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Modelling and Voltage Control of the Solar Wind Hybrid Micro-Grid with STATCOM

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Abstract

Wind and solar photovoltaic (PV) systems exhibit high sensitivity to weather conditions, impacting their electricity production capabilities. This sensitivity stems from the inherent variability of these renewable sources. Consequently, there is an increasing need for rapid adjustments within energy distribution and transmission networks. This necessity arises due to the fluctuations in energy output. To address issues related to reactive power compensation and voltage fluctuations resulting from both the grid and renewable energy sources, the utilisation of a "Static Synchronous Compensator (STATCOM)" becomes relevant [1]. The STATCOM serves as a solution to stabilise the grid by mitigating power quality concerns [2]. This study involved the modelling of a Solar PV-Wind Hybrid Micro-grid. The primary focus was to investigate the potential of using STATCOM to enhance the operational stability of the system. The complex and nonlinear characteristics inherent in a solar-wind hybrid microgrid pose challenges to achieving optimal responses and maintaining voltage stability. Conventional methods struggle to effectively address these challenges due to the system's intricate nature.

Keywords: Photovoltaic, Static Synchronous Compensator (STATCOM), PI controller, DSM-PI (Dual Sliding Mode Proportional Integral), Solar PV-Wind Hybrid Microgrid

1 Introduction

Climate change and the responsible management of the world's depleting fossil fuel resources rank among the most pressing challenges the planet is currently confronting. To secure a safe future for upcoming generations, it's imperative to curtail our reliance on fossil fuels and substantially decrease the release of greenhouse gases. This necessitates a considerable reduction in emissions to provide a safer environment [3]. The substantial drop in technology costs and the continuous enhancement of efficiency have driven a significant expansion in investments in renewable energy. This shift is pivotal as renewable energy is critical in mitigating global carbon emissions. Centralised power plants suffer from several drawbacks. Firstly, most of these plants rely on fossil fuels, leading to heightened CO2 emissions and wasted heat. Secondly, transmitting large power quantities across extensive networks involving transformers and lengthy transmission lines poses challenges. The extended transmission lines and transformers contribute to power losses and voltage drops, exacerbating the issue. Finally, centralised plants do not offer an economically feasible solution for supplying electricity to impoverished and remote communities. Transitioning to renewable energy sources such as wind and solar photovoltaic (PV) generation can alleviate our reliance on fossil fuels and ecological impact [4]. Microgrids represent small-scale power systems comprising renewable energy generators, battery storage, and end-use consumers. Their advantages include heightened reliability, enhanced controllability, and superior electricity quality. Microgrids come in two forms: interconnected with the main grid or entirely independent from it. Coordinating grid-connected microgrids with a robust electric power system minimises concerns regarding undesirable frequency fluctuations. Thus, financially, grid-connected microgrids emphasise boosting power exchanges and profits. Conversely, standalone microgrids face challenges sustaining voltage and frequency stability without access to the main grid [5]. Distributed microgrids founded on renewable energy generation methods such as solar, wind, and biogas offer a means to meet the escalating global electricity demand. Simultaneously, they cut costs and diminish emissions of hazardous greenhouse gases associated with conventional central power plants dependent on fossil fuels. Embracing renewable energy resources emerges as the viable pathway to forge a cleaner, pollution-free world. The feasibility of producing electricity from renewable sources is evident, with solar, wind, and hydropower constituting efficient and globally utilised solutions to the ongoing energy predicament [6].

1.1 Development of Distributed Generation (DG)

Distributed generation (DG) has become pivotal in contemporary residential, commercial, and industrial power systems. DG presents an alternative to the conventional power sources dominating today's landscape, encompassing oil, gas, coal, and hydroelectric resources. The term

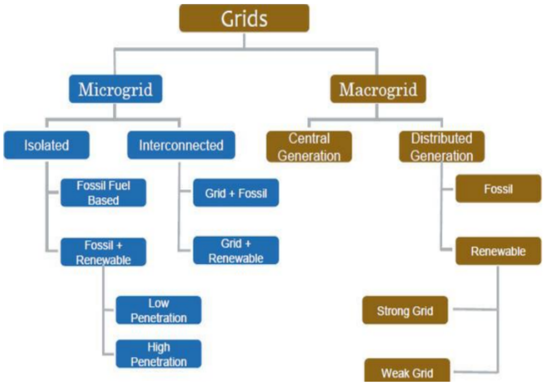

Figure 1: Grid classification

“DG” refers to small-scale power generation, typically ranging from 1 kW to 50 MW, or more informally, power generation units interlinked at the distribution level and situated near the load side [7]. The surge in DG’s popularity can be attributed to its remarkable efficiency, low emissions, and unobtrusive operational characteristics. The simplicity of using DG is akin to plugging in a device. This approach allows DG units to be relocated to the most convenient locations without significantly modifying the distribution system’s management infrastructure. DG, often embodied by diesel generators, is a secondary power source for numerous establishments such as factories, malls, hospitals, universities, and commercial buildings. This auxiliary power source comes into play when the primary power supply encounters disruptions. Examples of distributed generators encompass various technologies, including fuel cells, micro-turbines, batteries, flywheels, and supercapacitors. The spectrum of distributed generation systems also encompasses resources like “photovoltaic (PV) and wind turbine (WT) resources” [8].

1.2 Doubly Fed Induction Generator (DFIG)

Wind turbines have come a long way since their inception in 1975, when they were first used to generate electricity. In the 1980s, the first modern turbine was wired into the grid. The widespread use of DFIG may be traced back to the rise in popularity of wind energy and wind power generation. The term “doubly fed induction generator” refers to the electrical power generated being sent in both directions (between the stator and the rotor). Since these generators can adapt to changing wind conditions, they have garnered much interest. There are benefits to using variable-speed wind power plants rather than constant-speed wind power plants. Variable-speed wind farms cover a larger energy range than their constant-speed counterparts, and they do so with less mechanical stress and less noise than stationary wind farms. The advancement of power electronics has made it practical and inexpensive to regulate every speed. Working with varying wind speeds has unique challenges, and this research focuses on variable-speed DFIGs to address those needs. Wind power plants, as depicted in the figure, have a layout in which the stator’s orbit of the DFIG is connected directly to the grid. In contrast, the rotor’s orbit is connected to the grid through a back-to-back converter (generator-side converter and grid-side converter) with slippery rings.

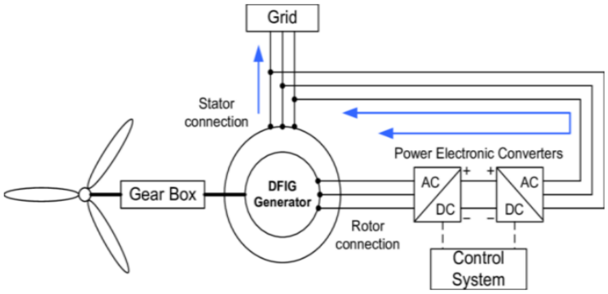

Figure 2: Schematic diagram of DFIG Generator

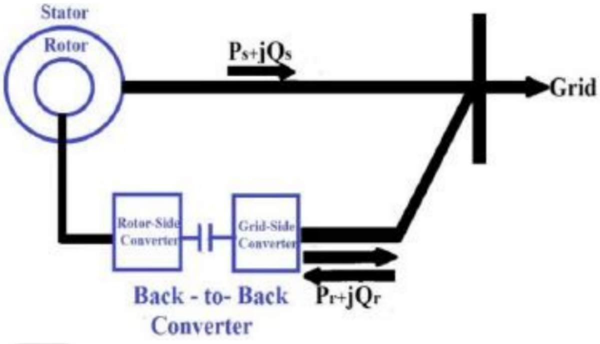

Figure 3: Doubly Faced Induced Generator

During its standard operational mode, the grid-side converter of a Doubly Fed Induction Generator (DFIG) enables autonomous adjustment of both active and reactive power. Furthermore, the need for a soft starter during grid connection can be obviated if the converter is situated on the rotor side. The control architecture of the DFIG can be divided into two primary subsystems, namely, the mechanical and electrical systems. Despite the multifaceted objectives underlying the development of control systems, maintaining precise regulation of grid-injected power has consistently taken precedence. Specifically, the rotor-side converter governs active power directed toward the grid, while the stator- and rotor-side converters manage reactive power injection. The power electronics devices used in Doubly-fed Induction Generators need only to process a fraction of the generator output power, i.e., the power supplied to or from the generator rotor windings, typically about 30% of the generator-rated power. For this reason, the power electronics devices being used in variable-speed wind turbines with doubly-fed induction generators are generally only approximately 30% of the size of the power electronics devices used for similarly sized three-phase synchronous generators. This results in lower overall power losses and lower costs for power electronics products.

2 LITERATURE REVIEW

Conducting a literature survey is an ongoing process, often spurred by research efforts. In this section, we delve into studies that explore various techniques for enhancing power quality. We'll explore and compare the merits and limitations of distinct power quality enhancement methods, including STATCOM and different controllers (such as PI and PID).

According to Manikandan et al. [9], the intermittency of renewable energy sources like solar photovoltaic panels and wind turbines imposes limitations on power generation regardless of weather conditions—solar photovoltaic (PV) and wind-generated power exhibit unique and volatile characteristics. To ensure a consistent power output, independent stabilization of each source is essential. This necessitates some form of control process. Consequently, rapid energy adjustment becomes imperative for efficient power transmission and distribution networks.

Khan et al. [10] underscore the weather-dependent nature of photovoltaic (PV) systems, which rely on sunlight and wind to generate electricity. Due to their erratic behavior, their output remains unpredictable. This underscores the growing importance of swift compensation mechanisms for energy distribution and utilization systems. The deployment of a "Static Synchronous Compensator (STATCOM)" is suggested to mitigate voltage fluctuations stemming from the grid and renewable sources, along with compensating for reactive power. The study introduces a Solar PV-Wind Hybrid Micro-grid and investigates whether integrating a STATCOM could enhance the system's stable operational limits.

Similarly, Kharadi and Christian [11] accentuate the pivotal role of sustainable energy sources in the electricity infrastructure. Various renewable sources like wind, solar, geothermal, ocean thermal, and biomass contribute to electricity generation. Due to its universal availability, solar energy stands out as a practical power source. Solar photovoltaic (PV) modules convert sunlight into electricity. However, wind and solar PV systems rely heavily on environmental conditions, leading to unstable electricity production. The paper emphasizes the need for rapid adjustments within energy distribution and transmission networks. To address reactive power compensation and voltage fluctuations arising from both the grid and renewables, the installation of a "Static Synchronous Compensator (STATCOM)" is proposed. The study models a Solar PV-Wind Hybrid Micro-grid and explores the potential benefits of incorporating a STATCOM to augment the system's operational stability. The study employs genetic algorithms (GA) to optimize PI controller gain parameters within STATCOM, resulting in improved response times and consistent voltage levels.

Prasanna et al. [12] echo the sentiment regarding the weather dependence of photovoltaic (PV) systems. Due to the unpredictable behavior of these systems, their output remains uncertain. This underscores the critical need for rapid compensation mechanisms within energy distribution and utilization systems. The Static Synchronous Compensator (STATCOM) is posited as a solution to mitigate voltage fluctuations and reactive power fluctuations stemming from the grid and renewable sources.

3 Renewable Energy Sources

Renewable energy sources encompass the sun, wind, water, geothermal heat, and the energy stored within plants. Renewable energy technologies can convert these resources into diverse forms, such as electricity, heat, chemicals, and mechanical power. The adoption of renewable energy holds the potential to establish energy self-sufficiency and enhance safety in energy generation.

Additionally, it's notable that nearly half of America's oil is imported, a significant increase from 34% in 1973. To address this dependence on foreign petroleum, using biofuels derived from plant materials presents a viable strategy for diminishing reliance on imported oil and fostering energy independence.

Renewable energy sources like solar and wind power are abundant, and their associated technologies are evolving rapidly. The versatility of renewable energy is evident as it finds applications across various sectors. Many of us are already utilizing alternative energy sources in various capacities.

Shifting focus to India, several key factors are driving the development of renewable energy in the country:

1. Rapid Energy Demand: The escalating energy demand necessitates the exploration of diverse sources to meet the growing needs.
2. Reducing Dependence on Imports: As reliance on foreign fossil fuel suppliers increases, the search for domestic and sustainable energy sources becomes crucial.
3. Remote Area Electrification: Providing electricity to remote regions is a challenge renewable energy can address effectively.
4. Peak Demand Management: The variable nature of renewable sources can help manage energy supply and demand during peak usage periods.

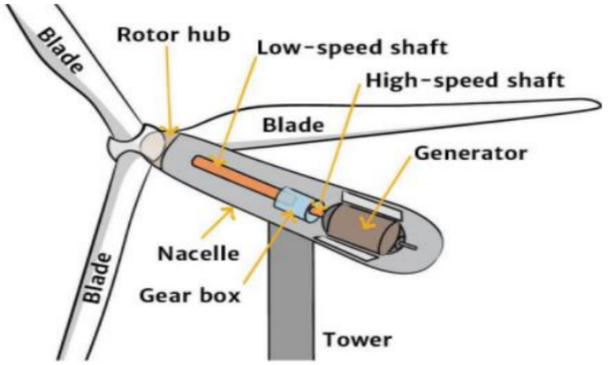

Figure 4: Components of Wind Turbine

5. Emission Reduction Pressure: Growing public and political concerns surrounding greenhouse gas emissions urge the adoption of cleaner energy options.

3.1 Wind Turbine

A wind turbine is a device that harnesses the kinetic energy of wind to generate electricity. There are two main types of wind turbines: those with fixed-speed rotors (where the rotor speed remains constant regardless of the strength of the wind) and those with variable-speed rotors (where the rotor speed varies with the strength of the wind to maximize efficiency). A wind turbine is a device that harnesses the power of the wind to create energy rather than utilizing electricity to spin a fan. Electricity is produced when the wind turns the turbine's impeller blades, which turns the rotor and generator.

Current wind patterns and speeds in the United States vary widely and affect water bodies, vegetation, and topography differences. People use this moving wind or energy for boating, flying kites, and generating energy. The terms "wind power" and "wind energy" define the method of using wind to produce mechanical power. A generator converts this rotational power into electricity, which may be used for various purposes. Wind turbines use rotor blade aerodynamic forces to transform wind energy into electricity.

To some extent, the rotor blades' working principle is the same as that of an aircraft wing. Air pressure is reduced on one side of the blades when air moves through the blades. Since one side of the blade has lower air pressure than the other, there is always going to be some amount of stress and strain. The rotor's revolution produces a pulling force, but the lifting force outmatches it. In a straight-axis turbine, the rotor will connect directly to the generator. Still, in a curved turbine, the rotor will be linked to the generator through a crankshaft and a set of gears (reducer) to enhance the rotation speed and enable a smaller generator. Electricity is produced when the aerodynamic force on the generator's spin varies.

4 Methodology

4.1 Essential Components of the System

The suggested model treats photovoltaic (PV) and wind power systems as modular systems, allowing for the required installed capacity to be obtained by adjusting the number of PV modules and wind turbines. The system size may be optimized by calculating the optimal area covered by the PV modules and the number of wind turbines. The suggested HRES cost-optimization approach may be used in various settings, owing to its adaptability in light of the typology of the various renewable power subsystems. To achieve this, the user needs to modify the input variables that pertain to the size of the system, such as the installed capacities and efficiencies of the biomass or wind subsystems, and the location, such as the sun irradiation and wind speed data series.

The system is structured such that renewable energy sources like sun and wind are preferred over grid-based energy sources like biomass. Suppose there is a shortage of renewable energy sources like solar panels or wind turbines. In that case, the biomass engine is run at maximum capacity, and any excess electricity is sent to the grid and sold. When renewable sources like solar, wind, and biomass aren't able to meet current demand, the system will turn to the grid for backup.

The literature study reveals a lack of studies on the effects of hybrid solar-wind microgrids on voltage variations in the STATCOM system. To keep up with the growing demand for PV and wind power systems, traditional FACTS devices must undergo further refinements of controllers and in-depth study across a wide range of operating situations. This research aimed to include STATCOM for reactive power compensation into the current power system design to expand its dependable working limit. Moreover, it aims to mitigate voltage fluctuations brought on by the intermittent nature of renewable energy sources.

4.2 STATCOM

A “Static Synchronous Compensator (STATCOM)” serves the vital role of rapidly supplying or absorbing reactive current to uphold a consistent voltage at the connection point within the power grid. These devices are categorized as FACTS devices, denoting “Flexible AC Transmission System.” The technology's foundation lies in modular, multi-level VSC architecture employing semiconductor valves. Additionally, non-symmetrical designs are attainable by incorporating mechanical or thyristor-switched shunt components. This adaptable approach, controlled cohesively, caters to a broad range of applications, given

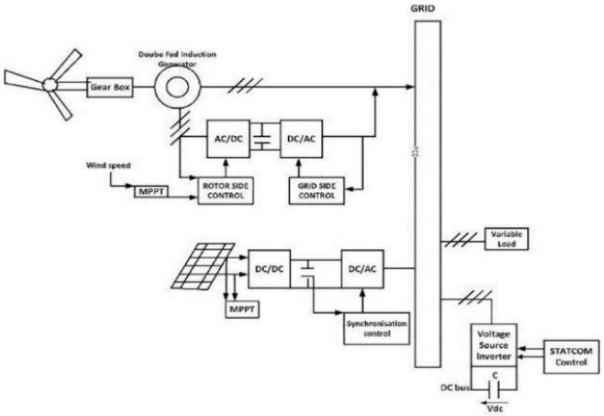

Figure 5: Components of Wind Turbine

the symmetrical dynamic reactive current output range under typical network disruptions. When network issues arise, STATCOMs can promptly inject current up to their rated capacity, stabilizing voltage in the short term. This capability is underpinned by the device's architecture and rapid responsiveness.

Beyond voltage stabilization, STATCOMs wield the capacity to enhance power quality by engaging in various tasks. These include rectifying power factor imbalances, managing reactive power, mitigating low-frequency power oscillations through reactive power modulation, conducting active harmonic filtering, reducing flicker, and more. In contexts where maintaining voltage stability and power quality are paramount, STATCOMs play a pivotal role. Their applications encompass electric power transmission, distribution systems, large industrial facility electrical networks, arc furnaces, high-speed rail systems, and diverse electric systems [51].

To curtail transmission losses and ensure that the system's active and reactive power remains within the confines of grid constraints, a STATCOM can function in either a capacitive or inductive mode for reactive power compensation. To diminish voltage fluctuations at the busbar's terminus and offset reactive power, the STATCOM has been positioned at the common coupling point. However, if the tuning constants of the controller are improperly configured, the stability and performance of the control system could be compromised. Hence, the efficacy of this control mechanism hinges greatly on the precise configuration of controller settings and the meticulous choice of tuning constants.

5 Conclusion

In this study, we investigated the impact of integrating a solar power generation system with a capacity of 0.1 MW and a wind power generation system with a capacity of 1.5 MW into the existing power grid. It was found that such integration could potentially introduce voltage fluctuations and power instability due to the intermittent nature of renewable energy sources. To address this issue, we proposed the use of STATCOM to compensate for reactive power in the hybrid system.

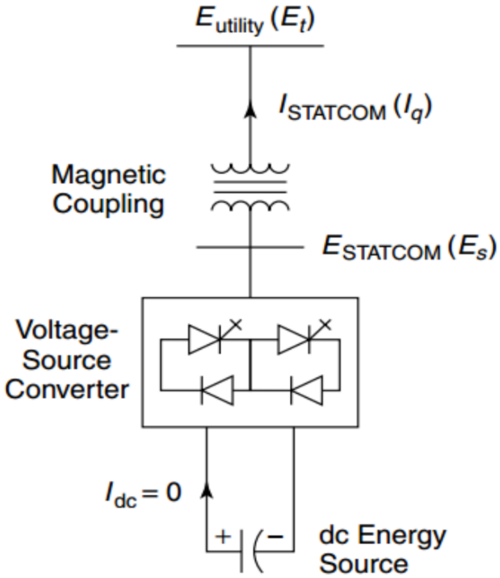

Figure 6: Principal Diagram of STATCOM

Through the analysis of output voltage profiles, it was observed that the implementation of STATCOM effectively stabilized the system's voltage profiles under both capacitive and reactive load conditions. This suggests that STATCOM has the potential to mitigate power instability in large transmission networks and reduce variations caused by the integration of renewable energy sources.

Moving forward, further research can explore the optimization of STATCOM control strategies to enhance its effectiveness in stabilizing hybrid solar PV-wind power systems. Additionally, investigations into the economic feasibility of integrating STATCOM into such systems would be beneficial. Moreover, studies can be conducted to assess the long-term performance and reliability of hybrid renewable energy systems with STATCOM integration under varying environmental and operational conditions.

Furthermore, the potential environmental benefits of reducing power instability and enhancing grid resilience through the adoption of STATCOM in renewable energy systems warrant exploration. Overall, continued research in this area holds promise for advancing the integration of renewable energy into existing power grids while ensuring stability and reliability.

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