Improvement of Power Quality in Distribution System Using PV Integrated UPQC

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ABSTRACT- **The presented work proposes a methodology for the automated transition of a solar PV array integrated unified power quality conditioner (PV-UPQC) between standalone and grid-connected modes of operation. The system consists of a shunt and series active filters connected back-to-back with a common DC link, addressing the challenge of integrating power quality improvement with clean energy generation. The automated transition ensures continuous power supply to critical loads, even during grid unavailability. Key innovations include implementing this automated transition in the PV-UPQC system with minimal disturbance to local loads. The system's performance is validated through experimental evaluation under various dynamic conditions, such as automated transition, supply voltage variations, grid unavailability, changes in solar power generation, and load variations - scenarios commonly encountered in modern distribution networks. The results are verified using MATLAB/Simulink simulations.**

Index Terms—**Power Quality, shunt compensator, series compensator, UPQC, Solar PV, MPPT.**

1. INTRODUCTION

The widespread adoption of clean energy systems based on solar and wind power has introduced new challenges in modern distribution systems. The intermittent nature of these renewable sources has led to increased voltage fluctuations, particularly in low-voltage distribution networks [1].

Concurrently, advancements in semiconductor technology have enabled the proliferation of sophisticated power electronic systems, such as computer power supplies, switched-mode power supplies, variable frequency drives, and servers. These energy-efficient systems draw highly nonlinear currents from the supply, causing increased losses in distribution transformers and distorting voltages at the point of common coupling [2], [3].

This growing complexity has also made distribution systems more sensitive to voltage disturbances. To address these power quality issues while supporting the integration of clean energy, future systems will require active filtering solutions. By mitigating the effects of nonlinear loads and intermittent renewable generation, active filtering can improve power quality in distribution networks and reduce reliance on fossil fuels, leading to a cleaner environment [4].Renewable energy integration with flexible AC transmission systems (FACTS) devices, such as the unified power flow controller (UPFC), has been discussed in previous literature [5], [6]. These FACTS devices are primarily used to improve the stability of power systems when integrating large-scale photovoltaic (PV) farms. Typically, FACTS devices like the UPFC are employed in transmission systems, where the shunt compensator is connected to the primary feeder and the series compensator is connected to the secondary feeder. However, the existing literature has mainly provided simulation results regarding the operation of FACTS devices with renewable energy systems.

In contrast, renewable energy integration with active power filters is more commonly used in distribution systems, where load current compensation is a major requirement. The proposed system compensates for load current harmonics, protects sensitive loads from voltage sags/swells, and injects active power from the PV array. While the structure of an active power filter is similar to FACTS devices, the shunt compensator of the active filter is connected at the load side to mitigate load current quality issues, while the series active filter is connected at the supply side. This structure has the benefit of a lower rating for the series active filter, as the current flowing through it is balanced and sinusoidal.

Previous research has focused on the integration of power quality with shunt-connected renewable energy systems [7]. However, these shunt-connected topologies cannot simultaneously regulate voltage at the load side and maintain grid current at unity power, as voltage regulation by the shunt compensator requires reactive power [8]. Moreover, the voltage compensation capability of the shunt compensator depends on the impedance of the supply system, which directly affects the rating of the shunt compensator.

To address these limitations, the universal active power filter (UPQC) has both shunt and series filters, which can protect sensitive nonlinear loads against voltage sags/swells at the point of common coupling (PCC) while also improving grid current quality. Due to the increased sags/swells in PCC voltages caused by the large-scale integration of intermittent renewable energy sources, there has been increased research on renewable energy systems integrated with universal active power filters [9]. The solar PV-integrated UPQC (PV-UPQC) provides a complete solution for integrating clean energy sources while improving the power quality of distribution systems [10]. Although the PV-UPQC incurs additional costs due to the extra series converter, this cost is justified in systems with highly sensitive loads, such as those found in semiconductor industries, PLCs, and adjustable speed drives, where any loss of production due to power quality issues can lead to significant economic losses.

This work proposes an adaptive filter-based technique for controlling a three-phase, three-wire PV-integrated UPQC (Unified Active Power Filter) system. The adaptive filter used is a fourth-order quadrature signal generator [22]. Two adaptive filters estimate the fundamental positive-sequence components of the distorted load currents. These positive-sequence components are then used to determine the reference signal for the UPQC system's shunt active filter.

The proposed method reduces computational burden and provides good dynamic response. The series active filter of the PV-UPQC is controlled using a synchronous reference frame theory-based technique to compensate for voltage sags/swells at the PCC. A maximum power point tracking (MPPT) algorithm is used to operate the PV array at its peak power point [23]. Since this is a single-stage system, the MPPT algorithm generates the reference DC-link voltage.

The key advantages of the system are:

- Provides clean, pollution-free energy from solar PV power, along with power quality improvement.
- The PV array's power supply reduces the active power demand from the grid.
- The adaptive filter-based sampling of positive-sequence currents, synchronized with the load voltage zero-crossing, enables estimation of the active component magnitude in all phases with a single-sampling.
- The system protects sensitive loads from PCC voltage sags/swells while maintaining grid current within IEEE 519 standards.
- The system performance is robust under various load disturbances, PCC voltage sags/swells, and changes in solar irradiation.

The performance of the PV-UPQC system is evaluated under both steady-state and dynamic conditions using a simulated environment. The steady-state performance is verified to ensure compliance with the IEEE-519 standard. The dynamic performance is evaluated under conditions such as PCC voltage sag/swell, load disturbances, and changes in solar irradiation.

II. SYSTEM CONFIGURATION

Fig.2.1 shows the configuration of a PV-UPQC system. This is at three phase system consisting of a shunt active filter and series active filter with a common DC-bus. The shunt active filter is interfaced near the nonlinear load whereas the series active is interfaced in series with the PCC. Other major components of the system include interfacing inductors, ripple filters and injection transformers. The PV array is coupled directly to the DC-bus of PV-UPQC system. A diode is used while integrating the PV array with PV-UPQC to prevent reverse power flow into PV array. The detailed design methodology of PV-UPQC is given in [2].

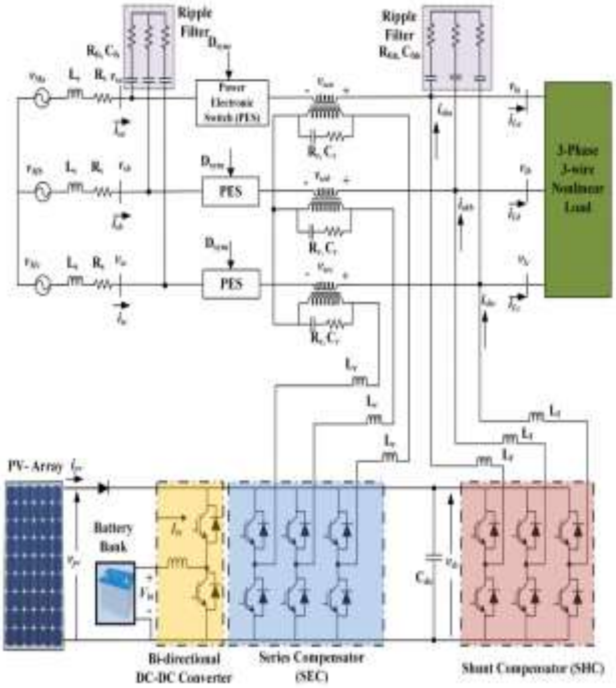


Fig.2.1. System Configuration of Solar Photovoltaic Integrated UPQC

The phasor representation of operation of PV-UPQC is given in Fig2.2. The signals under nominal condition have subscript'1' while signals under PCC voltage sag condition are represented with subscript '2' .The load voltage (VL1) and PCC voltage (Vs1) are equal under nominal conditions. The load current (IL1) lags behind VL1 with a phase angle φ. During sag condition, the series active filter injects a voltage (VSE)in phase with the PCC voltage (Vs2) to maintain load voltage(VL2) in same magnitude and phase as that of nominal PCC voltage (Vs1). The shunt active filter current (ISH1, ISH2) is combination of load reactive power and current corresponding to PV array power injection (Ipvg1, Ipvg1). The PV power generation is more than the load active power demand, and consequently the excess power is fed into the grid.

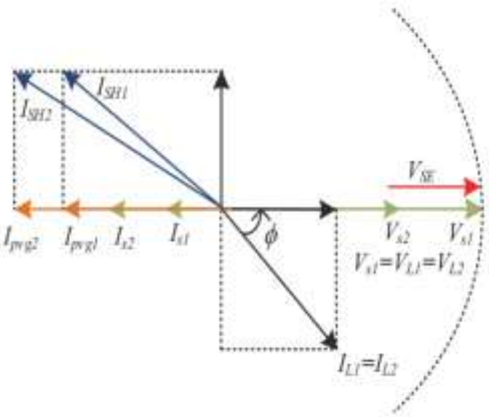


Fig.2.2. Phasor Representation of PV-UPQC system operating with a linear load

2.1 Shunt Active Filter:

The PV array is designed such that the maximum power point of the PV array is also the operating DC-link voltage of the PV-UAPF system. In this work, a perturb and observe (P&O) based MPPT controller is used due to its simplicity and ease of implementation. The perturb and observe algorithm is a hill-climbing search technique where the reference voltage is updated based on the difference in power between the present and past sampling instants. The P&O algorithm searches for the peak of the P-V curve by checking the slope on the P-V curve, dPpv/dVpv. The operating voltage of the PV array, Vpv, is perturbed with a small step change depending on the sign of the slope.

Two important parameters in MPPT operation are the MPPT sampling time (Tm) and the perturbation step size (δVpv). A smaller step size results in smaller oscillation around the MPP point, but it also results in a poorer dynamic response. Similarly, a larger sampling time enables the algorithm to track the MPP without getting disturbed by noise, but it also results in a poorer dynamic response.

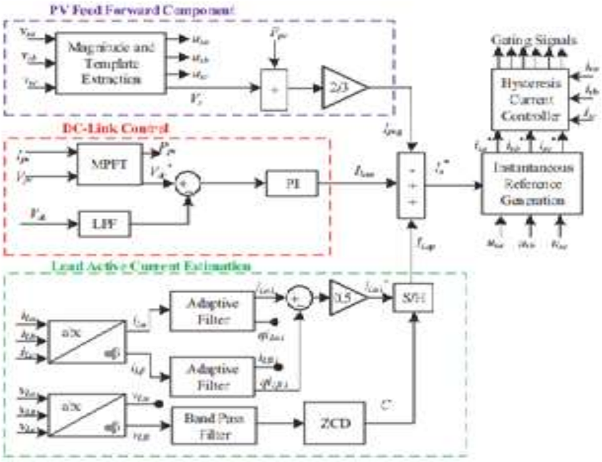


Fig. 2..3. Adaptive Filter Based Control of Shunt Active filter

A hysteresis current controller, after comparing reference signals with the sensed signals, generates appropriate pulses for the gating circuitry of shunt active filter.

2.2 Control of Series Active Filter:

Figure 2.4 shows the control block diagram for the series active filter. The PCC voltages (vsa, vsb, vsc) and load voltages (vLa, vLb, vLc) are converted to the d-q domain using the phase information of the PCC voltages. Since the series active filter injects voltages in-phase with the PCC voltages, the load voltages are also in-phase. Consequently, the direct component of the reference load voltage (VLd) equals the magnitude of the reference load voltage, while the quadrature component (VLq) is zero.

The direct component of the reference series active filter voltage is then obtained by subtracting the direct component of the PCC voltage (Vsd) from the direct component of the reference load voltage (VLd). A similar operation is performed to calculate the quadrature component of the series active filter voltage.

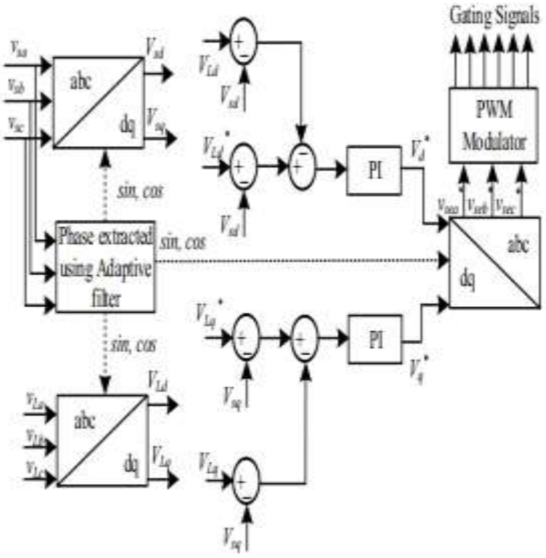


Fig.2.4. Control Configuration of Series Active Filter

III.MATLAB DESIGN:

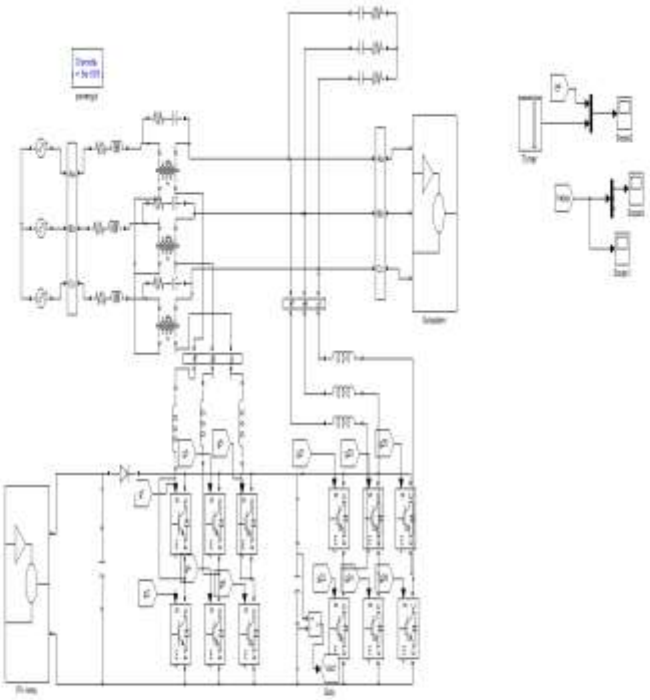


Fig 3.1 Simulation Block diagram

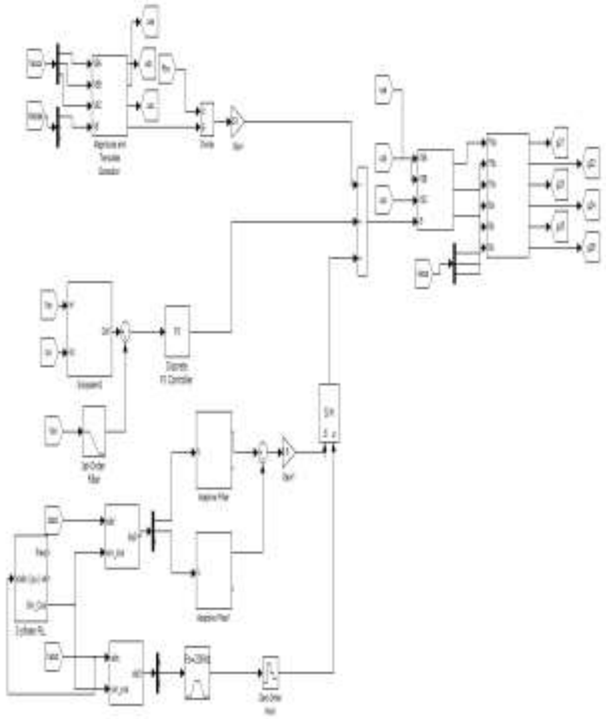


Fig 3.2 Simulation control diagram for Shunt active filter

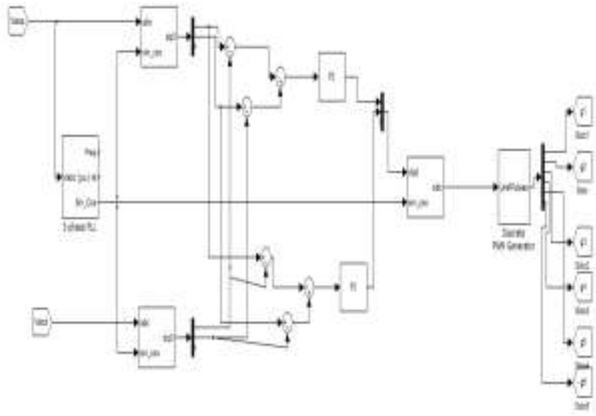
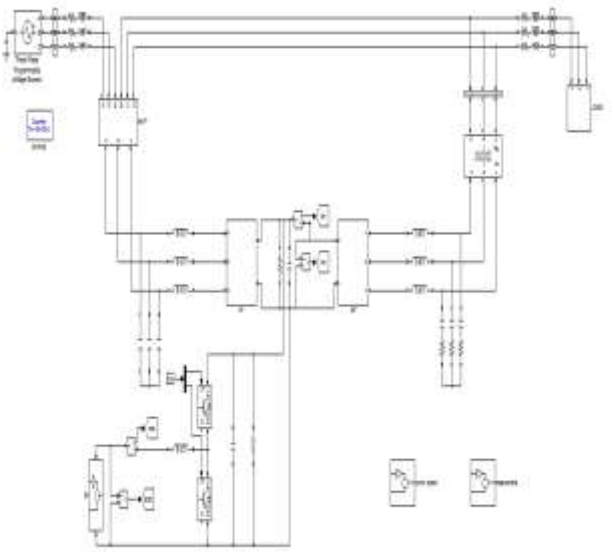
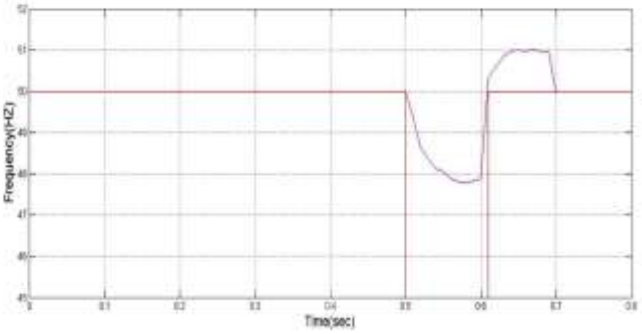


Fig 3.3 Simulation control diagram for Series active filter



Simulation Block diagram

1V SIMULATION RESULTS:



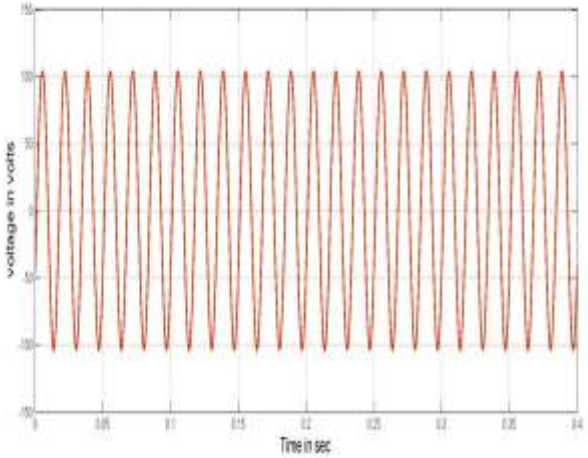


Fig.3.4. Frequency Tracking Response of the System. The frequency tracking capability of the adaptive filter is shown in Fig. The signal frequency changes from 50Hz to 48Hz and back to 50Hz. The adaptive filter is able to track the step change in frequency within 0.1s.

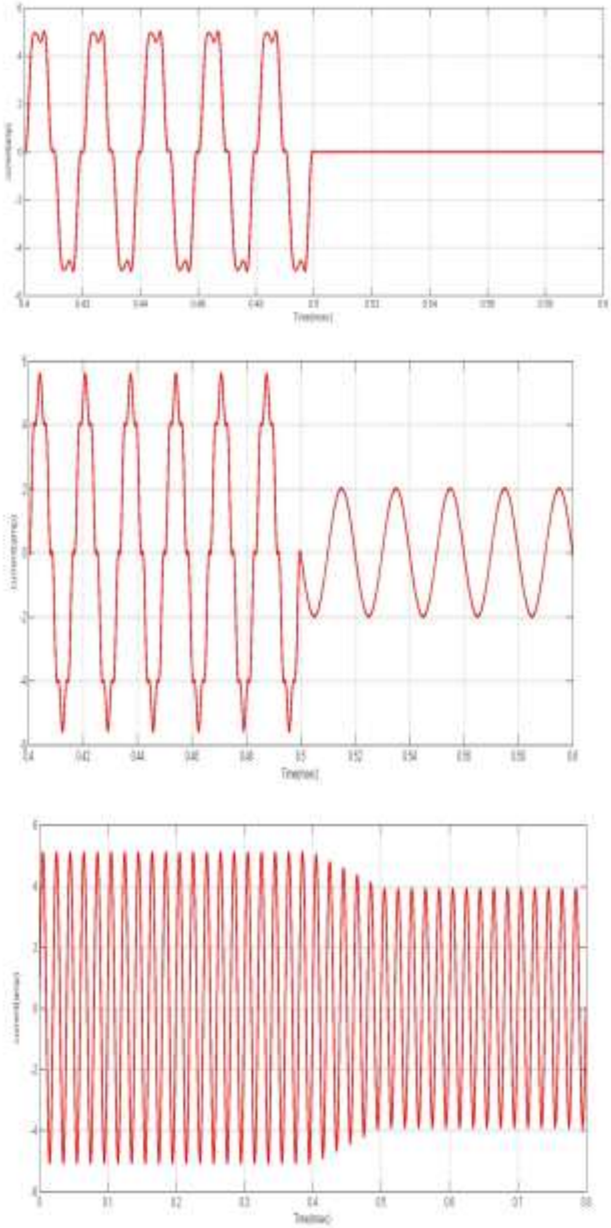
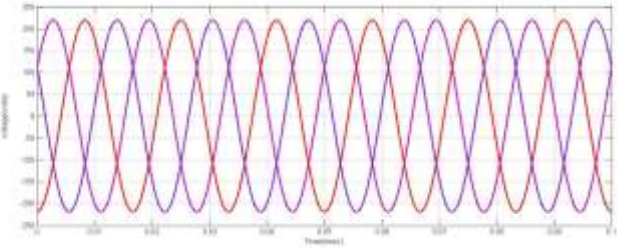


Fig. 3.5 Salient Signals in Extraction of Fundamental Positive Sequence Load Current



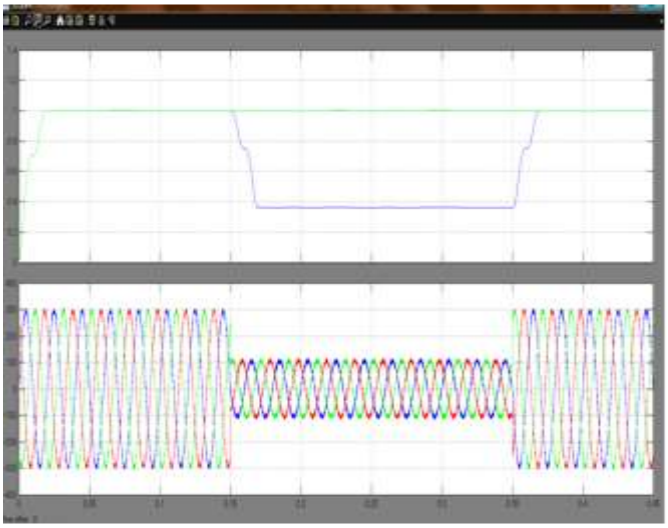


Fig3.6 Source And Load RMS Voltages and Source Voltages During Sag Condition:

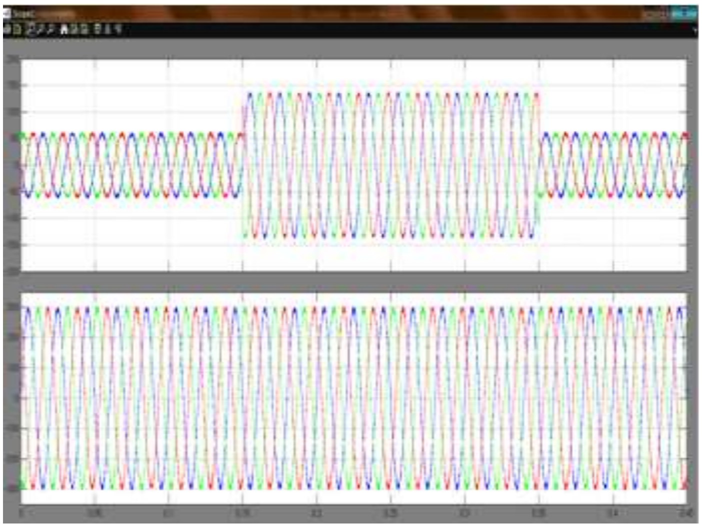


Fig3.7: Injected Voltages and Load Voltages During Sag Condition:

CONCLUSION

This paper presents the design and performance of a solar PV integrated UPQC (Unified Power Quality Conditioner) system. The inclusion of a battery bank allows the system to operate in standalone mode whenever the grid is unavailable, ensuring continuous power supply to critical loads. Additionally, the system mitigates power fluctuations in PV generation caused by weather conditions, enabling smooth power generation and increased overall system stability. The system's behavior under steady-state conditions was found to be satisfactory, with PCC (Point of Common Coupling) currents meeting the THD (Total Harmonic Distortion) limits prescribed in the IEEE-519 standard. The PV-UPQC's response was extensively evaluated under both standalone and grid-connected modes of operation, and it was found to perform satisfactorily under various conditions, including irradiation variations, load unbalance, and voltage sags/swells at the PCC.

In all these disturbance scenarios, the PV-UPQC was able to feed constant power into the distribution network, automatically transitioning between grid-tied and islanded modes with minimal disruption to the sensitive and critical loads. This three-wire PV-UPQC system is particularly suitable for applications with critical loads, such as data centers, hospitals, and factories, where uninterrupted power supply is of paramount importance. The integration of battery storage and renewable energy in this system enables reduced dependence on the grid for power demand, while the surplus PV power can be used to support the grid by providing power to nearby loads at the PCC.

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