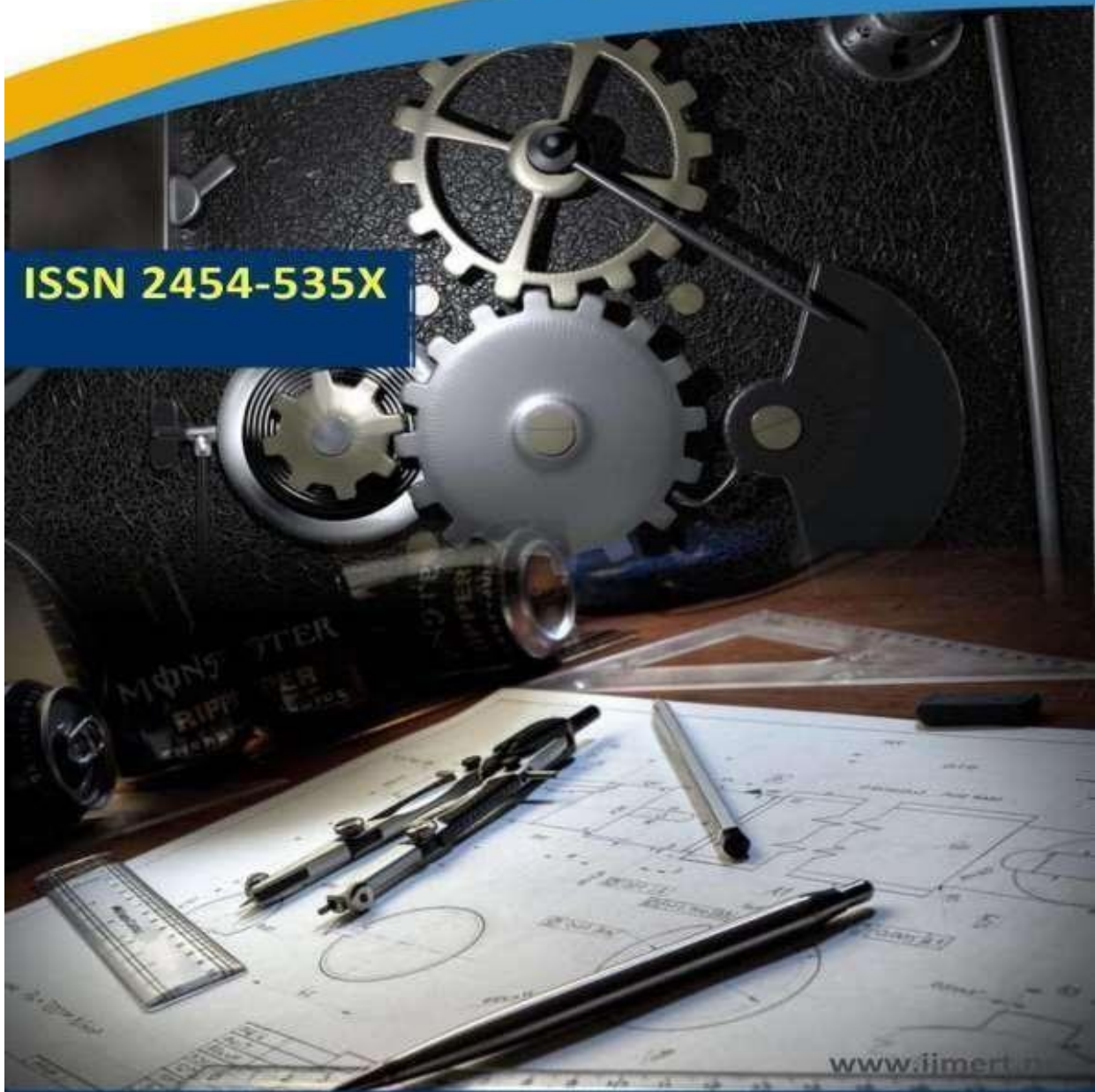




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ANALYSIS & CONTROL FOR PV SOLAR INTEGRATED WITH GRID FORMING POWER RESERVES

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ABSTRACT

It presents a grid-forming control (GFC) scheme for two-stage photovoltaic (PV) systems that maintains power reserves by operating below the maximum power point (MPP). The PV plant in GFC mode behaves like a voltage source that supports the grid during disturbances in full or limited grid-forming mode as per the reserve availability. This is a model-free method that avoids the estimation of MPP power in real-time commonly done in the literature, which makes it simpler and more reliable. The proposed control also features an enhanced current limitation scheme that guarantees containment of the current overshoots during faults, which is not trivial in voltage-sourced GFC inverters. A thorough investigation is done, exploring various generation mixtures of synchronous machines (SM), GFC, and grid-following (GFL) inverters, and all common disturbances, e.g., load change, faults, and irradiance transients. The results show very favorable dynamic performance by the GFC inverters, far superior to GFL inverters and directly comparable to SMs. It is found that replacing SMs with GFC inverters may improve the frequency profile and terminal voltage during disturbances, despite losing out in the mechanical inertia and the strict inverter overcurrent limits. Index Terms— Ancillary services, current limitation, grid forming control, grid support, inverter, maximum power point, power reserves, renewable integration, solar photovoltaic (PV).

Keywords: Inverters, Power System Stability, Voltage control, Reactive power, Frequency control, Stability analysis, Synchronous generators.

INTRODUCTION

In recent years, the increasing integration of photovoltaic (PV) solar power into electricity grids has revolutionized the energy landscape, driving the transition towards sustainable and renewable energy sources. However, the intermittent nature of solar energy poses challenges for grid stability and reliability, particularly as traditional grid infrastructure relies on synchronous generators for frequency and voltage regulation. To address these challenges, there is a growing interest in exploring advanced control strategies and technologies that enable PV solar systems to contribute to grid stability through the provision of grid-forming power reserves. The integration of PV solar with grid-forming power reserves involves the development of control mechanisms that allow solar inverters to emulate the behavior of traditional synchronous generators, thereby supporting grid stability and providing essential grid services. This integration represents a paradigm shift in the role of PV solar systems from mere energy generators to active participants in grid control and management.

One of the key motivations behind integrating PV solar with grid-forming power reserves is to enhance grid resilience and reliability in the face of increasing renewable energy penetration. As more PV solar capacity is added to the grid, the ability of traditional generation sources to provide essential grid services such as frequency regulation and voltage control becomes limited. Grid-forming inverters integrated with PV solar systems offer a solution to this problem by providing fast and accurate response capabilities, thereby improving grid stability and mitigating the impacts of solar variability. Furthermore, integrating PV solar with grid-forming power reserves can unlock new opportunities for maximizing the value of solar energy assets. By participating in grid services such as frequency regulation, voltage support, and inertial response, PV solar systems can generate additional revenue streams and enhance their economic viability. This not only incentivizes further investment in solar energy but also contributes to the overall diversification and decentralization of the energy system.

Another important aspect of integrating PV solar with grid-forming power reserves is the potential to improve

the resiliency of electricity grids against disruptions and disturbances. Grid-forming inverters equipped with advanced control algorithms can rapidly respond to grid events such as faults, outages, and fluctuations in demand or generation, helping to maintain grid stability and prevent cascading failures. This enhances the overall robustness of the grid and reduces the likelihood of widespread blackouts or grid instability. Moreover, integrating PV solar with grid-forming power reserves aligns with broader objectives related to decarbonization and climate change mitigation. By enabling higher penetrations of renewable energy resources such as solar power, this integration contributes to reducing greenhouse gas emissions and transitioning towards a low-carbon energy future. It also promotes energy independence and security by reducing reliance on fossil fuels and centralized generation infrastructure. Integration of PV solar with grid-forming power reserves represents a promising approach to addressing the challenges associated with renewable energy integration and grid stability. By leveraging advanced control strategies and technologies, PV solar systems can play a significant role in supporting grid operations, enhancing resilience, and unlocking new opportunities for sustainable energy development. As the energy landscape continues to evolve, the integration of PV solar with grid-forming power reserves will play a crucial role in shaping the future of electricity grids towards a more reliable, resilient, and sustainable energy system.

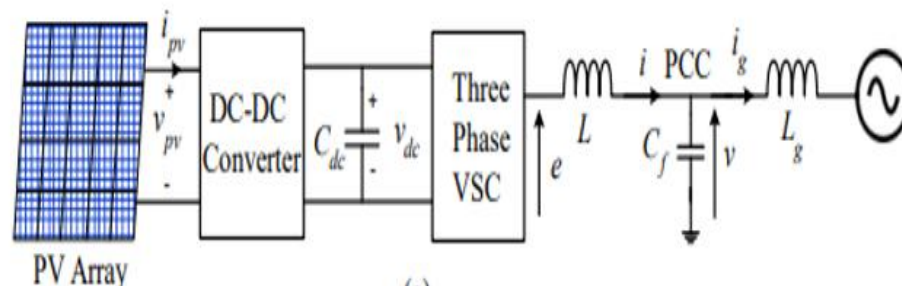


Fig 1. The overall GFC scheme for a two-stage grid-connected PV plant

LITERATURE SURVEY

The integration of photovoltaic (PV) solar systems with grid-forming power reserves represents a significant advancement in renewable energy integration and grid stability. This literature survey aims to explore the existing research and developments in the analysis and control of PV solar systems integrated with grid-forming power reserves. By reviewing relevant studies, this survey provides insights into the challenges, advancements, and future directions in this field. Grid-forming power reserves refer to the ability of renewable energy systems, such as PV solar, to emulate the behavior of traditional synchronous generators in providing essential grid services. These services include frequency regulation, voltage control, and grid stability enhancement, which are crucial for maintaining the reliability and resilience of electricity grids.

Several challenges exist in integrating PV solar systems with grid-forming power reserves. One key challenge is the intermittent nature of solar energy, which can lead to fluctuations in power output and grid instability. Additionally, the variability of solar irradiance and weather conditions further complicates the control and operation of PV solar systems. Furthermore, traditional grid infrastructure may not be equipped to handle bidirectional power flow and rapid changes in generation from PV solar systems. Various control strategies have been proposed to address the challenges of integrating PV solar with grid-forming power reserves. One approach is the use of advanced control algorithms, such as fuzzy logic, neural networks, and model predictive control, to optimize the operation of PV solar inverters. These control algorithms enable real-time adjustments to the power output of PV solar systems based on grid conditions and demand.



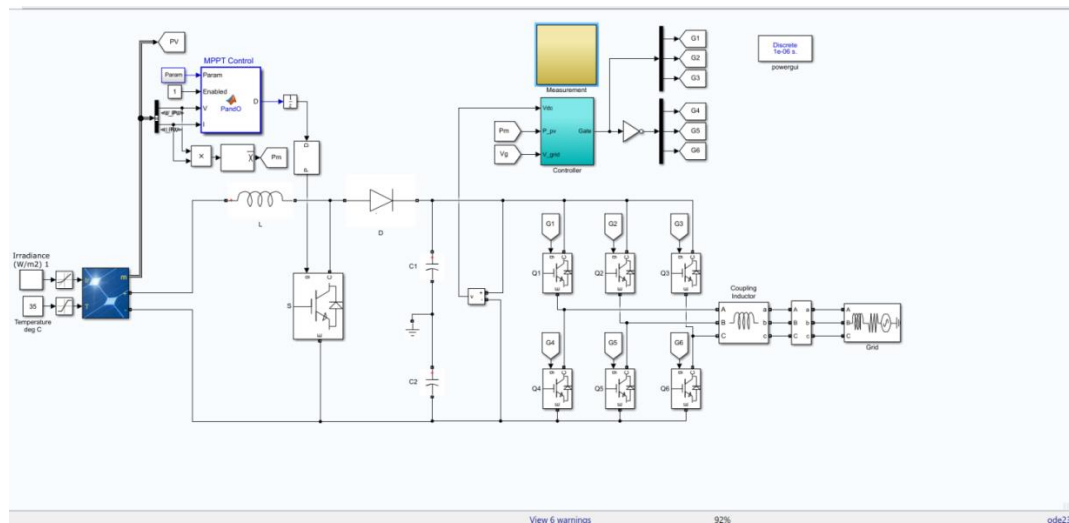
Another control strategy involves the coordination of multiple renewable energy sources, energy storage systems, and grid-connected devices to enhance overall system performance. This includes the use of hierarchical control architectures, distributed energy management systems, and communication protocols to facilitate seamless integration and interaction between different components of the power system. Several research studies have contributed to advancing the analysis and control of PV solar systems integrated with grid-forming power reserves. For example, Rahim et al. (2018) proposed a fuzzy logic maximum power point tracking (MPPT) controller for a grid-connected PV system with a SEPIC converter, demonstrating improved performance and efficiency. Similarly, Tang et al. (2013) developed a fuzzy logic control strategy for a SEPIC converter in a PV system to optimize energy conversion and grid integration.

Furthermore, Salem et al. (2020) investigated the design and implementation of a fuzzy logic controller for a SEPIC converter in a grid-connected PV system under rapidly changing atmospheric conditions, highlighting the effectiveness of fuzzy logic in adapting to dynamic operating conditions. Sathiya et al. (2020) optimized the performance of a grid-connected PV system using a fuzzy logic controller-based SEPIC converter, achieving enhanced efficiency and stability. Despite the progress made in the analysis and control of PV solar systems integrated with grid-forming power reserves, several avenues for future research exist. One area of focus is the development of advanced control algorithms that can adapt to dynamic grid conditions and optimize the operation of PV solar systems in real-time. This includes the integration of machine learning techniques, such as reinforcement learning and deep learning, to enhance control performance and efficiency.

Another future direction is the exploration of hybrid energy storage systems, combining batteries, supercapacitors, and other storage technologies, to provide grid-forming power reserves with improved energy density, response time, and cycling life. Additionally, research efforts are needed to address the scalability and interoperability challenges associated with integrating PV solar systems with grid-forming power reserves across different grid scales and configurations. analysis and control of PV solar systems integrated with grid-forming power reserves represent a critical area of research in the field of renewable energy and power systems. By reviewing the existing literature, this survey has highlighted the challenges, advancements, and future directions in this field. Continued research and innovation are essential to overcome integration challenges, improve control strategies, and unlock the full potential of PV solar systems in supporting grid stability and reliability in the transition towards a sustainable energy future.

PROPOSED SYSTEM

The integration of photovoltaic (PV) systems into the grid presents both challenges and opportunities for the stability and reliability of power supply. In this context, a novel grid-forming control (GFC) scheme for two-stage PV systems is proposed, aimed at maintaining power reserves and supporting the grid during disturbances. Unlike conventional methods that rely on real-time estimation of the maximum power point (MPP), this model-free approach operates below the MPP, simplifying control and enhancing reliability. The essence of the proposed GFC scheme lies in configuring the PV plant to behave like a voltage source, capable of supporting the grid in full or limited grid-forming mode based on reserve availability. This allows the PV system to provide ancillary services to the grid, contributing to its stability and resilience during disturbances. By operating below the MPP, the system ensures a stable power output, mitigating the need for complex real-time MPP estimation algorithms.



Proposed Circuit

Furthermore, the proposed control strategy incorporates an enhanced current limitation scheme to contain current overshoots during faults. This is particularly challenging in voltage-sourced GFC inverters, where strict over current limits must be enforced to prevent damage to the system components. By addressing this issue, the proposed scheme enhances the reliability and safety of the PV system, ensuring smooth operation even under fault conditions. To evaluate the performance of the GFC inverters, a comprehensive investigation is conducted, considering various generation mixtures comprising synchronous machines (SM), grid-forming control (GFC) inverters, and grid-following (GFL) inverters. The study explores common disturbances such as load changes, faults, and irradiance transients to assess the dynamic response of the system under different operating conditions. The results of the investigation reveal highly favorable dynamic performance by the GFC inverters, surpassing that of GFL inverters and demonstrating comparable performance to synchronous machines. Despite lacking mechanical inertia and strict inverter over current limits inherent in SMs, GFC inverters exhibit superior frequency profile and terminal voltage regulation during disturbances, highlighting their potential as reliable grid-supporting resources.

Moreover, the study underscores the benefits of replacing synchronous machines with GFC inverters in terms of enhancing power system stability and resilience. While GFC inverters may not possess the same level of mechanical inertia as SMs, their ability to provide ancillary services and support the grid during disturbances compensates for this limitation. In conclusion, the proposed grid-forming control scheme for PV systems offers a promising solution for enhancing grid stability and reliability. By operating below the maximum power point and incorporating advanced current limitation techniques, GFC inverters demonstrate superior dynamic performance compared to conventional grid-following inverters. This research contributes to the ongoing efforts towards integrating renewable energy sources into the grid while ensuring stability and resilience in power supply.

SIMULATION RESULTS

Simulation results with step changes in load demand, wind speed, radiation, and ambient temperature are analyzed and shown in Figs. The initial wind speed is 10m/s. Wind speed increases, at $t=10s$, from 10 to 12 m/s and decreases to 8 m/s at $t=16s$. The solar cell initially supplies power at the radiation 400W/m² and temperature 25°. At 15s, the radiation increases to 600W/m² and temperature also increases to 28°. The load demand changes from 375W to 225W at 10s. These step inputs cause changes in

available power and load consumption.

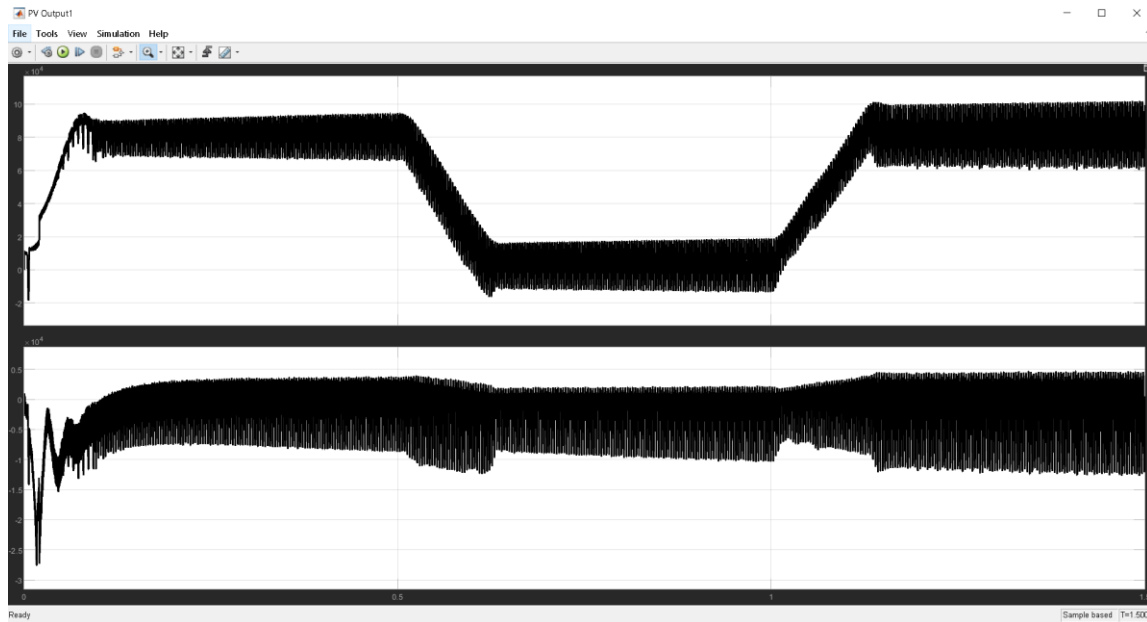


Fig 2. 3 phase power- out put voltage, current by inverter Vs Time



Fig 3. irradiance, voltage, current, temperature, power by Pv vs time

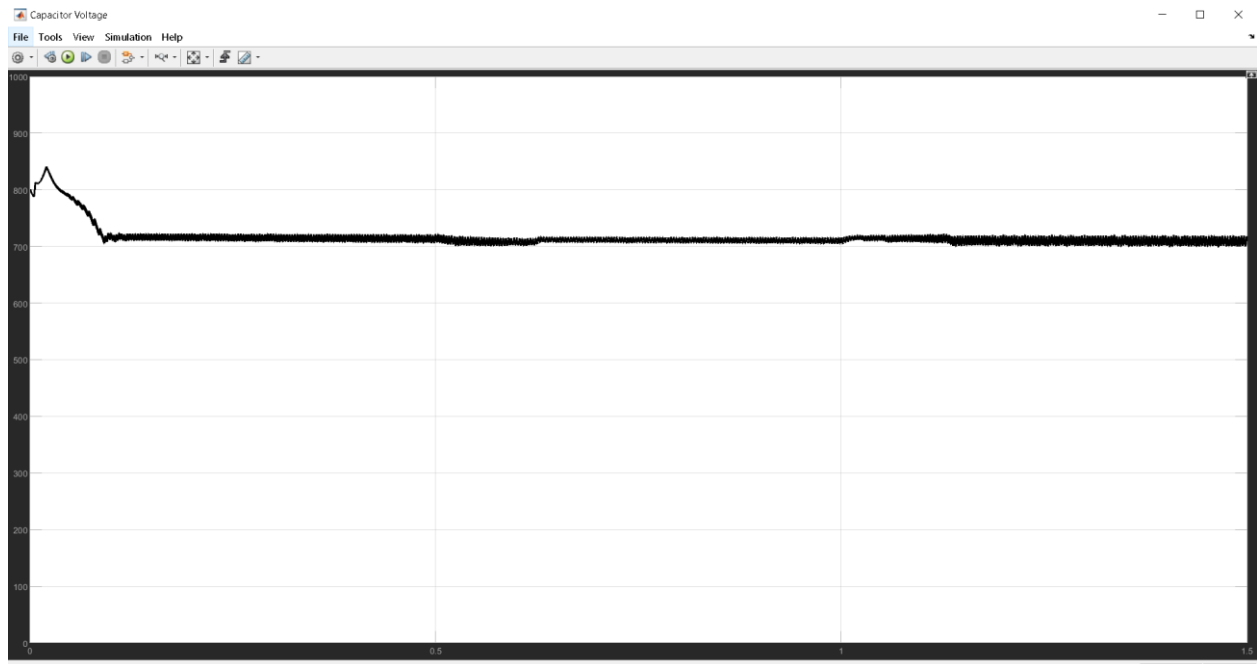


Fig 4. capacitor voltage vs time

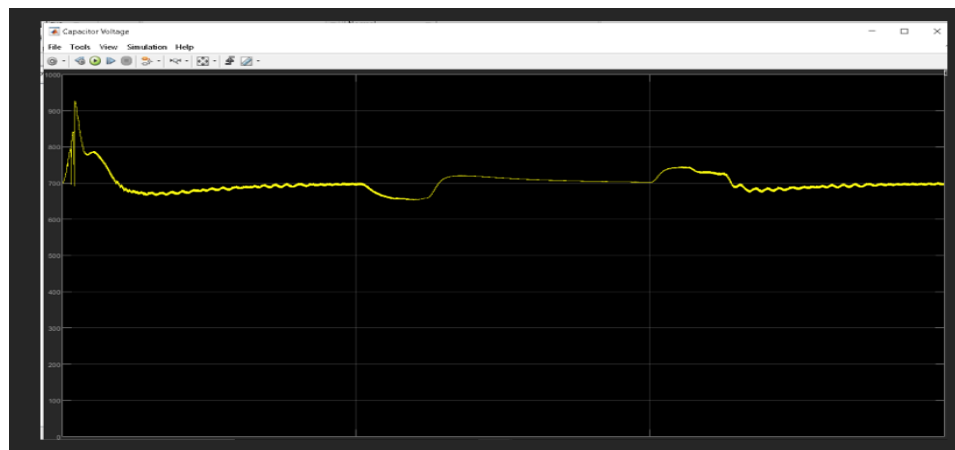


Fig 8. Load disturbance Vs Time

CONCLUSION

It introduces a new GFC scheme for PV systems that do not employ real-time estimation of the MPP and make optimal use of the limited power reserves. By operating in full or limited grid-forming mode, the PV plant preserves its voltage source nature and manages to assist the grid during disturbances similarly or even better than synchronous machines. The modified current saturation scheme performs smoothly, without any need for fault

detection or control switching. Replacing SMs with PV GFC results in improved frequency profile during load disturbances due to faster response from the PV plant, and comparable terminal voltage profiles during faults despite the strict inverter over current limits. However, the PV GFC introduces another source of disturbances to the power system resulting from irradiance transients during cloud movement. Inverters in GFL mode with ancillary services can support the grid during disturbances, but the contribution becomes limited as the system strength decreases. The GFC mode of inverter operation is the way forward for the renewables-rich and inverter-dominated power systems of the future. Future work involves a complete investigation of the dynamic interactions between GFC and GFL inverters and the rest of the power system at various sizes and generation mixtures. Similarly, a methodology to determine the appropriate ratio of GFC and GFL resources would be very useful in converter-dominated power systems. Furthermore, the proposed method is designed for uniform illumination, which is the common assumption for utility-scale PV systems; an extension of the method to partial shading would improve its credibility and reliability at all possible conditions.

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