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POWER QUALITY IMPROVEMENT USING UNIFIED POWER QUALITY CONDITIONER IN PV SOURCED STAND ALONE MICRO GRID SYSTEM

[1]Mallikarjuna G D, [2]Dr. G.S.Sheshadri,

[1]Assistant Professor, [2]Professor,

[1]Electrical and Electronics Engineering,

[1]Tontadarya College of Engineering, Gadag, Karnataka, India

Abstract: The electrical and electronic equipments, when subjected to any of the power quality issues, are highly prone to misbehave which leads to the failure of those equipments. This paper analyses the power quality issues and means to improve the power quality in three-phase PV (Photo Voltaic) sourced micro grid using unified power quality conditioner (UPQC). The proposed UPQC comprises of active filter on the shunt side and dynamic voltage restorer on the series side. A integrated control of instantaneous reactive power and synchronous reference frame theories are employed to formulate control reference signals for the UPQC. The simulation results validate the efficiency of proposed UPQC compensated power quality issues such as voltage sag, harmonics, voltage imbalance in the micro grid system. The comparison is made of various individual compensation devices such as shunt active filters , dvr and upqc. The proposed system is simulated in MATLAB/Simulink software.

***Index Terms* - Power quality, Micro grid, Power filters, Total Harmonic Distortion, Renewable Energy**

I.INTRODUCTION

Electricity is a major part of contemporary society. To operate the day to day appliances, electronic and electrical equipments for instance, people require electricity. Because of this, electricity has developed into a crucial service, and its quality directly affects how well electrical devices work and, ultimately, how well people live. As a result, in recent decades, network operators and end users have paid increasing attention to the quality of the power utilized by the electrical system. The two primary types of power quality issues are steady-state issues, including both current and voltage harmonics, and transient issues, like voltage fluctuations, voltage profile, and interrupts [1]. As the usage of adjustable speed drives, variable power supplies and rectifiers in the existing distribution system, current and voltage harmonics are typically regarded as the most severe issues. Distribution networks are subjected to current harmonic injections brought on by nonlinear loads, which subsequently impact the reliability of the system voltage. Also, disruptions caused by the grid fault like voltage swell and sag and voltage imbalance and interruptions are also regarded as expensive power quality issues. Due to material damage and missed production, these disturbances frequently result in the malfunction or interruption of electronic-based apparatus, which results in significant financial losses. Enhancement of voltage stability for the distribution grid has become a necessity due to the serious effects of low power quality. Power filters and customized power equipment can both enhance power quality. Dynamic voltage restorers (DVRs) [2, 8], Shunt active power filters (APFs) [9] and unified power quality conditioners (UPQCs) [3–7] are examples of common custom power devices. The main purpose of shunt APFs is to reduce the harmonics present in the system current due to the presence of nonlinear and unbalanced loads. The DVR, meanwhile, is a voltage compensation device which is connected in series with the system that buffers against voltage disturbances such voltage droop, voltage unbalance, and supply-side voltage distortion. Although the majority of these compensatory devices can only address few or fewer power quality issues, they are nonetheless useful solutions. A sophisticated and potent compensating device called UPQC has recently been created to address the power quality issues concurrently. The UPQC is made up of a unified DC-link capacitor and a pair of series and shunt APFs. To safeguard the sensitive loads present in the distribution system and to enhance the voltage profile, a UPQC can efficiently correct problems with power quality such as voltage and current harmonics, voltage unbalance, and voltage sag or swell. The use of UPQC to optimize power quality at the distribution level has considerably increased over the past few decades due to its promising potential, and numerous studies on UPQC control have been conducted. This study focuses on creating cutting-edge control schemes [10] to enhance the UPQC's compensating performance so that it can efficiently handle a variety of power quality issues.

A PV based micro grid system is designed and provides supply to the non linear loads, unbalanced, loads and subjected to voltage sag, harmonic disturbances, etc. Shunt active filters is added in order to reduce the effects of non linear loads and unbalanced loads and DVR is added to compensate the voltage sag issues. DVR and active filters are combined to form UPQC and used to compensate the power quality issues and the simulation results with the above mentioned compensation devices are compared.

II.POWER QUALITY

Power quality enables an electric energy user to successfully utilize electrical power out from distribution system without disruption or interference. According to the definition given above, "power quality" refers to both the standard of the power delivered by the utility company and the standard of the current used by the end consumer. The quality of the voltage is affected by variations from the ideal voltage.

Similar to this, contemporary standards have to do with how much the present has deviated from the ideal. A solitary sinusoidal waveform represents the optimal current. The load current must also match the supply voltage in phase, which is another criterion.

The following figure represents the distribution system associated with various types of electrical loads.

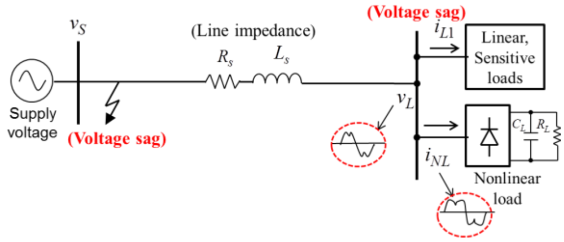

Fig 1. Power Distribution system

The usage of irregular draws harmonic current into the system, which results in load voltage disruptions. Moreover, voltage sagging and unbalance at the load terminal are brought on by grid failures in the main transmission or distribution system.

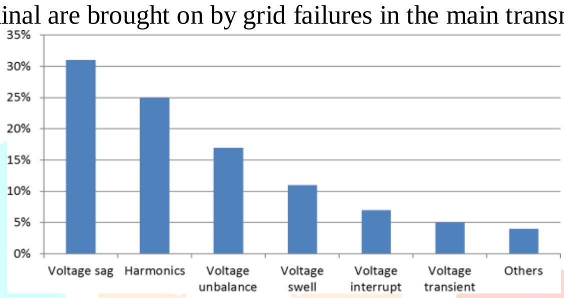

Fig 2. Power quality issues

A. SHUNT ACTIVE POWER FILTER

In power systems at the small to medium voltage distribution system, shunt active filters (APFs) is frequently recognised as a versatile and acceptable solution for balancing harmonic currents and reactive power. In order to verify that any supply currents (iS) only contain the fundamental component, a shunt APF is used to inject currents (iF) with same amplitude and the phase opposite to that of harmonic current flow in the distribution system.

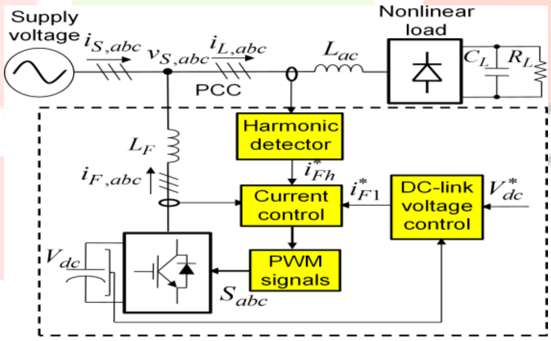

Fig 3. Shunt Active Filter

Voltage/current monitoring, harmonic detection, production of reference signals, regulation of DC voltage, shunt active filter current, and pulse generation unit formulates the control unit. When it comes to the harmonic detection stage, filters like high-pass, low-pass, adaptive filters, and complicated mathematical functions are frequently used.

B. DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer (DVR) is used to improve the load voltage profile of the system by regulating the system voltage. gate signal production are the major components of a DVR's control system. It induces voltages of the appropriate magnitude & phase in a series with the source voltage to reduce voltage disturbances. DVR does not consume or give real power while in standby mode. The source voltage feed-forward with in d-q reference frame has been designed in conjunction with the standard PI controller to address voltage sags in the DVR system. Nevertheless, the device itself can only really address voltage-related issues; current harmonic issues cannot be resolved.

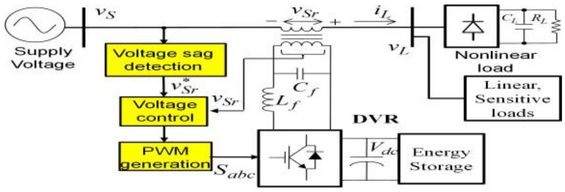

Fig 4. Dynamic Voltage Restorer

C. UNIFIED POWER QUALITY CONDITIONER

A UPQC has the ability to correct voltage distortions on the supply side along with current harmonics on the load side, resulting in pure sinusoidal voltage and current at the load and the supply. To get a UPQC to function well in terms of

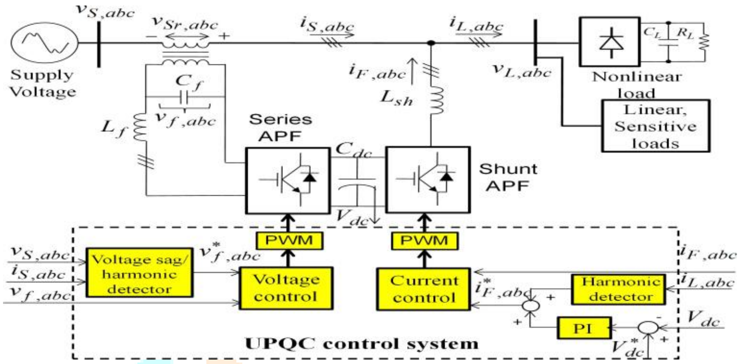

Fig 5. Unified Power Quality Conditioner

compensation, the control technique is crucial. Two distinct control strategies should be devised for these two converters since the UPQC is made from two different converters, the shunt as well as the series APF, each of which plays a different control target. This is a diagram of a typical UPQC control system, which includes the following steps:

Series APF control: In this, the reference voltage is generated and compared with the load voltage and the error is provided to controller which generates the pulses for the voltage source inverter which is connected in series with the system. Depending on the error voltage, the inverter injects the voltage to the system.

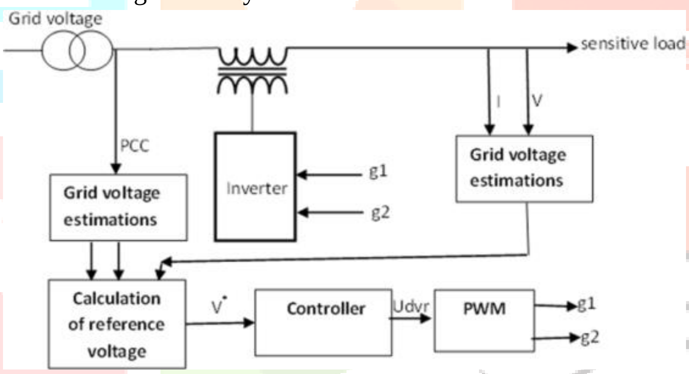

Fig 6. Series active filter control

Shunt APF control: Voltage sag monitors and voltage controllers determine how well a UPQC compensates for voltage sags. To assure that UPQC can promptly identify and react to voltage sags, voltage sags must be recognized properly and without any delay. Voltage sag is often detected by observing the supply voltage's magnitude with in fundamental (d q) reference frame. A voltage standard for UPQC is generated after detecting various voltage sag, as well as the voltage controller is then put into action to make sure that load voltage is not tampered with. Hence, in order to obtain a quick transient response and strong steady-state behavior of the voltage output during voltage sags, the voltage regulator also has an important function in a UPQC control system. The harmonic currents are extracted based on the traditional PQ Theory as provided in Fig 7. In a symmetrical three-phase system, the extraction process is essentially realized across a series of mathematical computations of Instantaneous Power. All of the three-phase signals required in the calculations are first translated into the - domain using a mathematical transformation described by the matrix given as

$$[M] = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta_1(t) & \cos\theta_2(t) & \cos\theta_3(t) \\ \sin\theta_1(t) & \sin\theta_2(t) & \sin\theta_3(t) \end{bmatrix}$$

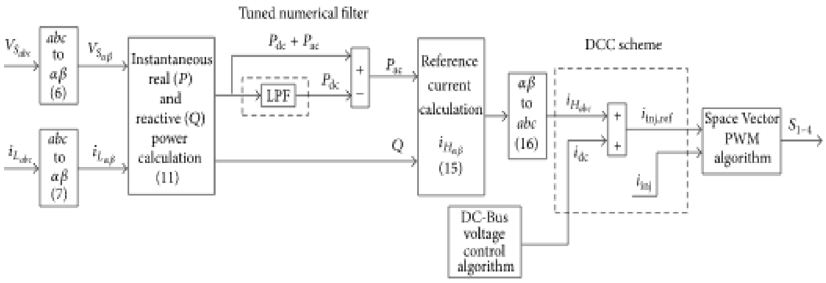

Fig 7. Controller block diagram for Shunt Active Filter

The three-phase quantities are converted into their respective *α*-*β* coordinates using Clarke-transformation which is provided below

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix},$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix},$$

The power is measured and represented in *α*-*β* coordinates is provided below

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}.$$

The harmonics can be extracted by obtaining the power oscillations as shown in the following equation

$$P_{ac} = P - P_{dc}.$$

The real and reactive power can be expressed as below after the harmonics are extracted

$$\begin{bmatrix} P_{ac} \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{H_\alpha} \\ i_{H_\beta} \end{bmatrix}$$

The reference injected current is calculated using the inverse Clarke-transformation which converts the *α*-*β* coordinates to three-phase quantities as provided below

$$\begin{bmatrix} i_{H_a} \\ i_{H_b} \\ i_{H_c} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{H_\alpha} \\ i_{H_\beta} \end{bmatrix}.$$

The generated reference current is provided to hysteresis control and pulses are generated accordingly.

The Simple hysteresis band (SHB) is calculated using the following relation:
SHB= $(1/8fL_f)*(Vdc-(4*Vg^2(t)/Vdc))$

III.SIMULATION RESULTS

The simulation parameters are provided in the following table 1:

Table 1: Simulation parameters

Parameters			Values
PV SOURCE	Voltage		120 V
	Power		90 KW
	BOOST CONVERTER	Inductor	58 µH
		Capacitor	2.2 mF
		Switching Frequency	10 KHz
Load	Voltage		415 V
	Frequency		50 Hz
Load Arrangements	Linear Loads	ABC	50 KW
	Non Linear Load	R	10Ω
	Unbalanced Loads	Phase - A	15Ω
		Phase - B	8Ω
		Phase - C	12Ω

The simulation circuit without any compensation devices is provided below:

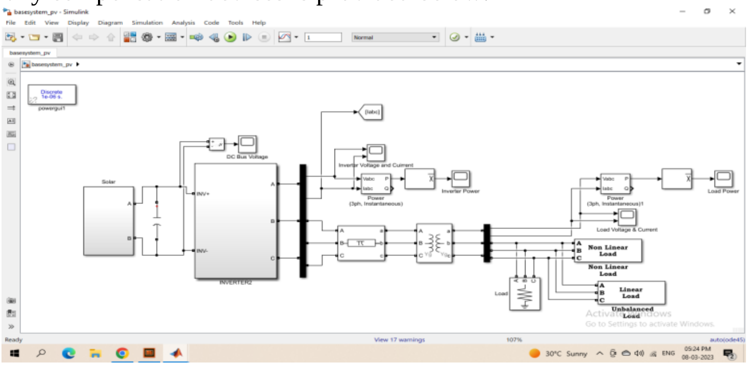

Fig 8. Simulation circuit of Base system

The PV source is connected to the boost converter and provided to inverter. The inverter supplies the load. The unbalanced load is disconnected initially until t=0.7s. The PV power reduced as the irradiation reduced from 1000W/m2 to 900W/m2 at t=0.8s and recovered at t=0.9s. The PV voltage, current and power is provided below:

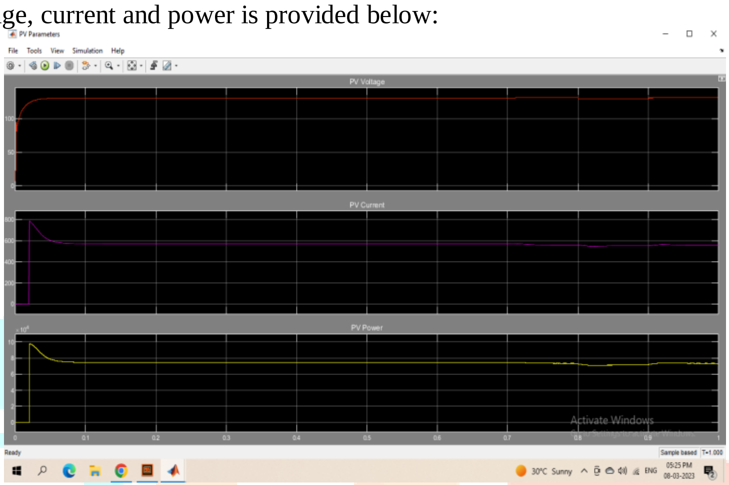

Fig 9. PV Voltage, current and power

Due to the changes in irradiation, the PV power slightly reduced at t=0.8s and recovered at t=0.9s. The load voltage and current is provided below:

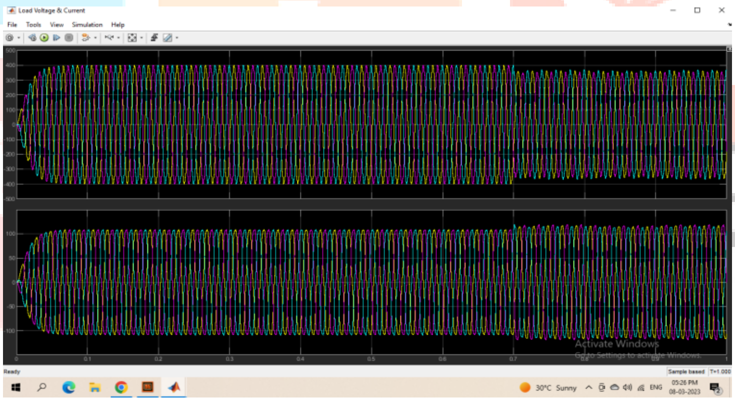

Fig 10. Load voltage and current

In this due to the inclusion of additional load at t=0.7s and reduction in PV power generation at t=0.8s, the load voltage is reduced. The same is reflected in the load power curve as shown below:

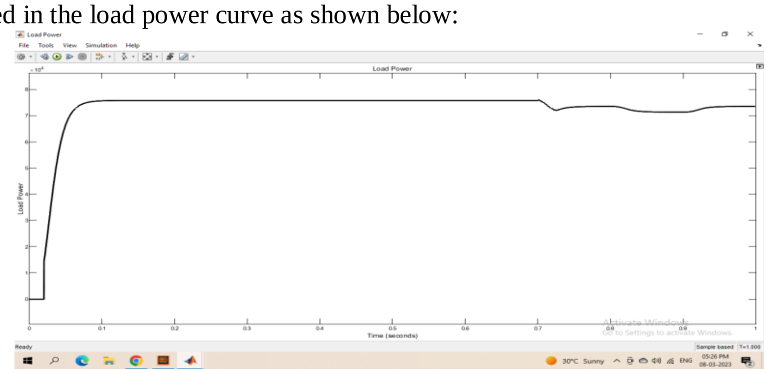

Fig 11. Load power

The %THD of the load current is provided below:

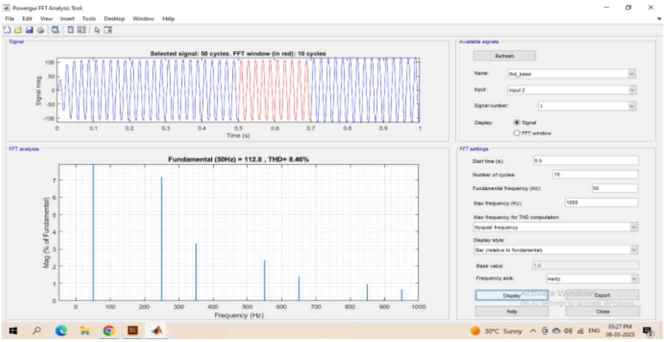

Fig 12. %THD of load current without compensation

The %THD of the load current is around 8.46% which is higher than the IEEE recommendations. The simulation circuit of the base system with dvr is provided below:

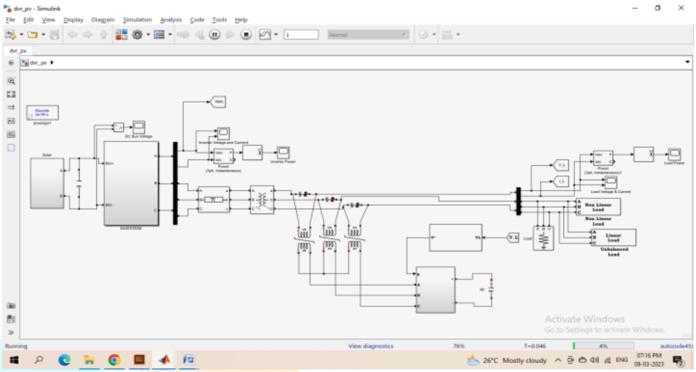

Fig 13. Simulation circuit of Base system with DVR

The control circuit of the dvr is provided below:

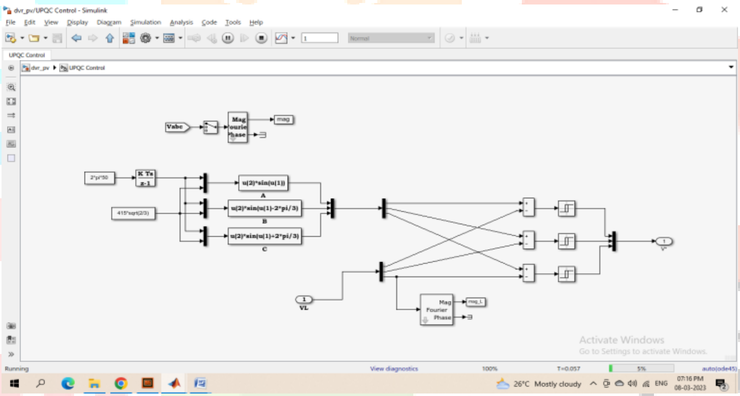

Fig 14. Control circuit of DVR

In this, the reference voltage of amplitude 415V and frequency 50 Hz is compared with the load voltage and the error is provided to hysteresis control which generates the pulses for the voltage source inverter which is connected in series with the system. The load voltage and current with dvr is provided below:

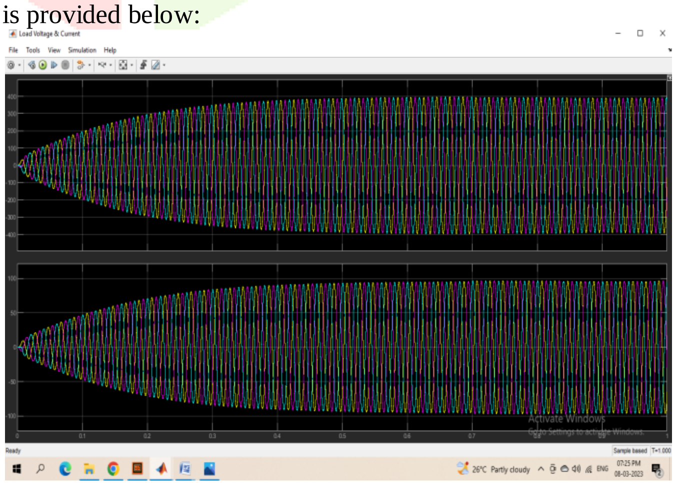

Fig 15. Load voltage and current with DVR

In this, the load voltage is regulated by the dvr and the voltage sag is removed. The %THD of the load current with dvr is provided below:

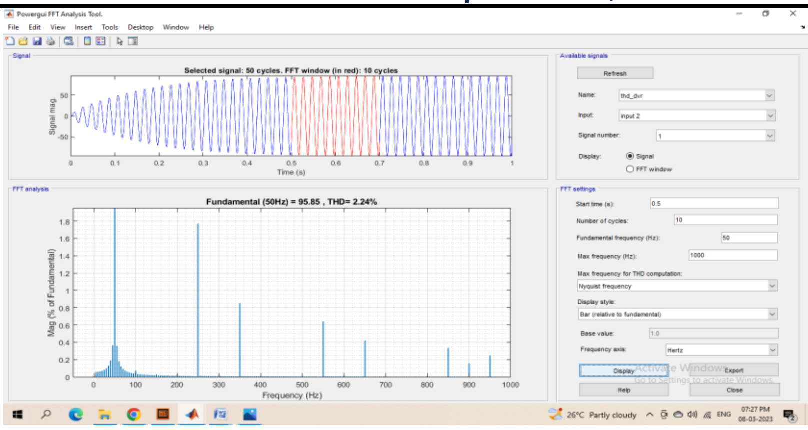

Fig 16. %THD of Load current with DVR

The %THD of load current with dvr is around 2.24% which is 4 times lesser than that of base system without compensation devices. The simulation circuit of the base system with shunt active filter is provided below:

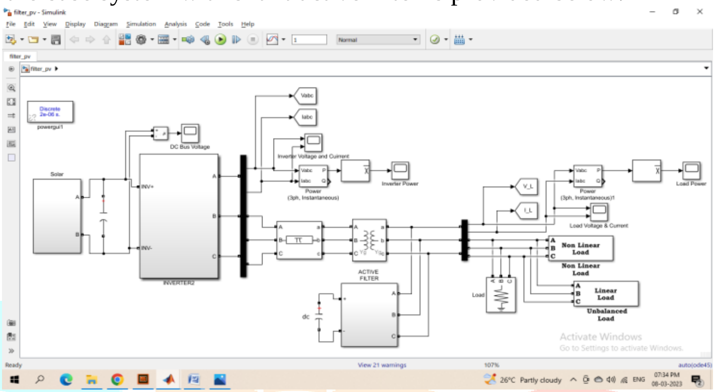

Fig 17. Simulation circuit of Base system with APF

The control circuit of the active filter is provided below:

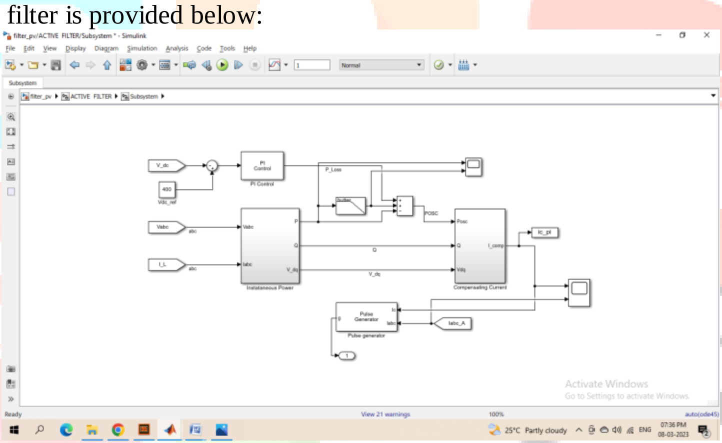

Fig 18. Control circuit of APF

In this, the reference dc voltage of amplitude 400V is compared with the measured dc voltage and the error is provided to PI control which generates the Power loss which is again compared with measured power oscillations in order to generate the power compensation signal which is used to generate reference compensation current and compared with output filter current and the error current is provided to hysteresis control which generates the pulses for the voltage source inverter which is connected in parallel with the system. The load voltage and current with filter is provided below:

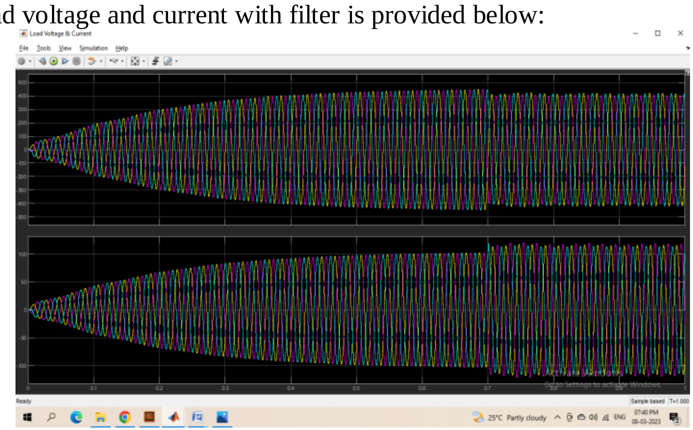

Fig 19. Load voltage and current with APF

In this, the load current is regulated by the filter current and the oscillations are reduced. The %THD of the load current with shunt active filter is provided below:

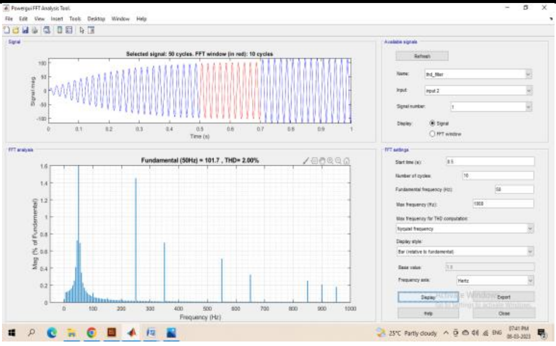

Fig 20. %THD of Load current with APF

The %THD of load current with filter is around 2% which is 4.25 times lesser than that of base system without compensation devices. Both dvr and shunt active filter is combined to form upqc and connected to the base system was shown below:

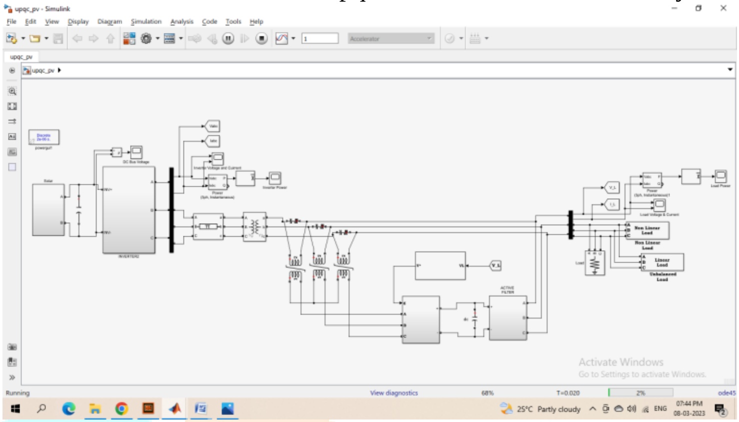

Fig 21. Simulation circuit of Base system with UPQC

The load voltage and current with upqc is provided below:

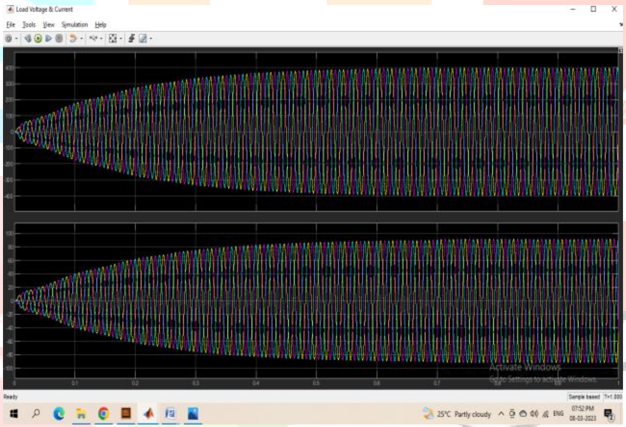

Fig 22. Load voltage and current with UPQC

In this, the voltage sag is removed as well as the oscillations in current waveforms are minimized. The %THD of the load current with upqc is provided below:

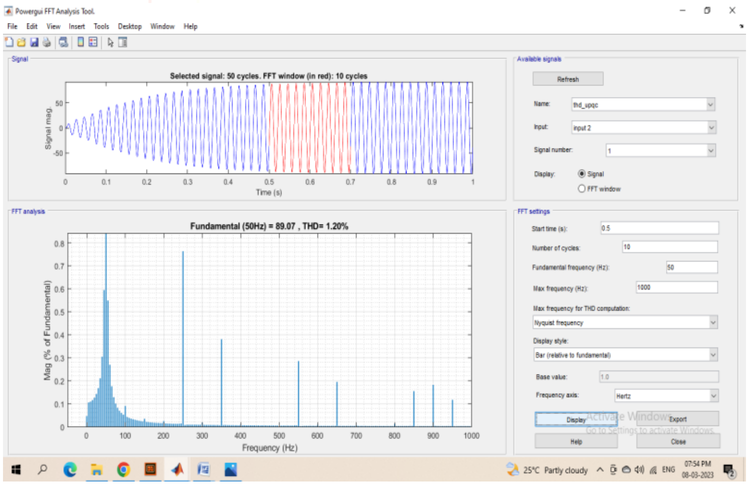

Fig 23. %THD of Load current with UPQC

The %THD of the load current with upqc is around 1.2% which is nearly 7 times lesser than that of base system without any compensation devices. Table 2 shows the Comparison of simulation results.

Table 2: Comparison of simulation results

Models Parameters	SPV Base System subjected to load	DVR Filter	APC Filter	Proposed UPQC Filter
Voltage	Voltage Oscillation	Voltage sag removed	---	Voltage regulated
Current	Current Oscillation	---	Load current harmonics reduced	Load current regulated
THD%	8.46	2.24	2	1.2
Performance Evaluation	---	4 times lesser than base value	4.25 times lesser than base value	7 times lesser than base value

IV.CONCLUSION

A PV sourced base system is designed and subjected to voltage sag/harmonics using non linear and unbalanced loads. Various devices such as DVR, APF and UPQC are designed to provide the required compensation to improve the load profile by reducing the harmonics and regulating the load voltages. The DVR regulates load voltage but the APF provides better solution in reduction of harmonic currents compared to DVR. These devices are combined to form UPQC which provides better voltage regulation and also minimized the harmonics present in the load current and most suitable for improving the power quality of the proposed system.

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