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CONTROLLING OF DVR UNDER SEVERE SAG AND SWELL CONDITIONS BY MODIFIED DQ METHOD

VISWAPRAKASH BABU[1] A.ALEKHYA[2] M.PREMKUMAR[3] P.PRUTHVI RAJ[4] G.MADHU[5]

[1]Associate Professor, Department of EEE, Jyothishmathi institute of technology and science, Nustulapur, Karimnagar, TS, India
[2,3,4,5]Ug scholar, Department of EEE, Jyothishmathi institute of technology and science, Ramakrishna colony Nustulapur, Karimnagar, TS, India

vishwaprakash0078@gmail.com, alekhyaammu970@gmail.com, premkumar.mittapally555@gmail.com pruthvirajpakala44@gmail.com, ganjimadhu042@gmail.com

Abstract: Nowadays, power quality under the excessive implementation of power electronics devices is quite challenging issue. The compensation of non-sinusoidal; reactive and harmonic; components is the main role for power quality devices which highly depend on the robustness of the control system. Some common control systems are implemented using Synchronous Stationary Frame (DQ) theory. This paper proposes a new version of DQ control technique to control dynamic voltage restorer under severe transient voltage conditions. The power system network with the new DQ control technique is studied and analysed under different scenarios to compensate for severe balanced and unbalanced voltage sags and swells. This new scheme is based on extraction of positive sequence components to implement the control algorithm. A mathematical model of the Dynamic Voltage Restorer (DVR), hysteresis voltage control, converter controller model, new DQ scheme with complete system equations are carried out and verified using Simulink / MATLAB. The obtained results of the proposed compensation algorithm are compared with the results obtained from the traditional DQ method. Simulation results are correlated and show effectiveness of the proposed DQ control scheme.

Keywords: Power Quality (PQ), Dynamic Voltage Restorer (DVR), using Synchronous Stationary Frame (DQ) theory

I.INTRODUCTION

Medical equipment, factory automation, semiconductordevice manufacturers, and paper mills are among the sensitive loads that are sensitive to power-supply disturbances [1], [2]. The increase in demand of high power quality and voltage stability becomes a progressively critical concern with serious threat and frequently occurring power-quality problem in today's power grids. voltage sag, swell are now recognized as severe costly consequences such as sensitive loads tripping and production loss [3]. Voltage sag and swell are significant power quality issues that occur frequently during contingency, switching and unexpected load changes [4]. Severe storms and lightning on electricity lines trigger line to ground fault leading to voltage sag over a wide section of electrical network. Some other factors that results in this disturbances are short circuits at the starting of power transmission line, the parallel power distribution line linked to the point of common coupling (PCC), high inrush currents related with the starting of large machines, abrupt changes in load, the energizing of power transformers, and switching operations in the power system network [5]. Voltage sag is the temporary drop of the root mean square (R.M.S.) voltage at a location in the electrical system below a predetermined threshold. It is a short-duration variation of the RMSvalue of voltage from 10 to 90% of nominal voltage over a time longer than 0.5 cycles (10ms) of power frequency but less than or equal to 60 seconds [6]. The terms used to define the extent of voltage sag are frequently misunderstood [7], [8]. According to IEEE 1159-2019, a sag to 70% is permitted, which indicates that the line voltage is dropped to 70% of its standard value, not dropped by 70%. A voltage dip of 70% will signify voltage reduced by 70% from the normal 100% voltage. The remaining voltage will be 30% or a sag to 30% [9]. The impacts of a sag are frequently more perceptible than the effects of a swell. A sag with more than three cycles is frequently observable as a reduction in voltage output. Sags are frequently unrecognizable from brief outages because the effects on the equipment are similar [2], [10], [11]. Computers and other sensitive equipment may encounter unexpected shutdowns or distorted voltage waveform [6]. Even motor starter relays and contactors can be hypersensitive to voltage sags, resulting in process shutdown when the drop out occurs. For over 1000 cycles, a wide disparity has been discovered, varying from 20% to 65% sags [12]. Swells are due to large loads shutting down, quick changes in load resistivity, and other factors. A voltage swell is an electromagnetic disturbance that occurs in two dimensions [12], [13]. When a voltage swell occurs, the RMS voltage will increase temporarily at a point above a specified level. Both voltage level and length of duration influence the voltage swell; the voltage swell's start threshold is 110 percent, and the length ranges from 0.5 cycles (10ms) to 60 seconds. The repercussions of a swell are frequently more damaging than that of a sag. The overvoltage issue results in malfunctions of the power supply equipment, though the effect may be gradual and cumulative. If the duration is longer than three cycles, the increase in output in a voltage may be noticeable [7]. When the industries were using solid state devices, there was no much importance for the quality of the supplied voltage. But when the industries replace the solid-state devices with the power electronic devices, the quality of the voltage supplied became the most important aspect [14], [15]. The short scale solutions available for voltage sag and swell are using a universal power supply (85V-264V), using Semiconductor Equipment and Materials International (SEMI F47) compliance power supply, adjusting the trip threshold, reprogramming the response of adjustable speed drives (ASD), using reverse powered relays, single phase power conditioners, uninterrupted power supplies, constant voltage transformers, drip proofing inverters etc. The large scale solutions available are using three phase power conditioners, three phase uninterrupted power supplies, active voltage conditioners, data wave, fly wheel, dynamic voltage restorer (DVR) etc [9]. Several power electronic devices have been developed to improve voltage stability and overcome the harmful impacts of voltage sag/ swell. DVR is an effective component for compensation of voltage disturbance that is commonly utilized in practice [16]–[18]. Among the power electronics devices, DVR is a switching device that induces synchronous voltage and can be thought of as a series active power filter. To have an economic and efficient power supply, DVR is used. It's a power electronic FACTS device used for compensation of voltage sags and swells in electrical power distribution [19]. The first DVR system with static VAR devices, which was installed in 1996 in Anderson, South Carolina, was a 12.47 kV system. DVR help in resolving problems of a power system that has voltage disturbances. it is an active inverter that adjusts the voltage, either through a transformer or without a transformer in series and in synchronization with the grid at the PCC [20], [21]. Calculation of the compensation voltage is done by comparing the reference load voltage and the actual voltage of the grid. under a voltage sag or swell, the controller identifies the magnitude and phase of the compensated voltage required. the generated reference voltages are sent to the modulator to generate the switching pulses. These pulses would shoot the DVR switches, and the voltage from the DVR would be injected into the PCC to substitute for the voltage disturbances. Therefore, DVR can be considered or presumed as a filter that separates the grid from the load and compensate for any voltage sag or swell. Thus, the end user would not be able to sense or get effected with the problem of voltage disturbance induced by the utility [4]. The main concern in utilizing DVR is the efficient control of DVR when injecting real and reactive power [22]. In a DVR, the main functions of the control system are to identify the voltage drops or swells, to generated voltage reference signal, controlling converter and the protection of the system [21], [23]. The quality and accuracy of the detection methods will have a big impact on the performance of the control algorithm. For example, the detection algorithms like Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), and Kalman filtering (KF) are used to accurately predict voltage disturbances in the supply voltage [23], [24]. These algorithms are called detection algorithms. The KF is a decent way to figure out which sags are balanced and unbalanced. Clark's transformation and Park's transformation are used by the Synchronous Rotating Frame (SRF) to identify sag and swell [25]. The Park's transformation or DQ transform can only be used to figure out balanced three phase sags. The multiple DQ transform is a different method that can be used for harmonics and unbalanced sag conditions. Multiple DQ transform was made easier by having separate modules for retrieving positive and negative sequence components from fundamental and harmonic waves [26], [27]. Though easy extraction of sequence components, this methodology is incompatible for single phase system, fails to identify the unbalance sag and swell voltages and it has complex procedure to get the reference voltage to control the DVR. The DQ has advantage of short duration for detection of sag/swell in a three-phase system. This paper proposes a modified DQ method for DVR control. The proposed detection technique is based on a time-domain algorithm for identifying positive sequence component of grid voltage. This DQ method rely on detection technique of sequence components which doesn't constitute both adaptive mechanism (like PI controller) and signal filtering [26], [28]. This provides less computational time leading to fast response of the control system with decent stability and wide range of operating conditions including extreme sags and swells. Unlike other method, the proposed method is compatible for both balanced and unbalanced systems. In addition, this control method achieves almost zero tracking error in all abnormal-operating conditions. The control system is mathematically represented and verified in simulation as well as experimentally validated. Finally, the proposed control is compared to the traditional DQ method to confirm the superiority of the proposed method.

II.LITERATURE SURVEY

[1] S. Hasan, K. Muttaqi, D. Sutanto, and M. A. Rahman, ''A novel dual slope delta modulation technique for a current source inverter based dynamic voltage restorer for mitigation of voltage sags,'' IEEE Trans. Ind. Appl., vol. 57, no. 5, pp. 5437–5447, Sep. 2021, doi: 10.1109/TIA.2021.3089984.

This article investigates the use of a dual-slope delta modulation (DSDM) technique to control a dynamic voltage restorer (DVR) that can mitigate the voltage sag problems in power systems. Traditionally, the DVR uses a pulsewidth modulation technique to control the power electronic switches in a voltage source inverter (VSI). However, the VSI suffers from several disadvantages, such as ripples in the output voltage, high dv/dt, and high total harmonic distortion. To overcome these problems, this article proposes a novel DSDM technique for a current source inverter (CSI) based DVR. The proposed DSDM technique generates the switching pulses for the power electronic switches in the CSI to produce the required missing voltage waveforms with the necessary phase angle jump to restore the load voltage to its nominal value following power systems faults. The DVR usually requires an energy storage device to support the system voltage during voltage sag, which is referred to as a storage-energy-supplied (SES) DVR. However, the energy storage device makes the DVR bulkier and costlier. A line-energy-supplied (LES) DVR scheme has been proposed in the literature that can eliminate the need for the energy storage device and hence has the potential to reduce the cost of the DVR. To validate the proposed DSDM technique, different types of fault-induced voltage sags are simulated in a radial distribution system. The proposed DSDM technique is tested to control the CSI-based SES-DVR and LES-DVR to mitigate the voltage sag. The simulation results show that the proposed DSDM technique is effective to mitigate the voltage sags by accurately injecting the required missing voltage both in magnitude and phase angle.

[2] B. Bae, J. Jeong, J. Lee, and B. Hen, ‘‘Novel sag detection method for line interactive dynamic voltage restorer,’’ IEEE Trans. Power Del., vol. 25, no. 2, pp. 1210–1211, Apr. 2010, doi: 10.1109/TPWRD.2009.2037520.

This letter proposes a novel sag detection method for the line-interactive dynamic voltage restorer (DVR). The DVR with proposed detection method can compensate the voltage sag or interruption within 2-ms delay, which is faster than the existing delay time of 4 ms. The feasibility of proposed method was verified through computer simulations. The DVR with proposed detection method can effectively compensate the voltage sag or interruption for sensitive loads.

[3] M. Vilathgamuwa, A. A. D. Ranjith, S. S. Choi, and K. J. Tseng, ‘‘Control of energy optimized dynamic voltage restorer,’’ in Proc. IECON Conf. 25th Annu. Conf. IEEE Ind. Electron. Soc., vol. 3, Dec. 1999, pp. 873–878.

The dynamic voltage restorer (DVR) is a custom power device used for voltage compensation of sensitive loads against voltage disturbances in power distribution lines. This paper illustrates a correction technique, which draws a minimum amount of energy from the DVR during the process of compensation of a voltage sag or swell. Using the proposed method it can be shown that a particular disturbance can be corrected with less amount of storage energy compared to that of existing in-phase boosting method. The paper also discusses a multiloop feedback control method applicable for the DVR to obtain good dynamic performance.

[4] P. Li, L. Xie, J. Han, S. Pang, and P. Li, ‘‘New decentralized control scheme for a dynamic voltage restorer based on the elliptical trajectory compensation,’’ IEEE Trans. Ind. Electron., vol. 64, no. 8, pp. 6484–6495, Aug. 2017, doi: 10.1109/TIE.2017.2682785.

In this paper, a novel decentralized control for a dynamic voltage restorer is proposed to deal with its captivity by improving the voltage quality of loads. The proposed technique controls the magnitude and the phase angle of the injected voltage to accomplish low-voltage ride-through based on the instantaneous calculations of voltages and currents and the application of elliptical compensation properly demonstrated at first. A set of generalized equations based on symmetric-sequence components are represented, aiming to separately control active and reactive powers with two individually adaptable parameters. Moreover, this approach can also describe a theoretical methodology by regulating the status parameters so that the multiple alternatives can be provided. The two parameters are an external voltage contribution of this work utilized to raise and equalize the phase voltage for a particular purpose of positive- and negative-sequence injected powers. Furthermore, a control algorithm for reference generators that provide flexible voltage support is proposed simultaneously to improve ride-through ability. Results of the simulation in the MATLAB indicate that the proposed control strategies can compensate voltage sags in a considerable short-time period.

[5] N. C. S. Sarita, S. S. Reddy, and P. Sujatha, ‘‘Control strategies for power quality enrichment in distribution network using UPQC,’’ Mater. Today, Proc., vol. 10, Feb. 2022, doi: 10.1016/j.matpr.2021.07.053.

Unified Power Quality Conditioner (UPQC) is a cutting-edge Custom Power Device (CPD) that is being used to improve power quality in the distribution network. UPQC contributes to the distribution network by compensating for both voltage and current-related power quality disturbances. Its control strategy in unbalanced and distorted weak grid conditions is of particular interest for research. In addition, the performance of UPQC in the presence of unbalanced and non-linear harmonic loads is critical for maintaining desirable power quality. This paper investigates the implementation of UPQC control strategies and algorithms for improving power quality (PQ) and proposes a versatile control strategy to improve UPQC performance. When tested on a critical distribution network, the proposed dynamic control strategy provides better steady-state and dynamic response. Models developed in MATLAB/SIMULINK are used to validate the proposed control scheme.

III.PROPOSED SYSTEM

a)DYNAMIC VOLTAGE RESTORER (DVR)

To restore the load side voltage to the desired amplitude and waveform, injection of compensation voltage with desired magnitude and frequency is necessary . The system can inject up to 50% of nominal voltage, but only for a short time (up to 0.1 second). However, most voltage sags are much less than 50 percent. This is said to be Dynamic voltage restoration or regulation. The regulating device is said to be DVR . DVRs may provide good solutions for end-users subject to unwanted power quality disturbances. Figure 1 shows a basic DVR power system circuit supported with control circuit to inject compensated voltage for maintaining the voltage at desired value. DVRs usually installed on a critical feeder supplying the active power through DC energy storage and the required reactive power is generated internally.

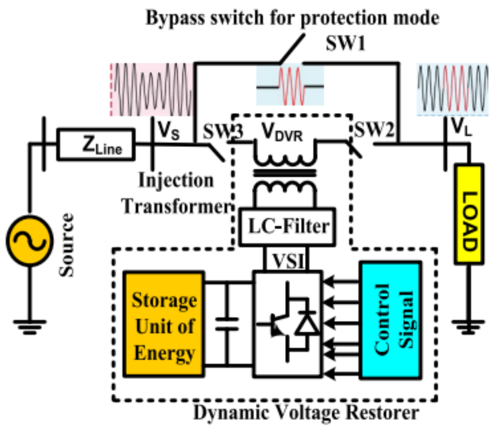

FIGURE 1. Basic circuit of power system with DVR.

b) OPERATION MODES OF DVR

Based on the functioning, a DVR modes of operation are divided in to three modes, which are, Protection, Standby and voltage injection . In protection mode, exceeding the load current over permissible value due the short circuit or large inrush current, DVR will be isolated from the power system using switches, SW2 and SW3 as shown in Figure 5.1 and thus providing an alternative path for the load current flow through SW1 [13]. In standby mode, the low voltage winding of the booster transformer is shorted by the converter and full load current is passed through the primary of the booster transformer. In this mode of operation, the DVR will not inject any compensation voltage into the power system network. This mode of operation is initiated when a disturbance in voltage is detected and ends when the voltage is recovered to its normal operating condition.

c) COMPENSATION METHODS

Voltage compensation methods are selected based on the DVR power rate, load types, situations, fault types and so on. The compensation methods are divided into pre-sag, in-phase, and energy minimized. In pre-sag, the controller monitors the supply voltage and identify any voltage fluctuations, then generates and injects the difference of voltage. As a result, the load voltage remains unchanged as the pre-sag voltage. In-phase compensation approach, the injected voltage and voltage of supply are in phase with each another. This approach is not suitable for sensitive loads as phase shift occur during most voltage sag scenarios. On the other hand, it is suitable for linear loads when the voltage magnitude is significant. The main drawback of the pre-sag and in-phase methods is to provide real power at the DC-link. This can be overcome by Energy-minimised (EM) method, as the exchange of active power is not carried out during the compensation stage. It can be stated specially for sag mitigation that real power is neither injected into the network or absorbed from the power supply .

d) CONTROL STRATEGIES AND ALGORITHMS OF DVR

The detection of voltage disturbances is the major emphasis of the DVR's control system. Specifically with sensitive loads, the detecting system should be fast enough to identify the voltage disturbance accurately for assessment of DVR performance. As shown in Figure 2, various methods for voltage disturbance detection have been proposed, including RMS, Peak Value, DFT, Fourier Transform (FT), Wavelet Transform (WT), Windowed Fast FT (WFFT), ABC to DQ axis transformation, KF, Phase-Locked Loop (PLL), and SRF .

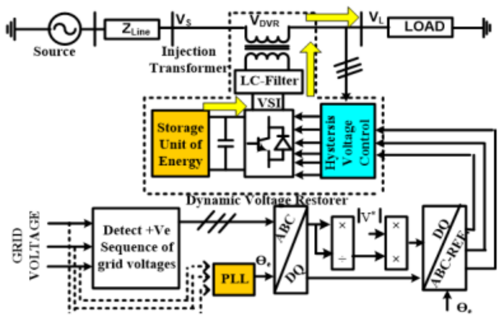

FIGURE 2. Schematic diagram of the proposed system with DVR

IV. COMPONENTS OF PROPSOED SYSTEM

a)ENERGY STORAGE UNIT AND DC-LINK CAPACITOR

The energy storage system (ESS) and the dc link capacitor are two essential components in a DVR system that supplies the active power required to protect against prolonged disruptions. The dc link capacitor is an energy storage device that generates high-power short-time pulses to offer dynamic response [12]. A DVR's ESS is generally made up of a battery. Table 2 illustrates the energy and power density of typical capacitors and batteries, as well as their life cycle count and discharge times. A battery and a capacitor can be used together to meet the energy requirements of a DVR. The application determines the size of an energy storage device. A DVR system's energy storage capacity must be sufficient to fulfil the power quality and custom device requirements for a few seconds and cycles, respectively. The energy stored in a capacitor is given in the following equation as a function of capacitance and voltage.

b) LC FILTER DESIGN

To decrease harmonics caused by the pulse with modulation (PWM) voltage waveform, the output side of the DVR's inverter is connected to an LC filter. The cutoff frequency for an LC filter is designed to eliminate the output voltage waveform's lowest order harmonics. The cutoff frequency or resonant frequency is dependent on the filter capacitance and inductance, as presented in equation (4). The capacitor value should be chosen so that the resonant frequency is less than one-third of the switching frequency of the inverter.

c) INJECTING TRANSFORMER

The DVR uses three single-phase injection transformers, as shown in Figure 4, to inject the three phase voltages created by the voltage source inverter. To maximize the output voltages produced by the inverter, the secondary side (low voltage side) of each transformer is coupled in a wye arrangement.

V. NEW DQ ALGORITHM

In abnormal operating conditions, symmetrical components (positive and negative sequence components) appear in the system voltages affecting the load voltages. Based on the appearance of negative sequence components, the proposed control system is intended to separate the positive sequence components from the system voltage by the proposed detection technique. These positive sequence components are transformed into dq coordinates to generate the reference of load voltages. The reference voltages are compared to the actual load voltages to generate firing signals of voltage source inverter (VSI) switches using Hysteresis voltage control. This proposed detection technique allows instantaneous and continuous detection of positive sequence components and compensation for disturbances in the load voltages. It also aids to set up the desired voltage amplitude with appropriate period of compensation. The control system consists of a reference signal generation technique and voltage controller. The reference signal generation technique is a new version of DQ method. The traditional DQ method has deficiency under unbalanced conditions. Similar to the traditional DQ method, the modified DQ method has phase locked loop (PLL) and Park transformation. A detection technique of positive sequence components and a peak finder technique are included in the modified DQ method. Algorithm of the technique is elaborated as follows

a)**DETECTION OF POSITIVE SEQUENCE COMPONENTS**

The detected grid voltages during abnormal conditions have positive, negative and zero components as shown in Figure 3. The technique aims to separate three phasors that have equal magnitudes, displaced by 120◦ and rotate anticlockwise, which are the positive sequence components [50].

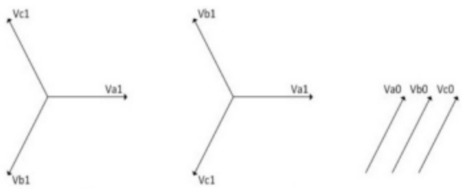

FIGURE 3 Symmetrical components of grid voltages

As stated earlier, this technique is based on time domain. The time period is related to the phase angle as:

$$t_{dis} = \frac{\text{phase angle}}{360^\circ} \times \frac{1}{f} \qquad (5.5)$$

where tdis is the displacement period between two voltage phasors, f is the frequency. The symmetrical three-phase voltages of ungrounded system can be expressed as:

$$\mathbf{V_{abc}\,(t)} = \begin{bmatrix} V_a \cos(\omega t + \theta) \\ V_b \cos\left(\omega t + \theta - \frac{2\pi}{3}\right) \\ V_c \cos\left(\omega t + \theta + \frac{2\pi}{3}\right) \end{bmatrix} = V^{(1)} \begin{bmatrix} \cos\left(\omega t + \theta^{(1)}\right) \\ \cos\left(\omega t + \theta^{(1)} - \frac{2\pi}{3}\right) \\ \cos\left(\omega t + \theta^{(1)} + \frac{2\pi}{3}\right) \end{bmatrix} + V^{(2)} \begin{bmatrix} \cos(\omega t + \theta^{(2)}) \\ \cos(\omega t + \theta^{(2)} - \frac{2\pi}{3}) \\ \cos(\omega t + \theta^{(2)} + \frac{2\pi}{3}) \end{bmatrix} \qquad (6)$$

The equation of symmetrical components is converted into time-domain to extract the positive sequence components as follow:

$$V^{(1)}_{(abc)}\,(t) = \begin{bmatrix} V^{(1)}_a\,(t) \\ V^{(1)}_b\,(t) \\ V^{(1)}_c\,(t) \end{bmatrix} = \begin{bmatrix} V^{(1)}\,(t) \\ V^{(1)}\,(T_\alpha) \\ V^{(1)}\,(T_\beta) \end{bmatrix} \qquad (7)$$

$$V^{(1)}_{(t)} = \frac{1}{3}\left[\left(V_a\,(t) + V_b(T_\alpha) + V_c(T_\beta) \right) \right] \qquad (8)$$

$$T_\alpha = \frac{240^\circ}{360^\circ} * \frac{1}{f} \quad T_\beta = \frac{120^\circ}{360^\circ} * \frac{1}{f} \qquad (9)$$

where $V^{(1)}_{(t)}$ is the time domain representation of the positive sequence component for the three phase grid voltages, tdis−α and tdis−β are the time phase shift of the symmetrical component. Where, Tα = t − tdis−α and Tβ = t − tdis−β. Figure 6 illustrate the extraction of grid voltage positive sequence component.

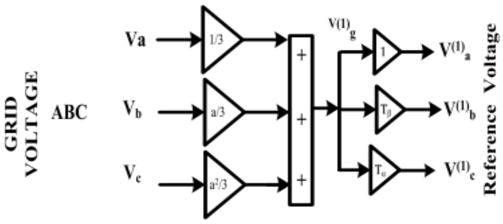

FIGURE 4 Extraction method of positive sequence components.

b) THE MODIFIED DQ TECHNIQUE

In the modified DQ technique a phase locked loop (PLL) is utilized to synchronize the signal to the grid fundamental voltage, $V_{g-abc}^{(1)}(t)$. Then the Park's transformation is used to transforms these voltage components to DC components (vd, vq) is derived in (18), as shown at the bottom of the next page. To obtain the amplitudes of the reference signals at the desired voltage amplitude, peak finder is applied to $V_d^{(1)}$ as following

$$v_d^{(1)} = V_{desired}^{*} \frac{v_d^{(1)}}{v_d^{(1)}} \tag{10}$$

To transform the reference signal in abc coordinate system, inverse Parks transformation is applied as follow:

$$v_{L-abc,ref}(t) = \begin{bmatrix} v_{La,ref}(t) \\ v_{Lb,ref}(t) \\ v_{Lc,ref}(t) \end{bmatrix}$$

$$= \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t+\theta) & -\sin(\omega t+\theta) \\ \cos\left(\omega t+\theta-\frac{2\pi}{3}\right) & -\sin\left(\omega t+\theta-\frac{2\pi}{3}\right) \\ \cos\left(\omega t+\theta+\frac{2\pi}{3}\right) & -\sin\left(\omega t+\theta+\frac{2\pi}{3}\right) \end{bmatrix} \times \begin{bmatrix} v_d^{(1)} \\ v_q^{(1)} \end{bmatrix} \tag{11}$$

To explain the superiority of new DQ scheme compared to traditional DQ method, block diagrams for reference voltage generation in both schemes of new and traditional DQ are shown in figure 5.5 and 6 respectively. In modified DQ we can observe that the low pass filters are eliminated leading to less computation and fast response of the control system.

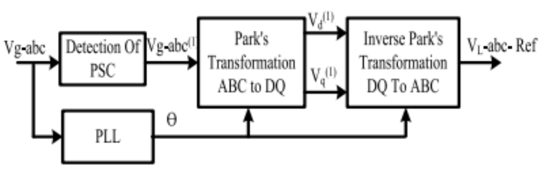

FIGURE 5 Modified DQ method

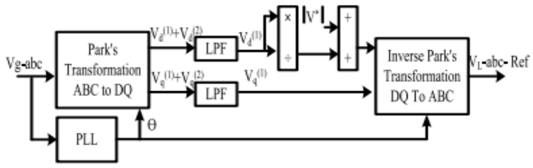

FIGURE 6 Traditional DQ method.

c) HYSTERESIS VOLTAGE CONTROLLER

A hysteresis voltage controller is applied to generate the switching signals for voltage source inverter. The hysteresis controller is preferred over traditional controllers like PWM, SVPWM because of its advantages of effective dynamic response, good accuracy, low cost and can be implemented easily. The disadvantages of traditional techniques like switching losses with high switching frequency electromagnetic interference issues due to higher order harmonics, decrease in available voltage are overcome in the hysteresis control method. The generated voltage references are compared with the actual load voltages. The error between reference and actual voltage values are processed through the hysteresis band to produce the firing signals of inverter IGBT switches as shown in figure 7

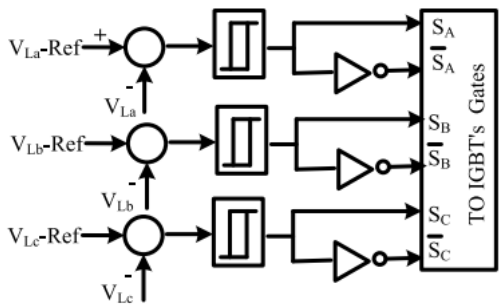

FIGURE 7 Hysteresis voltage controller.

VI.SIMULATION RESULTS

Table-1 System parameters

Parameters	Rating
Grid voltage	110 Vpeak
Fundamental frequency	50 Hz
Switching frequency	10 kHz
Load	P_{Load}=1 kW
Series transformer	1:1 ratio, 10 kVA
DC power supply	280 V
Lf, Cf, Rf	3 mH, 50 µF, 0.5 Ω

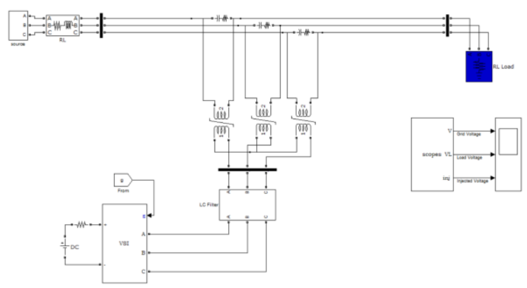

Fig.8 MATLAB/SIMULINK circuit diagram of the proposed system

CASE-1: TRADITIONAL PQ METHOD

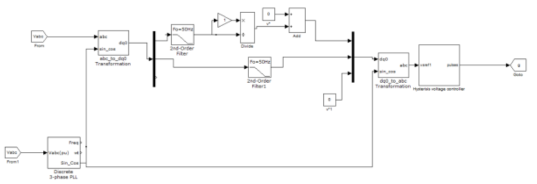

Fig .9 Traditional pq control system

A)20% BALANCED SAG

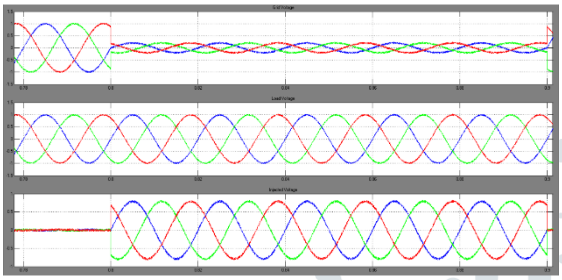

FIGURE.20 Simulation results of grid voltages, load voltage and DVR voltages (traditional DQ) under balanced 3ϕ grid voltage sag of 20%.

B)70% BALANCED SWELL

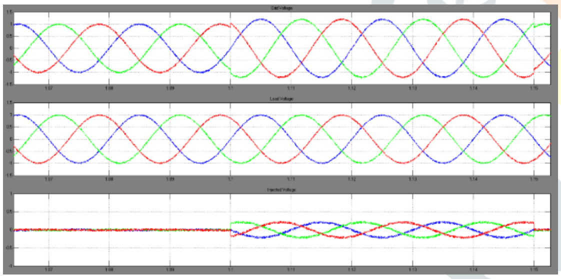

FIGURE.21 Simulation results of grid voltages, load voltage and DVR voltages (traditional DQ) under balanced 3ϕ grid voltage swell of 70%.

C)20% UNBALANCED SAG

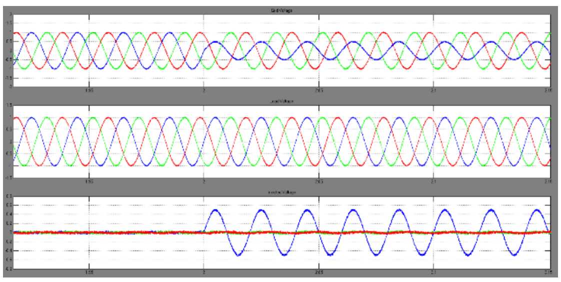

FIGURE .22 Simulation results of grid voltages, load voltage and DVR voltages (traditional DQ) under unbalanced 3ϕ grid voltage sag of 20%

D) 70% UNBALANCED SWELL

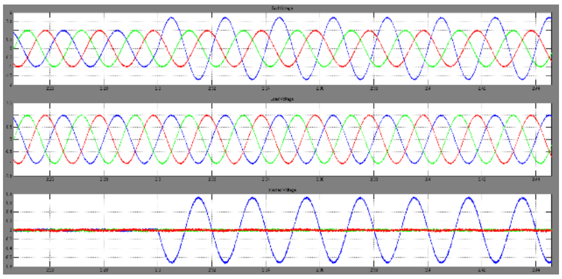

FIGURE.23 simulation results of grid voltages, load voltage and DVR voltages (traditional DQ) under unbalanced 3ϕ grid voltage swell of 70%.

CASE-2: MODIFIED PQ METHOD

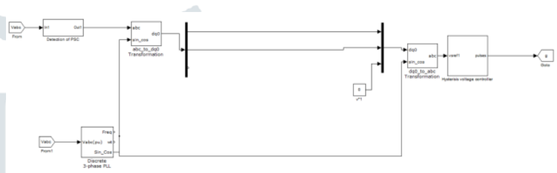

Fig.14 Modified pq control system

A)20% BALANCED SAG

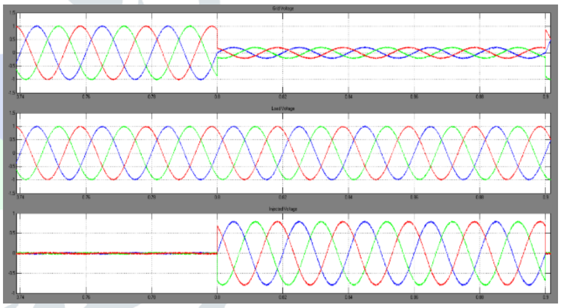

FIGURE .15 Simulation results of grid voltages, load voltage and DVR voltages (modified DQ) under balanced 3ϕ grid voltage sag of 20%.

B)70% BALANCED SWELL

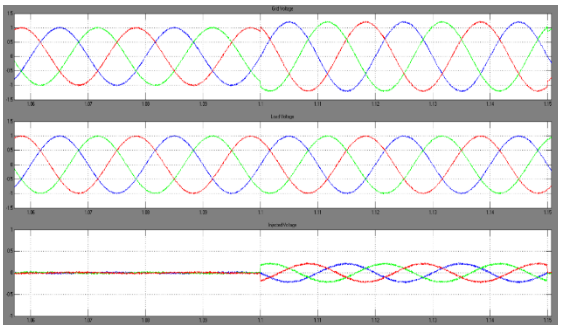

FIGURE.16 Simulation results of grid voltages, load voltage and DVR voltages (modified DQ) under balanced 3ϕ grid voltage swell of 70%.

C)20% UNBALANCED SAG

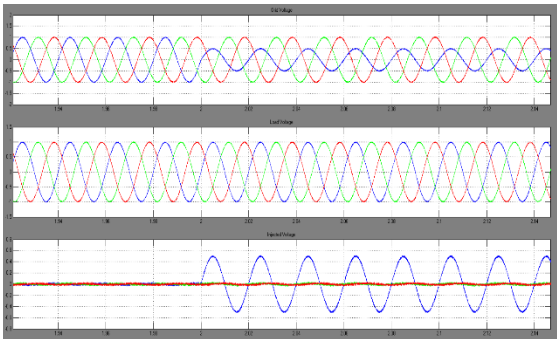

FIGURE.17 Simulation results of grid voltages, load voltage and DVR voltages (modified DQ) under unbalanced 3ϕ grid voltage sag of 20%

D) 70% UNBALANCED SWELL

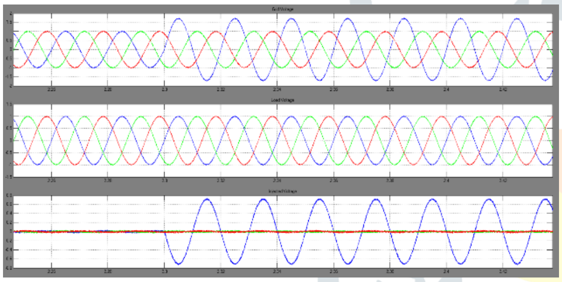

FIGURE.18 Simulation results of grid voltages, load voltage and DVR voltages (modified DQ) under unbalanced 3ϕ grid voltage swell of 70%.

CONCLUSION

This paper inspects the control of DVR with modified DQ algorithm to generate reference voltage signals to control the DVR. The proposed DVR control method relies on a modified version of DQ theory with a detection method for the positive and negative sequence components. The modelled simulations are carried out in MATLAB Simulink. The results are shown good correlation between simulation and experimental results. The control of modified DQ method is compared with the traditional DQ control technique under the conditions of severe sag and swell. The performance of the controllers is also compared during balanced and unbalanced situation with severe cases of sag and swell.

The comparative results suggest that the new modified DQ control method shows effective in compensating voltage during severe sag swell in balance and unbalance conditions with advantages of

• Less computational effort

• Faster response

• Less transient oscillation in the fundamental frequency under unbalanced voltage sag and swell

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AUTHOR PROFILE

Viswaprakash Babu graduated in B.Tech., Electrical and Electronics Engineering, M.Tech in Industrial Engineering & Management and pursuing Ph.D (Power Quality) at B. S. Abdur Rahman Crescent Institute of Science and Technology, Deemed to be University, Chennai, Tamilnadu, India.Currently working as Associate Professor in Jyothishmathi Institute of Technology and Science Karimnagar,Telangana,India.He is having more than 18 years of teaching experience in the department of Electrical and Electronics Engineering.He was awarded with prestigious "Global teacher award 2021" by AKS education awards in the year 2021.He published 15 research articles in the international and national journals and conferences.He published a Patent on "A Novel Intrinsic Space Vector Tansformation based Solar Fed Dynamic Voltage Restorer for Power Quality Improvement in Distribution System".He is currently doing research in DVR on Power distribution System.

A.Alekhya completed his Diploma in Electrical and Electronics Engineeering, Currently pursuing his Graduation in Electrical and Electronics Engineering at Jyothishmathi Institute of Technology and Sciences.

M.premkumar completed his Diploma in Electrical and Electronics Engineeering, Currently pursuing his Graduation in Electrical and Electronics Engineering at Jyothishmathi Institute of Technology and Sciences.

P.Pruthvi Raj completed his Diploma in Electrical and Electronics Engineeering, Currently pursuing his Graduation in Electrical and Electronics Engineering at Jyothishmathi Institute of Technology and Sciences.

G.madhu completed his Diploma in Electrical and Electronics Engineeering, Currently pursuing his Graduation in Electrical and Electronics Engineering at Jyothishmathi Institute of Technology and Sciences.