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INTEGRATION OF VARIABLE INERTIA PV BASED VSG WITH FOR ENHANCED POWER SYSTEM TRANSIENT STABILITY

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Abstract—The integration of photovoltaic (PV) plants into power grids, connecting via voltage-source converters, presents notable distinctions in physical and electrical attributes compared to traditional synchronous generators. High PV penetration introduces critical challenges to power grid safety, notably impacting transient stability. In this project we are emulating the DC source as PV. To find solution to this problem, The study suggests a control approach that uses an synchronous generators with variable inertia. First, a representation of the PV-based virtual synchronous generator's (PV-VSG) generalized control approach is presented. This project was implemented in MATLAB Simulink software.

Keywords— *Virtual synchronous generator, Variable inertia, Transient stability, inverter.*

I. INTRODUCTION

One of the most important renewable resources is photovoltaic (PV) power, which is going to replace a significant quantity of fossil fuels in the future. Electrical system controllers will face more difficult challenges as PV electricity grows in popularity [1-3]. PVs are connected to the power grid using voltage-source converters (VSCs), as compared with synchronous generators. As a result, the physical and electrical features of PVs differ greatly from those of traditional synchronous generators. Consequently, the power system's frequency stability will degrade due to the significant penetration of PVs. The electrical system with high penetration for PV protection. PVs need to be able to ride through at both high and low voltages. Furthermore, it is important to monitor the transient stability of power systems with high penetration photovoltaics. The power system's ability to maintain synchronism in the event of a major disruption, such as a transmission equipment failure, a loss of generation, or the loss of a sizable load, is known as transient stability.

Conventional synchronous generators (SGs) can use the kinetic energy retained in their rotating inertia to balance the power grid's potential energy variance during disturbances. On the other hand, inverter-based photovoltaic (PV) power plants require rotating components and often run under the maximum power point tracking (MPPT) control strategy, indicating that it is unable to supply sufficient energy—either potential or kinetic—to maintain the stability of the power grid. As a result, once perturbed, a power system with a high penetration of photovoltaic cells is prone to losing stability.

Energy storage systems (ESS) have been extensively used in power systems in recent years as a crucial component of the smart grid [4-6]. The virtual synchronous generator is one application. One possible method to enhance the stability characteristic of a power system with a high penetration of renewable electricity is the VSG control strategy of ESS. The purpose of the VSG systems discussed in [7-9] is to link an energy storage device to the main grid. To synchronize with the grid, the VSGs use the swing equation instead of the conventional phase locked loop (PLL). To increase the electrical grid's stability, the VSGs could supply the grid with more active and reactive power [10, 11]. Several virtual synchronous generator control schemes have been put out in [12–15] to raise the frequency, voltage, transient stability, and damping properties of renewable energy generators in a power system. The control algorithms in [16, 17] are made to mimic the characteristics of synchronous generators with energy storage systems by managing PVs and wind power.

By combining the PV power station's active power production with an energy storage system (ESS), VSGs could simulate the rotating inertia of a synchronous generator [18]. The imbalanced energy could be dispersed by using the electrical power stored in the ESS once it is disturbed. After that, the PV-powered power system with high penetration could stabilize. Furthermore, compared to SGs' fixed moment of inertia, the adjustable virtual moment of inertia of the VSG is better for the power system's transient stability. Thus, this research investigates whether employing a PV-VSG control technique with variable inertia can enhance the power system's transient stability.

Our research focuses on enhancing the power system's transient stability, as opposed to the PV-VSG, which aims to improve frequency stability. As a result, the VSG's virtual inertia control technique differs from the VSG's for improving frequency stability. The VSG control approach is used in our paper to increase the power system's transient stability. To do this, the VSG's virtual inertia must adjust in accordance with variations in the power system's transient energy. Therefore, the primary innovation and contribution of this study is that, in contrast to the PV-VSG for improving frequency stability, the uses a variable inertia control approach that is intended to alter in response to changes in the transient energy of the power system.

This is how the remainder of the paper structured. Section 2 outlines the overall VSG control method. The inertia control approach is suggested in Section 3 for PV-VSG improves the power system's transient stability. To confirm the efficacy of the suggested tactic in Section 4, a case study on the power system is conducted. Sections 5 and 6 provide the discussion and conclusions, respectively.

II. VSG control strategies

VSC-based converters are inertia-free and have frequency control limited to grid frequency. As a result, electricity systems with high penetration PVs will become unstable. The idea of using converters to express as synchronous generators has been explored and is known as vectorized synchronous generators (VSG), as synchronous generators are good at controlling the frequency of the power supply. In order to regulate the power output of the VSC-based PVs and the ESS, we provide the PV-VSG control technique in this study. The following will provide an overview of the VSG's general control strategy.

2.1 **Overall control scheme**

The VSG control strategy's entire control scheme is depicted in Figure 1. The ESS and the PV power plant are linked to the same point of common coupling. (PCC) using transformers that step up. The PV combined system will henceforth be referred to as "VSG" for convenience. Since the PV power plant uses an MPPT control method, the temperature and intensity of the sun's radiation in real time determine how much power the PVs can produce. The PV-VSG control strategy determines the ESS's active power output. To determine the power output (Pout) and rotation speed (Wgrid) of the power grid, the PV-VSG controller measures the voltage (Vgrid) and current (Igrid) at the PCC bus. Next, the PV-VSG controller fails.

2.2 **Block diagram of VSG control strategy**

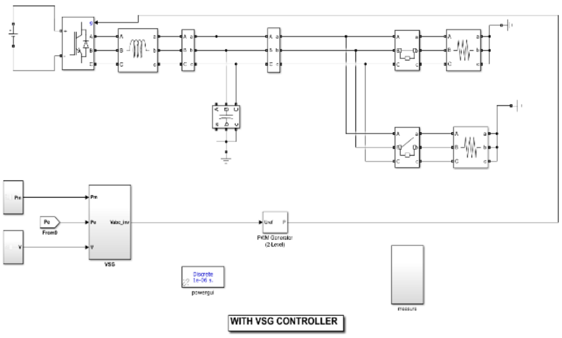

Fig 1. Schematic diagram of the VSG

The detailed control strategy block diagram of the PV-VSG controller is shown in Fig. 2. The PV-VSG control strategy aims at modeling the well-known swing equation of SGs:

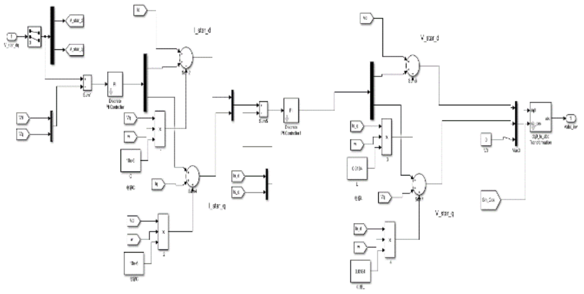

Fig 2. VSG control

$$\text{Jvsg}\frac{d\omega}{dt} = P_{in} - P_{out} - D(\omega_{vsg} - \omega_{grid}) \tag{1}$$

where Pin, Pout, Jvsg, ωvsg and D are the input power (the same as the prime mechanical power of the SG), the output power, the virtual moment of inertia, the virtual angular velocity, and the virtual damping factor of the VSG, respectively. ωgrid is the grid frequency.

2.2 Transient energy function (TEF)

According to the TEF can be used as a measurement of the unbalanced power when the power system is under disturbance. The transient energy (TE) of the power system is defined as follows:

$$TE = \frac{1}{2}\omega^2 - \int_{\delta_{AB0}}^{\delta_{AB}} \left[\frac{(P_{A0}-P_{A})}{J_A} - \frac{(P_{B0}-P_{B})}{J_B}\right] d\delta_{AB} \tag{2}$$

where δAB and ωAB denote the difference in power angles and angular speed between the center of inertia (COI) of areas A and B, respectively. PA0 and PB0are the intimal differences between the total power generation and consumption in the two loads. PA and PB are the transmission power.

II. STABILITY CONTROLLER FOR THE VSG

Virtual synchronous generators (VSGs) are a fascinating concept within power systems. They mimic the behavior of traditional synchronous generators while being implemented inverter-based systems, like those found in renewable energy sources. Stability in virtual synchronous generators is crucial for the reliable operation of power systems. Here are some key points regarding stability in VSGs:

Inertia Emulation: One of the main features of VSGs is their ability to emulate the inertia of traditional synchronous generators. In a traditional power system, the inertia of synchronous generators helps stabilize the grid against disturbances. Similarly, VSGs utilize control algorithms to emulate this inertia effect, contributing to stability.

Frequency Regulation: VSGs can regulate the frequency of the power system just like synchronous generators. This is important for maintaining system stability, as frequency deviations can indicate imbalances between generation and consumption. By controlling their output power in response to frequency changes, VSGs help stabilize the system.

Voltage Regulation: In addition to frequency regulation, VSGs also contribute to voltage regulation. They adjust their output voltage to maintain system voltage within acceptable limits, ensuring stable operation of connected loads.

Control Algorithms: The stability of VSGs heavily relies on the design and implementation of their control algorithms. These algorithms should be carefully designed to ensure smooth and coordinated operation with other generators and loads in the system. Proportional-integral-derivative (PID) controllers and advanced control techniques like model predictive control (MPC) are commonly used to achieve stable performance.

Communication and Coordination: In a power system with multiple VSGs, effective communication and coordination between units are essential for stability. VSGs need to exchange information about system conditions and synchronize their control actions to collectively stabilize the grid.

Transient Stability: VSGs should exhibit good transient stability to recover quickly from disturbances such as sudden changes in load or generation. This requires robust control algorithms and appropriate tuning to prevent destabilizing oscillations.

Modelling and Simulation: Before deployment, VSGs are often modeled and simulated extensively to assess their stability performance under various operating conditions and scenarios. This helps identify potential issues and refine control strategies before real-world implementation.

Overall, stability in virtual synchronous generators is achieved through careful design, control, and coordination to emulate the behavior of traditional synchronous generators while leveraging the advantages of inverter-based technologies.

III. RESULTS

The above system was tested in two cases, in first case the load was added to the system suddenly at that time the inverter is operating without the VSG control is experiences some fluctuations in voltage, current and frequency. The frequency was distorted when the load was added to the system we can observe change in the frequency. And the changes in the active power and reactive power changes are observed in both the case. In second case the system was Simulated with VSG controller. When the VSG controller is used in the controlling of the inverter. Frequency was stabilized and active and reactive powers are changes linearly without any fluctuations.

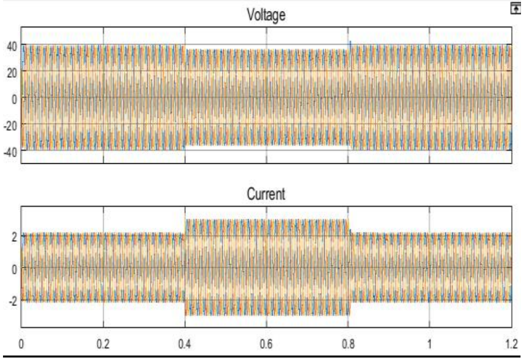

Fig 3. Load voltage and current without VSG

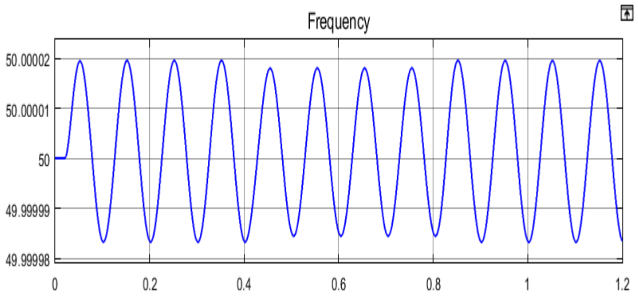

Fig 4. Frequency

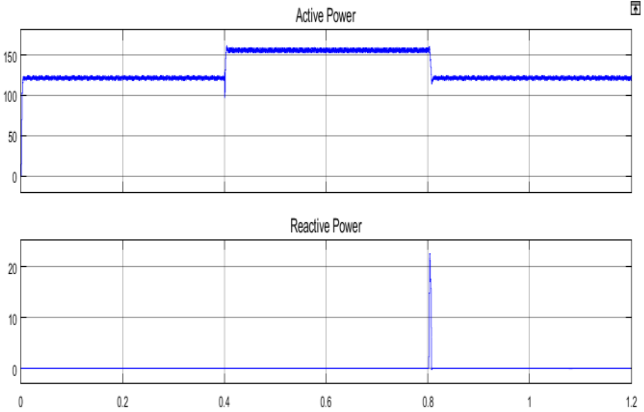

Fig 5. Active and Reactive Powers consumed by load

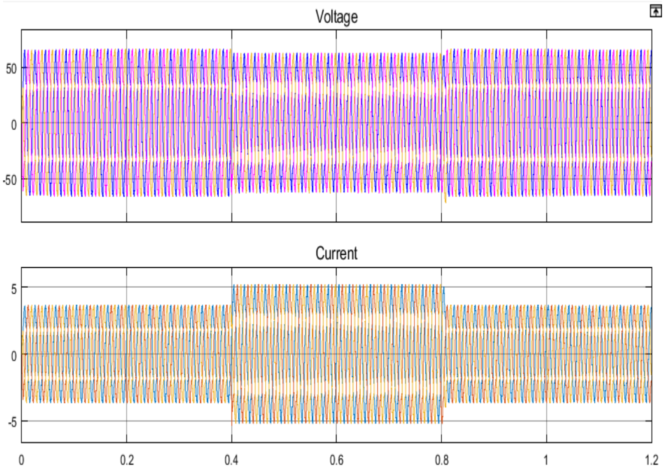

Fig 6. Load voltage and current

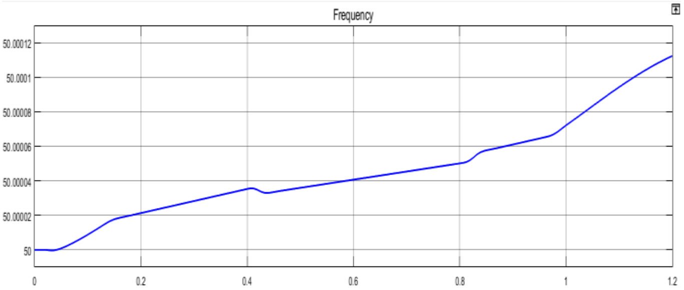

Fig 7. Frequency

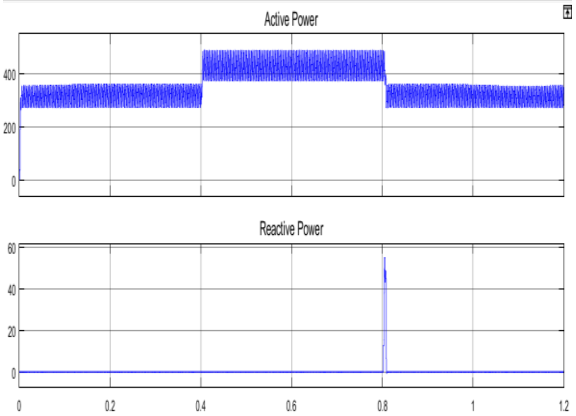

Fig 8. Active and Reactive Powers

From the above figures shows the results of the system in two conditions, from fig(3) to fig(5) those are the results for the case 1 in that figures you can observe that the load was added at a time of 0.4 sec to 0.8 sec. In that instant the frequency was dropped and fluctuations are formed in active and reactive power of the loads. Where as in second case the inverter is controlled by the VSG the figure from fig(6) to fig(8) these results shows the increased stability in frequency , active and reactive powers.

IV. CONCLUSIONS

The VSG control strategy has been introduced to improve the power output characteristic of the renewable energy. Considering the adjustability of VSG's virtual moment of inertia, we proposed a bang-bang control strategy for the VSG's virtual inertia-based method. When the VSG is on the receiving side, and the difference of the angular speed between the sending side and receiving side is positive, the inertia of the VSG is set to a larger value, otherwise, it is set to a smaller value. Under this control strategy, the TEF of the power system after disturbance will decay quickly, and the transient stability of the power system with high penetration PVs will be improved.

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