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Enhanced Instantaneous Reactive Power (PQ) Theory Based Control of DVR for Compensating Extreme Sag and Swell

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ABSTRACT: - In today's power system, power quality is a critical topic having several impacts on customers and utilities. In the current electric power system, the integration of renewable energy sources, smart grid technologies, and significant usage of power electronics equipment has generated a slew of issues. The sensitive equipment might be damaged by harmonics, voltage sag, and swell. These devices are vulnerable to Interference with other elements of the system resulting in input voltage changes. As a result, in the contemporary period, Power quality is becoming more important as the number of sensitive and costly electronic devices grows. To overcome the challenges of non-standard voltage, the Dynamic Voltage restorer (DVR) device has been extensively utilized to keep the load voltage stable. To have a dynamic and fast response of the DVR a modified instantaneous reactive power (PQ) theory is proposed to control DVR under extreme transient voltage circumstances. The proposed technique is based on the extraction of the positive sequence component of grid voltage and the negative sequence component of load current for generating a voltage reference signal. The power system network with the proposed PQ control scheme is investigated and assessed under various scenarios to compensate for severe balanced, unbalanced (voltage sags and swells), and load change. MATLAB/Simulink is used to verify the mathematical models of the conventional PQ and proposed PQ control system for DVR. The complete system is implemented experimentally using ads PACE 1104 based laboratory system to validate the presented control scheme. The simulation and experimental results are correlated, demonstrating the efficacy of the suggested modified PQ control technique.

INDEX TERMS: - Instantaneous reactive power (PQ) theory, dynamic voltage restorer (DVR), balanced and unbalanced load, voltage sag, voltage swell, load change.

I. INTRODUCTION

Power quality is a criterion of a pure and regularized power supply in terms of load. Many factors, including sensitive, non-linear loads, the integration of distributed generation (DG), and advancements in power electronics equipment affect the power quality of the grid [1], [2]. Electrical power quality has massive consideration in the electrical distribution system. The major source of concern is power quality issues relating to distribution system voltage stability [3]. Voltage sag and swell are the two most common power quality issues that impact sensitive loads [4]. Voltage sag is defined as an abrupt fall in the amplitude of supply voltage to a level of 10-90% [5], [6]. Short circuit faults in power systems lead to voltage sags. Many disadvantages have been explored in recent years resulting from voltage sags, such as electrical equipment malfunctioning, loss in the manufacturing line, and complete equipment failure [7], [8]. Voltage swell is defined as the rise in voltage level to 110-180% of its rated value. Voltage swell is the result of sudden disconnection of the large load, open circuit faults. This issue will lead to insulation breakdown, overheating of electrical equipment, and damage to electronic equipment.

According to Essam et al., voltage sag is a severe problem with power quality that causes havoc with delicate loads in the distribution system [9]. To make up for problems in power quality, Power filters, unified power flow controllers (UPFC), static compensators (STATCOM), distribution static compensators (DSTATCOM), and dynamic voltage restorers (DVR) are only a few examples of electronics-based devices that are employed [10], [11]. To protect critical distribution system loads from power quality issues, DVR needs a complicated control mechanism [12].

On distribution feeders, DVR is used to protect loads from issues brought on by voltage sags and swells. In order to modify the active and reactive power requirements for voltage sags and voltage swells, DVR is connected in series with the load, and a battery energy storage system (BESS) relates to a transformer and an inverter [13]. The DVR injects voltage into the distribution system, which is linked to the system through the transformer, to maintain voltage stability [14]. DVR is a FACTS device that corrects for load-related disturbances such voltage sags, swells, and harmonics.

In typical configurations, DVR injects a small amount of voltage in series with the transmission lines.

However, DVR uses sinusoidal pulse width modulation (SPWM) to calculate the voltages necessary to protect the load when a disturbance occurs [15]. To maintain a stable situation, the voltages are then sent back into the system. When a disturbance occurs, however, DVR either delivers or absorbs active or reactive power from the dc-link. In the steady state, DVR either absorbs or provides active or reactive power. The installation of a DVR in a PT DSS power plant, where the DVR serves as a compensator and is connected in series with the distribution line, has been recommended by Margining's et al. Power quality constraints can be recovered using the recommended PI-based DVR [16], [17]. Estimably et al. created a DVR-based method for decreasing voltage sag in order to enhance the performance of power systems. to a decline in the performance of electrical equipment. The results demonstrate that DVR correctly implements voltage adjustment and sag/swell compensation [18]. J. Han et al. introduced a distinctive DVR with a power electronic transformer (PET) to reduce symmetrical and asymmetrical sags and swells [19]. The results demonstrate that the novel design effectively resolves the symmetrical and asymmetrical issues.

The DVR control method can shield the load from voltage-related power quality problems [5]. A flawless reference generating technique must be used in order to have good control. There have been many different methods for reference generation proposed, such as Clark's and Park's transformations, the phasor parameter, symmetrical components, instantaneous real and reactive power, and instantaneous components [20].

Direct-quadrature-zero (dq0) Park's transformation is a mathematical transformation technique used in electrical engineering to streamline the study of three-phase circuits. The three AC values are converted to two DC quantities when the dq0 transform is applied to three-phase circuits [8], [21]. Using streamlined calculations on these fictitious DC variables, the inverse transform is applied to recreate the actual three-phase AC findings. It is frequently employed to simplify calculations for three-phase inverter management as well as the research of three-phase synchronous machines [22]. The Phase Locked Loop (PLL) must provide a signal with the same fundamental frequency and phase angle as the reference signal generation for the two techniques Clarke and Park's transformation and the dq0 transform when applied to three-phase voltages and currents [23].

The Phase Locked Loop (PLL), also known as the Phasor parameter, is a control system that seeks to produce an output signal whose phase is related to the phase of the input "reference" signal. A phase detector and a variable frequency oscillator make up the electrical circuit [24]. This circuit compares the phases of the signals coming into it with the signals coming out of it, then modifies the frequency of the output signal to keep the phases in sync [25].

The initial version of the theory, which was designed for three-phase, three-wire systems, briefly cited the "Generalised Theory of Instantaneous Active and Reactive Power," "Theory of Instantaneous Power," or simply "PQ Theory System with a Neutral Wire" [7], [26], [27]. Later, three-phase four-wire systems (systems with phases a, b, and c in addition to a neutral wire) were added. The three-phase voltages and currents in the ABC coordinates are translated algebraically (Clarke transformation) to the coordinates, and the instantaneous power components of the PQ theory are calculated [6], [28], [29].

This article proposes an enhanced PQ approach for the creation of reference signals in terms of the grid voltage's positive sequence component and the load current's negative sequence component. As a result of problems with power quality including voltage sag, swell, load change, harmonic influence, balancing, and unbalanced load, the appearance of load current in the negative sequence occurs [30]. The key benefit of the improved approach is the avoidance of phase-locked loop and low-pass filters, which eliminates the drawbacks of phase shifting and inadequate compensation. Through various power quality issue scenarios, a comparison analysis of the performances of traditional and proposed PQ approaches is shown. The suggested strategy is more effective in identifying and correcting power quality problems.

The following sections make up the paper's structure. A discussion of dynamic voltage restorers (DVR) is presented in Section II. Section III provides details on the suggested PQ algorithm. In Section IV, the experimental setup is detailed. Section V presents the discussion and the result illustration. Section VI provides an overview of the proposed DVR control system's performance.

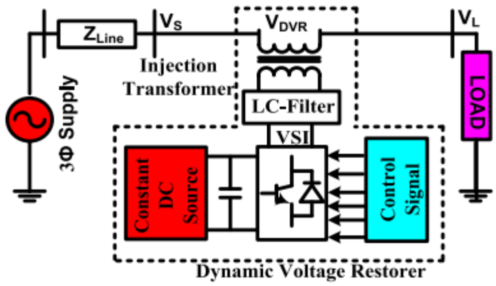

FIGURE 1. Single line diagram of power network with DVR.

II. PHILOSOPHY DYNAMIC VOLTAGE RESTORER (DVR)

To return the load side voltage to its proper amplitude and waveform, a compensation voltage injection with the exact magnitude and frequency is necessary. For a limited moment (up to 0.1 seconds), the system may inject up to 50% of the typical voltage. On the other hand, most voltage sags are much below 50%. This is referred to as dynamic voltage restoration or control (DVR) [31].

The regulating device is referred to as a dynamic voltage restorer (DVR) [12], [16], and [32]. DVRs could help end users who are having issues with power quality [33]. A straightforward DVR power system design with a control circuit to inject compensated voltage and keep the voltage at the proper level is shown in Figure 1. DVRs are frequently installed on a vital feeder and offer active power via DC energy storage while producing the necessary reactive power on their own [34], [35].

A compensating voltage of the requisite size and frequency must be injected in order to raise the load side voltage to the required level [36]– [39]. Only briefly (up to 0.1 seconds), the system can inject up to 50% of the rated voltage. Voltage drops are often much less than 50%. The regulating device is a dynamic voltage restorer (DVR). For end customers who are prone to unfavourable power quality concerns, DVRs may be helpful [40]. DVRs are frequently installed on the main feeder, providing active power via DC energy storage, and internally generating the necessary reactive power [30], [41].

A. DVR OPERATING MODES

Based on operational states, a DVR's switching states are divided into three groups: voltage compensation, standby, and protection [42]. If the load current is present during the protected condition. The DVR will be removed from the grid if its current short circuited or significantly over currented exceeds the permissible value [43]. The injection transformer's secondary winding is shorted by the inverter. During standby, the primary winding should be allowed to receive the entire load current. In this mode of operation, the DVR will not add any correction voltage to the electrical grid. When the grid is in the voltage compensation state, the DVR injects the necessary compensating voltage via an injection transformer [44]. When a disturbance in the load voltage is detected, this mode of operation starts, and it ends when the voltage recovers to normal operating levels.

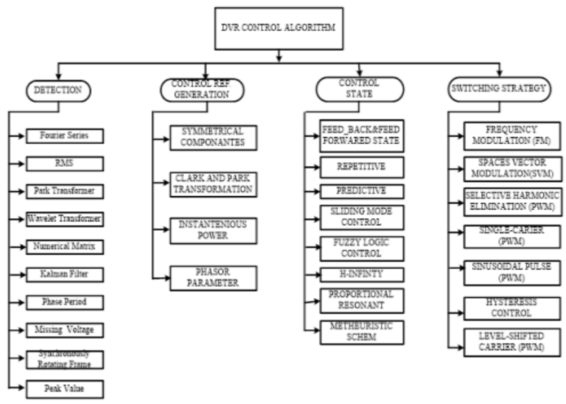

FIGURE 2. Flow chart for control strategies of DVR.

B. PROPOSED SYSTEM DESCRIPTION

The suggested configuration is depicted in Figure 3 and consists of a three-phase load, an injection transformer, a supply (grid) voltage with grid impedance, and a DVR system. The Voltage supply Inverter (VSI) of the DVR system, together with a harmonic passive filter and a DC link capacitor, is powered by a DC power supply. This approach considers a three-phase balanced and an imbalanced load [16], [47], [48].

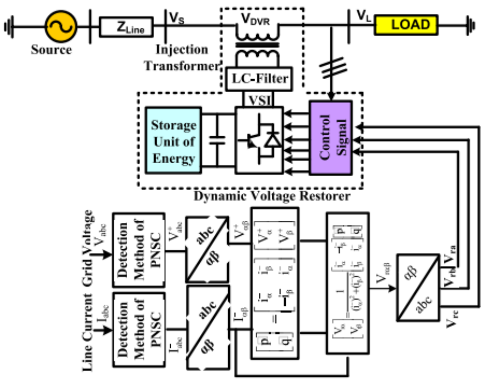

FIGURE 3. Proposed system configuration.

III INSTANTANEOUS REACTIVE POWER CONTROL TECHNIQUE

Generalised Theory of the Instantaneous Reactive Power in Three-Phase Circuits, also referred to as "Theory of Instantaneous Real Power and Imaginary Power," "Theory of Instantaneous Active Power and Reactive Power," "Theory of Instantaneous Power," or "Theory of Instantaneous Power," was developed by Akagi et al. in 1983 for the regulation of active filters in three-phase power systems. With a brief discussion of neutral wire systems, the concept was initially developed for three-phase, three-wire systems. Phases a, b, c, and neutral wire were later added to the list [6], [29], and later three-phase four-wire systems.

A. PQ THEORY

Instantaneous power is represented in the time domain via PQ theory. Based on Clarke's Transformation, this hypothesis. The voltage and current are converted from values in the ABC range to coordinates in the 0 range. With this technique, three-phase voltages and currents are converted into the 0 stationary reference frames [5], [50] using a real matrix. The voltages and current can be linked to ABC and 0 using Clarke's transformation as shown below:

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

And the three phase ABC currents to αβ0

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2)$$

The following matrix can be used to depict the instantaneous active (P), reactive (Q), and zero sequence instantaneous power (P0) values in 0 of instantaneous phase voltage and current values:

$$\begin{bmatrix} P_0 \\ P \\ Q \end{bmatrix} = \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} \quad (3)$$

The following equation illustrates how the 0 or ABC components of voltage and current can be used to represent the instantaneous three-phase active power.

$$P = V_\alpha I_\alpha + V_\beta I_\beta + V_0 I_0 = V_a I_a + V_b I_b + V_c I_c \quad (4)$$

If the zero sequence components of voltage and current, V0 and I0, are disregarded in a balanced three-phase system, the instantaneous three-phase active power is:

$$P = V_\alpha I_\alpha + V_\beta I_\beta \quad (5)$$

Like this, the system's instantaneous reactive power (Q) can be expressed as

$$Q = V_\beta I_\alpha - V_\alpha I_\beta \quad (6)$$

In the two equations above, P and Q can both be written as matrices.

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (7)$$

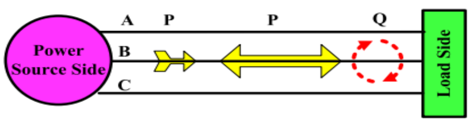

FIGURE 4. Power components of PQ scheme.

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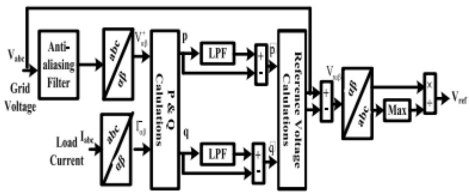

FIGURE 5. Traditional PQ method.

As the PQ control approach is inherently a 38 system, it can be employed in balanced or unbalanced applications, with or without a neutral line. Both steady-state and transient state implementations are possible. It acknowledges two control techniques, sinusoidal supply current and constant instantaneous power [5], [21]. Figure 4 depicts the PQ scheme's power components.

B THE TRADITIONAL PQ CONTROL TECHNIQUE

The control architecture for creating Vref with Traditional PQ is displayed in Figure 5. the location of the three-phase voltage and load current measurements. The antialiasing filter is used to treat the sensed three-phase grid voltage before obtaining the positive grid voltage components (V +), which are then used in equation (1). In parallel, the load current is measured, and the negative load current component, I, is discovered as illustrated in equation (2). Using equations (5) and (6), both components are processed to calculate the real (P) and reactive (Q) power. P and Q are then processed through a low pass filter to generate real and reactive power in the components, where the voltage reference Vref is generated using a reference voltage calculation block and an inverse Clark's transformation.

B. THE MODIFIED PQ TECHNIQUE

This improved approach involves creating a reference signal to offset any power quality problems. This reference is dependent on the grid voltage and the load current's negative sequence component. voltage sag, swell, load change, harmonic impact, balancing, and other power quality issues. The load current's negative sequence component is caused by an unbalanced load. The size of the compensation and the phase of the reference signal, which is locked with the grid voltage, are the two difficulties that must be resolved in order to acquire the compensation. The load current negative sequence component must be assessed to determine the compensating power's magnitude. The level of the load current's negative sequence component, which is determined by the following equation, corresponds to the magnitude of the compensatory power.

$$i_{abc}^{-}(t)f_n = \begin{bmatrix} i_a^{-}(t) \\ i_b^{-}(t) \\ i_c^{-}(t) \end{bmatrix} \tag{8}$$

The source side voltage is used to calculate the phasing of the reference signal from the grid voltage's positive sequence component. This equation is used to evaluate it.

$$v^{+}(t) = |V_{ref}| \frac{v^{+}(t)}{v^{+}(t)} \tag{10}$$

Per unit (pu) measurements are used to determine the grid voltages (vabc) and load currents (iabc). The three-phase positive sequence components of vabc and negative sequence components of the current signals are then transformed into two signals using Clark's transformation $(V_\alpha^{+}, V_\beta^{+})$ and $(I_\alpha^{-}, I_\beta^{-})$ using:

$$\begin{bmatrix} V_\alpha^{+} \\ V_\alpha^{+} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a^{+} \\ V_b^{+} \\ V_c^{+} \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} I_\alpha^{-} \\ I_\beta^{-} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a^{-} \\ I_b^{-} \\ I_c^{-} \end{bmatrix} \tag{12}$$

Equations (11) and (12) are used to evaluate the and components of the positive sequence voltage and negative sequence current vectors in order to get the instantaneous active and reactive powers.

The instantaneous active and reactive power (p and q), expressed as positive grid voltage sequence components and negative load current sequence components, is calculated as follows:

$$\tilde{p} + j\tilde{q} = v_\alpha^{+} i_\alpha^{-} + v_\beta^{+} i_\beta^{-} - jv_\alpha^{+} i_\beta^{-} + jv_\beta^{+} i_\alpha^{-} \tag{13}$$

The matrix form of the equation is given as:

$$\begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} = \begin{bmatrix} i_\alpha^{-} & i_\beta^{-} \\ -i_\beta^{-} & i_\alpha^{-} \end{bmatrix} \begin{bmatrix} V_\alpha^{+} \\ V_\beta^{+} \end{bmatrix} \tag{14}$$

The DVR's inverter is powered by a steady DC power source. Therefore, dc voltage regulation is not required. The following matrix's inverse can be used to determine the reference voltages used to regulate the inverter:

$$\begin{bmatrix} V_{r\alpha} \\ V_{r\beta} \end{bmatrix} = \frac{1}{(i_\alpha^-)^2 + (i_\beta^-)^2} \begin{bmatrix} i_\alpha^- & -i_\beta^- \\ i_\beta^- & i_\alpha^- \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (15)$$

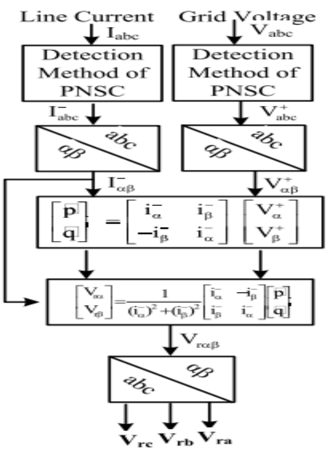

FIGURE 6. Block diagram of the modified PQ method.

Then, using the inverse Clark's transformation, these reference signals are converted into ABC coordination as follows:

$$\begin{bmatrix} V_{ra} \\ V_{rb} \\ V_{rc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{r\alpha} \\ V_{r\beta} \end{bmatrix} \quad (16)$$

The suggested technique for generating voltage references is shown in Figure 6.

C. HYSTERSIS VOLTAGE CONTROL

A hysteresis voltage controller is used to produce the switching signals for the voltage source inverter. The measured load voltages are contrasted with the load voltage references. The hysteresis band is then used to process the erroneous signals. This plan is shown in Figure 7. The advantages of a hysteresis voltage controller over conventional controllers like PWM and SVPWM are effective dynamic responsiveness, greater precision, low cost, and ease of installation [51]. The hysteresis control method fixes issues with traditional systems such switching losses brought on by high switching frequencies, problems with electromagnetic interference brought on by higher-order harmonics, and a decrease in available voltage [2], [52].

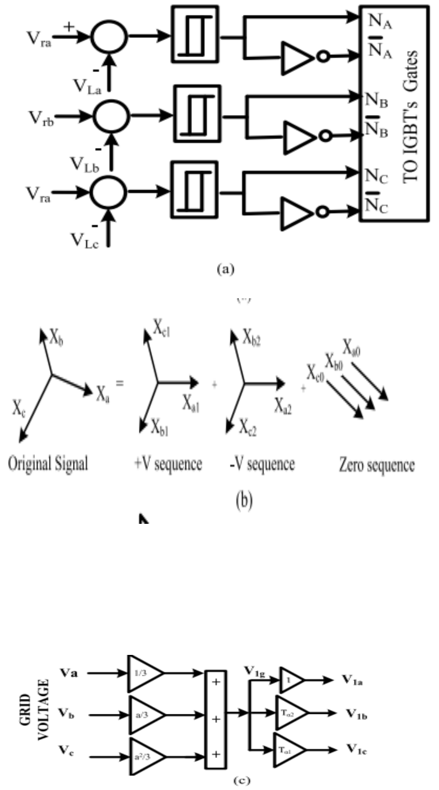

FIGURE 7. (a) Hysteresis voltage controller. (b) Symmetrical components (X: grid voltages or load currents. (c) Extraction method of positive components of grid voltage.

The produced voltage references are contrasted with the actual load voltages. Figure 8 demonstrates how the firing signals of inverter IGBT switches are produced by processing the difference between the reference and actual voltage values.

The system grid voltages and load currents exhibit asymmetrical components (positive and negative sequence components) due to aberrant functioning. The suggested control system is built to separate the load current's negative and positive sequence components from the grid voltage. Using equations (11), (12), the active and reactive power is calculated using the positive grid voltage and the negative load current sequences. Equation (15) produces the reference voltage in the () coordinate system, which is then translated by equation (16) using the inverse Clarke transformation to obtain the reference of compensating voltages. In order to produce firing signals for VSI switches, hysteresis voltage control compares reference voltages to actual load voltages. Under any scenario of power quality problems, such as voltage sag, swell, load unbalanced harmonics, phase failure for a brief period, and load shift, this reference generation technique enables the control system to adjust for the load voltage by identifying the negative sequence components.

TABLE 2. Parameters of the system under TEST.

	Parameters	Values
Source	voltage of Grid	100 V_{peak}
	Frequency	50 Hz
	DC power source	280 V
VSI	Switching frequency (SW)	10 kHz
Load	Load parameters	S_L=1 kVA, 0.5kVA
DVR	Injection transformer	1:1 ratio, 10 kVA
	L_f, C_f, R_f	3 mH, 100 µF, 0.5 □

The phase-locked loop (PLL), standard PI controller, and filters for the creation of voltage references are not used in this improved PQ control approach, resulting in an instantaneous, continuous, and quick dynamic reaction for adjusting the load voltage.

D.POSITIVE SEQUENCE COMPONENTS CALCULATIONS

In abnormal circumstances, Figure 7b displays the positive, negative, and zero components. The method aims to extract three identically sized phasors that are 120 apart and rotate anticlockwise, which are the positive sequence components of the grid voltage [30].

This methodology was developed in the time domain. The phase angle can be expressed as follows in a time interval:

$$t_{ph} = \frac{\text{phase angle}}{360^\circ} \times \frac{1}{f} \qquad (17)$$

where f is the fundamental frequency and tph is the phase shift (8) in time between two phases. The three-phase ungrounded voltages system's symmetrical components can be written as follows:

$$\mathbf{V_{abc}}\,(\mathbf{t}) = \begin{bmatrix} V_a \cos(\omega t + \Phi) \\ V_b \cos\left(\omega t + \Phi - \frac{2\pi}{3}\right) \\ V_c \cos\left(\omega t + \Phi + \frac{2\pi}{3}\right) \end{bmatrix} = V_1 \begin{bmatrix} \cos(\omega t + \Phi^1) \\ \cos\left(\omega t + \Phi^1 - \frac{2\pi}{3}\right) \\ \cos\left(\omega t + \Phi^1 + \frac{2\pi}{3}\right) \end{bmatrix} + V_2 \begin{bmatrix} \cos(\omega t + \Phi^2) \\ \cos(\omega t + \Phi^2 - \frac{2\pi}{3}) \\ \cos(\omega t + \Phi^2 + \frac{2\pi}{3}) \end{bmatrix} \qquad (18)$$

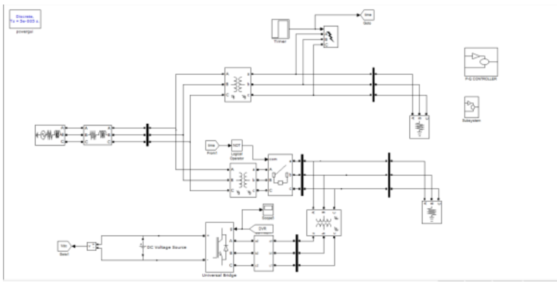

FIGURE 8. Simulink setup.

The positive sequence components are separated using the following time-domain conversion of the symmetrical component's equations:

$$V_{1abc}\,(t) = \begin{bmatrix} V_{1a}\,(t) \\ V_{1b}\,(t) \\ V_{1c}\,(t) \end{bmatrix} = \begin{bmatrix} V_1\,(t) \\ V_1\,(T_{\alpha 1}) \\ V_1\,(T_{\alpha 2}) \end{bmatrix} \qquad (19)$$

$$V_1\,(t) = \frac{1}{3}[V_a\,(t) + V_b\,(T_{\alpha 1}) + V_c\,(T_{\alpha})] \qquad (20)$$

$$t_{(\alpha 1)} = \frac{240^\circ}{360^\circ} * \frac{1}{f} \quad t_{\alpha 2} = \frac{120^\circ}{360^\circ} * \frac{1}{f} \qquad (21)$$

T1 and T2 are the time phase angle shifts of the symmetrical component where V1 (t) is the positive sequence component in the time domain interpretation of the 3-phase grid voltages. No matter where, T1= t+tph t1 and T2= t+tph + t2. The removal of the grid voltage's negative sequence.

IV Simulation Results

Using MATLAB, a straightforward distribution network is simulated in order to demonstrate the DVR's effectiveness in mitigating voltage sags and swells (fig. 8).Different impedances are temporarily connected at the supply side bus to simulate voltage sags and swells. A series transformer that can insert a

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maximum voltage of 50% of the phase to ground system voltage is used to connect a DVR to the system. In addition, a series filter is employed to eliminate any high frequency power components. The In-Phase Compensation (IPC) approach is applied in this simulation. The study's load has a 5.5 MVA capacity and 0.92 p.f. of lagging.

A. Voltage SAG:

Figure 4 displays the results of simulating a scenario of three-phase voltage sag. A 50% voltage sag that starts at 100 ms and lasts until 300 ms, totaling 200 ms, is shown in Figure 9 (a). The voltage that the DVR injects and the compensated load voltage are shown in Figure 9(b) and (c), respectively. The load voltage is maintained at 1 p.u. throughout the simulation, including the voltage sag period, thanks to DVR. Observe how the DVR does nothing while it is operating normally. Upon detecting voltage sag, it instantly injects the required voltage components to smooth the load voltage.

Single-phase voltage sag at supply bus bar is simulated in order to better understand how the DVR performs in unbalanced situations. The findings are displayed in Figure 10. Figure 10(a) depicts the supply voltage with one phase's voltage reduced to 50%. Figures 10(b) and (c) respectively illustrate the load voltage and the DVR injected voltage. The results show that the DVR can quickly provide the necessary voltage components for various phases and contribute to the maintenance of a stable and balanced load voltage at 1.00p.u.

B **Voltage Swells**

Investigated is the DVR's performance under a voltage swell condition. The supply voltage swell in this instance is produced as seen in Figure 11(a). About 125% more supply voltage amplitude than nominal voltage is present. Figure 11 (b) and (c) show the injected voltage that DVR generates to correct the load voltage and the load voltage, respectively. The results show that the DVR helps to maintain the load voltage at the nominal value. The DVR responds fast to inject the proper voltage component (negative voltage magnitude) to rectify the supply voltage, much like it would in the case of voltage sag.

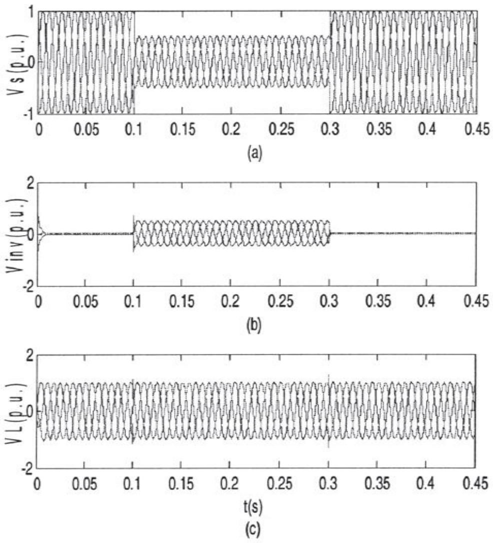

Fig 9: Three-phase voltages sag: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

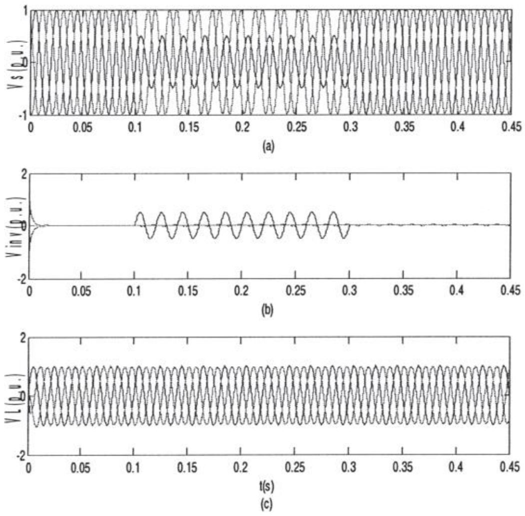

Fig. 10 Single-phase voltage sag: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

Figure 12 displays the DVR's performance in the presence of an unbalanced voltage swell. According to Figure 12(a), two of the three phases in this situation are 25% higher than the third phase. Figures 12(b) and (c) show the injected voltage that DVR generates to correct the load voltage and the load voltage, respectively. Throughout the simulation, including the imbalanced voltage swell occurrence, observe the consistent and balanced voltage at the load.

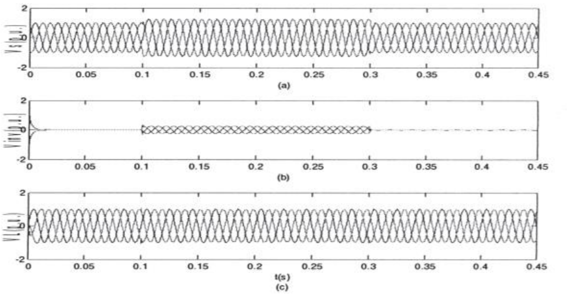

Fig. 11 Three-phase voltages swell: (a)-Source voltage, (b)-Injected voltage, (c)-Load

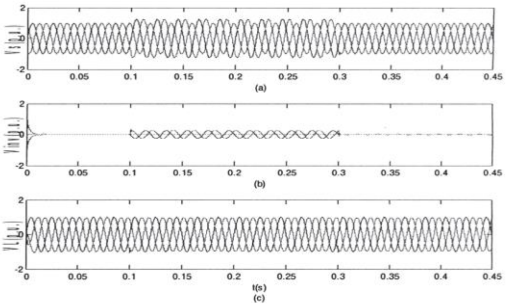

Fig. 12 Two-phase voltages swell: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

III. CONCLUSION

This paper presented a technique for voltage compensation. Interruptions when using the DVR. The suggested method protects load voltages while enhancing their quality. Against unexpected grid voltage. A modified version of PQ theory that uses a detection technique for the positive and negative sequence components forms the foundation of the suggested DVR control solution. The time domain is used for the detection technique. Extensive simulations in MATLAB/Simulink and tests are used to evaluate the effectiveness of the suggested method under several specific disturbance scenarios, including severe unbalanced sag and swell, load shift, and voltage harmonics. The ability of the suggested strategy to enhance voltage quality and voltage profile has been demonstrated. The outcomes have highlighted the usefulness of the suggested DVR compensating mechanism. Overall, the benefits listed below sum up how well the suggested system performs:

- less work in the computation.
- A quicker reaction.
- Balanced load voltages during extreme sags and swells in unbalanced voltage.
- Harmonic cancellation that works well.
- A decrease in the fundamental frequency's transient oscillation.

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