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Power Quality Improvement in Micro Grid System Using Fuzzy-UPQC Controller

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Abstract: *This research proposes a micro grid based on a single stage converter to reduce the number of converters in a single ac or dc grid. Microgrids, characterized the ability to operate in both grid-connected and islanded modes has made devices an essential element for integrating renewable energy sources and enhancing local energy resilience. However, Issues with the intermittent nature of renewable energy sources like solar and wind creates power quality issues such voltage sags, swells, harmonics, and flickers. To deal with these challenges, this research proposes a new book approach for using power quality in microgrid systems using a fuzzy logic-based Unified Power Quality Conditioner (Fuzzy-UPQC) controller. The power system experienced distortions as a result of either non-linear load utilisation or variations in load. The Fuzzy-UPQC integrates to simultaneously reduce voltage and current disturbances, utilise a shunt and series converters. By reducing the output power aberrations, fuzzy logic controllers and the conventional proportional integral (PI) are used to improve power quality.*
known for their ability to handle nonlinearities and uncertainties, enable the UPQC to adjust dynamically its operation based on data received in real time from the microgrid, ensuring optimal performance even under fluctuating load and generation conditions. Simulation results demonstrate that the Fuzzy-UPQC controller effectively improves voltage stability and reduces harmonic distortion in a microgrid environment. The proposed system also shows robust performance in compensating for transient disturbances, making it a viable solution for improve the modern microgrid's electricity quality applications. Its study highlights the potential of fuzzy logic-based control systems in improving the reliability and efficiency of microgrids, paving the path for more sustainable and resilient energy systems..

Keywords: Microgrid, The Power Quality, Fuzzy Logic, Unified Power Quality Conditioner (UPQC), Renewable Energy, Voltage Stability, Harmonic Distortion.

I. INTRODUCTION

An increasing demand for efficient, reliable, and high-quality energy systems has led to the development of microgrids. One of the major challenges in microgrid operation is maintaining quality of power disturbances such voltage sag, voltage swell, harmonic distortion, and voltage imbalance can significantly impact the performance of sensitive electrical loads. To address these issues, advanced power quality enhancement methods, such as the Conditioner of Unified Power Quality (UPQC), are employed. This project aims to improve power quality within a microgrid by implementing a Fuzzy Logic-based UPQC Controller. Fuzzy logic provides a robust approach for managing the uncertainties and nonlinear behavior often present in power systems, offering more adaptive and efficient control compared to conventional controllers.

1.1 General Overview

In recent years, microgrids have gained significant attention as a viable solution for enhancing energy reliability, sustainability, and resilience. A localised energy system which integrates many energy sources is called a microgrid.including renewable energy (solar, wind, etc.), energy storage devices work with conventional generators to supply energy to a specified region.While microgrids provide benefits such as reduced transmission losses, enhanced energy security, and environmental sustainability, they also present significant challenges in maintaining high quality of power one such device is the Unified Power Quality Conditioner (UPQC). Power electronic equipment which provides shunt and series compensators to mitigate a wide range of power quality issues. The series compensator is used to correct voltage-related disturbances, while the shunt compensator deals with current-related disturbances like harmonics, reactive power, and load imbalances. Although traditional controllers like Proportional-Integral (PI) controllers have been used to operate UPQCs, they often lack flexibility and adaptability when dealing with non-linear and dynamic systems, such as microgrids

1.2 Power Quality Definition

Power quality describes the attributes of electrical power delivered to consumers, ensuring it adheres to the necessary standards for reliable and efficient operation of electrical equipment.". Good power quality is essential to prevent disruptions, damage, or inefficiency in electrical systems and devices.

The power supplied to homes, businesses, and industries typically comes in the form of alternating current (AC) with specific characteristics, such as voltage, frequency, and waveform. When these characteristics deviate from the expected levels or become distorted, power quality problems arise, potentially affecting the performance of connected devices and machinery.

Power quality is crucial in preventing disruptions in the operation of electrical equipment, minimizing energy loss, and extending the lifespan of devices. It is especially important in industries, healthcare, and businesses where sensitive equipment needs to function continuously without interference.

1.3 Key Elements Of Power Quality Include

- **Voltage**: The potential difference between two points in the electrical circuit. For devices to operate correctly, the voltage must remain within specified limits.
- **Frequency**: The rate at which the current alternates, usually 50 or 60 Hz depending on the region. Any significant deviation in frequency can affect motor-driven equipment, clocks, and other sensitive systems.
- **Waveform**: The electrical signal's shape. A perfect sine wave is pure, but variation can happen, resulting in distortions or harmonics that could destroy delicate electronics.
- sensitive electronics.
- **Load**: The demand for electrical power can vary, which may cause fluctuations in voltage, frequency, or waveform, leading to power quality issues.

1.4 Power Quality Issues in Microgrids

Microgrids are prone to several power quality issues, including:

- **Voltage Sags and Swells:** Sudden drops or rises in voltage can damage sensitive equipment.
- **Harmonics:** Distorted waveforms resulting from nonlinear loads (e.g., computers, variable speed drives).
- **Voltage Imbalance:** Unequal distribution of voltage among the phases, causing stress on equipment.
- **Flicker:** Voltage fluctuations that affect lighting and sensitive loads.

To address these issues, the UPQC can be used, consisting of an active filter combining shunt and series.The series compensator mitigates voltage sags and harmonics, while the shunt compensator corrects current distortions and balances the power.

Voltage Sags

Takes occur when the rms voltage decreases by 10% to 90% for three half cycles to one minute. A half cycle in a 60Hz power supply lasts around 8 milliseconds, while a full sine wave lasts about 16 milliseconds.

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Voltage Swells

Swells are defined by a rise in the rms RMS voltage of more than 110% for a half-cycle to a minute.

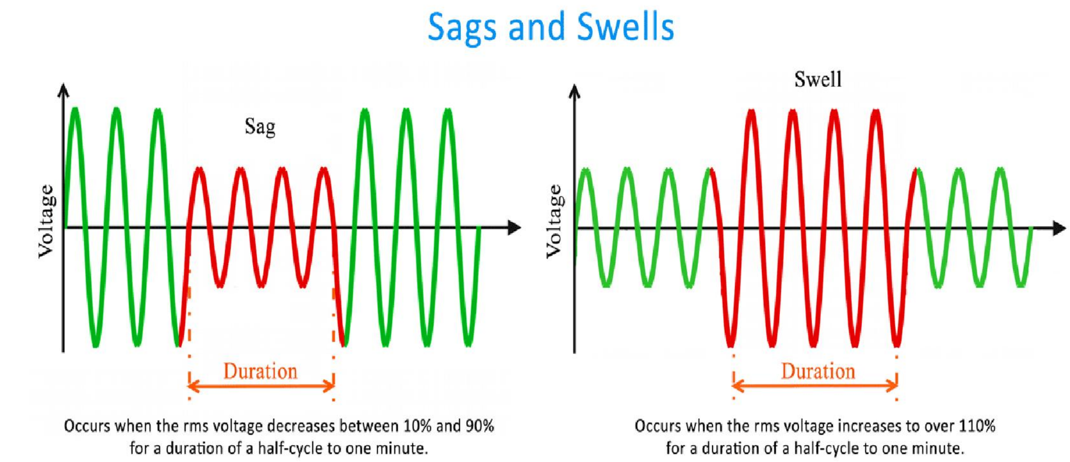

Fig 3.1 Voltage Sag **Fig 3.2 Voltage Sweel**

Harmonics

A sound wave with an integer multiple associated with a fundamental frequency or fundamental pitch is called a harmonic. The fundamental frequency is the lowest frequency that a sound tube can produce A collection of notes that connect to the fundamental frequency in whole integers are known as a harmonic series.

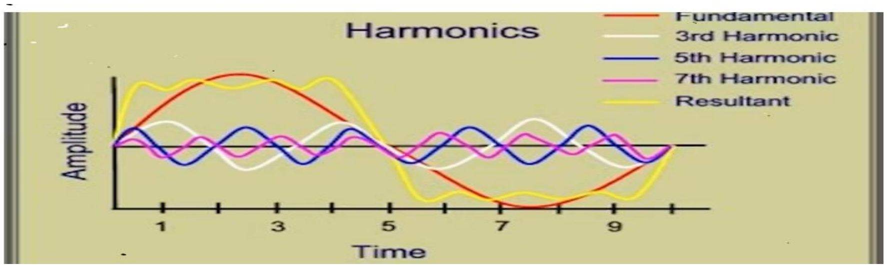

Fig:3.3 Harmonics

Voltage Imbalance

Voltage imbalance refers to a variation in a power system where either the phase angle differences or the voltage magnitudes between phases are unequal. This phenomenon primarily affects **polyphase systems**, as it arises when the symmetry of the three-phase voltage is disrupted, leading to adverse effects on equipment performance and overall power quality.

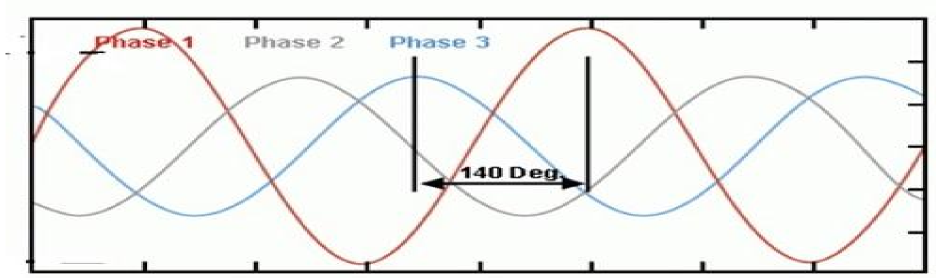

Fig 3.4 Unbalanced Phase

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Introduction of microgrid

A microgrid is a compact and self-contained energy system tailored for a particular location, such as a college campus, neighborhood, factory, or military installation. It can function either on its own or in coordination with the primary power grid.Microgrids enhance energy reliability, adaptability, and local energy control, promoting efficiency and lessening reliance on the main grid, which can sometimes experience fluctuations and power quality issues.

Key Characteristics of a Microgrid

Resources for Distributed Energy (DERs):
Local Energy Management: .
Grid-Connected or Mode of Islands:
1) Mode of Grid Connection:.
2) Islanded Mode: Energy Storage Systems:

Benefits of Microgrids

Energy Resilience
Cost Savings
Energy Efficiency
Environmental Benefits
Grid Support:

Applications of Microgrids

Urban and Rural Communities
Industrial Facilities and Campuses
Critical Infrastructure
Renewable Energy Integration

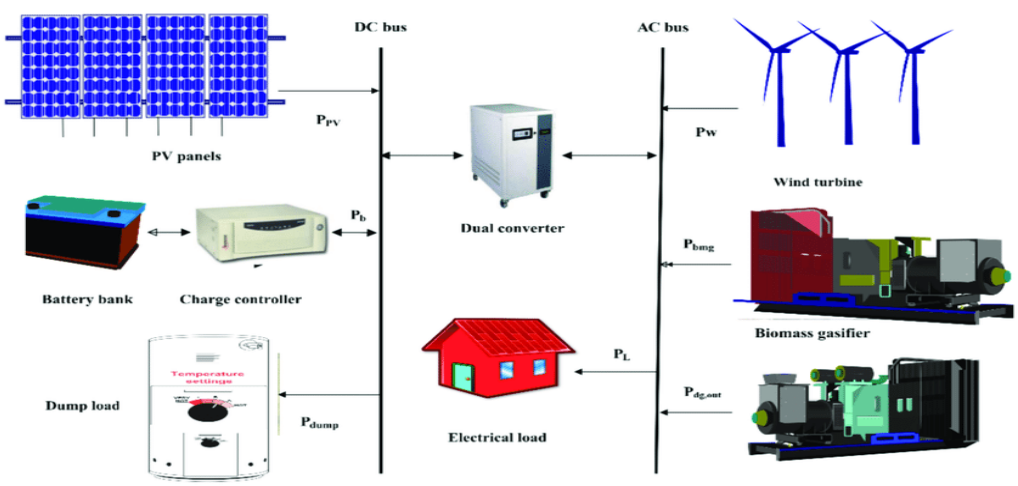

Fig.4.1: Component of Microgrid System

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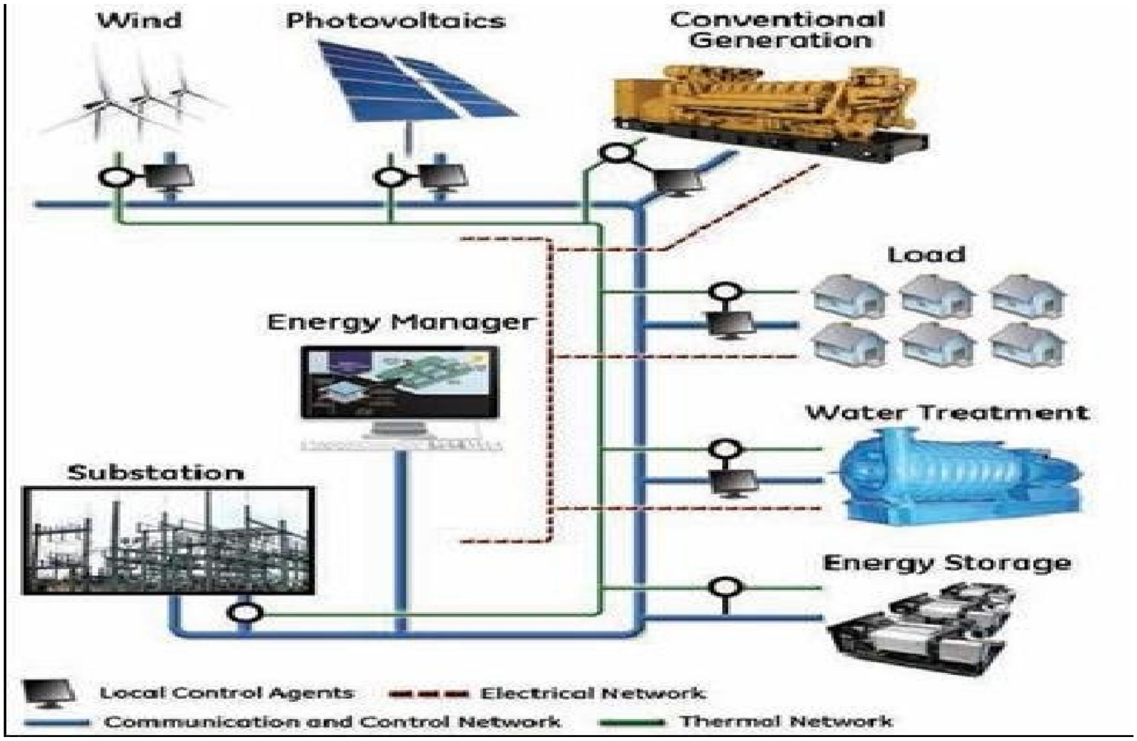

Fig.4.2 Microgrid Power System

II. UNIFIED POWER QUALITY CONDITIONER

Introduction:

The UPQC is made up of two main components:

1. Series Active Power Filter: It improves for harmonic distortions, voltage sags, and swells by injecting a compensating voltage in series with the load.

2. Shunt Active Power Filter: It improves power quality by injecting or absorbing current to make up for current imbalances and harmonics when connected to the load in parallel.

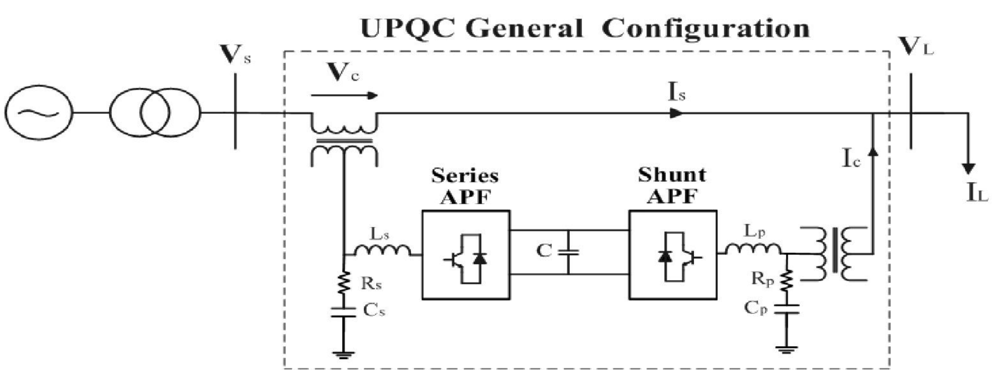

Fig. 5.1 Circuit Diagram with UPQC

Applications of UPQC

- Industrial Systems
- Renewable Energy Integration

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- Power Electronics
- HVDC Systems

Advantages of UPQC

- Comprehensive Power Quality Improvement
- Enhanced Load Protection
- Reduced Harmonics
- Improved System Stability:
- Energy Savings

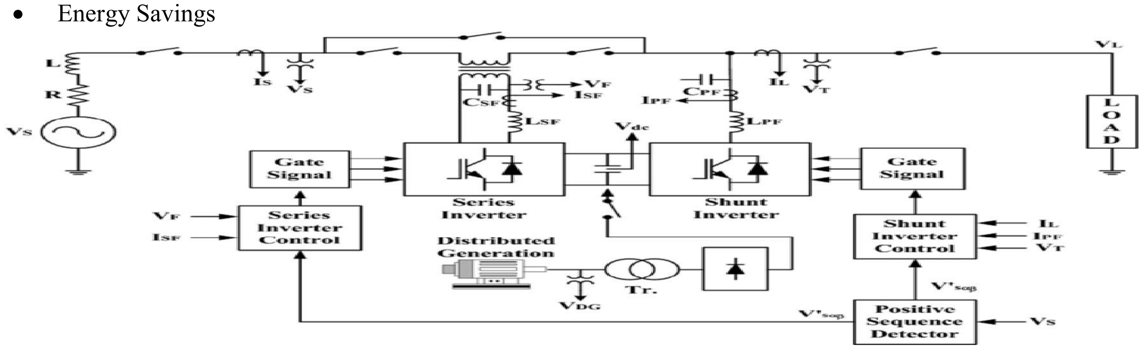

Fig. 5.4 Control Block Diagram.

III. FUZZY LOGIC CONTROLLER

Introduction:

A form of many-valued logic, focuses on approximate reasoning rather than relying on rigid, precise reasoning. This concept serves as the foundation for a Fuzzy logic controller (FLC), which is a type of control device designed to handle uncertainty and imprecision in decision-making processes. Unlike traditional controllers that require precise inputs and mathematical models, fuzzy logic controllers work with imprecise or uncertain inputs, using a set of linguistic rules to make decisions

Basic Concept of Fuzzy Logic ;

In classical logic, variables exist as either false (0) or true (1). However, variables in fuzzy logic may have values that range from 0 to 1. representing degrees of truth. For example:
Temperature is "Hot": 0.8
Temperature is "Warm": 0.4
Temperature is "Cold": 0.0

Control by Fuzzy Logic:

Using fuzzy logic, the design of the controller for the UPQC because of its ability to handle nonlinearity and uncertainty, which are common in power systems. The fuzzy controller uses linguistic variables like "error" with "change in error" to determine the control action. The key advantages of fuzzy logic in this context are:

- **Adaptability**: Can handle complex and nonlinear relationships in power systems.
- **Robustness**: Performs well under uncertain or fluctuating conditions.
- **Simplicity**: Fuzzy logic controller works by evaluating the deviation of system parameters (voltage and current) from the desired values and adjusting the compensating actions accordingly.

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Example:
Use Case: Fan Speed Controller
Input: Room Temperature
Output: Fan Speed
Rules:

- When the temperature is cold the fan speed is low.
- When the temperature is warm the fan speed is medium
- When the temperature is hot the fan speed is high

Advantages of Fuzzy Logic Controllers:

- Can handle uncertain or imprecise input
- Easy to understand and modify using linguistic rules
- Robust to system changes and noise

Limitations:

- Not always optimal
- Rule base can become complex for large systems
- Designing membership functions may require expert knowledge

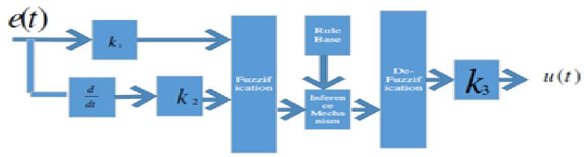

Figure : Fuzzy Logic Controller block diagram

Example: Mamdani Fuzzy Inference System Rule Table

A basic fuzzy inference system (FIS) can be created to regulate the speed of a fan using two input factors: temperature and humidity. The system provides an output that adjusts the fan's speed accordingly.

Input Parameters:
Temperature: Categories – Low, Medium, High
Humidity: Categories – Low, Medium, High
Output Parameter:
Fan Speed: Categories – Low, Medium, High

Table: 1 Fuzzy Rules

Rule	Temperature	Humidity	Fan Speed
1	Low	Low	Low
2	Low	Medium	Medium
3	Low	High	High
4	Medium	Low	Medium
5	Medium	Medium	Medium
6	Medium	High	High

Introduction to Fuzzy-Based Controller with UPQC:

An efficient and helpful tool for improving power quality in electrical distribution systems is the Unified Power Quality Conditioner (UPQC).It combines the features of both a series compensator (to address voltage sags, swells, and harmonics) and a shunt compensator (to mitigate current-related issues like reactive power, harmonics, and as well as power factor correction). The UPQC is typically employed in industrial, commercial, and residential applications where quality of power disturbances can significantly impact operations. However, conventional controllers used to regulate the UPQC may not effectively handle complex and nonlinear power quality disturbances because of them reliance on

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fixed parameters and algorithms. This is where fuzzy logic comes into play. Fuzzy logic-based controllers have gained popularity because of their ability to handle uncertainties, imprecision, and nonlinearities in real-world systems. By mimicking human decision-making processes, a fuzzy-based controller may improve UPQC systems' performance and adjust to changing operational circumstances.

Key Concepts:

Unified Power Quality Conditioner (UPQC):

- **Series Compensator**: It introduces or absorb voltage to make up for issues related to voltage (such sags, swells, and harmonics) through a series transformer and converter.
- **Shunt Compensator**: It current-related issues by infusing reactive power and current harmonics, or absorbing current through a shunt converter.

Fuzzy Logic Controller:

An FLC represents input and output using "fuzzy sets" as opposed to binary sets (such as 0 or 1). It enables more adaptable and human-like control system decision-making.

Fuzzy logic uses language concepts (such "low," "high," and "medium") to explain variables rather than exact values. Then, using expert knowledge, rules are developed to specify how the system ought to operate in certain scenarios.

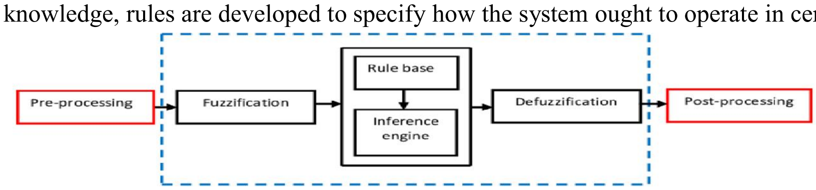

Fig. 7.1 Block diagram of a fuzzy logic controller

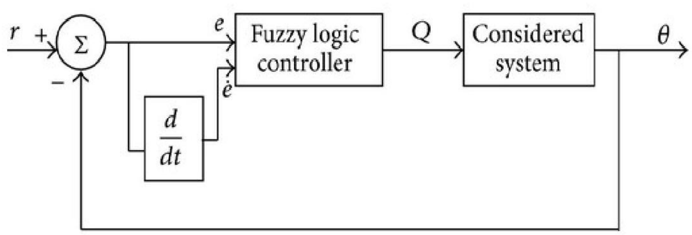

Fig: Controller Using Fuzzy Logic For The System In Question..

Fuzzy-Based UPQC Controller Working Principle:

The fuzzy logic controller of a fuzzy-based UPQC controller modifies the series and shunt compensators' operations in response to the real-time power quality disturbances detected in the system. The following steps outline how this works:

- **Power Quality Detection**: The system continuously monitors the voltage and current waveforms for disturbances like harmonics, sags, and swells.
- **Fuzzy Logic Input**: Key input parameters such as the voltage and current quality (e.g., amplitude, phase angle, harmonic content) are fed into the fuzzy logic controller. These inputs are typically expressed in fuzzy terms (e.g., "low", "medium", "high").
- **Rule-Based Decision Making**: Based on the fuzzy inputs, the fuzzy logic controller makes decisions using a set of predetermined rules. When a voltage sag is observed, for instance, the fuzzy controller might trigger the series compensator to inject an appropriate voltage to correct the sag. Similarly, if current harmonics are present, the shunt compensator can be activated to reduce them.
- **Defuzzification**: After processing the fuzzy inputs and rules, the controller generates control signals that are defuzzified to obtain crisp control values for the compensators (e.g., the voltage or current to inject or absorb).

- **Compensator Activation**: Based on the defuzzified output, the compensators (series and shunt) are adjusted to either inject or absorb the necessary power to restore the quality of the supply.

Advantages of Fuzzy-Based UPQC Controller:

- Handling Uncertainty: Fuzzy logic excels at handling uncertain, imprecise, or noisy data, making it ideal for real-world power systems where disturbances can be unpredictable.
- Adaptability: Unlike conventional controllers that require precise mathematical models, a fuzzy-based controller can adapt to various operational conditions and disturbances without needing exact parameters.
- Improved Power Quality: A fuzzy-based UPQC can greatly enhance the overall power quality by intelligently managing the compensators, lowering problems like reactive power, harmonics, and voltage sags.
- Enhanced Robustness: Fuzzy controllers are more robust to system disturbances and variations, providing stable and reliable performance in a variety of scenarios.

System Model and Configuration

The microgrid consists of the following components:

- **Distributed Generation (DG):** Includes sustainable energy sources like wind turbines and solar panels.
- **Storage of Energy:** Battery storage or other forms of energy reserves for grid support.
- **Loads:** Residential, commercial, and industrial consumers.
- **Power Conditioning Equipment:** Including the UPQC device with both Shunt and series filters.
- The fuzzy UPQC controller is applied to:
- **Voltage Sag and Harmonic Compensation:** Using the series active filter.
- **Harmonics in Current and Power Factor Correction:** Using the shunt active filter to adjust for power factor and harmonics

IV. SIMULATION AND ANALYSIS

PV Array Parameters (3 kW System):

Designing for a **grid-tied 3-phase 3 kW PV array**.

Parameter	Value/Description
Total PV Array Power	3KW-(3000W)
PV Module Type	Mono-crystalline Silicon
Rated Power per Module	330 W
No. of Modules (approx.)	10 modules (3.3 kW total)
Configuration	5 modules in series × 2 strings in parallel
Voc (Open Circuit Voltage)	~45 volt
Vmp (Max Power Voltage)	~37 volt
Isc (Short Circuit Current)	~9 Amp
Imp (Max Power Current)	~8.5 Amp

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Array Output Voltage	~185 V DC (5 × 37V)
Array Output Current	~17 A (2 strings × 8.5 A)

UPQC Parameters (Fuzzy Logic Controlled)

A Shunt Active Filter and a Series Active Filter make up the Unified Power Quality Conditioner (UPQC), with control governed by a **Fuzzy Logic Controller (FLC)**.

General UPQC System Parameters

Parameter	Value/Description
Topology	3-phase 4-wire UPQC
Voltage Rating	400 V (L-L), 50 Hz
DC Link Voltage	700 – 800 Volt
DC Link Capacitor	2000 µF – 3000 µF
Filter Inductance (Lf)	3–5 mH (per phase)
Filter Capacitance (Cf)	5–10 µF (for series filter)
Converter Type	Voltage Source Inverter (IGBT / MOSFET based)
PWM Switching Frequency	10 kHz (typical)

Fuzzy Logic Controller (FLC) Parameters

Microgrid Parameter

Output Range	
Parameters	**Value/Description**
Grid Voltage	400 V (3-phase), 50 Hz
Grid Impedance	0.1 – 0.3 pu (for testing sag/swell)
Connected Load	Linear and Non-linear (inductive loads + rectifier)
Load Power	2.5 kW – 3.5 kW (simulate varying load)
Power Quality Issues Simulated	Voltage sag (10%–40%), harmonics, imbalance

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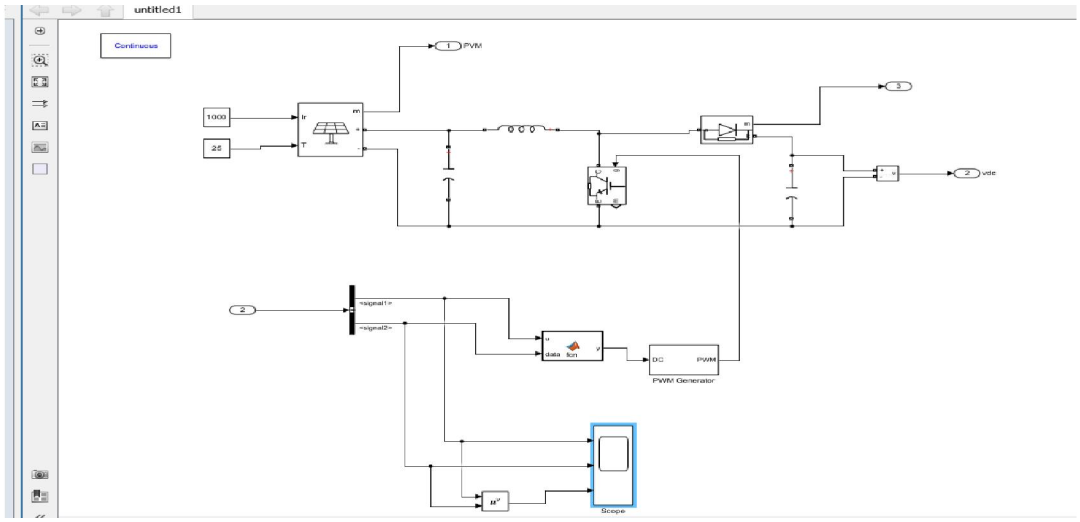
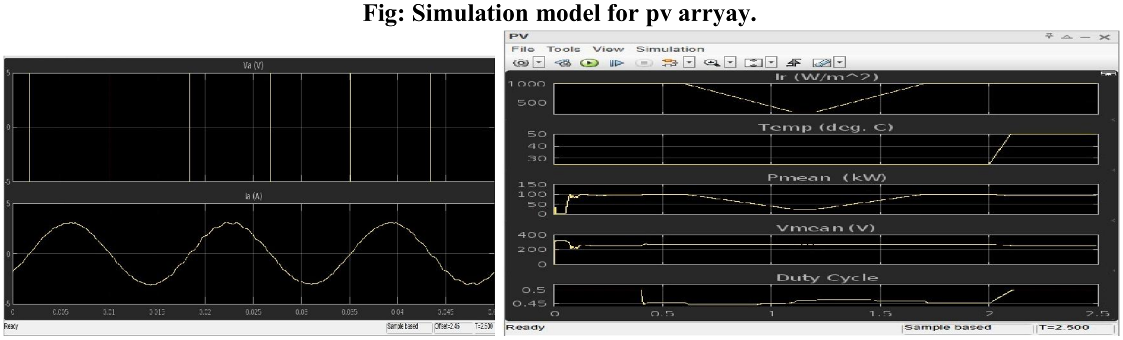
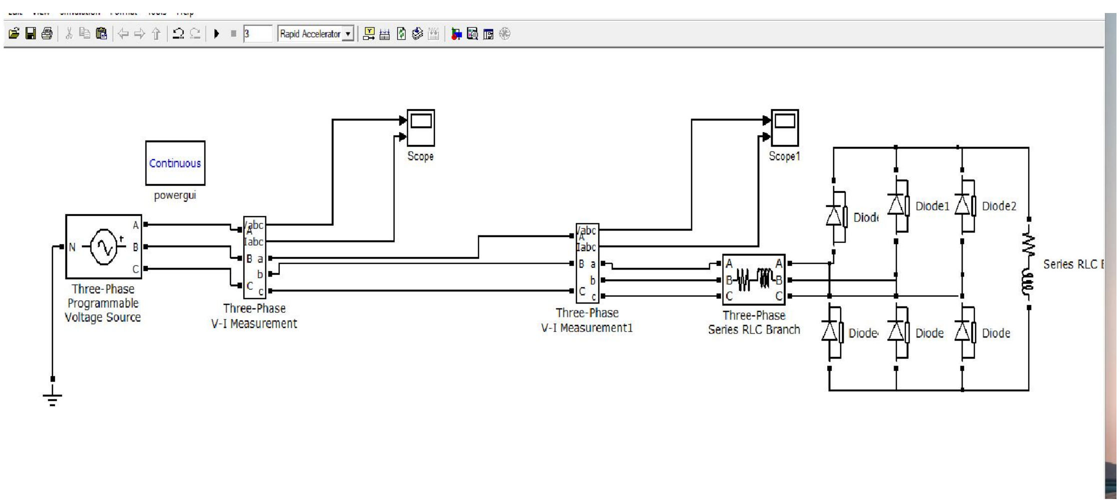


Fig: Simulation model for pv arryay.





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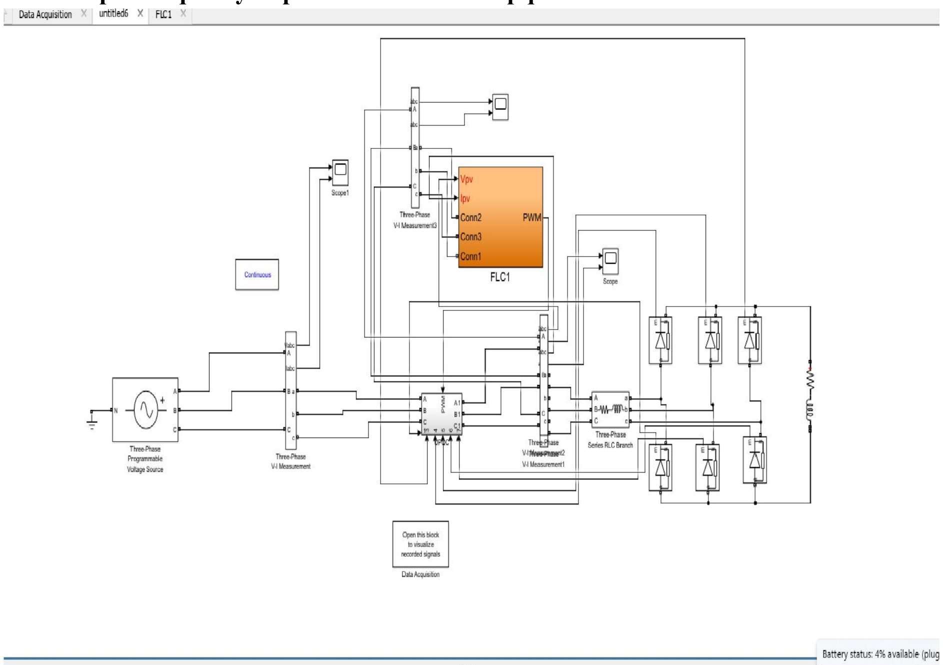
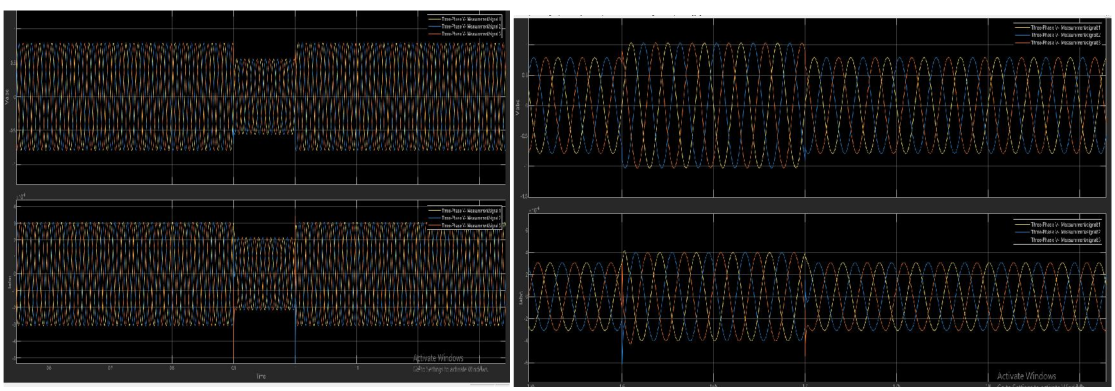
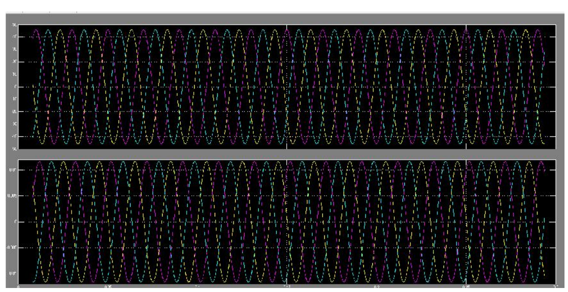
Simulation model for power quality improvement without upqc



Simulation model for power quality improvement with upqc





V. CONCLUSION

Using fuzzy logic-based Unified Power Quality Conditioners (Fuzzy-UPQC) is a successful way to improve power quality in microgrid systems. A fuzzy-based UPQC controller provides a sophisticated solution to the complex problem of power quality management. By leveraging the adaptability of fuzzy logic, it can effevely handle a widerange of power quality issues in a nonlinear and uncertain environment, improving the reliability and efficiency of the electrical power system

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