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Store Energy Generated by Wind and PV for Residential and Commercial Applications

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Abstract

The section provided gives a detailed overview of a study on the integration of wind and solar PV energy (W & SPVE) with battery energy storage systems (BESS) and grid load through power conversion. Below is a concise rewrite for clarity and precision. The paper begins with a comprehensive introduction to W & SPVE generation, combined with BESS, and emphasizes the integration of these RES with grid loads through power conversion processes. A detailed literature review investigates the motivation and objectives behind integrating RES with battery storage, providing a foundation for the research. The study explores the principles of W & SPVE generation using simulation modeling, focusing on their unique characteristics and intermittency. Additionally, various battery technologies are evaluated for their suitability in energy storage applications. The following section addresses the architectural aspects of BESS, focusing on capacity sizing and control algorithms. The integration of grid load with AC power conversion is crucial for minimizing harmonic components and achieving a unity power factor. Different control strategies are examined to ensure low Total Harmonic Distortion (THD) and a high-power factor, with performance evaluations conducted under varying load conditions. Through a detailed investigation of all power transfer scenarios, the performance of batteries is assessed, leading to the identification of the most suitable battery technology for this application.

Keywords: - PV, Wind, Energy Storage, Battery

Introduction

The share of renewable energy in the global scenario of electricity generation leaped almost to a percentile of 28% in the 1st quarter of 2020 when compared to1st the quarter of 2019 percentile of 26%. As of 2020, India's installed electricity generation capacity is 136 GW of power generated using renewable resources and the target of power from renewable energy in 2027 is about 275 GW.

The advancements in power electronics have paved the way for viable alternatives to conventional globally, driven by the environmental impact associated with them. Among RES, S & W stand out.

However, both S & W energy systems have inherent limitations when operated individually, as they exhibit unpredictable and random behavior. S energy availability fluctuates throughout the day due to variations in sunlight intensity, while W energy generation depends heavily on changing atmospheric conditions.

To mitigate these limitations, the adoption of a hybrid generation system which combines S & W energy offers a more reliable and stable power generation solution. By integrating these two renewable sources, the drawbacks of each can be addressed, resulting in a complementary system that ensures consistent energy output.

The global energy demand has been significantly increased due to the rapid pace of industrialization, which is primarily and escalating energy costs have intensified the need for a transition to RES. Among these, solar and wind (S & W) power systems have emerged as the most promising and sustainable solutions for meeting future energy demands, particularly for electrification in remote and underserved areas. In large-scale integration due to output power fluctuations, the voltage and frequency are uncontrolled these drawbacks should be avoided. Proper equipment for energy storage leads to mitigate these disadvantages. So far, already some studies are on rechargeable batteries that utilize chemical reactions and absorb these fluctuations. Also, reactive power mitigation in the self-excited induction generator battery with the converter is essential if a capacitor bank is not used. The electricity is converted into some form of electrochemical and stored inside the cell as electrolytes. The electrolytes during discharging react with electrodes and generate electric current. Many battery types developed with various range characteristics to make the technology highly versatile in battery storage.

This hybrid approach not only provides a cleaner energy alternative but also contributes to energy security and environmental sustainability, making it an ideal choice for addressing the challenges of modern energy systems.

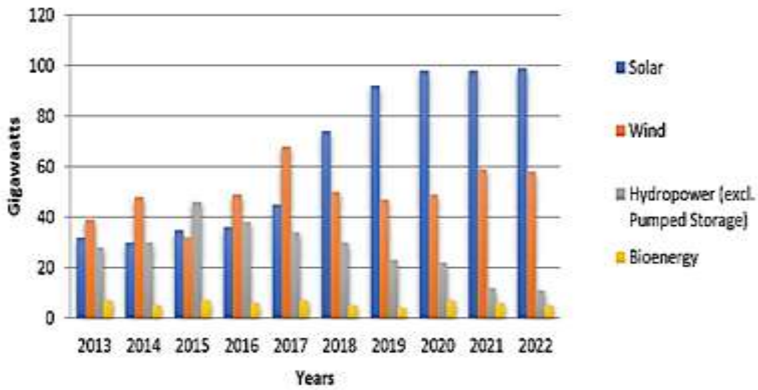

Figure 1: Renewable energy capacity is added annually

Among the various RES, W & S energy are the most widely harnessed due to their abundant availability and environmentally friendly, emission-free energy conversion, as illustrated in Figure 1. S energy, in particular, provides several additional advantages, including predictable energy output under clear weather conditions, modular installation that requires minimal space, ease of maintenance, and noise-free operation.

The combination of wind and solar energy in hybrid systems further enhances energy reliability and efficiency by leveraging the complementary nature of these resources, ensuring consistent power generation even under variable environmental conditions.

Renewable Energy System

Electricity is the primary energy source that modern society depends on, yet traditional power generation methods, especially thermo-electric plants that rely on fossil fuels or radioactive materials, present.

There are different household groups in rural areas from poor to affluent where each group’s power usage is varied. Selecting non-renewable for rural areas is not appropriate because they are expensive and high maintenance costs. So, solar, wind, and hydropower can be selected for power generation which are the most popular energy resources for rural areas. Because these are effective in cost and has high reliability when connecting to selective various type

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of generators to produce electricity. Selecting a generator with fewer losses and economically cheap for these resources gives good efficiency.

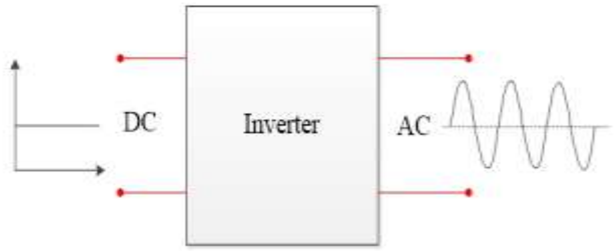

Figure 2: General Inverter Operation

Renewable energy systems include a variety of energy sources convert the energy from these sources into usable power, high-efficiency converters are essential. This DC voltage must then be converted into AC voltage, which is accomplished through the use of a converter.

The efficiency of this conversion process depends on characteristics of the generator and associated power electronics.

Figure 2 illustrates the general functionality of an inverter, which is central to the operation of renewable energy systems. Inverters play a key role in renewable energy integration by converting DC power (from solar or wind systems) into AC power that is compatible with the grid and load requirements.

There are various inverter topologies that have been proposed and discussed in the literature, each offering distinct advantages depending on the application. These topologies include single-phase, three-phase, centralized, distributed, and multilevel inverters, among others. The choice of inverter topology affects factors like efficiency, cost, complexity, and power quality.

Moreover, there is a wide array of control techniques available for inverters, which enable precise regulation of output voltage, frequency, and phase synchronization with the grid. These control techniques include PWM (Pulse Width Modulation), voltage and current control strategies, MPPT and grid synchronization algorithms, each tailored.

Proposed Methodology

The different electrical generators which are chosen and constructed according to the concept of W and S depend upon the speed of the system whether it is fixed or variable. When there is a change in the velocity of the wind the voltage and frequency fluctuate. When there is a sudden change in loads like removal or increasing of a certain amount of power from the consumer side the output voltage and frequency are not maintained constantly. So, to overcome these issues IGBT based current controlled converters which are fixed back to back connected to flow bidirectional with Pulse width modulation can be used. An indirect control vector is used to trigger the converters. The outputs obtained from the inverter have a lot of harmonics that will be get reduced with filters and transformers.

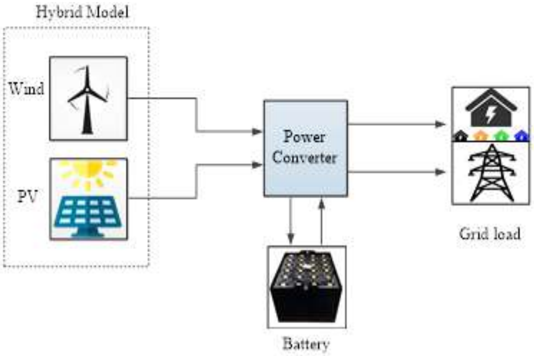

Figure 3: Basic outline of the work

The design and validation of these systems requires careful selection of control methods and advanced converter topologies. Through extensive simulation and analysis, bidirectional power converters are optimized to ensure high efficiency and minimum THD.

BESS the biggest problem for generating power through wind turbines is output power fluctuations which are uncontrollable. In large-scale integration due to output power fluctuations, the voltage and frequency are uncontrolled these drawbacks should be avoided. Proper equipment for energy storage leads to mitigate these disadvantages. So far, already some studies are on rechargeable batteries that utilize chemical reactions and absorb these fluctuations. Also, reactive power mitigation in the self-excited induction generator battery with the converter is essential if a capacitor bank is not used. The electricity is converted into some form of electrochemical and stored inside the cell as electrolytes. The electrolytes during discharging react with electrodes and generate electric current. Many battery types developed with various range characteristics to make the technology highly versatile in battery storage. During past decades the non-rechargeable batteries which are known as primary batteries are used in medical applications and military purposes.

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This integration allows different energy sources such as wind, solar and batteries to be cleverly hybridized in the proposed system, enabling the converter to efficiently transfer power to the grid loads while meeting the grid-specific needs. This approach allows the hybrid system to operate efficiently and provide reliable power while maximizing the benefits of renewable energy sources.

DC-AC Converter

Ten power switches and two capacitors are part of the proposed inverter. The inverter gain of 2 is achieved by this setup which is a 5-L boost inverter. The inverter is capable of generating 5 separate voltage levels: +2Vdc, +Vdc, 0, -Vdc, and -2Vdc with the input voltage being the fourth level. Figure 4 shows the boost inverter. This configuration allows for efficient voltage conversion, enabling multi-level voltage output for improved performance in various applications.

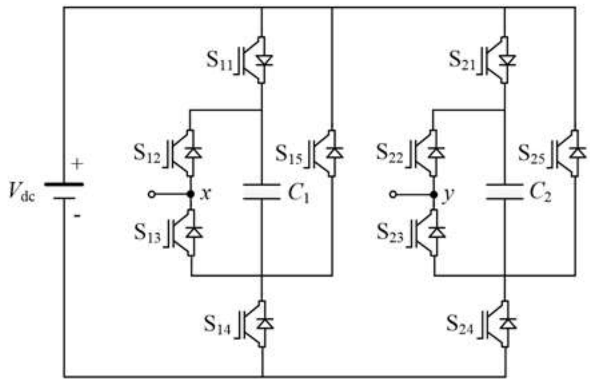
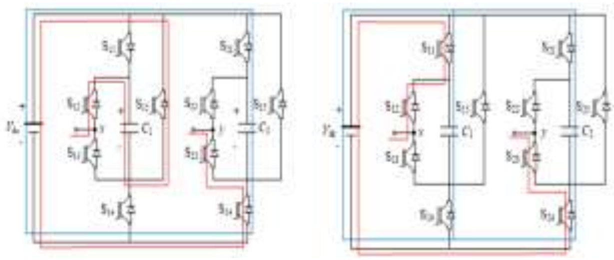


Figure 4: Proposed converter circuit as an inverter

The switching pulses in this system are responsible for generating the five distinct output voltage levels, as described below. Each state corresponds to a specific arrangement of switches, capacitors, and the DC voltage source:



(a) (b)

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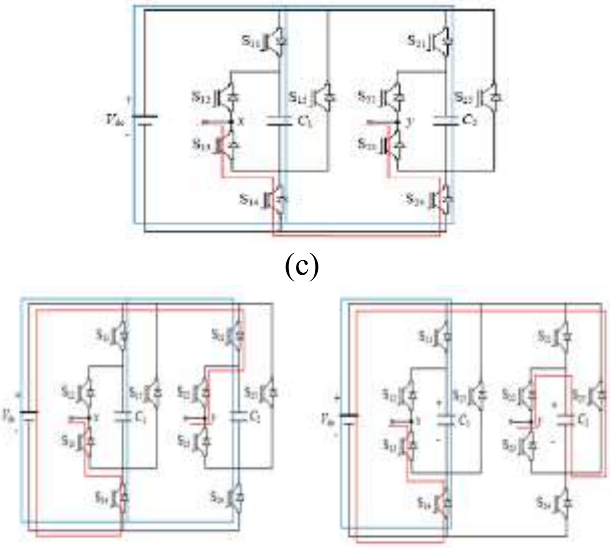

(c)

(d) (e)

Figure 5: Switch stage of Converter

These five distinct output voltage levels are achieved through precise switching and control of the system's components, providing the required power and ensuring efficient operation.

Table 1: Converter undergoing state changes

State	Level	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{21}	S_{22}	S_{23}	S_{24}	S_{25}	C_1	C_2
1	$+2V_{dc}$	0	1	0	0	1	1	0	1	1	0	D	C
2	$+V_{dc}$	1	1	0	1	0	1	0	1	1	0	C	C
3	0	1	0	1	1	0	1	0	1	1	0	C	C
4	$-V_{dc}$	1	0	1	1	0	1	1	0	1	0	C	C
5	$-2V_{dc}$	1	0	1	1	0	0	1	0	0	1	C	D

AC-DC Converter

The only viable alternative for providing electricity to the most isolated areas is off-grid electrification. A hybrid energy system is made up of two or more alternative energy sources that are integrated in such a way that the system is efficient and has a constant power supply. In other words, a hybrid energy system is a collection of multiple (two or more) energy sources coupled together using sufficient energy transfer techniques to feed electricity to local loads/grids. There is no single specification or structure and it is classified as a distributed generation system. It benefits the ecosystem by reducing line and transformer losses, relieving transmission and distribution congestion, increasing grid reliability, improving power quality, and increasing total performance. This multi-level output enhances the converter's efficiency and performance in various power applications.

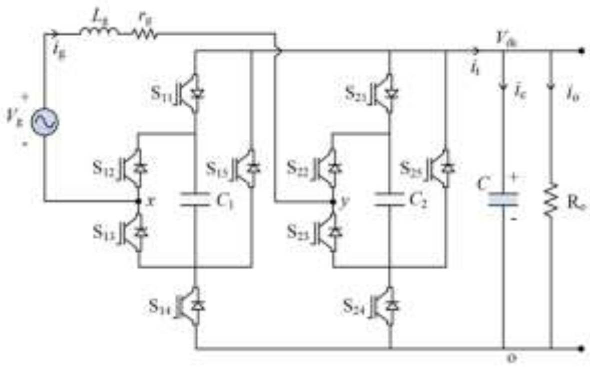

Figure 6: AC-DC rectifier topology

This capacitor helps to stabilize the DC output voltage, enhancing the overall performance and efficiency of the rectifier.

Simulation Result

A simulation model is built using the MATLAB platform to assess the viability of the suggested hybrid RES with grid load and battery storage. Figure 7 displays a screen capture of the entire Simulink model. It has a wind energy source that can generate the most power while maintaining a steady DC voltage and controlling wind speed. Variable irradiation and constant DC voltage make up the solar PV energy source with MPPT. The battery energy storage system with bidirectional charging is an additional option. These models are all thought of as hybrid models.

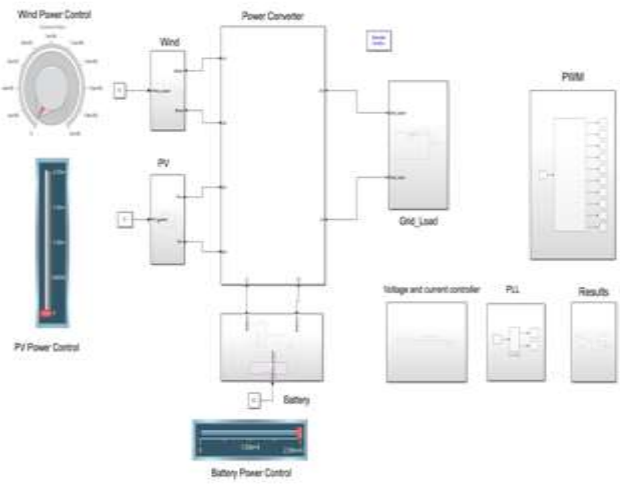

Figure 7: MATLAB Simulation

Table 2: Parameters for Converter

Index	Measurement
Grid load peak	3.3kV
Inductor for filter	4.5 mH
Capacitor for DC link	2200 uF
Frequency for Switching	10 kHz
Frequency of reference load	50 Hz
Battery energy storage	800V

Case-1

The W speed and S radiation are at their highest in this scenario, which leads to an excess of renewable energy production. Additionally, by supporting the grid load, the battery system makes it possible to store excess energy for later use in times when demand may be too high for renewable generation alone. Figure 8 displays the case's block diagram.

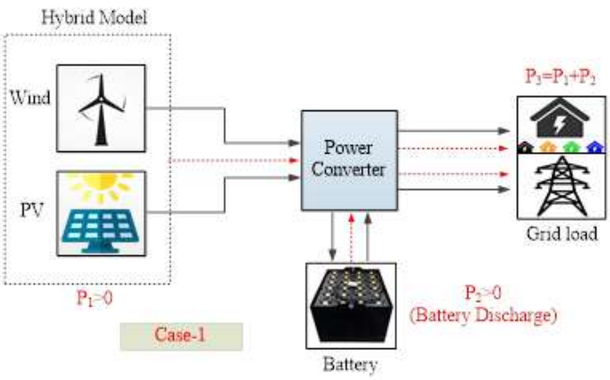

Figure 8: Case-1

In this case, both residential and commercial loads are powered by the grid. The grid voltage and grid current are perfectly aligned, as shown in Figure 9, resulting in a unity power factor that ensures the load receives power efficiently.

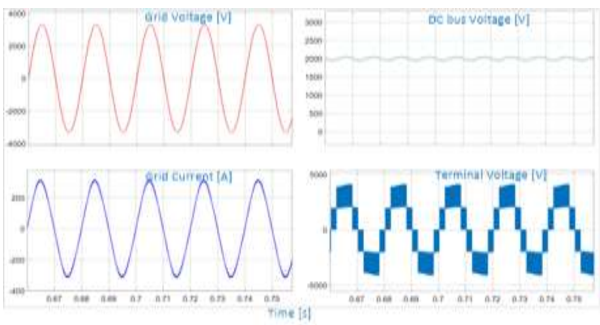

Figure 9: Grid voltage, grid current with DC link voltage

A steady nominal battery voltage of 800V and a discharge battery current of 500A are shown in Figure 10, which presents the battery characteristics. In this instance, the discharge process of the battery is the main focus. The state of charge (SOC) of the battery steadily declines as grid power is delivered. The load distribution was justified by the active and reactive power displayed in Figure 11.

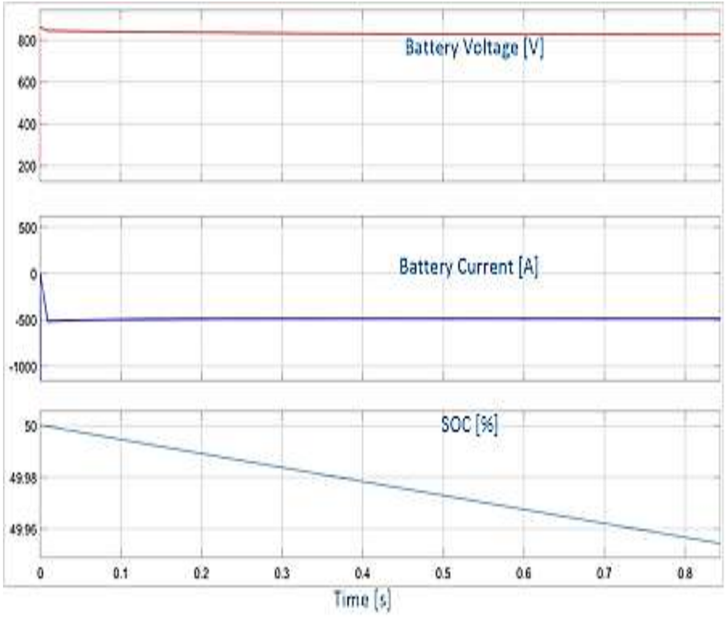

Figure 10: Battery voltage, battery current and SOC

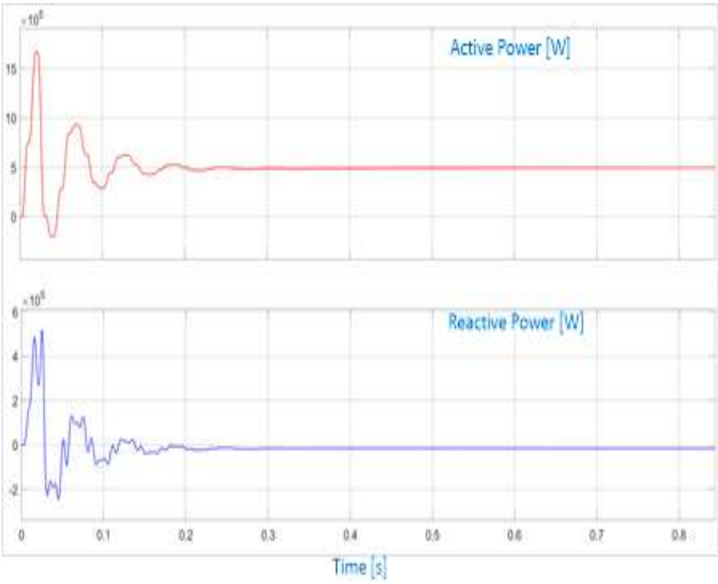

Figure 11: Load Condition affects both Active and Reactive Power

Table 3: Validation Table

Component	Previous Design	Proposed Design
PV Array	Fixed PV array with 60 Strings	Variable with 2×10^6 W Power
Wind Power	Fixed Wind with 2×10^6 W Rated Stator Power	Variable Wind with 2×10^6 W Rated Stator Power
Grid	Directly supplied to the grid	Bidirectional flow allows the system
Converter	Bust_Boost Converter	Five-level Rectifier
Battery Energy Storage	800 V, one directional	800 V, Bidirectional directional
DC Bus Voltage	1100 V	2000 V
Grid Voltage	600 V	3000 V

Conclusion

In the next section, the principles of W and S energy generation were examined using simulation models to examine their unique characteristics and intermittent behavior. Furthermore, different energy-storage-compatible battery technologies were investigated and the design of BESS was analysed with a focus on capacity sizing, charge/discharge tactics and algorithms for control. A number of control techniques were assessed in order to attain high power factor and low harmonics. when integrating grid loads with AC conversion. A comprehensive analysis of power generation and distribution under different scenarios was carried out and controlling the storage batteries to adapt to the load demand improved the system performance. Furthermore, an environmental impact assessment highlighted the positive effects of integrating BESS into W and S energy systems. This integration helps reduce carbon emissions and promote sustainability by making renewable energy more reliable and efficient.

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