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A Unified Power Quality Conditioner(UPQC) in Distribution Network

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ABSTRACT

Inutility systems andindustry, electrical power quality is critical.The widespreaduse ofpowerelectronicequipment withnonlinearloadsinresidential,commercial,andindustrialsettingsdistortsthewaveformsofvoltageandcurrent.Studieson power quality are becoming more and more important as power electronic-based loads are used in industry. Industrial loads become less resilient to power quality issues such as voltage dips, sags, flickers, harmonics, load imbalance, real and reactive power issues, etc.because electronic devices are highly susceptible to disturbances. In addition to these, the system now has additional power quality issues that lower the system's overall efficiency. Suppliers and customers typically experience direct financial effects from the quality of the power. Problems with power quality are caused by rising customer demands. Power quality issues like voltagesag, swell, harmonics, and voltage interruptions may have a serious negative technical and financial influence on a large number of consumers. The primary subject of this essay is UPQC. Power quality concerns such as harmonics, sags, swells, imbalances in power sources or loads, and poor power factor can be eliminated or lessened by using unified power quality conditioner (UPQC), which function as controlled voltage and current sources in power systems. This paper present a new algorithm to generate the reference signals to control the series and parallel power inverters in "UPQC" to enhance power quality. The algorithm is based on theinstantaneous power tensor formulation which it is obtained by the dyadicproduct between the instantaneous vectors of voltage and current in n-phase systems. The model was tested by means of simulations in Matlab-Simulink.

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I. INTRODUCTION

Power Quality (PQ) has emerged as a critical concern for the continuous operation of sensitive equipment, particularly whens uch equipmentis interconnected in more severe industrial processes and networks. As power electronics areusedmoreoften, PQis becomingmoreandmore important.Nowadays,alotofequipmentis vulnerable to malfunctions or damage during low PQ events. For equipment that is more susceptible to disturbances, PQ monitoring is required (IEEE Standard 1346–1998,1998). These days, distribution systems frequently employ sensitive and non-linear loads that are based on power electronic devices. This leads to power quality issues like voltage and current imbalances, flickers, harmonics, and imbalances. Issues with the power system, like voltage spikes or falls, may result in Digital gadget malfunctions and other delicate loads. There is only one power quality stabilizer, according to recent techniques and equipment for improving power quality named unified power quality Conditioner (UPQC). An all-inclusive fix for any voltage and current-related issue. The results of tuning experiments were first published in 1998, but it has been presented for a while. Active power filters (APFs) that are shunted and connected in series are arranged closely together to form the UPQC. A common DC link capacitor connects them. In order to compensate for the load current harmonics, the APF in the UPQC is connected in parallel with the load [4-11].

The degree to which a power supply system's voltage, frequency, and waveform adhere to predetermined standards is known as electric power quality. A steady supply voltage that remains within the allowed range, a steady AC frequency that is near to the rated value, and a smooth voltage curve waveform which resembles a sine wave are characteristics of good power quality. Power quality can generally be defined as the compatibility of the load plugged into an electric outlet and what comes out of it. The phrase refers to the electric power that powers an electrical load and the suitability of the load for its intended use. An electrical device (or load) may malfunction, fail early, or not operate at all without the right power. There are numerous ways that electricity can be of low quality, as well as numerous reasons why it could be. The electricity industry consists of the production of alternating current (AC) power, its transmission, and finally its distribution to an electricity meter placed on the end user's property. After then, the electricity travels via the end user's wiring system to the load. There are numerous opportunities for the quality of supply to be compromised due to the complexity of the system used to transport electric energy from the point of production to the point of consumption as well as variations in weather, generation,demand,and other factors[2].

II. DIFFERENTAPPROACHESTOREDUCEPOWERLOSS

Power electronics-equipped gadgets are now the most crucial part of the modern distribution system. They have numerous advantages, but they also have numerous drawbacks. They draw harmonic current, which contaminates the distribution system, along with the fundamental power frequency.The concept to flexible AC Transmission Systems (FACTS) has been implemented to offer customized solutions for the new challenges placed on distribution systems. The control ability and power exchange capacity of the transmission framework are enhanced by these FACTS devices. One method uses self-commutated switching converters to control reactive and active power, while the other uses conventional thyristor switched capacitors (TSC) and thyristor switched reactors (TSR). Thesecond plan, however, can be used to offset voltage and current harmonics. Both plans contribute to the effective regulation of real and reactive power. Moreover, self-commutated switching converters provide better response times and more compensation flexibility [3].

2.1 StaticVarCompensator

There are several compensators in use, such as SVC, TSC, TCR, STATCOM, and others. Through the generation and absorption of reactive power by passive components like resistors and capacitors, static VAR compensators (SVC) regulate the AC voltage. In addition to the passive components, anti-parallel thyristors are the main components of SVC. The reactor in the case of a thyristor-controlled reactor and the capacitor if the capacitor is thyristor-switched constitute the passive elements. The primary issue with using SVC is that the size of the passive element limits the reactive power that the SVC can handle [8].

2.2 STATCOM

Among all the FACTS devices, STATCOM is one of the most notable. It offers a better response and could have a voltage source converter or a current source converter. It enhances stability and aids in keeping a healthy voltage profile. It can be referred to as D-STATCOM if we use it in the distribution system, i.e., the STATCOM distribution. It is primarily composed of an inverter circuit, an inductor, a capacitor that serves as a DC source, and a control circuit for the generation of reference current. D-STATCOM functions as a current source and aids in load harmonic compensation. Furthermore, it offers numerous other benefits such as balancing the source current, preventing DC offset in the load, and assisting the load in operating at a power factor of unity [2].

2.3 DynamicVoltage Restorer

In series compensation, a dynamic voltage restorer (DVR) operates. It is made up of a voltage source inverter that is connected in series with the supply line to help achieve a specific load voltage. When the VSI is conducted using an external DC voltage source, the DVR can be employed for voltage harmonic compensation, load voltage management, and voltage imbalance compensation [2].

2.4 ActivePowerFilter

Due to their excellent performance in addressing power quality problems in the distribution system, active power filters are also frequently utilized. These active power filters (AF) come in parallel and series configurations, as well as in combination with each other, i.e., referred to as the active hybrid power filter. Whereas shunt active power filters primarily address the compensation of harmonics in the load current, series active power filters primarily assist in the mitigation of harmonics in the voltage [3].

2.5 UPQC

UPQC is essential for improving the quality of power in the given context. It offers the benefits of both series and parallel active power filters. Because UPQC is a multipurpose power conditioner, it can be used to counteract a variety of voltage disturbances, voltage flicker, and harmonics in the load current. It also prevents harmonics from entering the power system and lowering power quality. This specialized power equipment is capable of mitigating issues that interfere with the operation of delicate machinery or loads. In addition to controlling power flow and mitigating voltage disturbances like voltage swell and sag, UPQC compensates for harmonics in both current (shunt part) and voltage (series part). The shunt inverter, series inverter, DC link capacitor, shunt coupling inductor, and series transformer are the main components of the unified power quality conditioner [3].

III. UPQCCLASSIFICATION

UPQC can be classified in two ways: based on physical structure and based on voltage sag compensation.

3.1 Based on physical structure

It can be furthersubdivided into three groups as follows [3].

(a) Based on converter topology, the converter used can be either:

- VSI (Voltage Source Inverter): Shares a common DC link capacitor. This is widely employed because it has low costs, minimal losses, and can also be used in the case of a multi-level inverter.
- CSI (Current Source Inverter): The DC link is formed by an inductor. This is not frequently used since it has a high loss rate.

(b) Based on Power Supply System: It can either use a single-phase supply or a three-phase supply.

(i) Single Phase:

- 2H bridge: It has a total of eight switches and is the most familiar configuration.
- 3-leg topology: It has 6 switches in total. It can be used for operations demanding lower cost and power.
- Half bridge: It uses the minimum number of switches, i.e., 4 switches. The reduction in the number of switches also has an impact on the level of compensation.

(ii) Three Phase:

- Three-wire: This is the most commonly used. It can be applied in arc welding, frequency converters, etc.
- Three-phase 4-wire: This type of wire is frequently utilized in industrial settings. A higher and better degree of compensation is required due to the additional neutral wire that is present. It can have several configurations, including a two-capacitor, three-half bridge, and four-inductor setup. The fourth leg of a shunt inverter adds to the load neutral current compensation in a four-inductor configuration, while two split capacitors function as a DC link in a two-capacitor configuration.

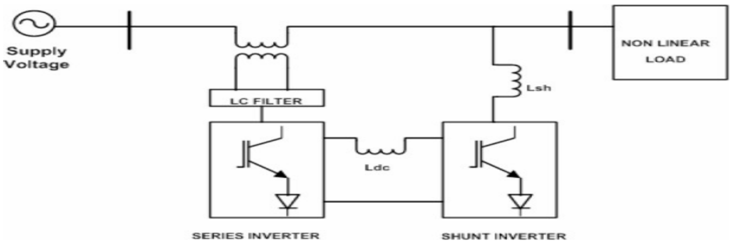


Figure1:CSI based UPQC

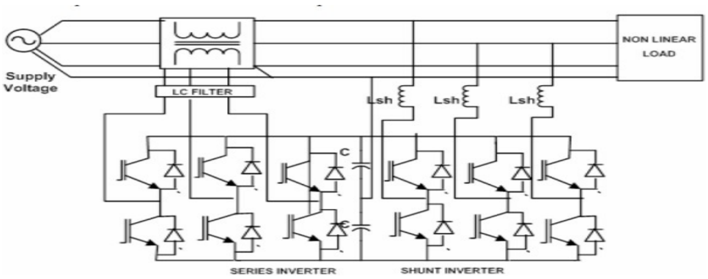


Figure2:Three Phase Four Wire UPQC

(c) Based on UPQC Configuration: There are five main types of UPQC configuration, which are explained below:

- Right and Left Shunt UPQC: The basis for this kind of UPQC is the parallel converter's orientation with respect to the series converter. A shunt converter placed on the right side of the series converter is referred to as UPQC-R, and a converter placed on the left side is referred to as UPQC-L. The one that is most commonly used is UPQC-R. It performs better when compared to the UPQC-L. UPQC-L is appropriate in a few particular circumstances.

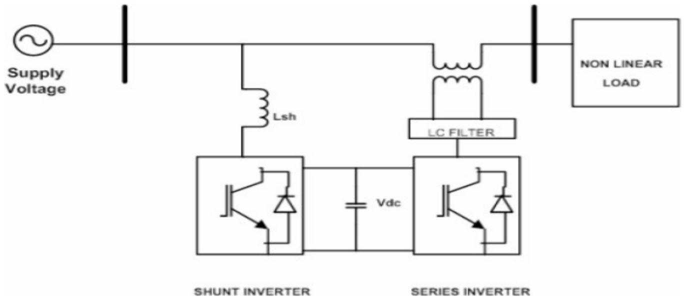


Figure3:UPQC-L

- Interline UPQC: In this case, two distribution feeders are separated by shunt and series inverters. One UPQC is connected to the first feeder in series, and the other is connected to the second feeder in parallel. In this manner, both feeders benefit from efficient voltage control. However, it also has certain drawbacks, so it should only be applied in specific situations.
- Modular UPQC: It is an H-bridge inverter module connection between multiple modules. The H-bridge inverter modules in the shunt part are connected in series with the transformer, while the distribution transformer can be connected directly to the series part without the need for a series transformer.
- Multilevel UPQC: Utilized to increase power levels. Depending on what is needed, it can have different levels. Three, five, seven, and other MLI (Multilevel Inverter) levels are typically realized. Although power level rises with level count, there is a drawback as well. The harmonic content rises in tandem with the number of levels.
- Multi-converter UPQC: There are three inverters used here. To help the DC capacitor voltage, a third inverter is employed. There are multiple methods for connecting the third inverter.

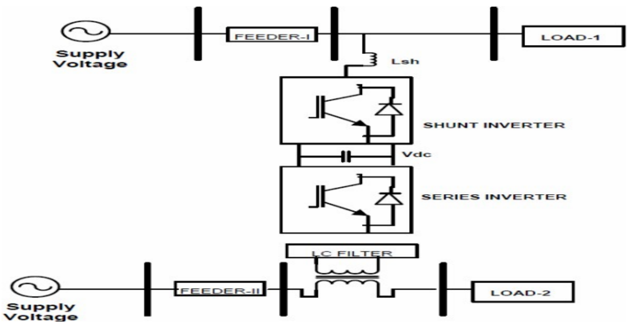


Figure4:Interline UPQC

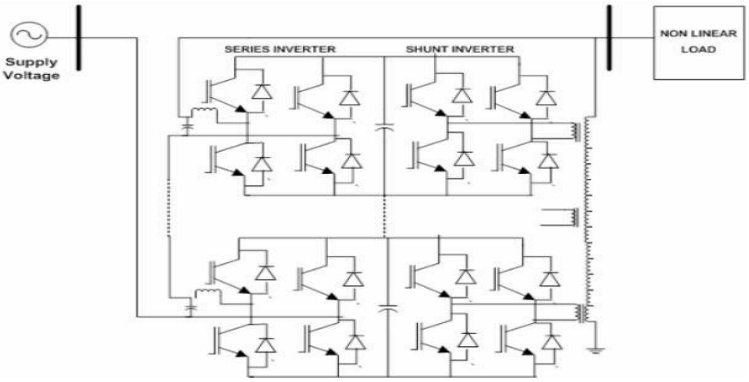


Figure5:Modular UPQC

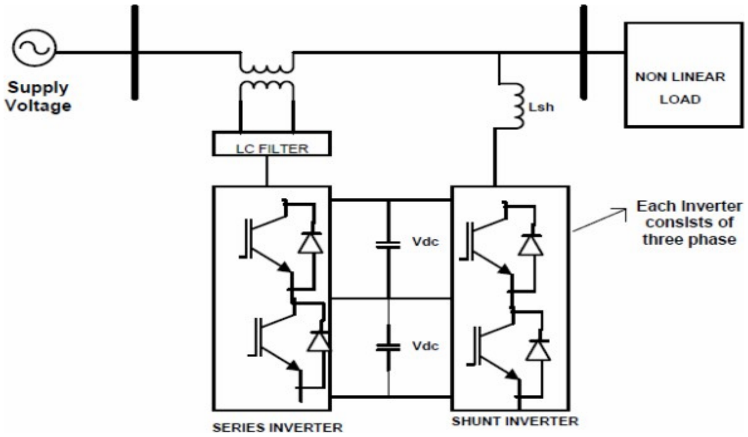


Figure6:Multi level UPQC

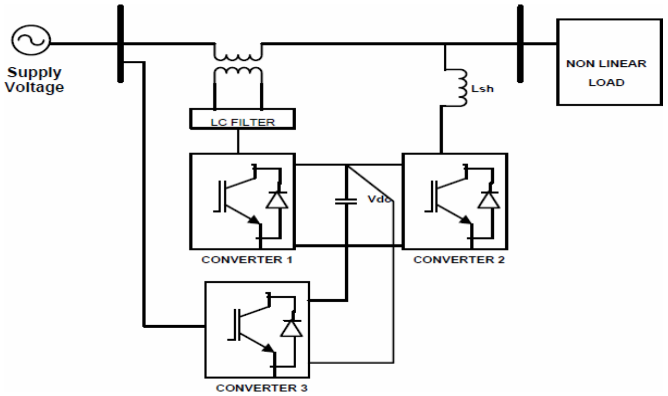


Figure7:Multi-ConverterUPQC

3.2 Based on Voltage Sag Compensation

- UPQC-VAmin: This is a UPQC loaded with a minimum voltage ampere. Its purpose is to reduce the voltage-ampere loading while performing compensation. In this instance, the voltage is injected at a specific angle to the current.
- UPQC-P: This is a type of UPQC that uses active power control to mitigate voltage sag. A voltage component is injected in series with the AC line. In this instance, the difference between the load and the current voltage is the voltage component that is injected into the system.
- UPQC-Q: This type of UPQC controls reactive power by using reactive power to lessen voltage sag. In this case, injecting a quadrature voltage is the main idea. However, UPQC-Q has the drawback of raising the series inverter's rating.
- UPQC-S: It provides control over reactive and active power simultaneously. A series inverter can be used efficiently in this system. Because of its somewhat challenging control, if the control is digital, it is utilized extensively [3].

IV. UNIT VECTOR TEMPLATE GENERATION

Unit vector template generation is the control technique applied here. In this instance, unit vector templates are extracted from the distorted supply voltage. In addition to the fundamental component, the distorted input source voltage also has harmonic components. In order to extract these unit vectors, the supply voltage must first be measured. Then, the gain (1/Vm) must be calculated, with Vm representing the peak fundamental supply voltage. Following this, a phase-locked loop is used to create vector templates for the units.

$V_a = \sin\omega t$

$V_b = \sin(\omega t-120)$

$V_c = \sin(\omega t+120)$

The supply voltage is then multiplied with the unit vector templates to generate the reference load voltage. The reference load voltage generated is given by V_{abc}.

$V_{abc} = V_m \cdot U_{abc}$

Subsequently, a comparison is made between the actual and reference load voltage. The series inverter's gate pulse is generated by calculating the error and sending it into a hysteresis band. To correct for current harmonics, a shunt active power filter is employed. Once the shunt inverter DC link voltage pulses have been generated, they are measured and compared to the reference DC link voltage. Unit vector templates are used to multiply the results of the error processing by a PI controller, which then generates the reference current. The creation of gate pulses for the parallel inverter circuit is completed. The reference and actual source currents are compared, and the error is processed using a hysteresis band controller.

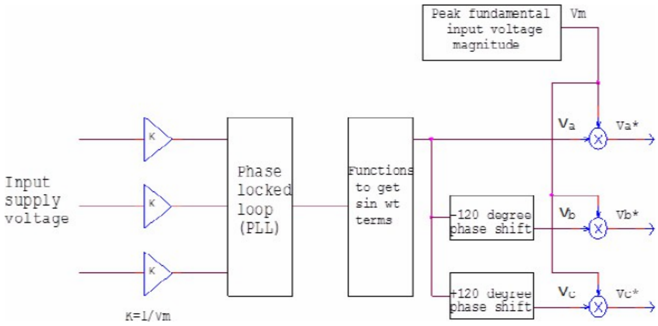


Figure8: Generation of Unit Vector Templates and Reference Load Voltages

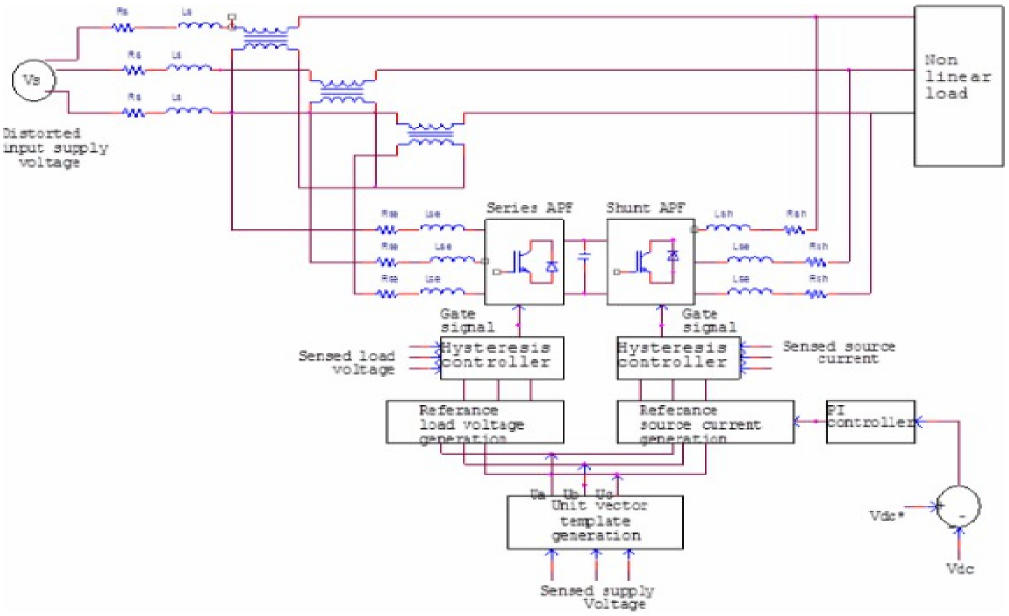


Figure9: Overall Circuit Configuration of UPQC 4

4.1 Control Method for Active Filter

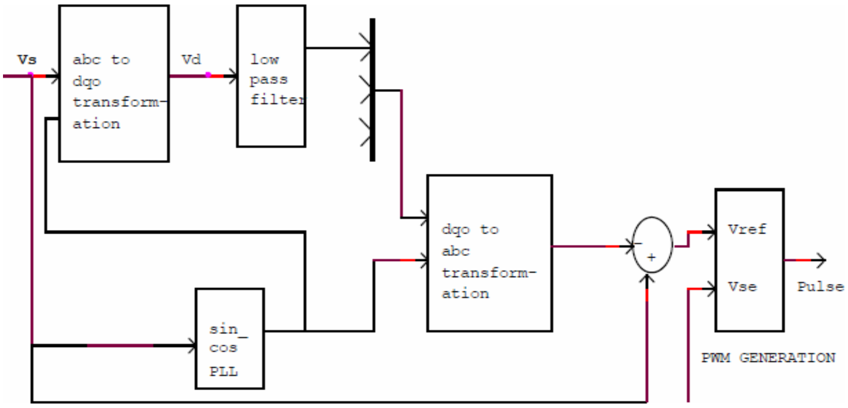
SAF (Series Active Filter) is used to control the source-side voltage aggravation. By comparing the positive-sequence component of the source voltage with the source voltage, this method determines the reference voltage that the series transformers must infuse. The following equation illustrates how supply voltage and load current are transformed into d-q coordinates and serves as an example of the reference generation calculation for SAF.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} \quad \text{......} \ (1)$$

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} \quad \text{.......} \ (2)$$

The d-axis voltage contains harmonics in addition to the fundamental component. The harmonic components are filtered out using a second-order low-pass filter (LPF). This is followed by an estimation of the reference voltage V_{ref} using the d-q to a-b-c transformation. Subsequently, a hysteresis band controller receives the output of the series active filter along with the generated reference voltage, which produces the gate pulses.

Figure 10:Control Algorithm for SAF



4.2 Control Method for Shunt Active Filter

For calculating the reference current, the P-Q methodology has been utilized. Clarke's transformation, given in equations (1), (2), (3), and (4), is used for the transformation of reference voltages generated at SAF and load current into α-β-0 coordinates.

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad \text{.......} \ (3)$$

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad \text{.......} \ (4)$$

Equation(5) is used for the calculation of real power and imaginary power in the Source side.These are instantaneous power-

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad \text{.......} \ (5)$$

For compensating reactive power and the harmonic component, real power is taken as the reference and the source current reference can be calculated by Equaion(6).

$$\begin{bmatrix} Is\alpha * \\ Is\beta * \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} P + \Delta P \\ 0 \end{bmatrix} \quad \text{.......} \ (6)$$

$$\text{Where} \quad \Delta P = Po + Ploss$$

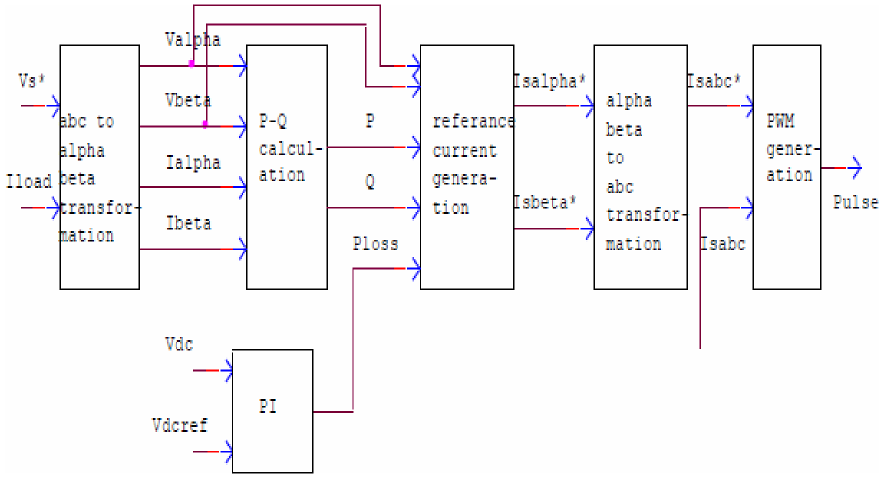


Figure11: Control Algorithm for PAF

Due to the absence of unbalance, the power PPP is zero. A comparison of the measured and reference DC-link voltage is done, and a Proportional-Integral (PI) controller is used for processing the error produced. The main reason for using this controller is that it helps in reducing the steady-state error to a zero value. The PI controller's output is termed as P_{loss}. Then, the reference source current is converted to the a-b-c frame of reference using Equation (7).

$$\begin{bmatrix} Isa* \\ Isb* \\ Isc* \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Is\alpha * \\ Is\beta * \end{bmatrix} \quad ...... (7)$$

Finally, the comparison of these currents and the actual source current is done with the help of a hysteresis band controller, and gate pulses for the shunt active power filter are generated.

V. SIMULATION RESULTS

Figure 12, which shows the power supply's single-phase waveform and the RMS value over the course of the simulation, is heavily contaminated by harmonics, demonstrating how current loads can distort source impedances. Additionally, a three-cycle voltage sag is demonstrated to confirm that the algorithm is capable of compensating for these network transients. In this instance, we've modeled a 30% decline in the RMS value.
The UPQC operates in four time intervals:

1. The first three cycles: No voltage or current compensation is applied.
2. The second time interval (starting at the fourth cycle): Only voltage compensation is activated. During this range, the series active filter isolates the load by compensating for harmonics. It is observed that the series filter's compensation voltage rises to make up for the voltage dip at the point where it is generated.
3. The next interval (beginning on the sixth cycle): Both reactive power and harmonic compensation are enabled. In this instance, the parallel inverter injects the necessary compensation current to remove harmonics produced by the load and to deliver power factor correction to the unit.

It is evident from the reference signals that an increase in the voltage signal reference offsets the length of the voltage sag time.

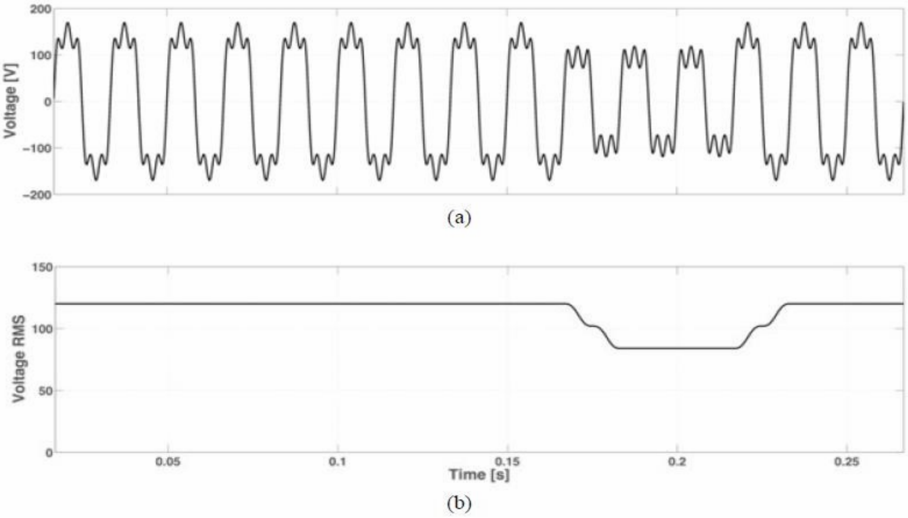


Figure12:(a) Supply's Single-Phase Waveform (b) RMS Value over the Course of Simulation

In Figure 13, the active and reactive power measurements are presented at the point of common connection (PCC). In this figure, it is noted that by performing voltage compensation, the ripple of the active and reactive power is decreased. Consequently, the reactive power and the oscillating part of the active power are removed. At the time of the voltage sag, one component of active power and reactive power oscillates due to the lack of compensation current produced by harmonics, resulting in limited power in the distributed generator.
Table 1 presents the most important simulation results before and after compensation and during the voltage sag.

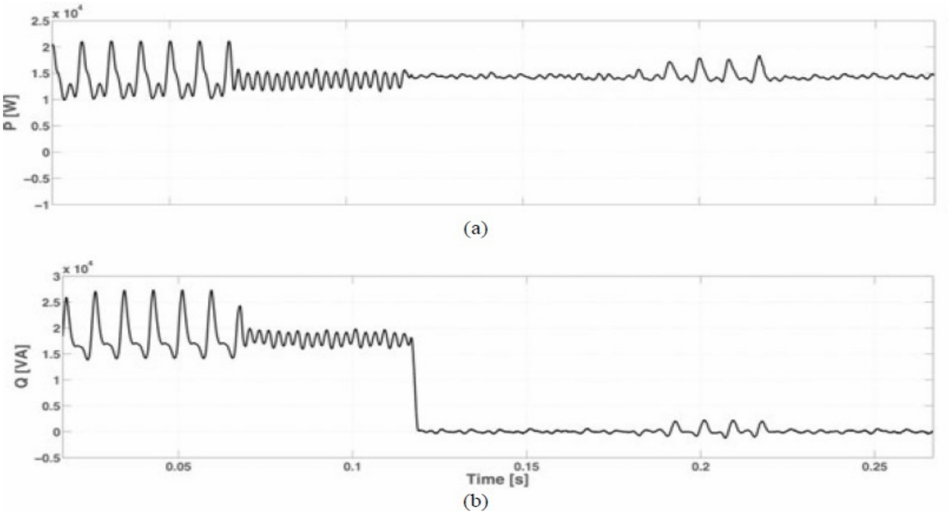


Figure13: Power at PCC (a) Active (b) Imaginary Power

Index	Before compensation	Aftercompensation	DuringSAG
RMScurrent	65A	40A	50A
RMSvoltage	120V	120V	84
THDv	15.70%	5.32	5.7%
THDi	25.72%	2.80	3.8%

VI. CONCLUSION

The control method for Unified Power Quality Conditioners (UPQCs), which combines shunt and series Active Power Filters (APFs), is presented in this paper. This paper discusses a control strategy based on unit vector template generation, concentrating on the mitigation of voltage harmonics in the utility voltage.

The classic discrete control model was applied in a three-phase power grid with harmonic distortion and imbalance in the power source. A new algorithm was developed to generate the reference signals to control the series and parallel power inverters in a UPQC to enhance power quality. Through unit vector template generation (UVGT), the Perfect Harmonic Cancellation (PHC) algorithm used to estimate the current reference in a shunt active power filter was modified to make it resilient to voltage sags. The voltage reference for the series active power filter is extracted from the same algorithm.

The findings demonstrated that both series and shunt APFs were effective in raising the power factor and filtering the source's voltage harmonics and the load's current harmonics. The algorithm's ability to compensate for transients was demonstrated when the power compensator successfully isolated the load from a voltage sag produced at the source.

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