A Sustainable Method to Improve Transient Stability in Renewable Driven Power Networks

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***Abstract* — Solar and wind energy are the popular form of renewable energy source harness over the past 10 years both these sources however suffer from intermittency of generation. Weather dependent generation also result in voltage stability problems. In case of solar energy the traditional boost converter with Mppt algorithm often failed to sustain the voltage within permissible limits. Apart from generation intermittency and voltage stability problems due to absence of rational parts solar driven power networks suffers from low inertia and remains vulnerable during in presence of disturbances and faults, thus modern renewable driven power networks deviate from the objective of smart grids for more sustainable , disaster free and flexible operation. This work presents an algorithm for improving the voltage profile of the solar output and the use of Virtual synchronous generators is used for the improvement of inertia of grids. A simulink model of VSG has been developed in this work with the help of phase lock loop which demonstrate to ensure better transient stability of the grid and thus makes Smarter. it For this purpose, smart grids use technologies such as advanced sensors, communication networks, data analysis, and the use of electricity to produce energy and energy fields.**

Keywords— Renewable energy, Smart Grid, Virtual Synchronous Generators (VSGs), Power System Transient Stability.

I. INTRODUCTION

In an age where the need for energy increases, environmental concerns become more important, and technological developments change our way of life. Enter the smart grid, a modern smart network that promises to revolutionize the way we generate, deliver, distribute, and use electricity. Smart grid is a concept and vision that encompasses professional knowledge, information, communication, management, and energy technology. In summary, electronic devices can be used to work intelligently across all user connections, from generators to users, from producers to electricity consumers ("prosumers"), to provide efficient, economical, and safe electricity. The Smart Grid concept stems from the realization that traditional energy grids are becoming increasingly vulnerable to increased demand, aging infrastructure, and the integration of new energy sources. In case of solar energy, the traditional boost converter with Mppt algorithm often failed to sustain the voltage within permissible limits when subjected to wide variation of load. the smart grid enables communication between utilities and the consumers, providing instant information and insights to both parties. Smart meters are installed in homes and businesses and provide detailed information about energy usage habits, allowing customers to make informed decisions about their usage and costs. At the same time, utilities can improve grid performance, provide efficient maintenance, respond quickly to faults, and allocate resources efficiently. Cyber security issues are becoming more important as the growth of connected devices increases the vulnerability of the power grid to cyber threats. Additionally, the upfront costs of implementing a smart plan can be high and require careful planning and investment. But the potential rewards of using smart technology are huge. Smart plates represent a revolution in our fertility and energy management by improving self-confidence and the ability to be more energetic and stable. Now that we are at the turning point of this transformation, smart plans promise a stronger, more sustainable energy future for future-generations.

A. *Technical Challenges of modern power grid*

1) Interoperability and Standardization: Smart grids involve the integration of diverse Technologies and systems from different vendors. Lack of standardization can lead to compatibility issues, hinder system integration, and increase costs.

2) Cyber Security and Risks: The increased connectivity and digitalization of smart grid components make them susceptible to cyber threats such as hacking, malware, and data breaches. Protecting smart grid infrastructure from cyber-attacks requires robust cyber security measures, including encryption, authentication, access control, and continuous monitoring.

3) Reliability and Redundancy: Smart grid components must be designed with reliability and redundancy in mind to minimize the risk of system failures and downtime. Redundant communication networks, backup power systems, and failover mechanisms are essential to ensure uninterrupted operation and maintain grid reliability.

4) Data management and analytics risk: Smart grids produce large amounts of data from sensors, meters, and other various devices. Effectively managing and analyzing this data to derive actionable insights presents major technical challenges. Advanced techniques i.e. machine learning and Artificial intelligence (AI), are needed.

B. *Inertia problems in Power Grids*

1) Decreased Inertia: The above energy sources typically lack the rotating masses that provide inertia in conventional power plants. When these sources replace conventional power plants, the overall inertia in the grid decreases, making it more susceptible to frequency fluctuations due to sudden changes in supply or demand.

2) Grid Resilience: Inertia provides a buffer against disturbances and helps the grid recover from sudden events like equipment failures or large load changes. In the absence of adequate inertia, the grid may become more vulnerable to disruptions, potentially leading to cascading failures.

3) Need for New Control Strategies: To address inertia-related challenges in smart grids, new control strategies and technologies are being developed. These include techniques such as virtual inertia, which emulates the behavior of traditional rotating masses using power electronics and Energy storage systems.

4) Integration of Energy Storage: Energy storage systems, such as batteries, can provide fast-acting response capabilities like inertia. By integrating energy storage into the grid, operators can enhance system stability and mitigate the impacts of reduced inertia from renewable energy sources.

5) Market and Regulatory Challenges: The movement to smart grids with higher levels of Renewable energy requires adjustments in market mechanisms and regulatory frameworks. Ensuring proper incentives for inertia provision and grid stability becomes essential to support the integration of renewable while maintaining system reliability.

II. Literature Review

The first step towards a sustainable energy development is the integration of renewable energy with smart grids. Although abundant and environmentally friendly alternatives to fossil fuels, renewable energy sources like solar, hydro and wind power nevertheless present special integration issues due to their intermittent nature. Smart grids offer a viable way to effectively manage and optimize the integration of renewable energy sources because of their sophisticated monitoring [1], communication, and control systems. This paper deals with addressing a few of the problems faced while integrating smart-grids with renewable energies, mainly dealing with the inertia problem and grid voltage stability problem [2]. Energy generation and management are relevant for both utilities and electricity users, and they can be improved by incorporating sophisticated technology on smart grid [3]. The growing level of distributed generation (DG) integration puts the grid under strain, resulting in perturbations with dynamic responses [4].

Smart grids can better Handle the intermittent nature of renewable energy sources, reducing the likelihood of outages [5]. The more use of renewable energy decreases greenhouse gas emission and reliance on fossil fuel, contributing to a cleaner environment [6]. The development and deployment of smart grids technology often require new regulation and policies, Which can be slow to implement. The upfront cost for the infrastructure of smart grid with renewable energy sources can be significant, though they are often offset by long term savings [7]. Managing the variability of renewable energy sources like solar and wind requires advanced forecasting and grids management techniques [8].

A. MPPT algorithm associated with renewable energy

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B. Consequences of reduced inertia

1) Grid stability: The above energy sources typically lack the rotating masses that provide inertia in conventional power plants. When these sources replace conventional power plants, the overall inertia in the grid decreases, making it more susceptible to frequency fluctuations due to sudden changes in supply or demand.

2) Virtual synchronous generator: Virtual synchronous generators provide an important role in enhancing the stability and reliability of smart Grids with a high level of renewable energy integration. By emulating the

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inertial and dynamic characteristics of traditional synchronous generators, VSGs addressed the inertia problem and supported critical grid functions such as frequency and voltage regulation [9].

VSGs offer a cost-effective solution for grid stability potentially reducing the need for expensive grid infrastructure upgrades and lowering overall system cost. These enhance the grid's ability to dynamically adapt to changes in supply and demand, making it more resilient to disturbance and less vulnerable [10].

III. MPPT Algorithm Flowchart

MPPT**,** also known as PPT, is a technique utilized to maximize energy extraction from variable power sources by tracking the power point. While commonly employed in photovoltaic solar systems, it can also be applied to wind turbines, optical power transmission, and thermos photo voltaic solar systems. These systems have different connections to inverter systems, external grids, battery banks, and other electrical loads. The main issue addressed by MPPT is the efficiency of power transfer, which depends on factors such as sunlight availability, shading, solar panel temperature, and the electrical characteristics of the load. As these conditions change, the load characteristic that results in the highest power transfer also changes. The system is optimized when the load characteristic adjusts to maintain the highest efficiency in power transfer.

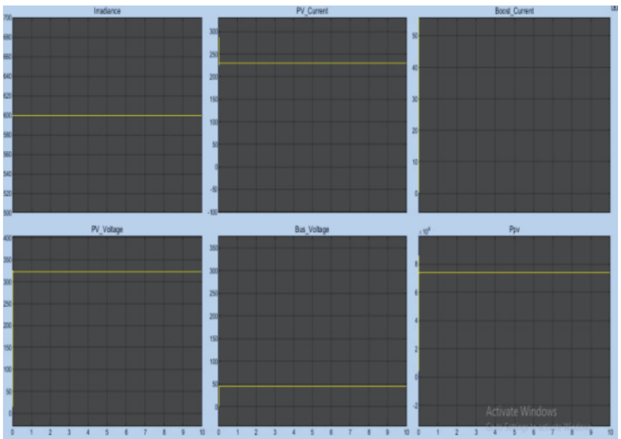

Fig.1. Showing poor initial voltage regulation with MPPT

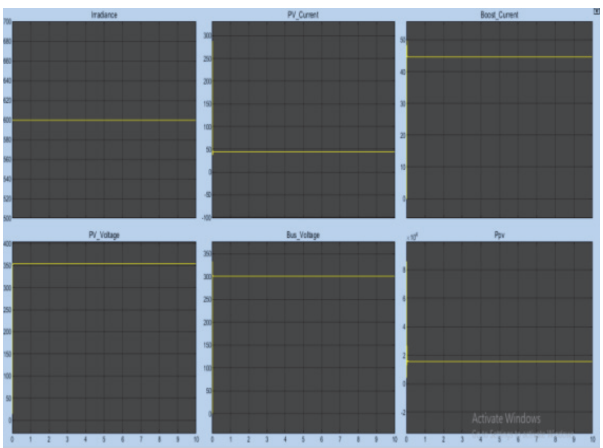

Fig.2. Manipulation showing improvement of voltage regulation

This optimal load characteristic is referred to as the maximum power point (MPP). MPPT involves adjusting the load characteristic as the conditions vary. Circuits can be designed to present optimal loads to the photovoltaic cells and then convert the voltage, current, or frequency to match other devices or systems.

In the solar Simulink model with MPPT algorithm (figure 3), the max power is extracted from the renewable source. Voltage stability plays a crucial role in facilitating the smooth integration of renewable energy sources into the grid. To test the voltage stability of the solar Simulink model with MPPT algorithm, the load on the circuits have been reduced in steps to monitor the change of voltage as shown in the figure 1 & 2.

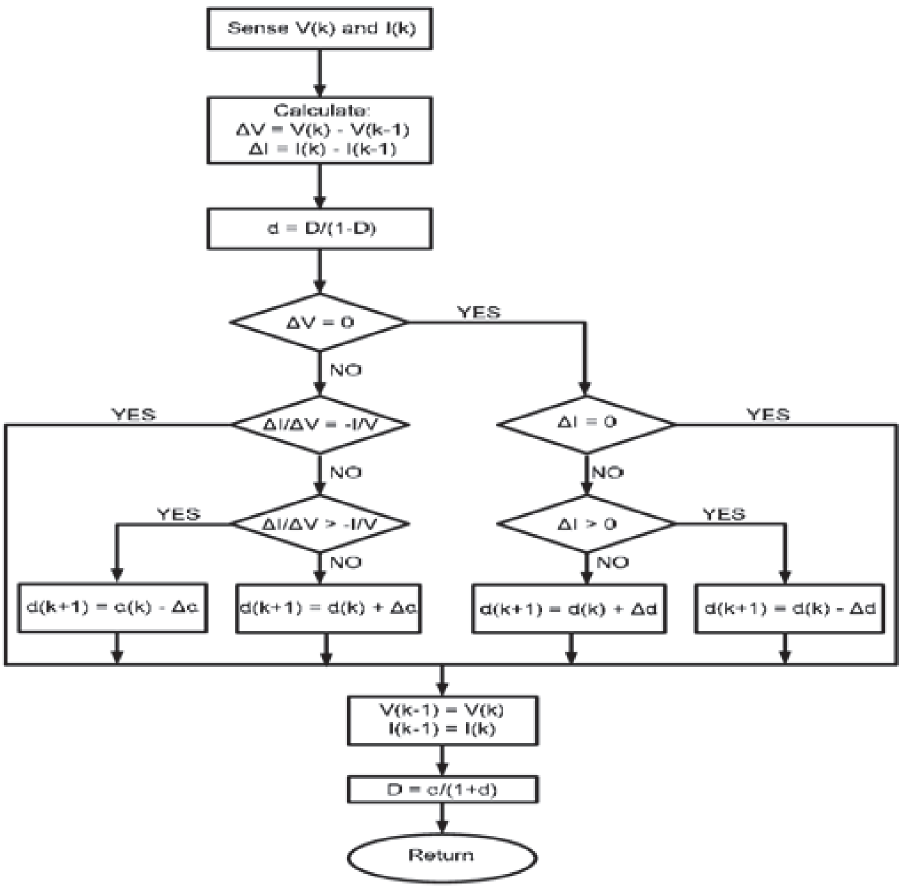

Fig.3. Flowchart showing MPPT Algorithm

The drop in voltage is quite steep in case of MPPT algorithm and the proportional integral derivative, (PID) with MPPT showing a better response and rather less sensitive to the variation of load.

IV. Improvement of Transient Stability by VSG

Virtual Synchronous Generators (VSGs) have surfaced as a hopeful resolution to tackle these difficulties, by emulating the behavior of synchronous generators through advanced control algorithms and power electronics. This literature survey provides a comprehensive overview of the research conducted on VSGs for improving Power systems with transient stability. Renewable energy integration Transient stability is the capacity of a power system to uphold synchronism after an interruption, such as a fault or abrupt alteration in load. It is crucial for preventing cascading failures and blackouts in power grids. The examination of the system's dynamic reaction to disturbances is an integral part of transient stability analysis and ensuring that it can recover and return to a stable operating state within an acceptable time frame.

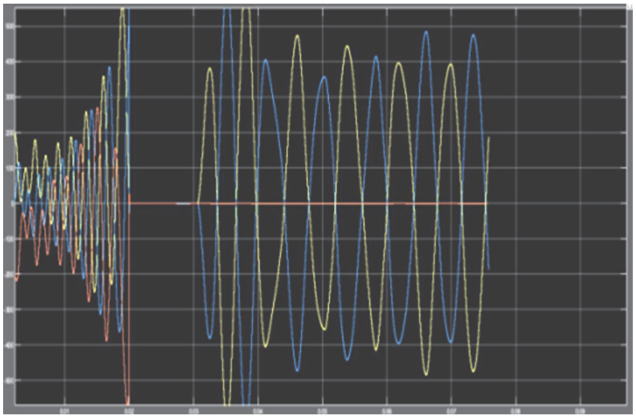

Fig.4. Fault voltage with VSG

The incorporation of sustainable energy sources, introduces variability and uncertainty into power systems, which can impact transient stability. Unlike conventional synchronous generators, renewable sources lack inherent inertia, making it challenging to stabilize the system during transient events. Additionally, the stochastic nature of renewable generation adds complexity to power system operation and control. When VSG was used in the same condition the voltage waveform in the post fault condition was found to be acceptable, as shown in figure 4 and the equal area criterion in investigating the possibility of improvement of transient stability with application of virtual synchronous generator, it has been found in figure 5, where the power delivered during the fault is higher with application of VSG.

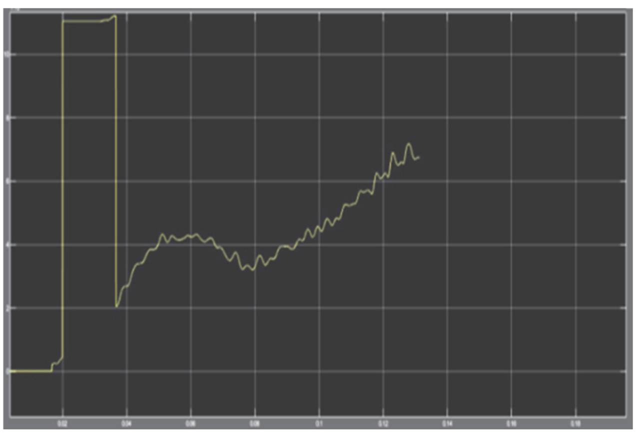

Fig.5. Fault Power with VSG

A. Transient Stability Analysis:

Transient stability analysis plays a crucial role in power system engineering, guaranteeing the dependable and safe functioning of electrical grids. The main goal of transient stability analysis is to evaluate if the system can uphold stability and return to a stable state following such disturbances, usually within a short timeframe ranging from a few seconds to a few minutes.

B. Improving Transient Stability:

To enhance transient stability, power system operators and planners employ various measures, including:

1) Generator and excitation system upgrades: Upgrading generators and excitation systems can improve the dynamic response of synchronous machines and enhance stability margins.

2) Power system controls: Utilizing sophisticated control techniques, like adaptive power system stabilizers (PSS) and flexible AC transmission systems (FACTS), can help stabilize the system during transient events.

3) Network reinforcement: Upgrading generators and excitation systems can improve the dynamic response of synchronous machines and enhance stability margins.

4) Dynamic modeling and simulation: Utilizing advanced modeling techniques and dynamic simulation tools allow engineers to accurately predict the transient behavior of power systems and assess the effectiveness of stability enhancement measures.

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