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

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Abstract: *Wind and solar photovoltaic (PV) systems are very weather-sensitive in terms of their ability to produce electricity. Their production varies because of how inconsistent they are. As a result, fast adjustment for energy distribution and transmission networks is becoming more crucial. As a means of compensating for reactive power and dampening voltage fluctuations brought on by the grid and renewable energy sources, a "Static Synchronous Compensator (STATCOM)" may be put into use. In this work, a Solar PV-Wind Hybrid Micro-grid was modelled, and the possibility of STATCOM's increasing the system's stable operational limit was investigated. Since the nonlinear nature of a solar-wind hybrid micro-grid makes it difficult to produce good responses and voltage stability using conventional methods.*

Keywords: *Photovoltaic; Static Synchronous Compensator (STATCOM); PI controller; DSM-PI (Dual Sliding Mode Proportional Integral); Solar PV-Wind Hybrid Micro-grid.*

1. Introduction

Climate change and the responsible management of the world's depleting fossil fuel resources are the two greatest problems the planet now facing. Reducing our dependence on fossil fuels and significantly cutting down on emissions of greenhouse gases is necessary if we want to provide future generations with a safe planet. Investment in renewable energy has expanded significantly as the price of technologies drops and their efficiency keeps getting better; this is because renewable energy is an essential aspect of lowering global carbon emissions. [1]

Centralized power plants have several drawbacks: First, most power plants use fossil fuel, which increases CO2 emissions and wastes rejected heat; second, large amounts of power must be delivered using transformers and long transmission and distribution lines; third, power losses and voltage drop seem to be significant problems due to the length of the transmission lines and the transformers; and fourth, this does not offer a financially viable solution to supply power to poor and isolated communities. We can reduce our reliance on fossil fuels and our impact on the environment by switching to renewable energy sources like wind and solar photovoltaic (PV) generation.

Microgrids are small-scale power networks made up of renewable energy generators, battery storage, and end-use consumers. There are various benefits to using a microgrid, including more dependability, greater controllability, and higher quality electricity. There are two types of microgrids: those that are linked to the larger grid and those that are completely separate from it. Operating the grid-connected microgrid in tandem with a reliable electric power system means worrying less about unwanted frequency fluctuations. Therefore, from a financial perspective, microgrids that are linked to the grid need to focus on increasing electric power exchanges and profits. In contrast, without access to the larger electric grid, isolated microgrids have challenges with voltage and frequency fluctuation maintenance. [2]

Distributed microgrids based on renewable power generation techniques like solar, wind, and biogas can help meet the growing global demand for electricity while reducing the associated costs and emissions of harmful greenhouse gases (GHGs) from traditional central power plants that rely on fossil fuels. Use of renewable energy sources is the only viable option for creating a better, pollution-free planet. Producing electricity from renewable resources is feasible.

Conventional renewable sources are being used efficiently over the world to provide a long-term solution to the energy dilemma, and they include solar, wind, and hydro.

1.1 Development of Distributed Generation (DG)

A major part of today's residential, commercial, and industrial power systems depends on the DG. Distributed generation (DG) offers an alternative to the conventional electrical power generating sources of today, such as oil, gas, coal, and water. Small-scale power generation (1 kW-50 MW) or, more colloquially, power generating units linked at distribution level closer to the load side is what is meant by "DG." [3] [4]

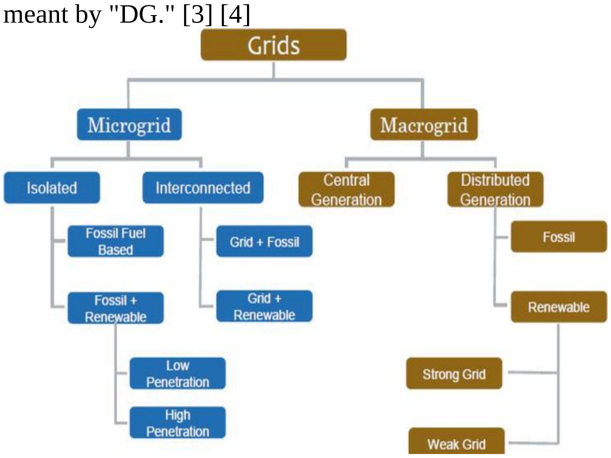

Figure 1 Grid classification

The DG's rising popularity may be attributed to its high efficiency, minimal emissions, and gentle operation. Using DG is as simple as plugging in a device. By using this route, the DG unit may be relocated wherever it is most convenient without requiring any adjustments to the distribution system's management infrastructure. DG, or diesel generator, is a secondary source of electricity used by many factories, malls, hospitals, universities, and other commercial establishments. Power from this device is used as a backup in the event that the main power source goes down.

Fuel cells, microturbines, batteries, flywheels, and supercapacitors are some of the examples of distributed generators. The distributed generating system also includes "photovoltaic (PV) and wind turbine (WT) resources." [5]

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 fact that the electrical power generated is sent in both directions (between the stator and the rotor). Since these generators can adapt to changing wind conditions, they have garnered a lot of interest. There are benefits to using variable-speed wind power plants rather than constant-speed wind power plants. [6]

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, while 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.

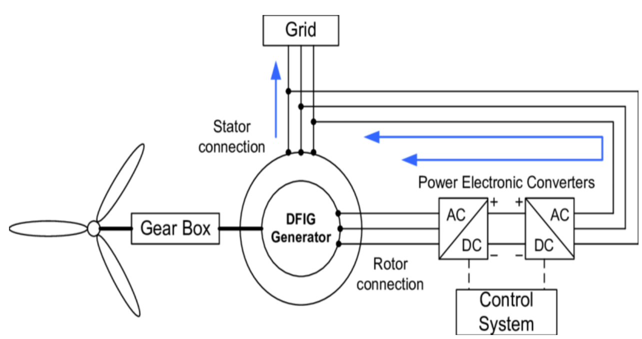

Figure 2 Schematic diagram of DFIG Generator

In its normal mode of operation, DFIG's grid-side converter allows for independent regulation of active and reactive power. In addition, the soft starter may be omitted during grid connection if the converter is installed on the rotor side. The DFIG's control plane may be subdivided into its two main subsystems, the mechanical and electrical systems. Although the control systems were developed with a variety of objectives in mind, regulating grid-injection power has always been a top priority. The rotor-side converter regulates the grid-exposed active power, while the stator- and rotor-side converters regulate the reactive power injection. [8]

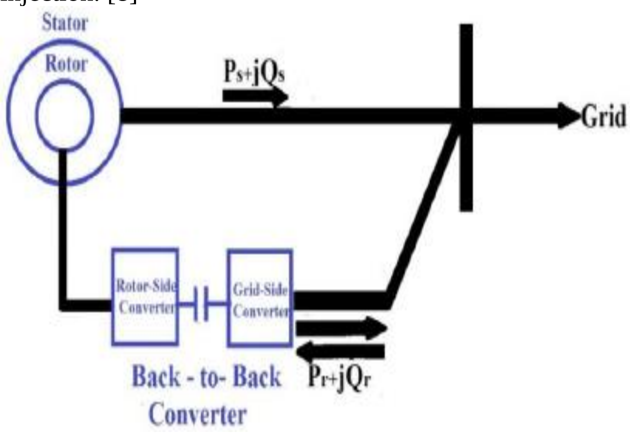

Figure 3 Doubly Faced Induced Generator

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 that is supplied to or from the generator rotor windings which is typically about 30% of the generator rated power. For this reason, the power electronics devices being used 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

A literature survey is an interminable procedure. Research efforts encouraged its execution. In this section, we will examine studies that focus on different power quality enhancement techniques. Here, we examine and contrast the strengths and weaknesses of several power quality enhancement methods, such as STATCOM and various controllers (such as PI and PID).
(Manikandan et al., 2023) [2] Whether or not the weather cooperates, renewable energy sources like solar photovoltaic panels and wind turbines can only provide so much power. Solar photovoltaic (PV) and wind-generated power are distinctive and very changeable. It is necessary to stabilise each of them independently in order to maintain a steady power output. Thus, some kind of regulating procedure is required. For this reason, fast energy adjustment is essential for power transmission and distribution networks.
(Khan, 2021) [3] Photovoltaic (PV) systems, which use the sun and wind to generate electricity, are very weather-dependent. Due to their erratic nature, their output is also unpredictable. This highlights the growing significance of fast compensation for systems that distribute and use energy. The "Static Synchronous Compensator (STATCOM)" may be used to smooth out voltage swings induced by the grid and renewable energy sources, thereby compensating for reactive power. Here, we demonstrate a Solar PV-Wind Hybrid Micro-lattice and investigate whether or not the inclusion of STATCOM raises the framework's stable operating limitation.
(Kharadi & Christian, 2021) [4] Sustainable energy sources are an integral aspect of our electrical infrastructure. Wind, solar, geothermal, ocean thermal, and biomass are just few of the renewable energy sources that may be used to create electricity. Because solar energy can be captured everywhere at no cost, it is the most practical source for power production. The solar photovoltaic modules can convert sunlight into electricity (PV). Wind and solar photovoltaic (PV) systems rely heavily on environmental conditions for electricity production. Its output is unstable due of their inconsistency. As a result, it's becoming more crucial that energy transmission and distribution networks have access to rapid correction. Reactive power compensation and voltage variations from the grid and renewables might be mitigated by installing a "Static Synchronous Compensator (STATCOM)." To such objective, this study modelled a Solar PV-Wind Hybrid Micro-grid and looked into whether or not adding STATCOM may raise the system's stable operating limit. In view of the nonlinear features of the solar-wind hybrid micro-grid, the primary contribution of this study is the application of genetic algorithms (GA) to optimise the gain parameters of four PI controllers in STATCOM, resulting in faster response times and more consistent voltage.
(Prasanna & Jyothi, 2021) [5] Photovoltaic (PV) systems, which use the sun and wind to generate electricity, are very weather-dependent. Due to their unpredictable nature, their output is also unpredictable. This highlights the growing significance of fast compensation for systems that distribute and use energy. The Static Synchronous Compensator (STATCOM) can smooth out voltage fluctuations and level down reactive power generated by the grid and renewable energy sources.

3. Renewable Energy Sources

The sun, the wind, the water, the heat from the earth, and the energy stored in plants are all examples of renewable energy sources. These fuels are converted by renewable energy technologies into electricity, heat, chemicals, or mechanical power.

The use of renewable energy sources will also aid in achieving energy autonomy and safety. More over half of America's oil now comes from abroad, up from only 34% in 1973. The use of biofuels, which are derived from plant materials, might help us reduce our reliance on imported petroleum and increase our energy independence. Solar, wind, and other forms of renewable energy are widely available, and their associated technologies are rapidly advancing. Renewable energy may be used in a wide variety of applications. The vast majority of us are already making use of other forms of energy.

The following are the primary reasons for the development of renewable energy in India:

- There is a rapid increase in demand for energy generally.
- Growth in dependence on foreign suppliers of fossil fuels
- There must be a practical way to provide electricity to remote areas.
- Power supply and demand at their peak
- Increased public and political pressure to reduce emissions of greenhouse gases.

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 in turn turns the rotor and generator.

Current wind patterns and speeds in the United States vary widely and affect the differences in water bodies, vegetation, and topography. People use this moving wind or energy for many purposes: boating, flying kites, and even generating energy. The form “wind power” and “wind energy” define the method of using wind to produce mechanical power. A generator takes this rotational power and converts it into electricity, which may then be used for various purposes. Rotor blade aerodynamic forces are used by wind turbines to transform wind energy into electricity.

To some extent, the rotor blades' working principle is the same as that of an aircraft wing. There is a reduction in air pressure 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 it's outmatched by the lifting force. In a straight-axis turbine, the rotor will connect directly to the generator, but 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.

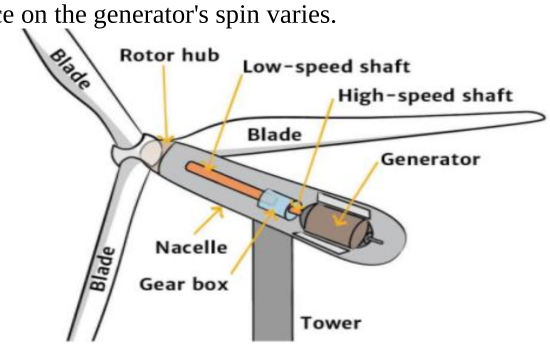

Figure 4 Components of Wind Turbine

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. By calculating the optimal area covered by the PV modules and the number of wind turbines, the system size may be optimised.

The suggested HRES cost-optimization approach may be used in a variety of settings, owing to its adaptability in light of the typology of the various renewable power subsystems. To achieve this, the user need just 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 to 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. If there is a shortage of renewable energy sources like solar panels or wind turbines, 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. In order 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.

The purpose of this research was to include STATCOM for reactive power compensation into the current power system design in order to expand its dependable working limit. Moreover, it aims to mitigate voltage fluctuations brought on by the intermittent nature of renewable energy sources.

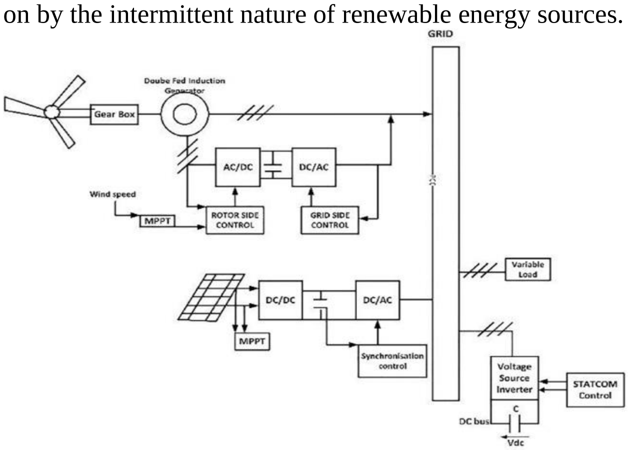

Figure 5 Solar-wind hybrid system including STATCOM

4.2 STATCOM

To maintain a constant voltage at the point of connection to the power grid, a “Static Synchronous Compensator (STATCOM)” may quickly provide or absorb reactive current. They are classified as FACTS devices, which stand for “Flexible AC Transmission System”. Semi-conductor valves in a modular, multi-level VSC architecture form the basis of this technology.

Furthermore, non-symmetrical designs are achievable by incorporating mechanically or thyristor switched shunt components with unified control systems to cover most common applications, since the dynamic reactive current output range is symmetrical (under typical disrupted network circumstances). When a network problem occurs, STATCOMs may quickly inject current up to their rated current, keeping the voltage stable in the short term. This is made possible by the device's architecture and quick responsiveness.

STATCOMs also have the ability to enhance power quality by performing tasks such as power factor correction, reactive power management, dampening low-frequency power oscillations (often through reactive power modulation), active harmonic filtering, flicker reduction, and more. Applications where voltage stability and power quality are of paramount significance include electric power transmission, electric power distribution, electrical networks of large industrial facilities, arc furnaces, high-speed rail systems, and other electric systems. [51]

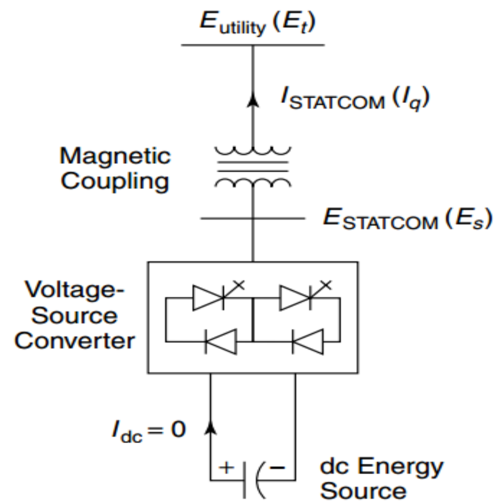

Figure 6 Principal Diagram of STATCOM

To reduce transmission losses and maintain the system's active and reactive power values within grid limitations, STATCOM may operate in either a capacitive or inductive mode for reactive power compensation. With the goal of lowering voltage fluctuations at the busbar's end and compensating for reactive power, the STATCOM was installed at its common coupling point. If the controller tuning constants are set incorrectly, the stability and quality of the control system might suffer. Consequently, the effectiveness of this control relies heavily on the accurate setting of controller settings and the careful selection of tuning constants.

5. Conclusion

This research looked at how adding 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 might affect the existing power grid. It has been suggested that STATCOM may be used to compensate for the reactive power in this hybrid system. The output voltage profiles of a hybrid solar PV-wind power system were analysed. STATCOM was implemented to analyse the system's voltage profiles under capacitive and reactive load conditions. These findings imply that the power instability in big transmission networks may be reduced, as can the variations brought on by the integration of renewable energy sources.

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