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MITIGATING POWER QUALITY ISSUES USING SOLAR-POWERED UNIFIED POWER QUALITY CONDITIONER IN THREE-PHASE SYSTEMS UNDER CONTINGENCIES

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ABSTRACT
Grid systems are always vulnerable to a variety of hazards, including faults, transmission line failures, feeder interruptions, and generator outages. These occurrences produce variances in the rated voltage, resulting in system instability. To guarantee stability in such situations, power quality conditioners are installed at various places along the power network. This work describes the design of a two-converter-based power quality conditioner for a three-phase system, often known as a Unified Power Quality Conditioner (UPQC), which addresses both voltage and current disturbances on the source and load sides. The converters are built using series and shunt voltage source inverter topologies, which are connected on the DC side by connecting capacitors. These capacitors are charged using solar electricity, which provides the load up to its rated capacity, with the grid meeting any further need. To assess the UPQC's performance, voltage sag and swell conditions are produced at the source, and the ensuing load profile is examined. The UPQC successfully addresses power quality concerns at both the source and load ends, keeping harmonic distortions well below acceptable limits. During voltage variations, the technology considerably decreases harmonic distortion, ensuring a reliable power supply.
Keywords: Unified Power Quality Conditioner (UPQC), Voltage Source, Inverters (VSI), DC coupling, voltage sag, swell, harmonics mitigation, Total Harmonic Distortion (THD).

1. Introduction
Electric power quality refers to the extent to which a power supply system's voltage, frequency, and waveform conform to established criteria. A consistent power supply is essential for optimal power quality, ensuring it remains within the prescribed range. Furthermore, it encompasses a smooth voltage curve waveform resembling a sine wave, together with a stable AC frequency close to the rated value [11]. Power quality is typically described as the compatibility between the output of an electrical outlet and the connected load. Electric power is characterized by power quality, which influences the electric load and the load's capacity to function effectively. Inadequate power supply can result in the malfunction, failure, or non-operation of electrical loads. The substandard quality of electric electricity can manifest in several forms and may arise from multiple causes [12,13]. Key components of the electric power sector include the transmission of electric power, alternating current (AC) power generation, and the distribution of electric power at the end user's location. Subsequently, the electricity is sent to the load. The complexity of the system for transmitting electrical energy from the production site to the point of consumption, along with variations in production, weather, demand, and other factors, can lead to many potential impairments in supply quality [14].
Currently, the concerns pertaining to electricity quality must be addressed. The design of electric loads has been enhanced due to multiple factors, including the widespread utilization of electronic equipment such as power electronics, computer systems, PLCs, changeable speed drives, and energy-efficient lighting. These loads induce disturbances in the voltage waveform owing to their non-linearity. The structure of the global economy has advanced towards globalization in conjunction with technical advancements, resulting in diminishing profit margins for certain operations. Power quality difficulties are prevalent in most commercial, industry, and energy networks. Natural phenomena, such as lightning, are the predominant source of energy efficiency problems. Electrical drives or sensitive components may sustain damage from transient voltage drops (sags), leading to expensive production

disruptions. Consequently, power quality issues will increasingly be a critical factor to address for sustaining competitiveness from the customer's viewpoint [15].

2. LITERATURE SURVEY

Joe H. Chow [1] This brief message articulates the author's perspectives on the need of developing grid stability functions for inverter-based resources, including controls to improve system stability. This discourse will concentrate on transient stability and frequency management. Future research directions are also delineated.

Sisir Kumar Yadav; Ashish Patel; Hitesh Datt Mathur [2] In the contemporary power distribution network, the impetus to use renewable and clean energy sources to meet energy demand is rapidly increasing. This has improved the use of power electronics-based conversion devices, resulting in a decline in power quality throughout the power distribution network. Numerous compensatory bespoke devices, including static compensators (STATCOMs), dynamic voltage restorers (DVRs), and unified power quality conditioners (UPQC), have been created in recent decades.

Ch. Rami Reddy; A. Giri Prasad; D. Chandra Sekhar [3] Harmonics are generated in the system when nonlinear loads are present. Harmonic emissions in low and medium voltage applications are detrimental. This research proposes a unique UPQC for the adjustment of voltage sags and swells.

Dinesh Mahendra Matlani; Mehul D Solanki [4]: To enhance power quality in the distribution system, different bespoke power devices such as dynamic voltage restorers (DVR), distribution static synchronous compensators (D-STATCOM), and unified power quality conditioners (UPQC) are used. The DVR addresses voltage-related issues such as sag, swell, and interruption. D-STATCOM either produces or consumes reactive current, hence offering reactive power compensation.

Maheswar Prasad Behera; Omkar Tripathy; Pravat Kumar Ray [5]: This paper discusses a Photovoltaic Generator (PVG) based Unified Power Line Conditioner (UPQC) using a Fuzzy Logic Controller in a three-phase system. The objective of the aforementioned endeavor is to provide compensation to the grid during periods of intense light and darkness. This publication presents a newly created control algorithm, accompanied by supporting data and debates, in comparison to the previous way.

Nirav Karelia; Amit Vilas Sant; Vivek Pandya [6]: The Unified Power Quality Conditioner (UPQC) is a specialized power device that delivers a comprehensive power quality solution. The only limitation of UPQC is its inability to sustain power during a grid disruption. Various UPQC topologies have been documented.

Mahmood T. Alkhayyat; Sinan M. Bash [7]: This study evaluates the performance of the traditional unified power quality conditioner and the open unified power quality conditioner powered by a lithium-ion battery, focusing on Volt Ampere rating, total harmonic distortion, and phase jumping mitigation. Numerous sensitive loads are impacted not only by voltage sags but also by fluctuations in phase angle, necessitating the use of a pre-sag compensation mechanism.

Ashish Patel; Hitesh Datt Mathur; Surekha Bhanot [8]: This work proposes an enhanced Power Angle Control (PAC) approach for UPQC-DG to effectively compensate for imbalanced loads. UPQC-DG offers a concurrent solution for power quality and renewable integration. PAC algorithms have been devised for UPQC-DG to optimize VA use of the series and shunt APFs of UPQC-DG. In instances of imbalanced loads, current PAC approaches lead to the circulation of reactive power and heightened VA loading of UPQC-DG.

Santanu Kumar Dash; Pravat Kumar Ray [9]: This study discusses the design, setup, and control of a photovoltaic interfaced unified power quality conditioner (PV-UPQC). PV-UPQC is used to sustain power quality amongst diverse current and voltage distortions. PV-UPQC is a multi-objective power conditioning apparatus that incorporates both shunt and series voltage source converters sharing a common DC connection. Furthermore, the solar system is integrated into the DC-link of the UPQC to provide electricity to the load.

Shilpa M Devaraddi; P. Sandhya [10]: This research seeks to construct a Multi-Converter Unified Power Quality Controller (MC-UPQC) and evaluates its performance using a PI controller, artificial neural network (ANN), and Support Vector Machines (SVM). The MC-UPQC system can concurrently rectify voltage and current aberrations in multi-feeder systems. A shunt compensator regulates current disturbances, whereas a series compensator mitigates voltage disturbances.

3. DESIGN OF PHOTO VOLTAIC ARRAY

Photovoltaic modules are interconnected in a solar array. A multitude of photovoltaic cells comprises each photovoltaic module, with these cells interconnected within the module. The cells of this photovoltaic module immediately convert solar energy into direct current power. Typically, solar panels are utilized in this sort of photovoltaic modules. Nonetheless, solar panels are more advantageous for air heating techniques or solar-thermal water systems. However, in photovoltaic modules, solar cells are not identical. These cells are fabricated in diverse environments, since they are appropriately sized and encased in weather-resistant housings for expedient and uncomplicated installation. These cells may be utilized in industrial, residential, and commercial applications. Photovoltaics (PV) are extensively utilized in both research and the application of PV devices.
The below equation illustrates the voltage of each cell:
Where, k represents the Boltzmann constant (1.38 × 10^-23 J/K), Ic denotes the cell output current, and Iph signifies the photocurrent. Io represents the diode's reverse saturation current, Rs denotes the series resistance of the cell, Tc indicates the reference cell operating temperature, and Vc signifies the cell voltage.
A DC-DC converter, functioning as a Maximum Power Point Tracker (MPPT), may be either a buck converter or a buck-boost converter. Concerning the provided intensity of the PVA, its voltage output must be either obscured or expedited. The converter adjusts voltage in response to fluctuations in light or temperature. The control mechanism generates a commitment cycle that significantly differs from the triangle waveform. Furthermore, the created wave is transformed into an exchange wave. The duty cycle is examined using the calculation approach outlined below:

4. PROPOSED WORK

A Unified Power Quality Conditioner (UPQC) is suggested for a three-phase 415 V AC system, including two converters. The right-side converter of the UPQC is shunted with a 3mH inductor across the load, while the left converter is linked in series with the source using a 12-terminal coupling transformer, resulting in a UPQC-R topology. A two-winding transformer with a 10 KVA rating is employed to connect the series converter of the UPQC to the source side. The AC sides of both converters are connected to the utility system, while the DC sides are linked via a DC connection. The DC-link is maintained at the necessary DC voltage through the output power of solar panels, which supplies the energy needed for the converter's operation, the active power demanded by the load, and compensation for voltage regulation during instances of sag and swell. The suggested configuration of the PVA-UPQC is illustrated in Fig 1.
The DC-link coupling of converters with solar energy may be achieved in two methods: one involves the integration of single-stage solar power conversion. Secondly, employing a two-stage solar power conversion process. In single-stage conversion, the electricity generated by the photovoltaic system is directly connected across the DC-link of the UPQC without the use of a DC converter. This PVA-UPQC topology is characterized by a straightforward design, cost-effectiveness, and excellent efficiency. However, the DC voltage is constant and regulated by the DC coupling of converters. A two-stage conversion involves a DC-DC converter coupled to the solar output, which manages power demand and generated power. Due to the high voltages involved in AC connections at the grid side, boost converters are typically employed. The two-stage photovoltaic power conversion system offers more DC-voltage flexibility compared to a single-stage system. However, the system's cost escalates due to the necessity for high-rated DC converters to manage power in conjunction with the AC grid. The system's efficiency diminishes due to the utilization of two-stage power converters, which also generate significant harmonics in the AC system.

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Therefore, if the DC-link voltage is constant for UPQC applications, a single-stage PV power conversion architecture is the optimal selection, which is exactly the topology employed in this research.

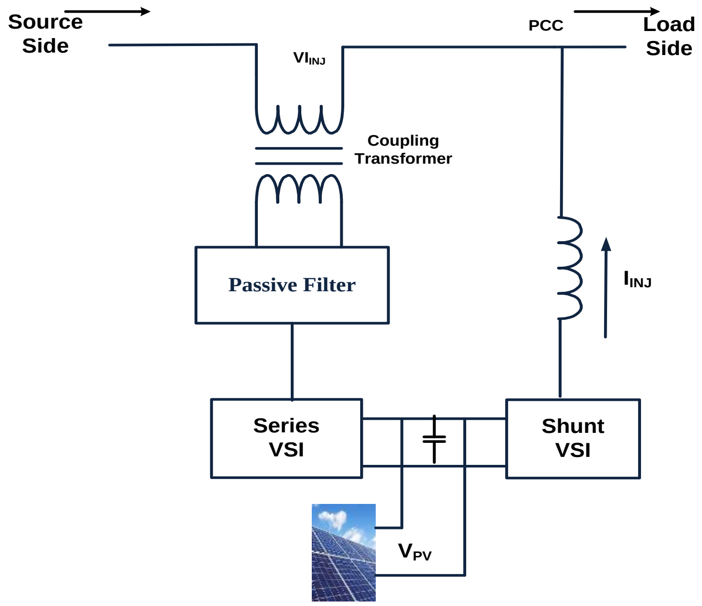

Figure 1: Proposed Model of Solar PV Integrated UPQC

The suggested method and system emphasize enhancements in power quality, integration of renewable energy generation, greater load current compensation, superior parallel voltage and current quality, and increased stability under dynamic loads and voltage fluctuations.

5. SIMULATION RESULT AND DISCUSSION

The suggested approach was implemented using MATLAB (R2016a). The Signal Processing Toolbox in the MATLAB Library facilitates the utilization of functions for different techniques such as windowing, scaling, and shifting.

5.1 SIMULATION PARAMETERS

Table 5.1: Parameters and their Values

PARAMETERS	VALUES
Three phase Voltage sources	415 V
Three Phase Series Resistance R_S	0.1 Ω
Three Phase Series Resistance L_S	1mH
Three Phase Rated Power of the transformer	10 KVA
Frequency	50 Hz
Irradiation	1000W/m^2
Temperature constant	30º C
PWM Switching frequency	10 KHz
Load Resistance (R_L)	25 Ohm
Internal Resistance of IGBT	1 mΩ
Proportional (K_p)	1.5
Integral (K_i)	0.1

5.2 SIMULATION RESULTS & ANALYSIS

The PVA-UPQC is a specialized power converter designed to enhance the quality of electricity supplied to various loads using solar energy. In addition to addressing multiple power quality issues and ensuring high-quality power delivery, the UPQC also integrates the benefits of eco-friendly solar energy. Notably, it can mitigate power quality challenges arising from solar generation's non-linear characteristics, as SPV-integrated power electronic devices produce energy.

For the simulation model, a three-phase programmable source operating at 415 V and 50 Hz is used to represent the grid. The series converter in the UPQC is connected through a 100 kVA coupling transformer with a resistance of 0.2 Ω, a reactance of 0.5 Ω, and an inductance of 3.6 mH. The photovoltaic array (PVA) in this study is designed to maintain a constant DC-link voltage of 700 V. The solar system consistently delivers 16 kW of power with a minimum current input of approximately 25 A, ensuring that the power electronic switches operate at a lower rating, thereby minimizing losses.

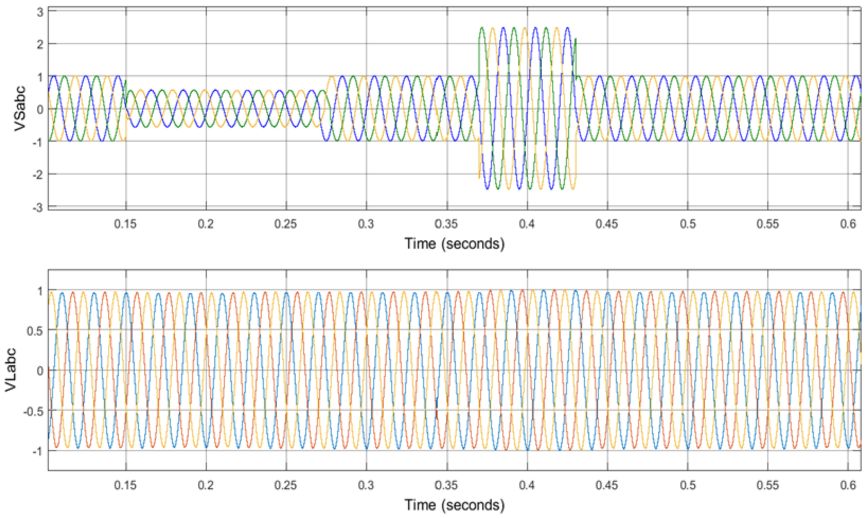

Figure 2: Source and load voltage under the condition of voltage sag and swell at source side

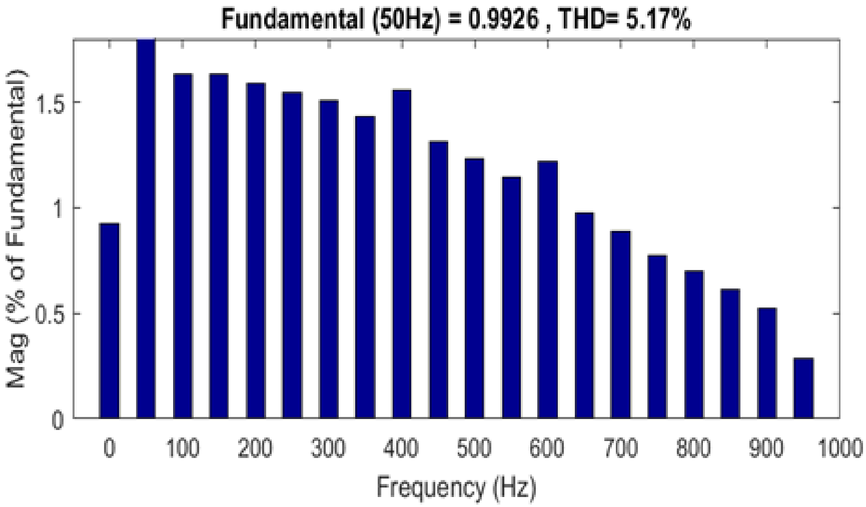

Figure 3: THD of source voltage under the condition of voltage sag and swell

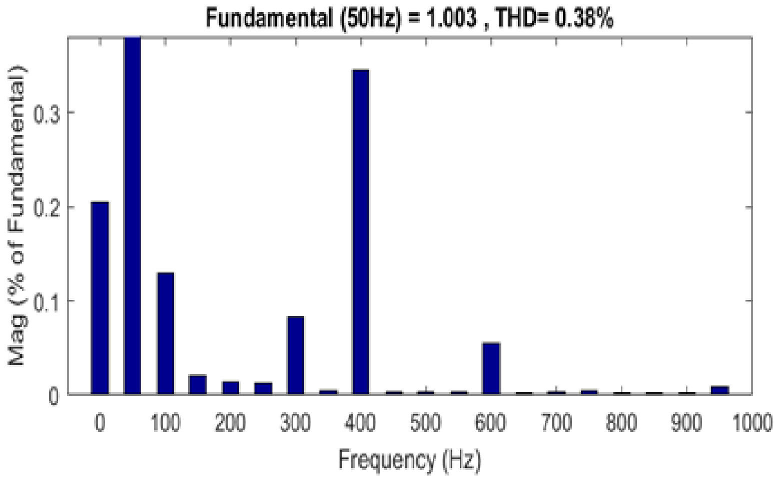

Figure 4: THD of load voltage under the condition of voltage sag and swell

6. CONCLUSION

UPQC allows you to alter the amplitude and phase angle of both voltage and current at the same time. The integration of renewable energy sources such as solar and wind with the utility system is an emerging field of study at UPQC. This work proposes PVA-UPQC, which supplies active and reactive power to the DSU at the same time, hence boosting system stability and dependability. A distribution system's ability to sustain reliability and efficiency is a highly desirable feature, motivating academics to examine its many applications.

The proposed PVA-UPQC attempts to reduce harmonics while rectifying voltage sag and swell caused by faults and excessive generation, respectively. The voltage sag and swell on the source side have no effect on the load bus voltage, which remains constant throughout operation. Furthermore, the system ensures that harmonics remain below 1%, hence improving overall power quality.

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