ABSTRACT

Renewable energy is crucial in the generation of electrical power, constituting 22% of the global electricity generation. Solar power generation is a latent solution to the environmental problems being triggered by fossil fuels. Despite solar cells having an efficiency of approximately 22%, the incorporated converter dynamically reduces mismatch losses, optimizes the harvest of solar energy, and enhances the reliability of solar systems. As the demand for electricity rises, the distribution of power generation is shared among thermal power stations, nuclear energy, and other conventional sources. Yet, if there is any collapse in the above assets, it will result in the unsafe impacts to the atmospheric conditions. As conventional energy resources are facing recession and negative impacts, there is a need for alternate reliable energy resources. The world hunts for sustainable power source that it is accessible, and that turns out the focus on solar and wind. As is the situation with other forms of clean energy, solar power is widely utilized to fulfill the energy requirements of households.

Currently, solar energy stands as a potent renewable resource capable of meeting the energy needs for domestic applications. The Government of India also plans to rise the renewable energy generation to 300 GW by 2025 to partially meet the load demand increase in the country. The adoption of Solar PV systems remains restricted due to the necessity for power optimization. Microgrids based on solar photovoltaics (PV), known for their distributed and decentralized features, are attracting significant interest for their ability to improve energy accessibility, reliability, and

sustainability. However, the intermittent and fluctuating nature of solar energy generation poses significant challenges to the stability and voltage regulation of microgrids. The proposed controllers sets the foundation for the subsequent discussions on control methodologies and their application in Solar PV based DC micro-grid scenarios.

The main objective is to design and assess innovative control methods that can effectively improve voltage regulation, enhance stability, and ultimately contribute to the efficient and reliable integration of solar energy into micro-grid systems, supporting the global transition towards clean and sustainable energy solutions.As compared to all conventional methods it is noted that the Model Reference Adaptive Control (MRAC) technique and model-free deep Q-learning controller is not attempted in the control schemes of Solar PV based DC micro-grid system. Hence, the use of MRAC controller and model-free deep Q-learning controller is recognized and adopted to control Solar PV based DC micro-grid system to improve the voltage regulation and thereby to enhance the stability and power management of the DC micro-grid system. In this context, the research work titled "Investigations on Control Strategies for DC Bus Voltage Regulation and Stability Enhancement of Solar PV-Based DC Microgrid" is aimed at addressing these crucial issues and advancing the performance of DC microgrids.

There are four parts of contributions constituted in the thesis. The first part concentrates on an in-depth analysis for designing an Model Reference Adaptive Controller(MRAC) and a model-free deep Q-learning (DQL) controller. This is aimed at optimizing the efficiency, reliability, and sustainability of a solar PV with a battery-based islanded DC microgrid system. Employing both MRAC and DQL controllers showcases sophisticated control strategies to manage voltage stability and adapt to load/source fluctuations in solar PV-based DC microgrid systems. This dual-controller approach illustrates a holistic method for addressing intricate control challenges during DC microgrid operation.An essential component of DC microgrid functioning, the DC bus voltage is the primary target of MRAC control strategy development. In order to maintain the bus voltage within predetermined limits, the MRAC controller offers an adaptive and methodical solution. The distributed generation with DC micro-grid system's adaptability to changing situations of operation is demonstrated by the use of the MRAC controller.MRAC allows the DC micro-grid to adjust its control parameters in real-time, making it well-suited for scenarios with varying power generation and load profiles, which are common in renewable energy systems. The implementation of a DQL model-free controller showcases the potential of reinforcement learning in DC micro-grid control. DQL allows the DC micro-grid to learn optimal control policies without relying on a predefined model of the system, making it versatile and suitable for dynamic and uncertain environments. The research substantiates its findings through rigorous MATLAB simulations. Simulation-based validation is crucial for evaluating the practical feasibility and efficacy of the suggested control strategies. It provides a basis for confidence in the controllers' performance before potential real-world implementation.

In the second part of the thesis, the focus is on developing a charge controller for a DC microgrid that is powered by solar PV. To handle the Power Management System, a Controller with Fuzzy Logic (FL) is utilized. The system aims to achieve fair power distribution in response to fluctuating load demands. This FLC is valuable for enhancing the efficiency, reliability, and sustainability of micro-grid operations and represents a step forward in harnessing renewable energy for distributed power generation and distribution. One of the most important contributions that this study has led to the creation of a system for power management that distributes the electricity generated by solar photovoltaic panels in the most efficient manner desirable among the various loads. Achieving equal power sharing based on load demands is a challenging task, especially in DC micro-grids with dynamic loads. This research work addresses this challenge by designing a charge controller using FLC that ensures fair and efficient distribution of power. The power management system design and performance are rigorously validated through MATLAB simulations. The results of this validation give an understanding of the system's behavior under different circumstances and loads, making it vital.It allows for the assessment of system robustness and reliability.

The third part of the thesis emphasizes an innovative approach that simulates the stabilizing impact of conventional rotating inertia in DC microgrid systems through Virtual Inertia Control (VIC). By presenting and implementing VIC approaches, the research work proposed in this part makes a substantial contribution by improving the dynamic performance of a DC microgrid that uses solar (PV) technology. By addressing important issues including power oscillations and low inertia, these contributions make DC microgrid operations more stable, reliable, and sustainable. This initiative also supports the seamless integration of renewable energy into future energy systems. By applying VIC, the research significantly enhances the stability of the DC micro-grid. It mitigates power fluctuations and oscillations that can result from the intermittent nature of solar PV generation, thus improving the DC micro-grids overall performance and reliability. Addressing power oscillations and low inertia issues contributes to improved power quality within the DC micro-grid. This has a positive impact on the reliability of the DC micro-grid, making it suitable for a broader range of applications, including critical loads and sensitive equipment. It also enhances the microgrid's resilience, ensuring it can withstand and recover from disturbances effectively. The virtual inertia control techniques and their impact on dynamic performance are rigorously validated through MATLAB simulations.

The final part of the thesis focuses on the development of a real-time prototype that aligns with practical applications of DC micro-grid technology. It can serve as a model for real-world DC micro-grid implementations, especially in off-grid or remote areas where reliable power supply is essential. Creation of physical prototype demonstrates a practical approach to DC micro-grid design and allows for the validation of theoretical concepts in a real-world setting. Experiments with different levels of solar irradiation and load circumstances are carried out as part of this research in order to empirically evaluate the efficiency of the suggested solutions for voltage control and power management efficiency. For the purpose of gaining important insights into the functioning of the system under dynamic operating settings, real-world studies are conducted.By assessing the isolated Direct Current micro-grid response to changes in load demand and the ability to maintain voltage stability under load changes is crucial for ensuring continuous power supply to connected loads.