POWER FLOW AND STABILITY ANALYSIS OF THREE-PHASE POWER SYSTEM WITH WIND POWER USING UNIFIED POWER QUALITY CONDITIONER

[1]N.KRISHNA MOHAN M.Tech., [2] S.SUNEETHA M.Tech.,
MD.SUMAYYA NAZ, G.AKSHAYA ,SK.MANAAL, N.NIRUPA
DEPARTMENT OF EEE,NARAYANA ENGINEERING COLLEGE,NELLORE

Abstract:. The Unified Power Quality Conditioner (UPQC) is one of the Custom Power devices (CP), and it mitigates both load current and supply voltage problems (voltage swells, sags, harmonics, etc.) simultaneously. By using CP, we are getting more familiar with renewable energy's high penetration on the electrical grid because of its intermittent nature, which causes power flection. We are also using powered electronic devices, and non-linear loads produce harmonics that affect the voltage and current waveform. In this paper, a UPQC will be used with a sensitive load that is connected to a grid (grid–wind turbine) power system. The UPQC will operate under different disturbances such as phase-to-ground fault, non-linear load on the grid side, and non-linear load in parallel with the sensitive load, using pulse-width modulation and hysteresis as switching techniques. Simulation results using MATLAB/Simulink are used to compare the two pulsing-generating techniques and show that electrical power is continuously fed to the load in all disturbances with total harmonic distortion (THD) less than 5% for voltage and 4.5% for current

Keywords: Unified Power Quality Conditioner (UPQC) , Pulse-Width Modulation (PWM) , Hysteresis , Total Hormonic Distortion (THD) , Wind Turbines.

I. INTRODUCTION

Distributed generation (DG) can be defined as small-scale, bidirectional generating units that are connected to the power system at the distribution level. These units are generally considered a sustainable source of electrical power, which have a low environmental impact and power losses and can balance demand and production at the end-user side. DG units could be renewable and non-renewable resources that work together. Renewable energy sources (RESs) play a major role in DG. Using different power sources such as photovoltaic systems, wind turbines, biomass, fuel cells, and other RESs, DG aims to cover load capacity at the distribution level under different operating conditions with minimum losses, dispatch costs, and gas emissions [1]. The incessant increase in electrical energy demand leads to RES penetration in DG increment, which can affect the power quality (PQ) parameters in the utility grid, so it is important to determine the optimal size and location for DG units under certain constraints in points of common connection such as voltage profile, power flow limits, and nominal voltage values [2]. The high penetration of non-linear loads and power electronics is the main cause of voltage and current harmonics in power systems. As well, the high penetration of renewable energy systems such as PV systems, wind turbines, etc., which are installed at distribution power grids, increases every day because of power systems structure development [3]. This penetration presents new power quality challenges for distributed generation systems. Additionally, low power quality can negatively affect the performance of sensitive loads connected to the grid. Many researchers are making efforts to improve power quality. Several solutions have been found for PQ improvement, such as the series active power filter (SAPF) to handle voltage harmonics and the parallel active power filter (PAPF) to eliminate current harmonics caused by non-linear loads..

II. FUNCTIONAL OVERVIEW

The UPQC Report presents a detailed functional overview of the Unified Power Quality Conditioner (UPQC), which is designed to enhance power quality in electrical systems. It begins by defining Distributed Generation (DG) as small-scale, bidirectional generating units that contribute to sustainability while addressing the challenges posed by high penetration of renewable energy sources and non-linear loads, which lead to voltage and current harmonics. The report outlines its objectives, including the simulation of systems with and without FACTS devices, the development of a hardware setup for UPQC, and the implementation of closed-loop control systems using PID and Fuzzy Logic controllers. The structure of UPQC is elaborated, highlighting its key components such as series and shunt converters, energy storage systems, filters, and transformers, all working collaboratively to regulate voltage and eliminate current harmonics. The literature review emphasizes various methods for improving power quality, particularly the integration of UPQC for simultaneous compensation of voltage and current issues. Simulation results using MATLAB and Simulink demonstrate significant enhancements in performance metrics, including voltage, current, real, and reactive power, when utilizing UPQC. Experimental results further validate these findings through hardware implementation with a PIC microcontroller, confirming the system's effectiveness. The report concludes that the UPQC system significantly outperforms conventional systems in improving power quality, with Fuzzy Logic controllers showing superior time-domain performance compared to PID controllers.

Things you need:

To create the power flow and stability of three-phase power system with wind power using unified power quality conditioner you need the following stuff

- Inverters, Resistors, Capacitors, and Inductors
- Transformers
- DC Capacitor Bank
- Filters
- Microcontroller
- MATLAB and Simulink, Sim Power Systems Toolbox
- Oscilloscope, Multimeter
- Breadboard or PCB
- Connecting Wires
- Drill machine

DESIGN

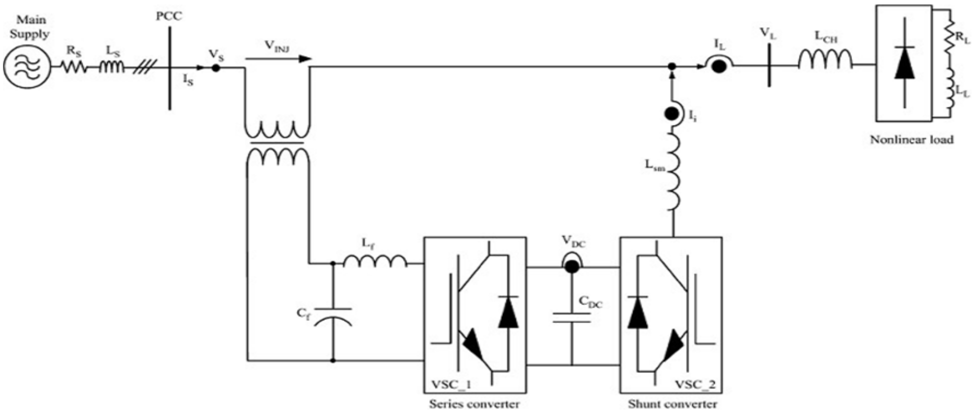


Fig.1 View of UPQC structure..

Below table shows basic required objects for the design and their functionality. In this, required Objects and their Functionality.

Following things are required for design:

- **Over Supply & System Components** – Three-phase AC source, transmission lines
- **Wind Energy System** – Wind turbine, PMSG/DFIG generator, AC/DC/AC converter
- **Unified Power Quality Conditioner (UPQC)** – Series VSC, Shunt VSC, DC link capacitor
- **Filters & Sensors** – LC/LCL filters, voltage & current sensors (CT/PT)
- **Load Components** – Non-linear loads (induction motor, rectifiers), linear loads (RLC)
- **Control & Measurement** – Microcontroller/DSP, PLL, PWM controller, oscilloscope, power analyzer
- **Software Tools** – MATLAB/Simulink, PSCAD/ETAP, Arduino IDE, Proteus/Multisim

Combined Hardware & Software Tools with Their Functionalities

Category	Tools/Components	Functionality
Power Supply & System Components	Three-phase AC source, transmission lines	Provides power and models power flow in the system.
Wind Energy System	Wind turbine, PMSG/DFIG generator, AC/DC/AC converter	Converts wind energy into electrical power and integrates it into the grid.
Unified Power Quality Conditioner (UPQC)	Series VSC, Shunt VSC, DC link capacitor	Compensates voltage and current disturbances to improve power quality.
Filters & Sensors	LC/LCL filters, voltage & current sensors (CT/PT)	Removes harmonics and measures real-time power parameters.
Load Components	Non-linear loads (induction motor, rectifiers), linear loads (RLC)	Represents system loads and introduces power quality issues.
Control & Measurement	Microcontroller/DSP, PLL, PWM controller, oscilloscope, power analyzer	Implements real-time control, synchronization, and measurement of power system parameters.
Software Tools	MATLAB/Simulink, PSCAD/ETAP, Arduino IDE, Proteus/Multisim	Simulates power flow, stability analysis, and control algorithms for the UPQC.

Level 1 Design

Hardware design involves the physical implementation of the power system**, including a** three-phase power source, wind energy system (turbine, generator, converter), and UPQC (series and shunt VSCs, DC link capacitor, and filters)**. The** control system (microcontroller/DSP, PLL, and PWM controller) ensures proper operation and synchronization **of UPQC with the grid. Measurement devices like** voltage/current sensors, oscilloscopes, and power analyzers **are used to monitor system performance.**

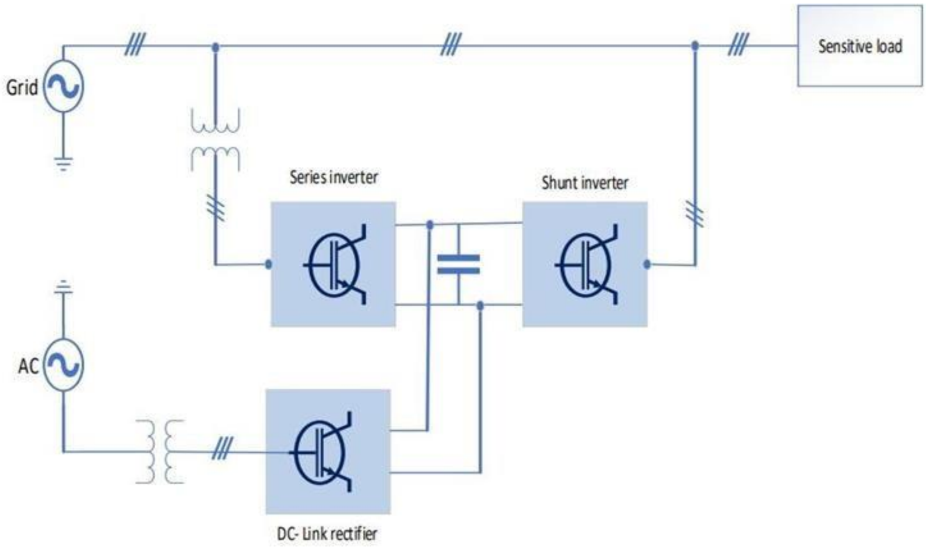


Fig 2: Basic structure of UPQC

The fig 3 shows the Block Diagram of Existing Simulation system.

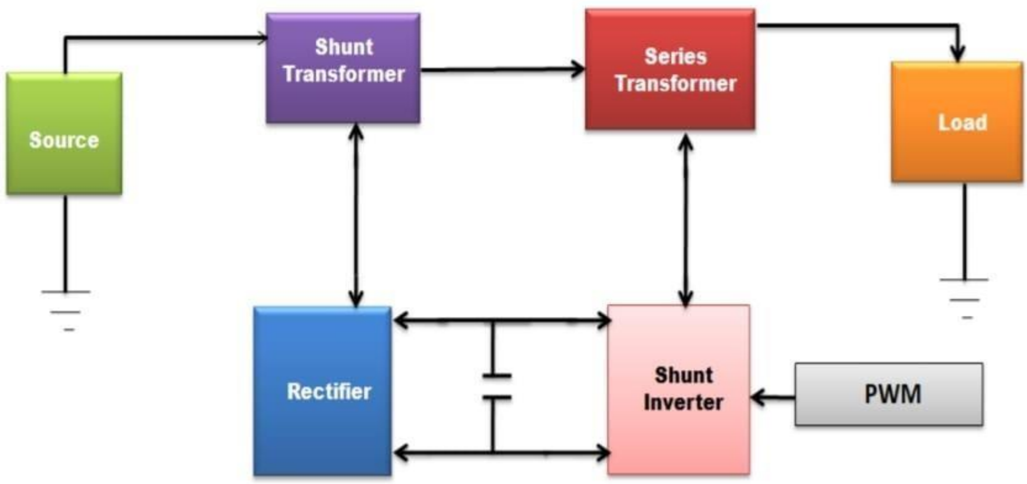


Fig 3 Existing Simulation Block Diagram

The fig 4 shows the open loop Block Diagram of proposed Simulation system.

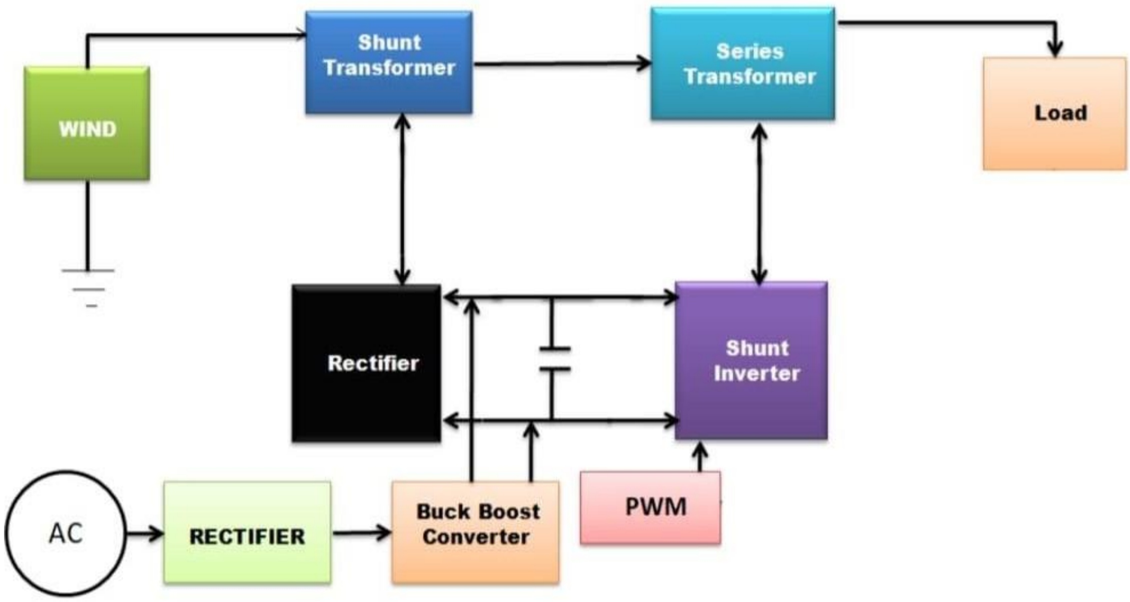


Fig 4 Proposed Simulation Block Diagram

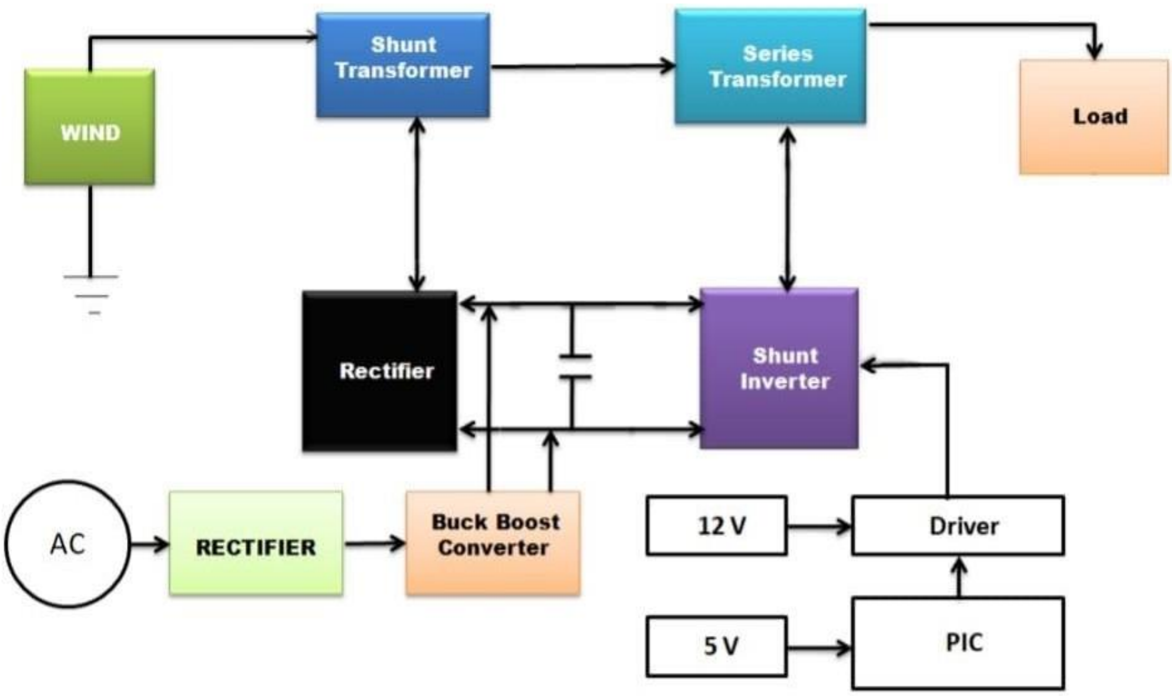


Fig 5 Hardware Block Diagram

Level 2 Design

Software design involves **modeling and simulating the power system using MATLAB/Simulink, PSCAD, and ETAP** to analyze power flow and stability. **Control algorithms for UPQC operation** are implemented using **Arduino IDE or Code Composer Studio** for DSP-based real-time control. Additionally, **Proteus/Multisim** is used for circuit-level simulations to validate system performance.

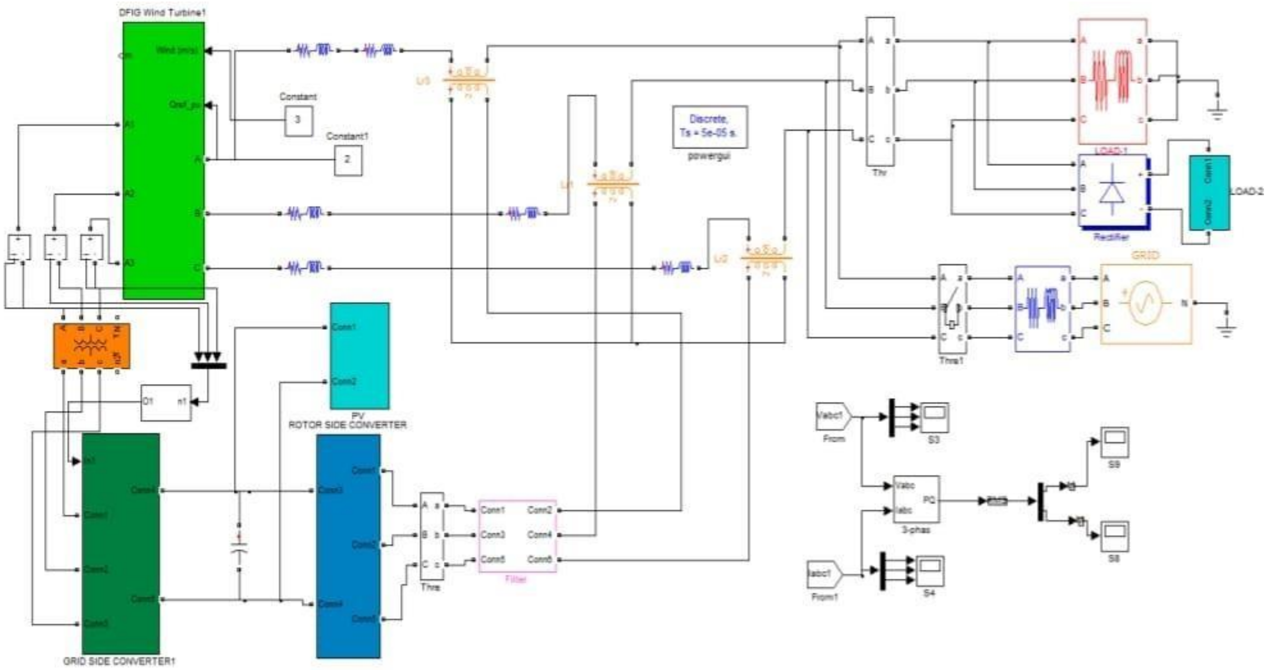
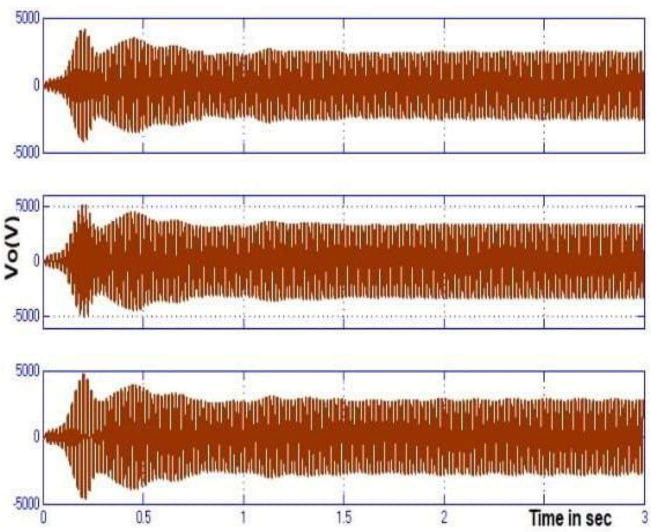


Fig 6 Circuit diagram of with UPQC



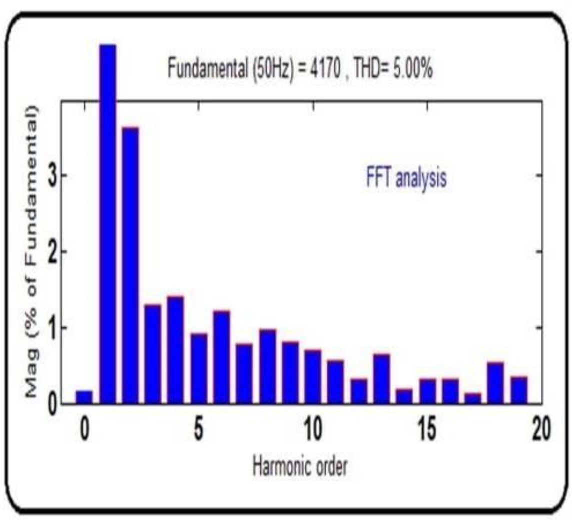
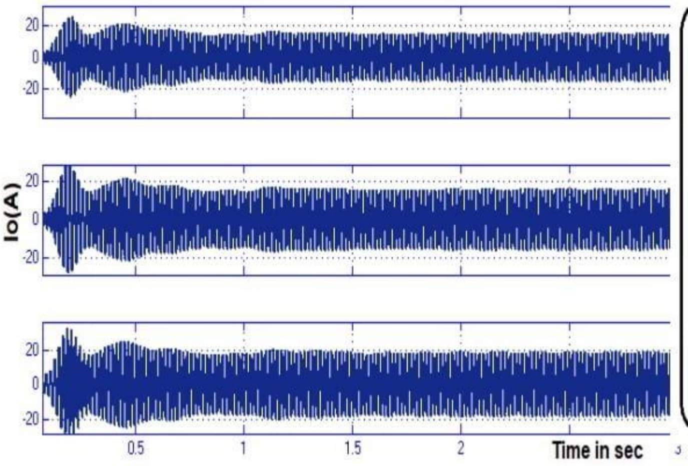
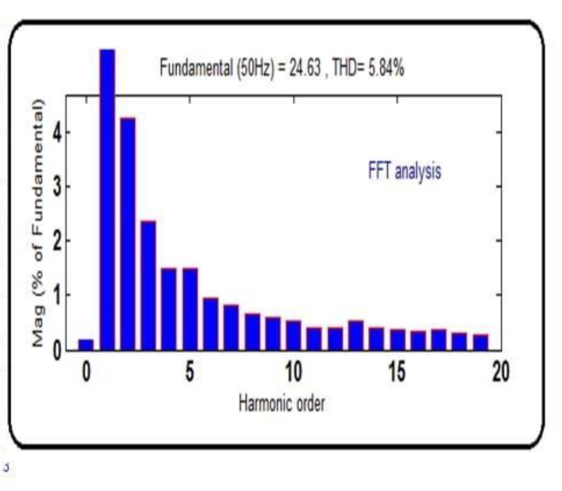


Fig 6.1 Voltage across RL load **Fig 6.2 Output voltage THD**

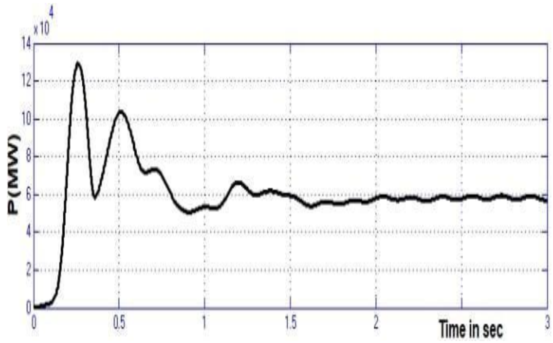




.

Fig 6.3 Current through RL load

Fig 6.4 Output current THD



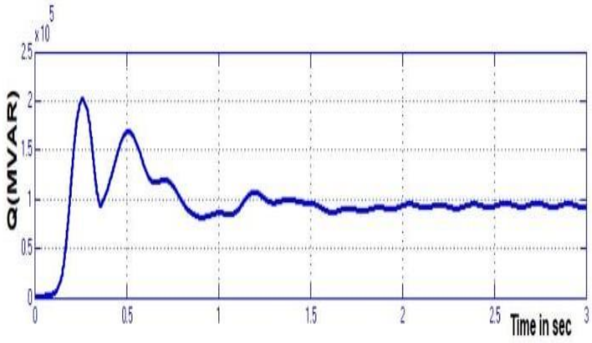


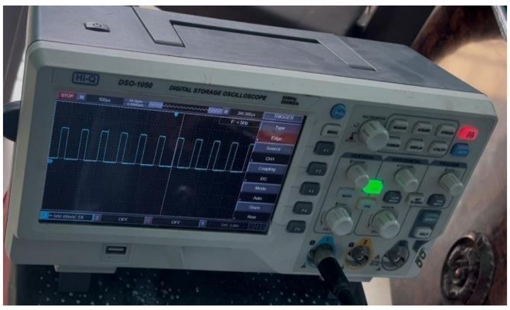
Fig 6.5 Real Power

Fig 6.6 Reactive Power

HARDWARE RESULTS

OUTPUT 1 :(at control circuit board)

When the CRO probes are connected to the regulator (ground terminal) and the input 5v and 10v resistor.



(a) The step wave at 5v input resistor

(b) The step wave at 10v input resistor

The 5v switching pulse and 4.7.1.b The 10v amplified

OUTPUT 2 : (At DC supply converter)
When the CRO probes are connected to capacitor at converter circuit the out put will be as follows

Fig.The dc stright line at capacitor

The above represents the dc voltage , here the voltage is being step up.

OUTPUT 3 : (At linear load)
When the cro probes are connected to phase to neutral,line to line,line to neutral at linear load circuit board the output in the cro will be as follows:

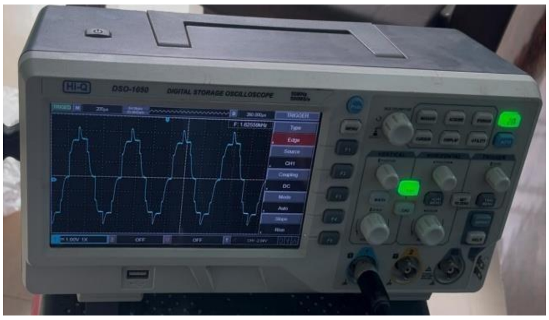


Fig.Wave from of phase to neutral

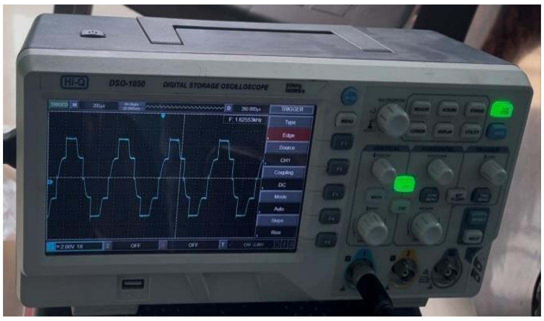


Fig.Output waveform of line to line

Fig.Output waveform to line to neutral

Figures of output 3 represents the output waveforms of phase to neutral,line to line,line to neutral.

IV.WORKING

The working of each components in this design is explained in this section. Let's talk about them one by one:

1. Three-Phase AC Power Source

The three-phase AC power source provides the main supply to the system, simulating grid conditions. It enables the study of power flow and stability by interacting with the wind power source and loads.5

2. Wind Energy System (Turbine, Generator, Converter)

The wind turbine captures mechanical energy from the wind and transfers it to the generator (PMSG/DFIG). The generator converts mechanical energy into electrical power, which is then processed by an AC/DC/AC converter to match grid requirements before integration.

3. Unified Power Quality Conditioner (UPQC)

The UPQC consists of a **series and shunt VSC**, a **DC link capacitor**, and **filters**. The **series VSC** injects compensating voltage to mitigate sag, swell, and voltage harmonics. The **shunt VSC** injects compensating current to eliminate harmonics and improve power factor. The **DC link capacitor** maintains a stable voltage between the converters, ensuring effective power exchange.

4. Filters (LC/LCL Filters)

Filters remove high-frequency harmonics generated by power electronics, ensuring smooth voltage and current waveforms. LC and LCL filters reduce total harmonic distortion (THD) and improve power quality.

5. Load Components (Linear & Non-Linear Loads)

Linear loads (resistive, RLC) draw a constant power, while non-linear loads (induction motor, rectifiers, inverters) introduce harmonics and cause power quality disturbances. The system is analyzed under different load conditions to evaluate stability.

6. Control System (Microcontroller/DSP, PLL, PWM Controller)

The **microcontroller/DSP** processes real-time data and generates switching pulses for the VSCs. The **PLL (Phase Locked Loop)** synchronizes the UPQC with the grid voltage, while the **PWM controller** generates precise switching pulses to regulate power quality compensation.

7. Sensors & Measurement Devices

Current and voltage sensors (CT/PTs) measure power system parameters for control and analysis. Measurement tools like oscilloscopes and power analyzers monitor power flow, voltage stability, and harmonic distortion.

8. Software Tools (MATLAB/Simulink, PSCAD, Proteus, Arduino IDE)

MATLAB/Simulink is used to model and simulate the system, analyzing power flow and stability. **PSCAD/ETAP** performs load flow and transient analysis. **Proteus/Multisim** simulates electronic circuits, and **Arduino IDE/Code Composer Studio** programs microcontrollers for real-time control.

,This integration of **hardware and software ensures effective power flow management and system stability**, improving overall power quality

V.INSTALLATION

- **Hardware Installation**

The hardware setup involves assembling and connecting various power system components to ensure smooth operation. The steps are as follows:

1. **Power System Setup**

- Connect the **three-phase AC power source** to the system.
- Integrate the **wind energy system** by connecting the wind turbine to the generator (PMSG/DFIG) and interfacing it with an **AC/DC/AC converter** for grid compatibility.

2. **UPQC Integration**

- Install the **Series Voltage Source Converter (VSC)** in series with the power line to compensate for voltage disturbances.
- Connect the **Shunt VSC** in parallel to eliminate harmonics and improve power factor.
- Install a **DC Link Capacitor** to balance power exchange between converters.
- Use **LC/LCL filters** to minimize high-frequency switching harmonics.

3. **Control & Measurement Setup**

- Connect a **microcontroller or DSP** for real-time UPQC control.
- Install **CT/PT sensors** to measure voltage and current.
- Integrate a **PWM controller** for switching signal generation.
- Set up **oscilloscopes and power analyzers** to monitor system performance.

4. **Load Connection**

- Attach **linear loads (RLC circuits)** and **non-linear loads (motors, rectifiers, inverters)** to analyze power quality effects.

- **Software Installation**

Software tools are essential for system simulation, control design, and real-time implementation. The following steps outline the installation:

1. **MATLAB/Simulink Installation**

- Download MATLAB from **MathWorks** and install it.
- Add necessary toolboxes such as **SimPowerSystems** for modeling and analysis.

2. **PSCAD/ETAP Installation**

- Install **PSCAD** or **ETAP** for power flow analysis, transient stability studies, and system simulation.

3. **Proteus/Multisim Installation**

- Install **Proteus** for circuit-level simulation of power electronics components.

- Use **Multisim** for PCB design and validation.

4. **Arduino IDE / Code Composer Studio Installation**

- Download **Arduino IDE** for programming microcontrollers used in the control system.
- Install **Code Composer Studio** for DSP-based real-time control of UPQC.

VI.CONCLUSION

I concluded that Circuit diagram of without facts device system is simulated. Circuit diagram of with STATCOM system is simulated. Circuit diagram of with UPQC system is simulated. Above systems are compared. By using with UPQC system, Output voltage is improved from 1550 V, 1850 V to 2500 V; Output current is improved from 12 A, 13 A to 13.5 A; Real Power is improved from 0.0235 MW, 0.0463 MW to 0.0600 MW; Reactive Power is improved from 0.0378 MVAR, 0.0726 MVAR to 0.0987 MVAR; Output voltage THD is condensed from 9.91%, 7.96% to 5.00% ; Output current THD is condensed from 10.97%, 7.48% to 5.84%. Hence with UPQC system has better performance than conventional with STATCOM and without facts device system. The closed loop PID and fuzzy logic controlled with UPQC systems are modeled and simulated successfully. The time domain parameters are compared with PID and fuzzy logic controllers. The comparison indicates that by using fuzzy logic controller, the rise time is reduced from 1.66 s to 1.62s; the peak time is reduced from 2.20 s to 1.68s; the settling time is reduced from 2.40 s to 1.70; the steady state error is reduced from 1.62V to 0.75V by using fuzzy logic controller. The voltage THD and current THD are compared with PID and fuzzy logic controllers. From that comparison, the voltage THD is reduced from 4.64% to 3.64%; the current THD is reduced from 4.41% to 3.41%. From the above comparison of time domain parameters, voltage THD and current THD the fuzzy logic controller of with UPQC system is advanced than PID controller.

VII. REFERENCES

[1] Lakshmi, G.S.; Rubanenko, O.; Divya, G.; Lavanya, V. Distribution energy generation using renewable energy sources. In Proceedings of the 2020 IEEE India Council International Subsections Conference (INDISCON), Virtual, 3–4 October 2020; pp. 108–113.

[2] Adeagbo, A.P.; Ariyo, F.K.; Makinde, K.A.; Salimon, S.A.; Adewuyi, O.B.; Akinde, O.K. Integration of Solar Photovoltaic Distributed Generators in Distribution Networks Based on Site's Condition. Solar 2022, 2, 52–63. [CrossRef]

[3] Ganthia, B.P.; Barik, S.; Nayak, B. Application of hybrid facts devices in DFIG based wind energy system for LVRT capability enhancements. J. Mech. Cont. Math. Sci. 2020, 15, 245– 256.

[4] Dhua, D.; Yang, G.; Zhang, Z.; Kocewiak, Ł.H.; Timofejevs, A. Harmonic active filtering and impedance-based stability analysis in offshore wind power plants. In Proceedings of the 16th Wind Integration Workshop, Hague, The Netherlands, 12–14 October 2017; pp. 1–8.

[5] Pinto, A.C.; dos Santos Neto, P.J.; Pereira, F.C. Passive Filters Applied to a Small Wind Turbine Based System. IEEE Lat. Am. Trans. 2016, 14, 3291–3298. [CrossRef]