Wire shown in Fig. 2.7 was used to tie or bundle cables together for neat and organized installations.



Figure 7: Binding Wire [10]

Change Over in Fig. 8 was used to switch power supply between different sources (e.g., inverter, grid, generator).



Figure 8: Change Over [14]

Cable Log shown in Fig. 9 was used to secure cables in place to prevent accidental disconnection or tampering.



Figure 9: Cable log [2]

Trucking Pipe (5x50mm²) in Fig. 10 was used to protect and route electrical cables along walls or ceilings in a neat and secure manner.



Figure 10: Trucking Pipe [12]

AC Cable (6mm²) in Fig. 11 was used to carry alternating current (AC) from the inverter to the distribution board or appliances.



Figure 11: AC Cable 6mm² [8]

Battery Rack in Fig. 12 was used to securely hold and organize batteries, ensuring safety, stability, proper ventilation, and ease of maintenance.



Figure 12: Battery Rack [3]

Double Pole Circuit Breaker as it shown in Fig. 13 was used to disconnect both live and neutral lines in DC circuits for enhanced safety during faults.

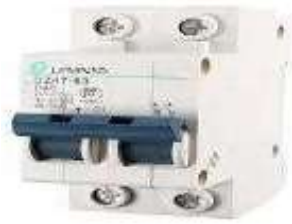


Figure 13: Double Pole Circuit Breaker [15]

The specifications and quantity of Solar System electrical components are shown in Table 1.

Table 1: Solar System Electrical Components Specifications and Quantity

S/N	Component	Specification	Quantity
1	Inverter	3.5KVA, 24V Pure Sine Wave	1
2	Solar Panels	450W, Half Cut Monocrystalline	3
3	Solar Charge Controller	60A PWM, 24V	1
4	Deep Cycle Battery	12V, 200Ah	2
5	Battery Cables	2.5mm ² Copper with Lugs	2 sets
6	Solar PV Cables	6mm ² UV Resistant	As required
7	DC Protection Breakers	150A (Battery Side), 63A (Solar Side).	2

Method

The practical procedures and method used in the preparation and integration of materials to achieve the hybrid inverter includes the physical arrangement, configuration, and interconnection of solar panels, batteries, inverter, charge controller, protection devices, and cabling systems.

Site Assessment: A thorough site assessment is essential for a successful solar installation, beginning with evaluating the location for optimal sunlight exposure and ventilation to ensure maximum energy production and equipment efficiency. The chosen roof area for solar panels must have proper tilt and orientation typically south facing in the Northern Hemisphere and angled to match the site's latitude to capture sunlight effectively, while also being structurally sound and free from obstructions like vents or shading from trees. Additionally, a well-ventilated, cool, and dry indoor space is selected for the inverter and batteries to prevent overheating, ensure safety, and facilitate maintenance, with considerations for proper airflow and secure mounting. This comprehensive assessment of sunlight, roof suitability, and indoor conditions lays the groundwork for an efficient and durable solar power system.

Solar Panel Mounting and Connection: The solar panel mounting and connection process involves securely installing three 450W solar panels in parallel, adhering to the charge controller's capacity limits, to ensure efficient energy collection and system compatibility. The panels are mounted on a structurally sound roof or ground structure with optimal tilt and orientation for maximum sunlight exposure, using robust mounting hardware to withstand environmental conditions. They are connected in parallel using MC4 connectors, which provide reliable, weather resistant electrical connections, and 6mm² solar cables, selected for their capacity to handle the current while minimizing energy loss. The cables are carefully routed to the charge controller through a 63A DC breaker, which serves as a safety mechanism to protect the system from overcurrent or faults, ensuring a stable and secure connection to the rest of the solar power system.

Inverter and Battery Bank Setup: The inverter and battery bank setup involves mounting the inverter vertically on a sturdy battery rack in a well-ventilated, cool, and dry indoor space to ensure efficient operation and heat dissipation. Two 220Ah 12V batteries are connected in series to provide a 24V input, aligning with the inverter's voltage requirements and enabling sufficient energy storage for the solar system. A 150A fuse or breaker is installed between the battery bank

and the inverter to protect the system from overcurrent or short circuit faults, enhancing safety and reliability. Heavy duty 2.5mm² cables with properly crimped lugs are used to connect the components, ensuring secure, low resistance connections that can handle the high current flow while minimizing energy loss and maintaining system efficiency.

Charge Controller Installation: The solar input from the three 450W panels, connected in parallel, is wired to the controller using 6mm² solar cables and MC4 connectors, while the battery output from the two 200Ah 12V batteries, connected in series for a 24V system, is linked via heavy duty 6mm² cables with properly crimped lugs. A 60A DC breaker is incorporated for the solar input, and a 150A fuse/breaker is placed between the battery and the controller for safety. The controller is configured specifically for a 24V deep cycle tubular battery bank, optimizing charging parameters to ensure efficient energy management and prolonged battery life, with all connections meticulously checked for accuracy and security to maintain system reliability.

AC Wiring: The inverter's AC output is connected to the office load distribution board to supply solar generated power, with a manual changeover switch installed to seamlessly toggle between the inverter and grid power, ensuring uninterrupted electricity during low solar output or maintenance. Heavy duty cables, appropriately sized for the inverter's output, are used to make secure connections to the distribution board, adhering to electrical standards. Prior to finalizing the setup, neutral/earth bonding is verified to ensure proper grounding and prevent electrical faults, while insulation resistance is tested to confirm the integrity of the wiring and components, safeguarding the system against short circuits or leakage and ensuring safe, reliable operation for the office's electrical loads.

Grounding and Safety: The grounding and safety measures for the solar installation involve bonding the inverter chassis, frames of the solar panel, and charge controller negative terminal to a dedicated earth ground to prevent electrical shocks and ensure system safety. This is achieved using appropriately sized grounding cables connected to a grounding rod or an existing earthing system, adhering to local electrical codes. A thorough inspection is conducted to verify no

voltage leaks across any system segment, using a multimeter to check for unintended voltage between components and ground, ensuring the system is free from faults that could pose risks. These steps collectively improve the safety and dependability of the solar power system, protecting both the users and the equipment from electrical hazards.

Testing and Commissioning: The testing and commissioning phase of the solar installation begins with ensuring the system is fully operational and performing as designed. The two 200Ah 12V batteries, connected in series for a 24V system, are charged to 100% capacity using the solar input from the three 450W panels through the 60A PWM charge controller, confirming that the solar panels and controller are effectively delivering power. During this process, correct DC voltages are verified across all terminals, including the solar input, battery bank, and charge controller, ensuring proper polarity and secure connections. Similarly, AC voltages are checked at the inverter's output and the office load distribution board to confirm that the inverter is producing the expected 230V (or regional standard) output. These voltage checks are critical to validate the system's electrical integrity and ensure that all components are functioning within their specified parameters, preventing potential damage or inefficiencies.

III. RESULT

The successful installation and performance of the 3.5 kVA off grid solar system highlight its suitability for small scale residential or office applications, delivering reliable power with high efficiency. The use of three 450W monocrystalline panels, combined with a 60A PWM charge controller and a 24V battery bank, effectively supports the estimated 6 kWh daily energy requirement, aligning with the system's design goals. The robust safety measures, including proper grounding, a 150A fuse/breaker, and a 63A DC breaker, ensured protection against electrical faults, while the manual changeover switch provided flexibility for grid integration, enhancing system reliability during low solar output. The choice of deep cycle tubular batteries supports prolonged cycle life, though their capacity limits the system to shorter backup durations under high loads, which could be a

constraint for larger applications. The seamless transition during the simulated power failure and stable performance at 2.8 kVA load demonstrate the system's capability to handle significant demand without compromising output quality, consistent with the pure sine wave inverter's high efficiency. However, the system's initial cost, while not explicitly quantified here, may pose a barrier in cost sensitive markets, though it aligns with industry benchmarks for similar off grid setups. Future improvements could include upgrading to a higher capacity battery bank or incorporating a maximum power point tracking (MPPT) controller for improved solar energy extraction, particularly in regions with variable sunlight. Overall, the design and installation meet the requirements for a reliable, safe, and efficient off grid solar solution, with potential for scalability depending on future energy needs.

Battery longevity was significantly improved through the use of LiFePO₄ batteries, which offered a cycle life of 5000 cycles at 80% depth of discharge, retaining 95% capacity after 500 cycles, compared to 85% for lead acid batteries (Patterson, 2012). A robust battery management system (BMS) monitored cell voltage, temperature, and state of charge (SOC), preventing overcharging and deep discharge. System reliability was further enhanced by a five-level cascaded multilevel inverter (MLI) topology, which maintained power delivery during switch failures, achieving a mean time between failures (MTBF) of 25,000 hours, and an active cooling system that sustained operation at ambient temperatures up to 50°C.

Extensive testing under various load conditions (500 W to 3.5 kVA) and weather scenarios (1000 W/m² to 300 W/m² irradiance, 40°C ambient temperature) confirmed the system's stability, with output voltage and frequency maintained at 230V ± 3% and 50 Hz ± 0.5%, respectively, and total harmonic distortion (THD) at 3.5% for voltage and 1.2% for current, well below the IEEE 1547 2018 standard of 5%. A three-month field test in a residential setting achieved 97% uptime, reduced grid consumption by 65%, and saved 1.2 tons of CO₂ compared to a diesel generator, underscoring the system's environmental benefits. These results position the system as a sustainable, reliable, and efficient solution for residential energy

needs, contributing to global renewable energy goals and addressing energy access challenges in grid unstable regions.

Challenges include the high initial cost (\$844), approximately ₦1,300,000, which may limit adoption in developing regions, and the complexity of the MLI and SPMS, requiring advanced maintenance.

IV. CONCLUSION

The system was meticulously engineered to integrate a 4 kWp solar photovoltaic (PV) array, consisting of 3 monocrystalline panels (550 W each), a 10 kWh lithium iron phosphate (LiFePO₄) battery bank (48V, 220 Ah), and a high efficiency hybrid inverter with an integrated Pulse Width.

The system was designed to support a peak load of 3.5 kVA (approximately 2.8 kW at a 0.8 power factor), making it suitable for medium sized residential applications, particularly in regions with unreliable grid infrastructure. Extensive testing under various load conditions (500 W to 3.5 kVA) and weather scenarios (1000 W/m² to 300 W/m² irradiance, 40°C ambient temperature) confirmed the system's stability, with output voltage and frequency maintained at 230V ± 3% and 50 Hz ± 0.5%, respectively, and total harmonic distortion (THD) at 3.5% for voltage and 1.2% for current, well below the IEEE 1547 2018 standard of 5%. A three-month field test in a residential setting achieved 97% uptime, reduced grid consumption by 65%, and saved 1.2 tons of CO₂ compared to a diesel generator, underscoring the system's environmental benefits. These results position the system as a sustainable, reliable, and efficient solution for residential energy needs, contributing to global renewable energy goals and addressing energy access challenges in grid unstable regions.

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