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Investigation of Power Quality Issues in Renewable Energy Systems and Mitigation Techniques

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Abstract

The movement to integrate small renewable distributed generation (DG) units into our existing power infrastructure is being propelled by several significant factors: Fast industrialization's increased demand for energy, worries about the effects of fossil fuel-based generation on the environment, the depletion of fossil energy resources, transmission network congestion, and declining technical performance. Whether it incorporates fossil or renewable energy sources, distribution network operators (DNOs) are aware of the problem of optimizing the technical benefits of DG installation. However, there are unique power quality (PQ) issues with renewable DG systems. This is especially crucial since nonlinear loads and renewable energy are become more common in distribution networks, and loads nowadays are more susceptible to PQ disruptions. Keeping power quality stable in these networks is becoming tougher, especially with the growing use of power electronics converters across residential, commercial, and industrial sectors. When power quality deteriorates, it can lead to higher losses, inefficient use of distribution systems, malfunctioning of sensitive equipment, and disturbances affecting nearby consumers, protective devices, and communication systems. Yet, as we strive for energy savings, which will lead to more AC power being processed through these converters, there's a pressing need to better understand the techniques for mitigating power quality issues.

Keywords: Power Quality, Distribution Network Operators, Renewable Distributed Generation.

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Introduction

"Power Quality" is all about how well an electrical system can deliver a flawless power supply, characterized by a clean, noise-free sinusoidal wave shape, and maintaining stability in terms of voltage and frequency. However, in practice, a lot of loads usually cause the system to malfunction, which results in departures from this optimal power source. EPRI carried out a study in the US from 1992 to 1997 that looked at the typical length of these disruptions. However, these methods are facing significant challenges, such as dwindling fossil fuel supplies, excessive emissions, and power losses from long transmission lines (Kumar et al., 2016).

Voltage stability is the main problem with power quality and requires careful control. This regulation is significantly influenced by the degree of reactive power balancing and the time constant of the excitation system. Harmonic values have a minor detrimental effect, according to a case study using a wind farm with twelve turbines. It is evident from the normal distribution of power quality disturbances by time that shorter disturbances are significantly more common than longer ones (Chawda et al., 2020). IEEE and IEC standards, among others, have been developed to specify Power Quality in order to address these problems. When renewable energy sources like solar and wind are added to the mix, distributed generation (DG), especially with the help of microgrids, can pave the way for cleaner and more efficient power generation and transmission. Electric power system operators commonly use specialized power equipment and reserve a portion of their generation capacity called Spinning Reserve (SR) in order to guarantee power quality (Almohaimeed & Abdel-Akher, 2020).

Literature Review

With the introduction of additional wind farms and solar power systems to guarantee sustainable and green energy, the integration of renewable power into electric power systems is growing daily worldwide (Sun, 2012). Wind variation causes fluctuations in the wind farm's total electricity output. In a similar vein, changes in incident lumens also affect a solar power plant's production. In the majority of locations where renewable electricity penetration is substantial, the current transmission and distribution networks are inadequate. Power quality has deteriorated as a result of the integration of renewable energy at these grid weak spots. Battery energy storage supplementation is one of the practical solutions to address power fluctuations and power quality problems that arise from the integration of renewable electricity into the power system (Tareen et al., 2018). In addition to the specific uses listed above, battery energy storage systems can be used to store renewable energy during periods of low demand and release it during periods of high demand. They can also support active and reactive power when coupled with a power conditioning system that can function at its terminals in all four quadrants.

Methodology

For power system applications, a brand-new generic modeling technique for battery energy storage systems is suggested. The suggested generic modeling approach as applied to vanadium redox batteries is discussed together with the different battery energy storage modeling approaches. The model created using the generic battery modeling approach makes the battery potential a function of the battery's thermodynamics (Singh et al., 2015). During simulation, the enthalpy and entropy blocks of the battery model use the thermodynamic data, which is kept in a look-up table. In order to demonstrate how battery thermodynamics affects its electrical properties, these thermodynamic data are purposefully changed, and the simulation results are displayed to show the proportion of boost and dip in battery voltage during charge and discharge. A wind farm connected to a radial power grid uses this paradigm. The model's performance is analyzed in terms of voltage and power balancing, harmonic distortion, and changing wind speed, battery thermodynamics, and grid conditions. To investigate the power quality problems that arise from wind farm integration into the grid, both with and without battery energy storage, a prototype model is created (Bajaj & Singh, 2020).

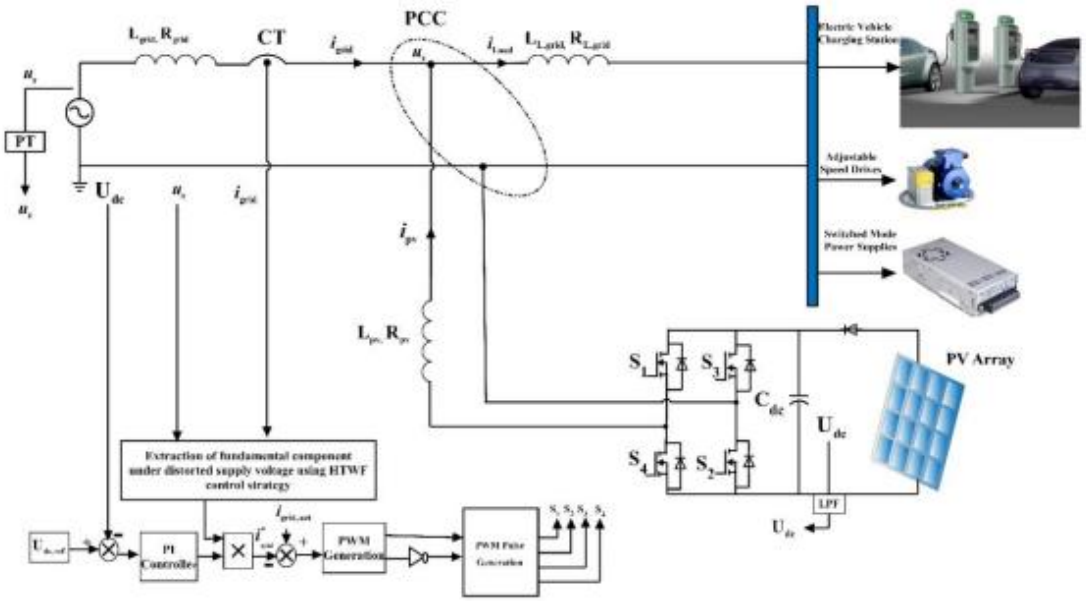


Fig. 1: Block diagram of single-phase grid-tied PV system.

Results and Discussion

Additionally, in the fourth stage of development, HPF technology is being assessed as a unified power quality conditioner (UPQC).

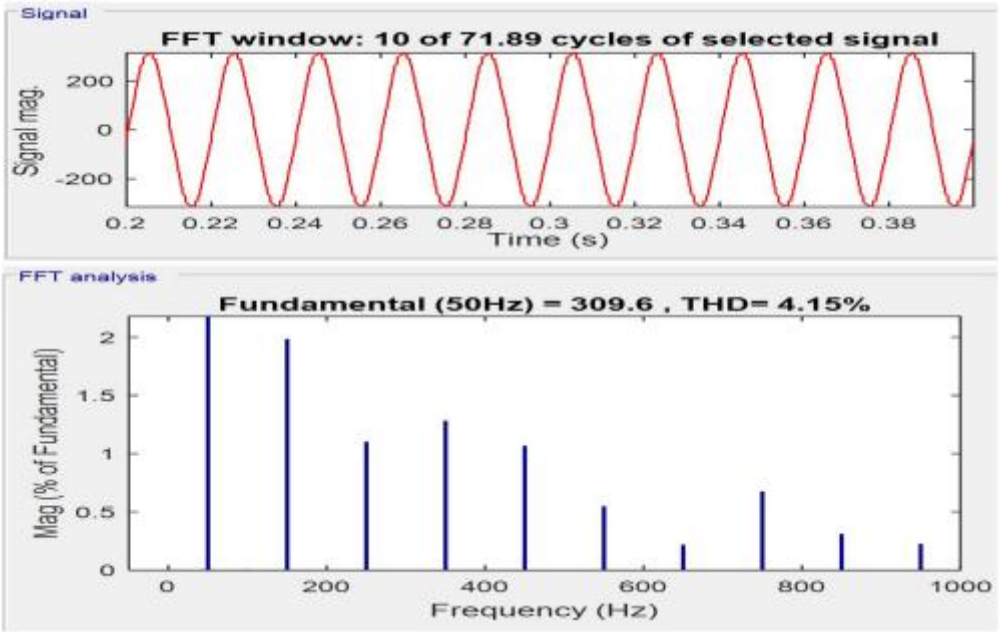


Fig. 2: Output Voltage waveform and its harmonic spectrum with R-L load.

Previous studies aimed at enhancing power quality have led to notable advancements in FACTS devices, such the distribution STATCOM (DSTATCOM), dynamic voltage restorer (DVR), and static volt-ampere reactive (VAR) compensator (SVC). These developments aid in resolving a number of power quality concerns, such as DC offset in loads, imbalanced load circumstances, load harmonics, and low load power factor.

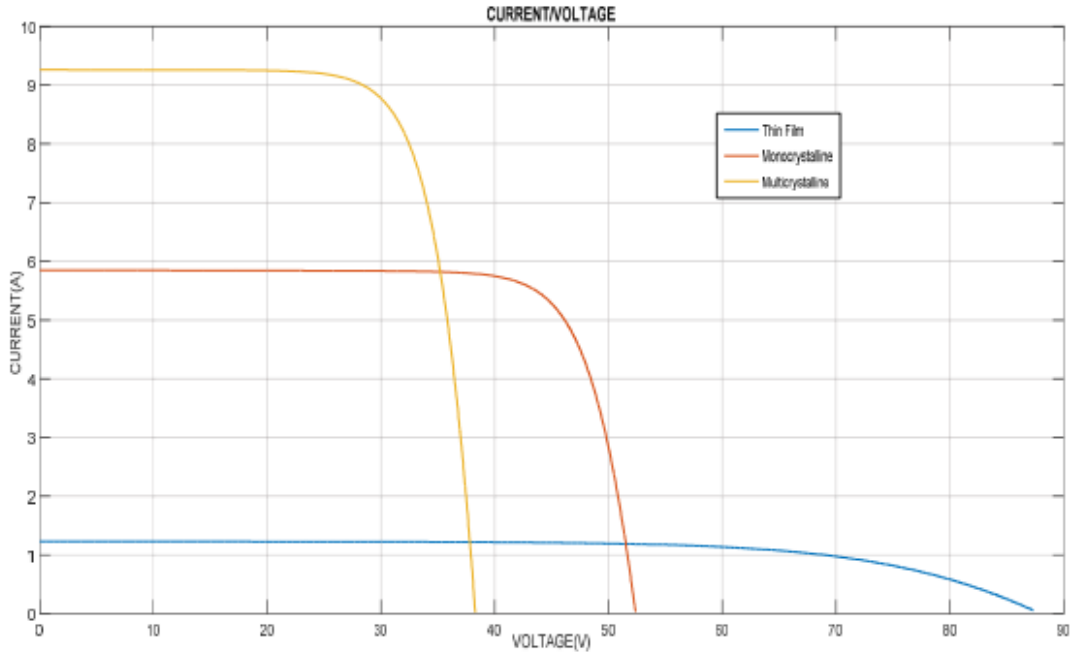


Fig. 3: I-V charactersistics

The rise of renewable energy outpaced the growth of global energy demand from 2019 to 2020. However, in 2022, we saw a significant surge in demand, driven by factors like population growth, improved living standards, and advancements in infrastructure. Countries like India and those in Southeast Asia are expected to see their energy consumption jump to 11% by 2040, further boosting global energy demand (Hossain et al., 2018). To meet this growing need, our electrical energy distribution systems will need to evolve, adapting to the future electrical grid that incorporates digital technologies, renewable energy sources (RESs), and a smart grid for distributed generation (DG).

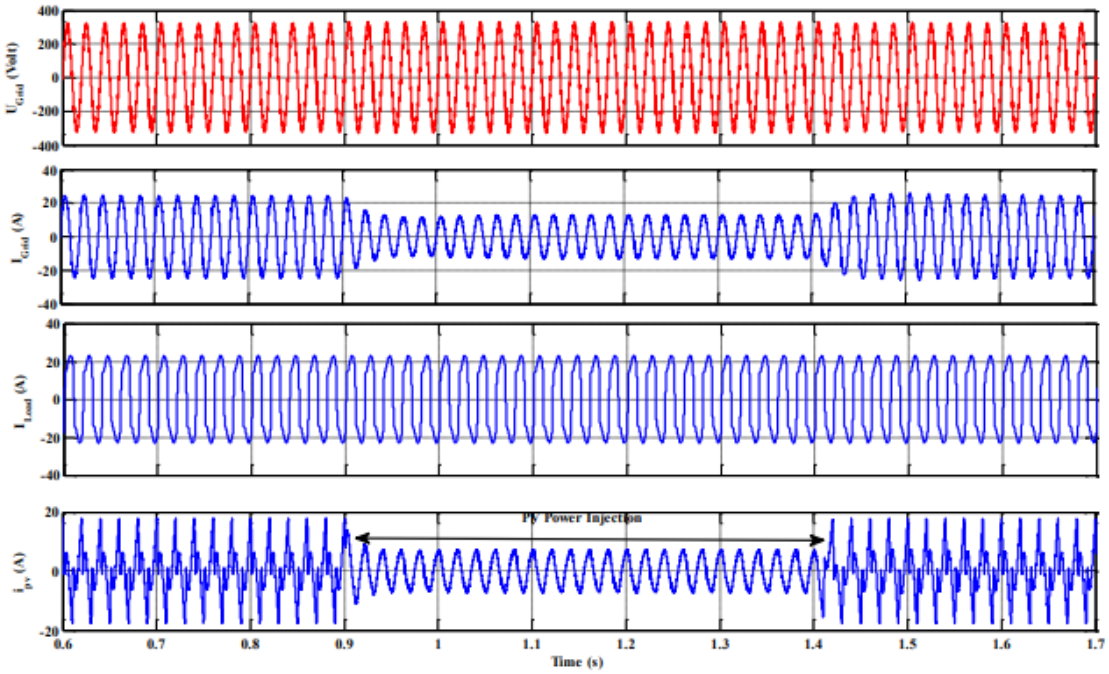


Fig. 4: Multifunctional operation of grid tied PV system

Renewable energy sources (RESs) have been very popular in recent years, particularly since they present an attractive option for utility grid integration. Electricity is a key indicator of a comfortable life, and the need for this vital energy source is only increasing. As power industries evolve, both linear and nonlinear loads within each system are growing. When working with nonlinear loads, a lot of solid-state switching converters remove reactive power and current harmonics from the AC grid. These nonlinear loads might cause harmonics that could disrupt the system and have an immediate impact on our daily operations. A reliable power supply is necessary for all modern equipment, including high-voltage systems, computer power supplies, communication systems, furnaces, renewable energy sources, and electrical power generation.

Conclusion

Now, more than ever, modern electronic gadgets, computing devices, microprocessor-based controls, energy efficient devices and drives are used in all types of industrial, commercial and domestic applications. This has been pivotal in making these applications more effective, easier, efficient and safer. However, this trend distorts the supply voltage and current from its pure sinusoidal nature and arises power quality problems. Power quality is associated with fluctuations in the power supply in the form of momentary interruptions, voltage sags, voltage swells, transients, harmonic distortion, electrical noise, power factor issues, overheating and flickering lights. The electrical power grid is designed for delivering power reliably, namely maximizing power availability to customers. However, power quality events become much concern for electrical energy producers and distributers.

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