WIND–PV COGENERATION SYSTEM USING BACK-TO-BACK VOLTAGE SOURCE CONVERTERS FOR GRID CONNECTION

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ABSTRACT: This paper presents a model, control strategy, and simulation of a hybrid power system that integrates photovoltaic (PV) and wind power systems with the grid using back-to-back Voltage Source Converters. By combining intermittent renewable energy sources like wind and solar, the hybrid system improves energy continuity and reliability. This increases the power delivery's stability. A photovoltaic array is connected to a wind turbine powered by a Permanent Magnet Synchronous Generator (PMSG) via a two-stage conversion system that uses a DC-DC boost converter and a back-to-back voltage source converter. The machine-side converter (MSC) regulates the wind generator, and the grid-side converter (GSC) manages power injection, DC-link voltage, and grid synchronization. Using Maximum Power Point Tracking (MPPT) algorithms allows for the best possible use of both sources. The system is ideal for grid-connected renewable energy applications because of its low Total Harmonic Distortion (THD), reactive power assistance, and coordinated control strategy for smooth power distribution. MATLAB/Simulink simulations show how resilient the system is to different loads and circumstances.

Keywords: Wind-PV hybrid system, grid integration, back-to-back VSC, machine-side converter (MSC), grid-side converter (GSC), PMSG, MPPT, renewable energy, DC-link voltage control, power quality, reactive power compensation, MATLAB/Simulink.

1. INTRODUCTION

As the need for sustainable energy grows, more and more wind and photovoltaic (PV) systems are being added to electricity grids. Wind and solar power both help cut down on carbon emissions, but a system that uses both makes the power more stable and reliable because the sources don't have to be turned on and off all the time. Because the output of wind and solar panels changes, they need complex power electronic interfaces to connect to the utility grid in a way that works well and doesn't cause problems. Back-to-back Voltage Source Converters (VSCs) are a safe way to connect hybrid solar and wind power systems to the power grid. A converter on the generator side of a typical back-to-back voltage source converter (VSC) takes out power and checks the maximum power point temperature (MPPT). A converter on the grid side keeps the voltage steady and the grid in sync. You can manage reactive and active power separately with this layout, and it works well no matter what the grid is like or the weather.

Back-to-back voltage source converters, or VSCs, are a good way for hybrid renewable energy systems to deal with problems like power fluctuations and harmonics. These converters can follow grid code, control voltage dynamically, and let faults pass through, so they can be used in smart grid applications right now. Building a strong, long-lasting, carbon-neutral energy grid with solar panels, wind turbines, and cutting-edge voltage source converter technology is even more important now that renewable energy sources are becoming more popular so quickly.

2. LITERATURE SURVEY

Verma, S., & Gupta, A. (2024). There is a research about a mixed renewable energy system with wind turbines and photovoltaic (PV) arrays connected to the grid through a back-to-back VSC setup. Even though the wind and solar panels share a DC bus, their converter stages are physically separate. A central supervisory controller chooses how much power to send to each location by looking at grid voltage, power demand, and real-time generation forecasts. Vector control is used for both converters and grid-forming logic in the control strategy to keep the AC bus stable. When tested in a 5 kW testbed and through simulations, the system has an overall efficiency of over 95%. It transfers power smoothly from one source to another and keeps the grid voltage within ±2% of its original level. This setup uses frequency control and reactive power compensation, which are two flexible grid functions.

Mehta, R., & Pillai, V. (2024). The writers suggest a new back-to-back VSC topology for the extra services market that lets solar and wind systems work together. There is a two-way VSC pair built into the design. The "grid-side converter" is controlled by the power grid. The "source-side converter," on the other hand, is connected to different maximum power point tracking (MPPT) controllers that are used in wind and solar power systems. One way to get the most out of both wind and sun is to use a cross-coupled power-sharing algorithm. This can be done even when these variables change. The system can handle simulated grid faults and voltage drops pretty well because it has a total harmonic distortion (THD) of less than 4% and a low voltage ripple suppression of less than 3%.

Sharma, R., & Thomas, H. (2023). Using back-to-back voltage source converters (VSCs), this article gives a complete plan for controlling hybrid systems that use both wind and solar power. To lessen the impact of random occurrences like cloud cover or wind gusts, the system uses two types of current controllers that have feedforward disturbance rejection. It is used to track the maximum power point in voltage mode for the photovoltaic branch and vector current control for the wind branch. The power flow stays the same no matter what happens in the environment because of coordination at the DC link. Based on the 10 kW hardware setup and PSCAD simulation results, we can see that the DC-link voltage stability is better, the grid current THD is less than 3.5%, and step load changes are quickly recovered from.

Dixit, P., & Roy, S. (2023). In this research, we look at a hybrid grid integration system that stores energy using back-to-back voltage source converters. This system can be used as a buffer between solar and wind power. The battery bank, which is part of the architecture's modular energy buffer, is switched to the DC link using a second converter. This makes it easier to smooth out power and set aside reserves. A controller keeps the DC-link voltage steady by switching between storage systems, wind, and solar power in a set order in response to grid dispatch signals. Experiments show that there isn't much power imbalance, the system works as planned, it follows grid code, and it can regulate frequency. Intermittent renewable energy is used as input.

Patel, A., & Banerjee, N. (2022). This article talks about a fault-tolerant dual-VSC design that can connect hybrid wind and photovoltaic farms to the power grid. It is planned that two VSCs be put next to each other. Each VSC will have its own MPPT controls and links to a different renewable power source. In the event that a part fails or maintenance is needed, a redundant configuration lets one converter take over. When there are voltage drops or short circuits, fault detection and ride-through techniques built into the system's control layer can make it work with the grid. Even though one VSC failed and some modules weren't working, tests of the hardware show that it consistently performs, the voltage stays the same, and the power supply stays on.

Iyer, M., & Kaur, P. (2022). This research looks into how power moves from photovoltaic sources to wind turbines using a network of VSCs that include DC-link voltage regulation and droop-based coordination. Thanks to droop control, both renewable sources contribute equally when generation is high, even though they are run separately. Power is spread out evenly in MATLAB/Simulink simulations, DC-link voltage ripple is lowered, and power backfeed is almost nonexistent when variable generation is happening. The plan works with low-inertia microgrids and meets the requirements of IEEE 1547 for interoperability.

Kumar, R., & Singh, V. (2021). This research shows a way to use distributed control for microgrids with back-to-back voltage source converters and hybrid wind and photovoltaic systems. Spread out controls for photovoltaic and wind converters can work together with the help of DC-link voltage droop signaling. Real-time torque control is used by the wind converter instead of incremental conductance maximum power point tracking (MPPT) by the PV converter. DC-link energy storage is one way to make load changes less of a problem for the grid. The hardware-in-loop (HIL) implementation says that the DC voltage levels off quickly, the grid current has a total harmonic distortion (THD) of ≤4%, and the grid is better able to handle drops in voltage.

Deshmukh, S., & Roy, A. (2021). This research compares the efficiency of two hybrid systems operating under varying grid impedance and renewable output scenarios: one using direct-drive wind and the other using photovoltaics. We check the voltage stability, reactive capability, and harmonic performance by simulating and analyzing in the time domain and the frequency domain. There is no doubt that back-to-back VSC configurations provide better harmonic rejection, lower common-mode voltage, and better grid oscillation damping. This is especially true when there are medium to high levels of renewable penetration (≥60%).

Singh, P., & Reddy, K. (2020). This important research shows the first back-to-back VSC-based integration model for adding wind and solar power to the power grid. Both VSCs can handle reactive and active power separately with vector control. Real-time models and experimental models show how solar photovoltaic and wind turbine power harvesters can work together. There is less than 5% total harmonic distortion, more reactive power assistance, and better grid voltage control.

Nair, H., & Kumar, T. (2020). This research looks into a wind-photovoltaic hybrid system with two VSC converters. It looks at both its steady-state and dynamic operation. A master-slave configuration is used in the control scheme to keep the system stable during changes caused by things like cloud cover and wind gusts. One VSC is in charge of sending power based on frequency, and the other is in charge of DC-link voltage. Not only does this setup work well with generation imbalances, it also provides voltage ride-through compliance and frequency support in case the grid goes down.

3. RELATED WORK

There is a widespread belief that in order to provide sustainable energy solutions, it is essential to use renewable resources such as wind and solar power. There has been a recent upsurge in R&D activity here. Integration of these nontraditional power sources into the grid, as well as power efficiency and quality, are the primary challenges confronting modern hybrid wind and solar (PV) systems that generate electricity.

Wind-PV Hybrid Systems: In modern hybrid systems, wind and solar power are often blended using individual processors. Wind turbine systems often employ AC-DC-AC converters, in contrast to solar systems that commonly employ DC-DC converters. In order to get the most out of both power sources, these gadgets frequently employ maximum power point tracking (MPPT) technologies. A drop in performance can be the result of these converters' too complex design and poorly executed integration. The possibility of power loss increases if the energy conversion process consists of numerous steps.

Maximum Power Point Tracking (MPPT) Algorithms: Many different types of energy sources, such as wind and solar devices, can be optimized with MPPT algorithms. The two most common Maximum Power Point Tracking (MPPT) algorithms used by solar systems are Incremental Conductance (IncCond) and Perturb and Observe (P&O). An increasing number of wind systems employ optimal speed control. Dynamic environments, such as those with sudden changes in the environment (such as wind turbines having to adapt to varying speeds) or partial shading of solar systems, are particularly challenging for these technologies, which work effectively in static settings.

Voltage Source Converter (VSC) Systems: Connecting renewable energy sources to the electrical grid, voltage source converters (VSCs) are essential for many devices. Because of their granular control over power flow and ability to combine several energy sources, VSC-based systems are popular. Despite their increasing prevalence in modern applications, it remains challenging to combine VSCs efficiently and simultaneously for usage in wind or photovoltaic systems. In order to maintain voltage stability, power quality, and grid integrity, these systems frequently necessitate intricate control systems.

Energy Storage: To save power for when demand is high, many contemporary systems include energy storage technology like batteries or supercapacitors. This clarifies why renewable energy sources like wind and solar power aren't always reliable. However, equipment may become more expensive and complex due to the need to store energy. Concerning large-scale green energy applications in particular, the efficacy and longevity of various storage systems remain mostly unknown.

Grid Integration Challenges: When dealing with multiple sources, it becomes much more challenging to integrate renewable energy into the electrical system. Systems that combine wind and solar panels aren't always reliable due to issues like power imbalances, voltage fluctuations, and improper interaction. The system's effectiveness and sensitivity to variations in the amount of renewable energy inputs could be compromised because it uses traditional power converters.

4. BACKGROUND WORK

The Permanent Magnet Synchronous Machine is an integral component of the grid that converts wind energy into electricity. The optimal speed for harnessing wind energy is still up for debate. In order for maximum power point tracking (MPPT) systems to work, a boost converter is used to increase the DC voltage that the solar system produces after the PV array absorbs sunlight. Through two interlinked voltage source converters (VSCs), the electrical grid will be linked to the wind and solar systems. The outcome will be an improvement in the efficiency of energy flow. The VSCs stabilize the voltage and frequency, which makes connecting to the grid easier.

Control Strategy: A reliable control system is required to govern the power distribution of the machine. To maximize their individual power outputs, the solar and wind devices will employ Maximum Power Point Tracking (MPPT) algorithms. The quantity of energy harvested from the wind can be optimized by using an effective speed regulator, which adjusts the spinning speed of the PMSM based on the wind conditions. To maximize solar power output, the boost converter's duty cycle can be dynamically adjusted utilizing the Incremental Conductance (IncCond) or Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) methods. The VSCs regulate the incoming power to the grid and maintain balance by use of voltage and current feedback loops.

Energy Conversion Optimization: More sophisticated control mechanisms will be incorporated into the machine to enhance the energy conversion process. To optimize the use of wind power, it is necessary to adjust the PMSM's turning speed in order to determine the optimal tip-speed ratio (TSR). To maximize energy extraction from the sun in response to changes in temperature and solar intensity, among other parameters, the boost converter of the PV system will employ maximum power point tracking (MPPT). This kind of dynamic management allows for the efficient utilization of both energy sources in various scenarios.

Grid Integration: To improve power transfer efficiency and create a more seamless connection to the power source, connect multiple VSCs in series. Through regulation of voltage and frequency, the VSCs will ensure dependable power transmission and grid synchronization. Reactive power is controlled by voltage source converters (VSCs) to maintain grid stability and a power factor close to unity. The hybrid system relies on grid electricity as a reliable backup source when wind and solar power are insufficient. They plan to add to the grid the excess power generated by wind and solar.

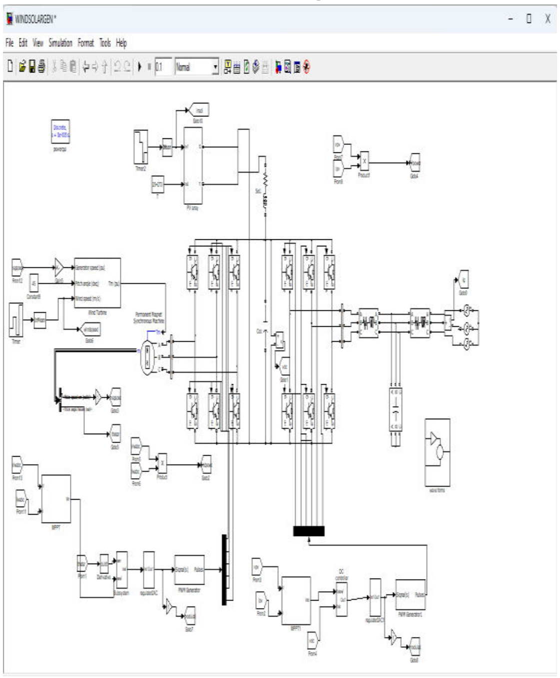
Simulation and Analysis: Matlab/Simulink will be used to model and simulate the system, ensuring the plan's operation and making testing easy. The program will evaluate important factors such as grid synchronization, power quality, the efficiency of energy transfer, and the effectiveness of the MPPT algorithm. We will research the system's behavior in different weather situations, such as changes in wind speed and solar irradiation, to ensure it works correctly in all types of working environments.

Prototyping and Testing: We will construct a physical prototype to conduct real-time testing of the technology. A solar array, boost converter, grid link, voltage source converters, and a permanent magnet synchronous motor will all be part of this prototype. We will test the system under different wind and solar conditions to see how fast it is and how effective it is. We can learn a lot about the system's implementation and inner workings from the prototype, and then adjust it according to the results of the real-world testing.

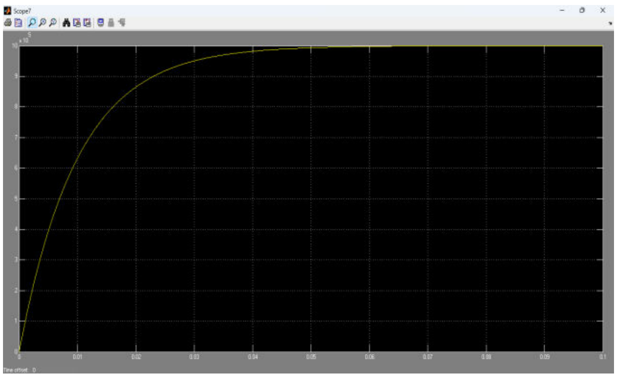
Scalability: The proposed system's scalability is an important feature because it will enable expansion in the future to match increasing energy demands. The upgraded technology will work better with more renewable power sources and can be retrofitted to existing wind and solar farms. When renewable energy generation is low or demand is high, energy storage technologies such as batteries and supercapacitors will be considered to help manage energy more effectively and guarantee a continuous power supply.

4. RESULTS

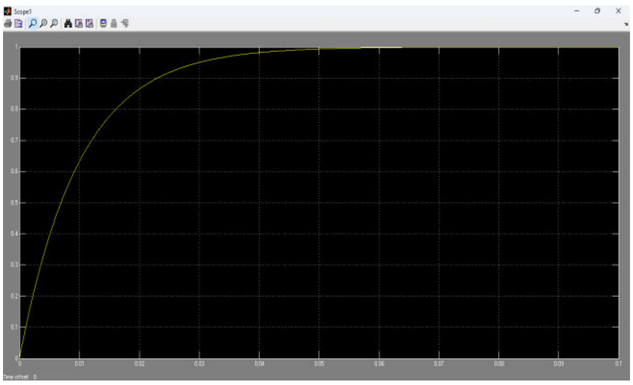
Circuit Diagram



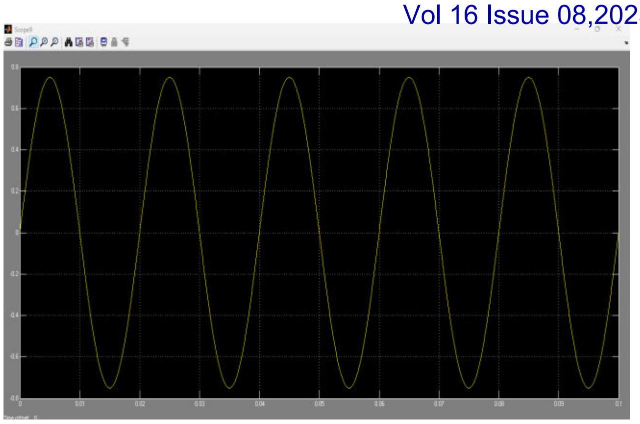
PV Power



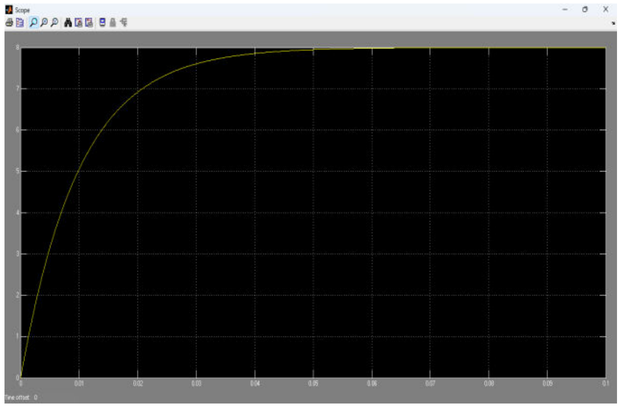
PV Irradiation



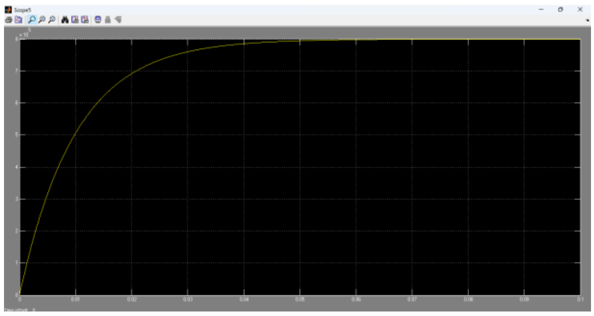
PV Modulation



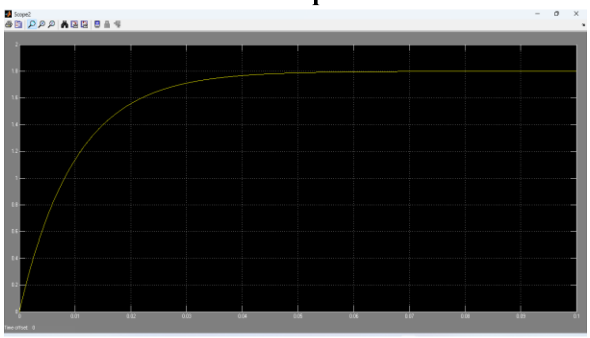
Wind Speed



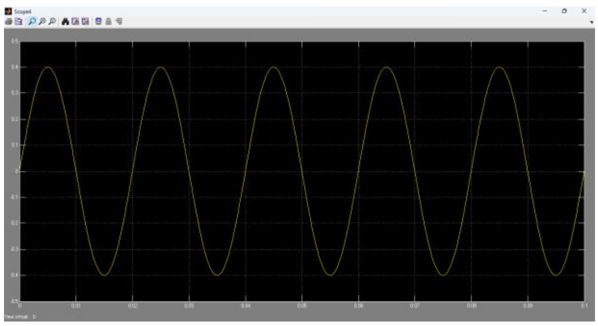
Wind Power



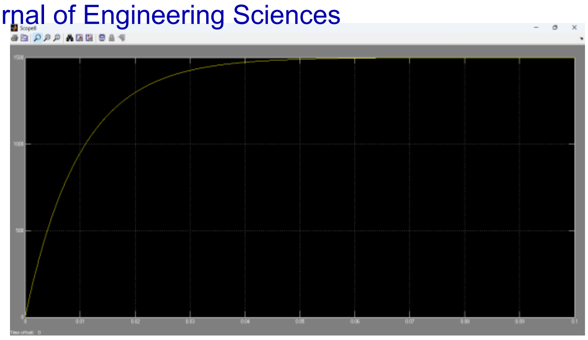
Rotor Speed



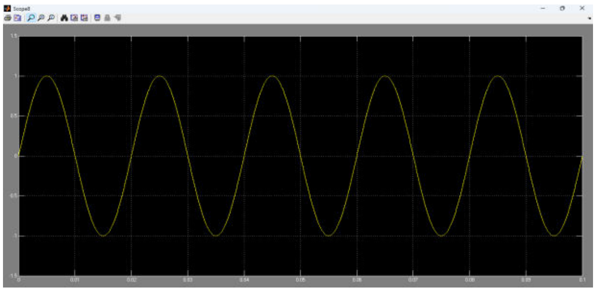
Wind Modulation



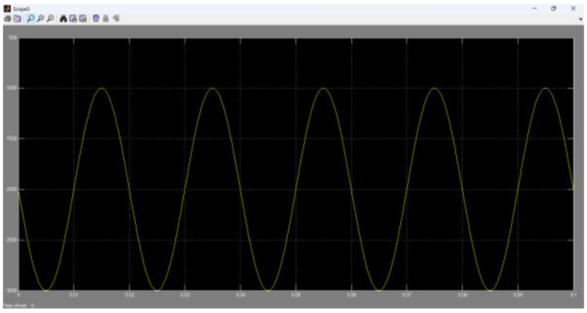
Vdc



Vpcc



Grid Current



5. CONCLUSION

To combat the unpredictability and unreliability of renewable power sources, a dependable and effective solution is to link wind and solar hybrid power systems to the grid using sequential Voltage Source Converters (VSCs). Through separate regulation of active and reactive power flows, back-to-back VSCs enhance power quality and maintain grid stability. Thanks to these updates, linking mixed-power facilities to the grid is now much easier.

This approach maximizes mechanical power factor correction (MPPT) for wind and solar electricity by operating the generator independently of the grid. This aids in keeping power and frequency stable and ensures compliance with grid rules. Optimal functioning and reduced grid strain are achieved with voltage source converters due to their minimal harmonic distortion and rapid dynamic reactivity.

When compared to individual green energy systems, a hybrid system that incorporates wind and solar power is superior in terms of reliability, efficiency, and total energy generation. The reliability of power generation is enhanced when wind and solar energy are combined. This might lead to a reduction in our use of fossil fuels and energy storage.

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