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OPTIMIZED PQ THEORY CONTROL OF DVR FOR SEVERE VOLTAGE SAG AND SWELL COMPENSATION IN DISTRIBUTION NETWORKS USING A THREE-LEVEL INVERTER

P. Sangeetha, Assistant professor, Department of Electrical and Electronics Engineering, JNTUH College of Engineering, Jagtial, Telangana-505501, India : sangeetha813@gmail.com

Dasarapu Pranay, M. Tech Student, Department of Electrical and Electronics Engineering, JNTUH College of Engineering, Jagtial, Telangana-505501, India :pranaydasarapu@gmail.com

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 and frequency stable. To have a dynamic and fast response of the DVR a modified instantaneous reactive power (PQ) theory with three level inverter 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 with three level inverter scheme is investigated and assessed under various scenarios to compensate for severe voltage sags and swells. MATLAB/Simulink is used to verify the mathematical models of the modified PQ and proposed PQ control system with three level inverter for DVR. The complete system is implemented to validate the presented control scheme. The simulation results , demonstrating the efficacy of the suggested modified PQ control of three level inverter technique.

KEY WORDS : Instantaneous reactive power (PQ) theory, dynamic voltage restorer (DVR), balanced 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. Essam *et al.* state that Voltage sag is a serious power quality issue that plays on sensitive loads in the distribution system [9]. To compensate for power quality issues, power electronics-based devices like power filters, unified power flow controller (UPFC), static compensator (STATCOM), distribution static compensator (DSTATCOM), and dynamic voltage restorer (DVR) are used [10], [11]. DVR requires a complex control mechanism to safeguard important distribution system loads from power quality issues [12]. DVR is used on distribution feeders to safeguard loads from problems caused by voltage sags and swells. DVR is linked in series with the load, and a battery energy storage system (BESS) is coupled with a transformer and inverter, which adjust the active and reactive power requirements for voltage sags and voltage swells [13]. For voltage stability, the DVR injects voltage into the distribution system, which is connected to the system through the transformer [14]. DVR is a FACTS device that adjusts for disturbances caused by loads such as voltage sags, swells, and voltage harmonics. In normal settings, DVR injects voltages in series with the transmission lines and injects a modest amount of voltage. When a disturbance occurs, however, DVR calculates the voltages needed to safeguard the load using sinusoidal pulse width modulation (SPWM) [15]. The voltages are then fed back into the system to keep the condition stable. DVR either absorbs or delivers active or reactive power in the steady-state, but when a disturbance occurs, DVR either delivers or absorbs active or reactive power from the dc-link. Martiningsih et al. have advocated installing a DVR in a PT DSS power plant, where the DVR functions as a compensator and is linked in series with the distribution line. The suggested PI-based DVR is capable of recovering power quality constraints [16], [17]. Eltamaly et al. developed a DVR-based technique for reducing voltage sag using DVR to improve the quality of power systems. To deterioration in electrical equipment performance. The findings show that DVR properly compensates for sag/swell and implements suitable voltage adjustment [18]. To alleviate symmetrical and asymmetrical sags and swells, J. Han et al. presented a unique DVR with a power electronic transformer (PET) [19]. The findings show that the unique design efficiently alleviates the symmetrical and asymmetrical problems. The DVR control strategy can protect the load from power quality issues related to voltage [5]. To have proper control, a perfect reference generation technique must be implemented. Various approaches for reference generation have been suggested, including, Clark's and Park's transformations, Phasor parameter and, Symmetrical components, Instantaneous real and reactive power [20]. Park's transformation is a mathematical transformation approach used to simplify the analysis of three-phase circuits is direct–quadrature–zero (dq0) in electrical engineering. The application of the dq0 transform on three-phase circuits reduces the three AC values to two DC quantities [8], [21]. In this article, an improved PQ method is proposed for the generation of reference signals in terms of the positive sequence component of the grid voltage and the negative sequence component of load current. The appearance of load current negative sequence component arises due to power quality issues such as voltage sag, swell,frequency, load change.The main advantage of the modified technique is the non-utilization of phase-locked loop and low-pass filters, because of which the disadvantages of phase shifting and insufficient compensation are eliminated. Comparison analysis between the performances of traditional and proposed PQ methods is presented through different scenarios of power quality issues. The proposed method is superior in detecting and compensating the power quality issues.

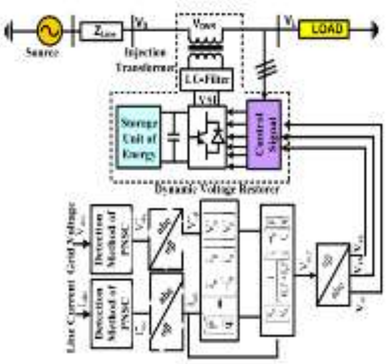

Fig 1. Proposed system configuration.

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II LITERATURE REVIEW

Discusses power and voltage quality issues, including voltage swells and sages, and provides a summary of dynamic voltage restorers (DVRs), a modern, efficient custom power gadget that compensates for voltage anomalies, maintaining load voltage balance and constant at nominal values.[1]

Examines the design and functioning of a dynamic voltage restorer (DVR) to detect voltage sag/swell and generate reference voltage. It compares SRF theory, Fourier Transform, and a hysteresis controller, finding that DVR is the best equipment to reduce voltage sag/swell while maintaining load voltage constant.[2]

A comprehensive analysis of micro grid voltage stability, examining its impact on power systems, interlinking converters, DC-link voltage, disturbance size, load dynamics, static and dynamic analysis techniques, embedded micro grid stability, and case studies for power system integration.[3]

The performance of DVR, a control system suitable for mitigating voltage sag and swell. It discusses its construction, operation, compensation schemes, and control strategies, highlighting its advantages over linear controllers in cost, computational work, and ease of operation.[4]

The proposed control scheme focuses on characterization of voltage sag and offers flexible compensation by alternating between pre-sag and in phase compensation. It provides information on compensation limits for different types of sag and offers 100% compensation for type sag and up to 50% for other types' sag magnitude. The algorithm can compensate in harmonics and imbalance, taking at most half a cycle to complete.[5]

Voltage sags can affect the operation of devices connected to power systems, such as the doubly-fed induction generator (DFIG) in wind energy conversion systems. The generator is highly sensitive to power quality disruptions due to its direct connection to the power grid. An algorithm based on aggregate value notion can quickly and accurately identify voltage sags, identifying both symmetrical and asymmetrical events, even in distorted supply voltage. This algorithm is suitable for real-world applications due to its popularity.[6]

III PROPOSED SYSTEM

The process of creating an enhanced Instantaneous Reactive Power (PQ) theory-based regulation of a Dynamic Voltage Restorer (DVR) in MATLAB/Simulink version 2021a involves several phases. System modelling is done using Simulink to depict the system's dynamic behavior during sag and swell events. The Instantaneous Reactive Power theory is used to calculate real and reactive power instantaneous values for control decisions.The proposed control algorithm for a DVR uses modified PQ theory of three level inverter is identify sag and swell events and adjust output voltage. The DVR model should be integrated into the power system's Simulink representation for efficient communication during excessive sag and swell. Performance evaluation will involve simulating the system in various sag and swell scenarios to assess its ability to reduce voltage fluctuations and maintain power quality. To optimize the DVR's response to disruptions, adjust the control algorithm's parameters, such as time constants and control gains. Then, evaluate the effectiveness of the enhanced control technique by comparing it with conventional methods. This process can create a reliable system that effectively mitigates extreme events and enhances power quality.

The proposed configuration includes a supply (grid) voltage with grid impedance, a three-phase load, an injection transformer, and the DVR system. The DVR system comprises a Voltage Source Inverter (VSI) powered by a DC power source with a dc link capacitor and a harmonic passive filter. A three-phase balanced,load is considered in this system .

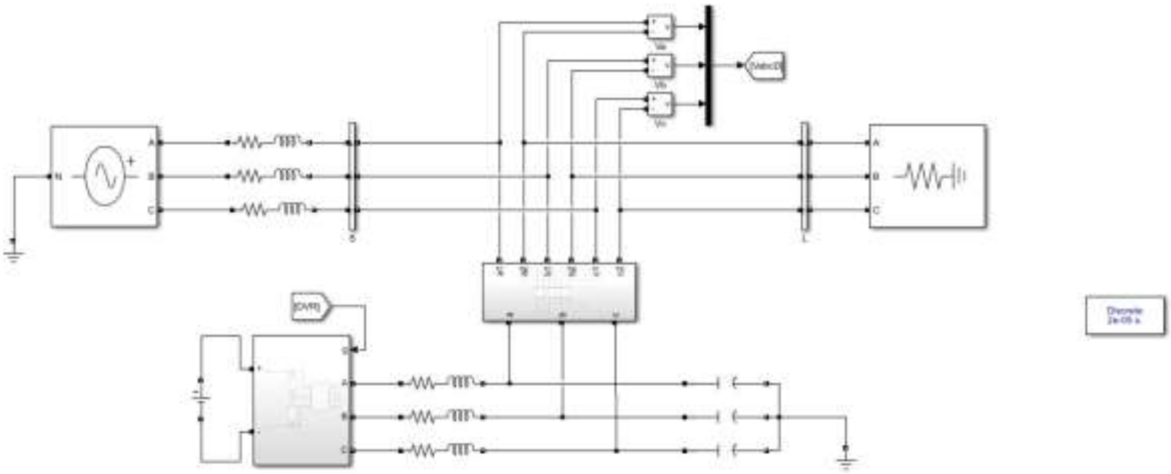

Fig 2. Block diagram

IV THREE LEVEL INVERTER

A three-level inverter is a power electronic device that converts DC (direct current) into AC (alternating current) with three distinct output voltage levels positive, zero, and negative. This is achieved using multiple semiconductor switches, such as IGBTs or MOSFETs, in a specific configuration.The most common three-level inverter topologies are the Neutral Point Clamped (NPC), Flying Capacitor (FC), and Cascaded H-Bridge inverters. In these designs, additional components like clamping diodes or capacitors help to manage and balance the voltage levels.The inverter generates three voltage levels by varying the states of the switches. For example, in the NPC topology, the switches are arranged to provide output voltages of +Vdc/2, 0, and -Vdc/2. This results in a staircase-like waveform that approximates a sine wave more closely than traditional two-level inverters, reducing harmonic distortion and improving output quality.The three-level inverter improves output voltage quality, reduces harmonic distortion, and enhances efficiency, making it suitable for high-power applications.

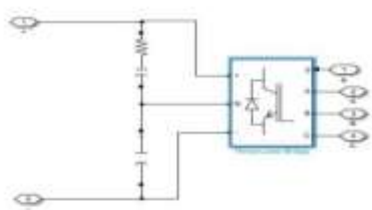

Fig 3. Three level inverter

V MODIFIED PQ THEORY CONTOLLER

The improved method involves creating a reference signal to compensate for power quality issues, based on grid voltage and load current negative sequence component. Power quality concerns like voltage sag, swell, load change, harmonic impact, balance, and unbalanced load induce this component. The compensation magnitude and reference signal phase are determined by evaluating the load current negative sequence component, which is determined by the following equation.

$$i_{abc}^{-}(t)f_n = \begin{bmatrix} i_a^-(t) \\ i_b^-(t) \\ i_c^-(t) \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; 1$$

The reference signal's phasing is calculated using the source side voltage and the positive sequence component of the grid voltage, and evaluated using the following equation.

$$V_{abc}^{1}(t)f_n = \begin{bmatrix} V_a^+(t) \\ V_b^+(t) \\ V_c^+(t) \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2$$

To obtain the phasing, amplitudes of positive sequence components are normalized at the desired value using the maximum amplitude detection as following:

$$V^+(t) = |V_{ref}|\frac{V^+(t)}{V^+(t)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3$$

The grid voltages (vabc) and load currents (iabc) are measured in per unit (pu) and converted into two signals using Clark's transformation, resulting in the outputs ($V^{+\alpha}, V^{+\beta}$) and ($I^{-\alpha}, I^{-\beta}$).

$$\begin{bmatrix} V_\alpha^+ \\ V_\beta^+ \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a^+ \\ V_b^+ \\ V_c^+ \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; 4$$

$$\begin{bmatrix} I_\alpha^- \\ I_\beta^- \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} I_a^- \\ I_b^- \\ I_c^- \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..5$$

The instantaneous active and reactive powers are calculated by evaluating the α and β components of positive sequence voltage and negative sequence current vectors using equations (4) and (5). These powers are expressed in terms of grid voltage and load current components.

$$\tilde{p} + j\tilde{q} = V_\alpha^+ i_\alpha^- + V_\beta^+ i_\beta^- - jV_\alpha^+ i_\beta^- + jV_\beta^+ i_\alpha^- \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 6$$

The above equation in the matrix form can be expressed as:

$$\begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} = \begin{bmatrix} i_\alpha^- & i_\beta^- \\ -i_\beta^- & i_\alpha^- \end{bmatrix}\begin{bmatrix} V_\alpha^+ \\ V_\beta^+ \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 7$$

There is no requirement for DC voltage management because the DVR's inverter runs on a steady DC power supply. The matrix can be calculated inversely to obtain reference voltages.

$$\begin{bmatrix} V_{r\alpha} \\ V_{r\beta} \end{bmatrix} = \frac{1}{(i_\alpha^-)^2 + (i_\beta^-)^2}\begin{bmatrix} i_\alpha^- & i_\beta^- \\ -i_\beta^- & i_\alpha^- \end{bmatrix}\begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 8$$

These reference signals are then transformed into abc coordination using inverse Clark's transformation as:

$$\begin{bmatrix} V_{ra} \\ V_{rb} \\ V_{rc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{r\alpha} \\ V_{r\beta} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

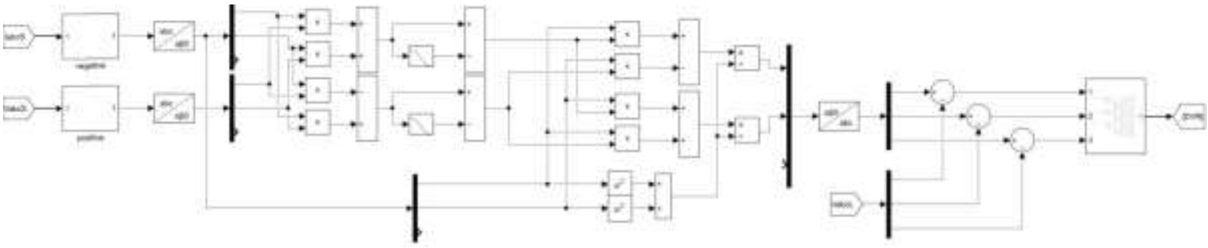

Fig 4. Modified PQ controller

VI RESULTS AND DISCUSSIONS

To verify the proposed modified PQ control with three level inverter system for reference generation the complete system model is implemented in MATLAB simulation of the system based on ‘‘mathematical equations’’ is implemented. Different scenarios of severe power quality conditions are extracted to verify and validate the efficacy of the proposed modified PQ control with three level inverter system scheme.

1) 20% SAG OF GRID VOLTAGE IN BALANCED LOAD CONDITION:

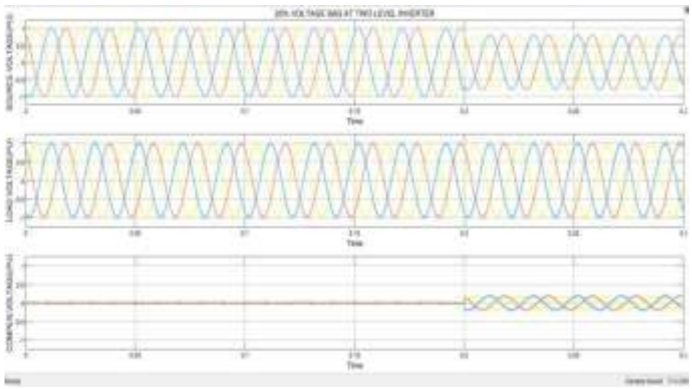

Fig 5. The Simulation Results Of 20% Sag of Grid, Load, And Compensating Voltages With Modified PQ connected by Two level inverter.

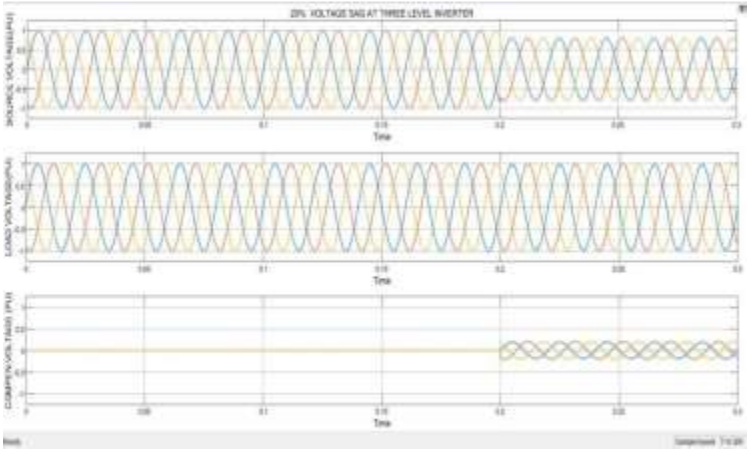

Fig 6. The Simulation Results Of 20% Sag of Grid, Load, And Compensating Voltages With Proposed Modified PQ connected by Three level inverter.

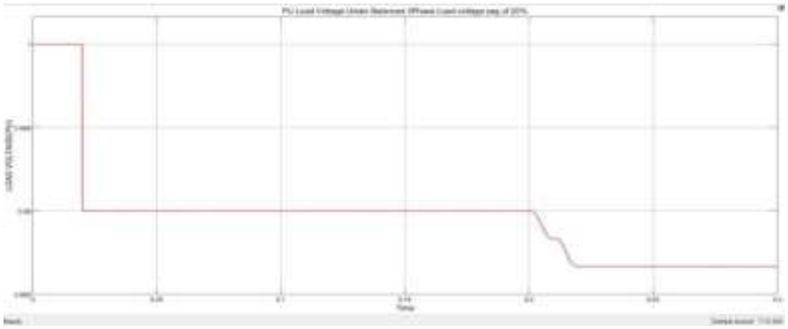

Fig 7. 20% sag load voltage at 2 level inverter

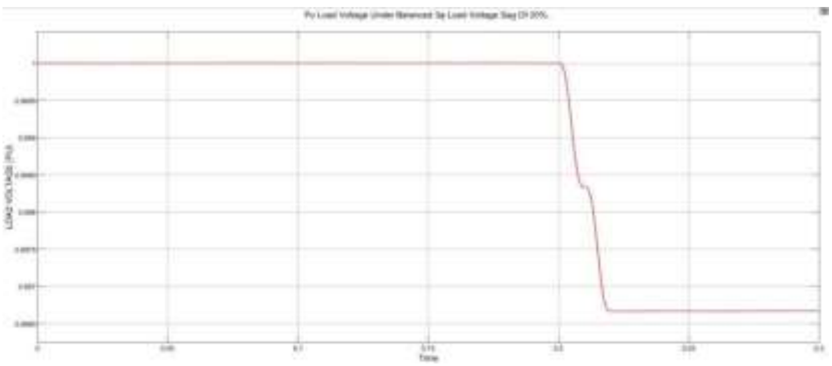

Fig 8. 20% sag load voltage at 3 level inverter

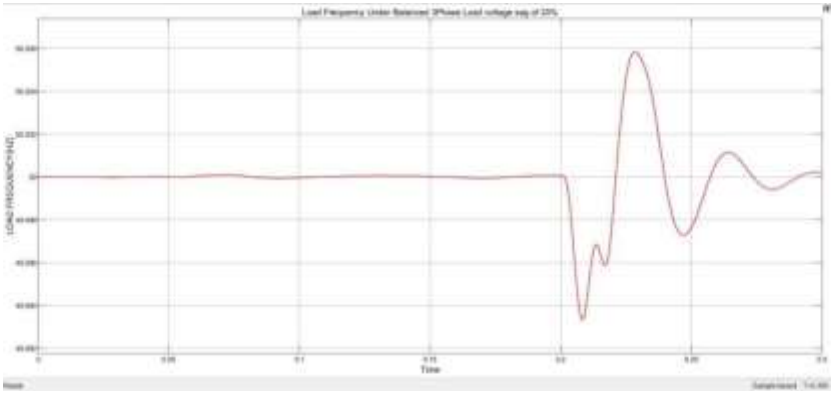

Fig 9. 20% sag load frequency at 2 level inverter

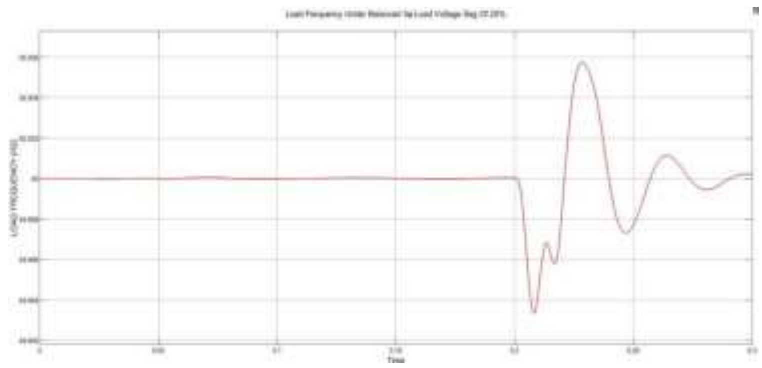

Fig 10. 20% sag load frequency at 3 level inverter

In this case of balanced load condition, the three-phase grid voltage is affected by a 20% sag. Fig 8.4 shows the simulation results of the grid, load and compensating voltage for the balanced load voltage scenario using the modified PQ technique with two level inverter . Here, the sag is starting at the instant of 0.2 seconds (s). With conventional PQ, it is observed that the load voltage waveform is distorted, and the associated compensating voltage is injected at almost the same instant of 0.2S. Fig 8.5 shows simulated waveforms of Gird voltage, load voltage, and appropriate compensating voltage With Proposed Modified PQ connected by Three level inverter with 20% sag of grid voltage under balanced load conditions. Under this balanced condition, the compensating voltage is injected instantaneously at 0.2s. The load voltage waveform shows very low distortion and a good voltage profile when the proposed Modified PQ with three level inverter control is used to compensate for 20 percent sag. This demonstrates fig's 8.6(a),8.6(b),8.7(a),8.7(b) show the proposed Proposed Modified PQ connected by Three level inverter technique's effectiveness and quick settlement to the nominal load voltage value and the load frequency has affected with a small change.

2) 70% SWELL OF GRID VOLTAGE IN BALANCED LOAD CONDITION:

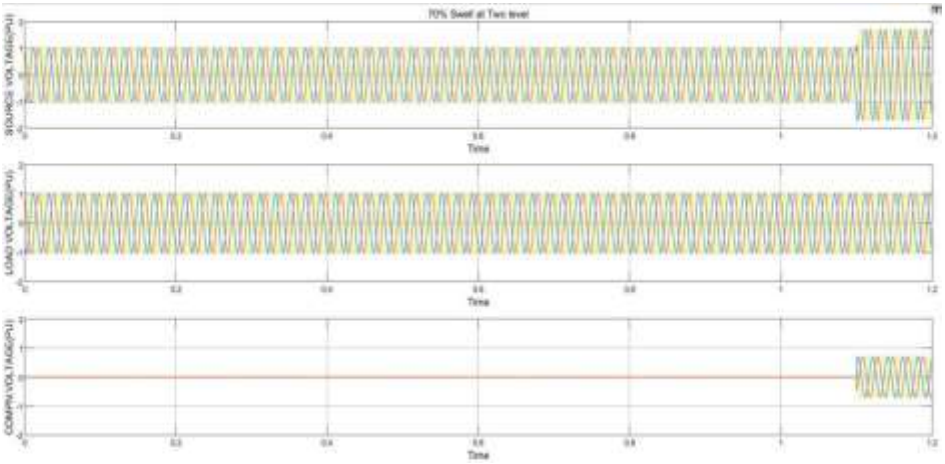

Fig 11. The Simulation Results Of 70% Swell of Grid, Load, And Compensating Voltages With Modified PQ connected by Two level inverter.

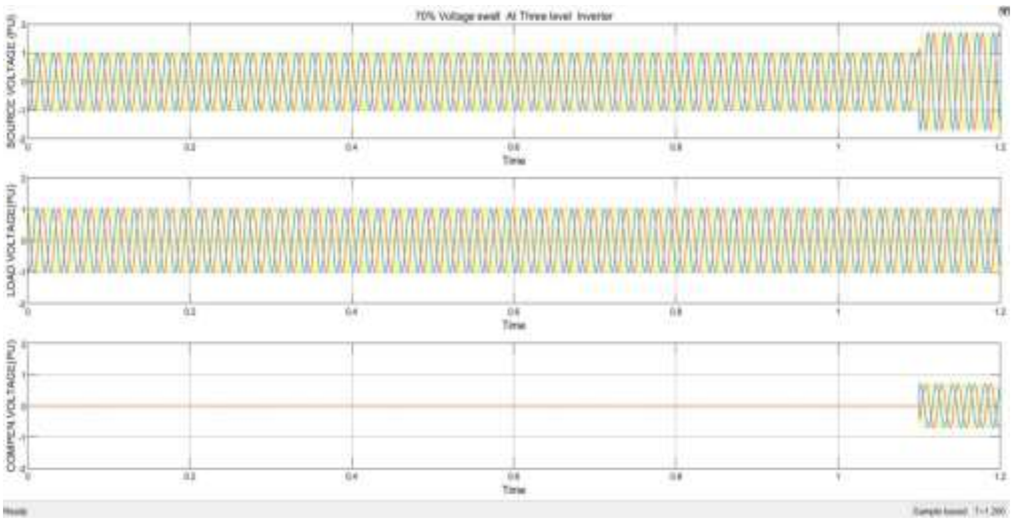

Fig 12. The Simulation Results Of 70% Swell of Grid, Load, And Compensating Voltages With Proposed Modified PQ connected by Three level inverter.

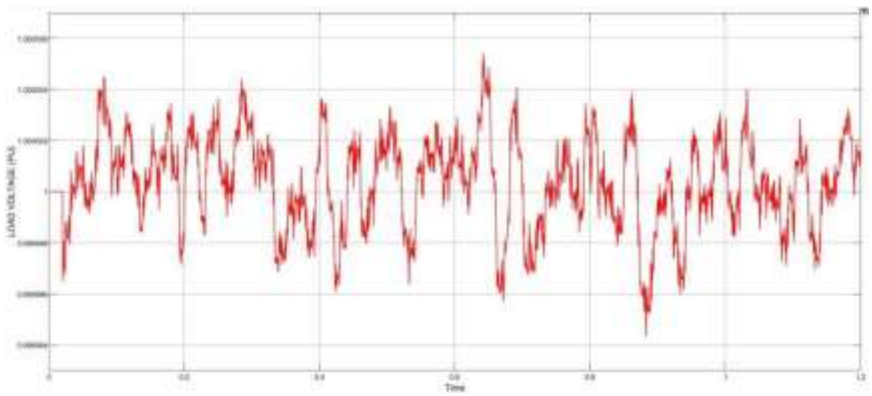

Fig 13. 70% swell load voltage at 2 level inverter

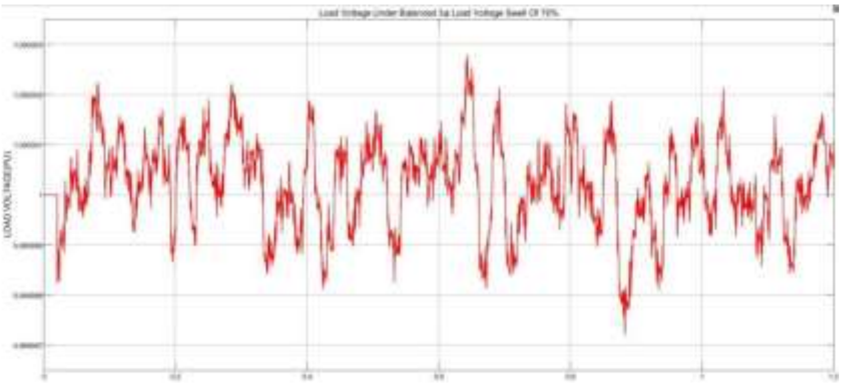

Fig 14. 70% swell load voltage at 3 level inverter

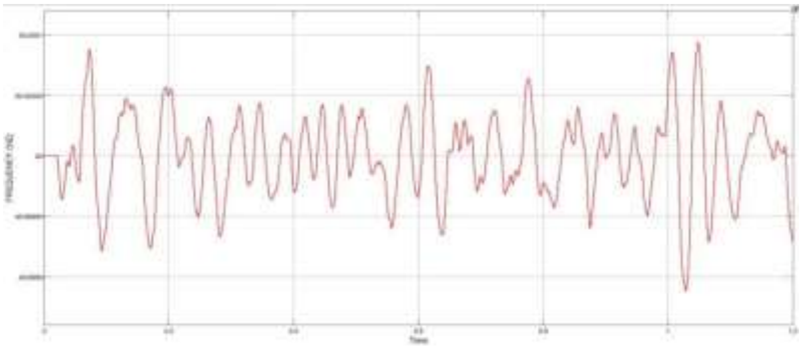

Fig 15. 70% swell load frequency at 2 level inverter

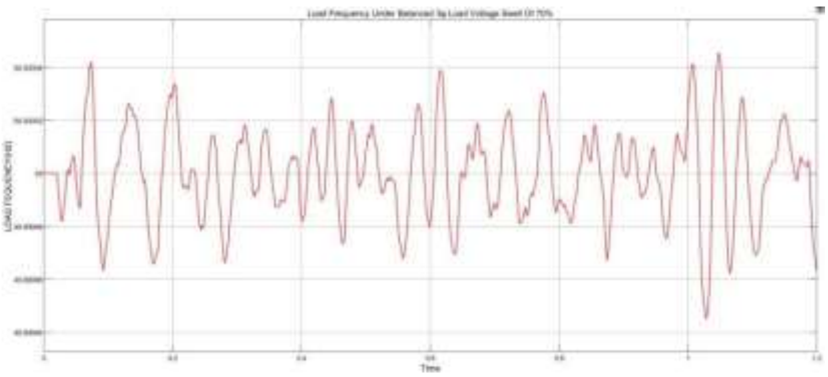

Fig 16. 70% swell load frequency at 3 level inverter

The Fig 11 represents the simulation results of the grid, load, and compensating voltages Injected by modified PQ with 2 level inverter under balanced load conditions with 70% swell in grid voltage. It can be observed that the swell in the system is initiated at 1.1 s. The corresponding compensation voltage is also injected at 1.1 s promptly. Though with the instantaneous injection of the compensation voltage the load voltage is severely distorted with still the load voltage having a swell of around 20% from 1.12 s to 1.14 s. Fig 11 illustrates the simulation results of the proposed modified PQ with three level inverter where the compensation voltage is injected instantaneously at 1.1 s. In this case, the load voltage is compensated to the maximum with a very low swell after compensation of around 10% between 1.12 s to 1.14 s. The load voltage has shown a fair improvement in the voltage profile and excellent compensation with the proposed PQ control technique with

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three level inverter.When fig's 13,14, 15and 16 comparing the Modified PQ connected by Two level inverter and Proposed Modified PQ connected by Three level inverter control approach in 70% Swell case, it can be observed that the load voltage and frequency fluctuations are larger with the Modified PQ connected by Two level inverter control approach.

TABLE 1: Comparison of modified PQ contoller with 2 level and 3 level inverter at Load voltages.

PARAMETER	2 LEVEL INVERTER		3 LEVEL INVERTER	
	20% sag	70% swell	20% sag	70% swell
Load voltage at phase-A volts in PU	0.9178 PU	1.009 PU	0.9896 PU	0.9996 PU
Load voltage at phase-B volts in PU	0.9615 PU	1.021 PU	1 PU	1 PU
Load voltage at phase-C volts in PU	0.9709 PU	1.03 PU	1 PU	1 PU

VII CONCLUSION

This project delivered a method for compensating voltage disturbances while using the DVR with three level converter. The proposed approach improves the quality of load voltages by protecting them against grid voltage abnormalities. The proposed DVR control approach is based on a modified version of PQ theory with three level inverter that employs a detection method for the positive and negative sequence components. The detection technique is carried out in the time domain. The efficiency of the proposed approach is assessed using extensive simulations in MATLAB/Simulink under several special disturbance scenarios: severe sag and swell. The proposed method has shown capability in improving the voltage quality as well as the voltage profile. The results have emphasized the applicability of the proposed DVR with three level inverter compensation method. To sum up, the following advantages summarize the performance of the proposed system Less computational effort,Faster response, Balanced load voltages under severe unbalanced voltage sag and swell.

REFERENCES

[1] S. A. Mohammed, A. G. Cerrada, A. M. M. Abdel-Rahim, and B. Hasanin, "Dynamic voltage restorer (DVR) system for compensation of voltage sags, state-of-the-art review," Int. J. Comput. Eng. Res., vol. 3, no. 1, pp. 2250–3005, 2013.

[2] A. I. Pathan, S. S. Vanamane, and R. H. Chile, "Different control techniques of dynamic voltage restorer for power quality problems," in Proc. 1st Int. Conf. Autom., Control, Energy Syst. (ACES), Feb. 2014, pp. 1–6.

[3] N. Hosseinzadeh, A. Aziz, A. Mahmud, A. Gargoom, and M. Rabbani, "Voltage stability of power systems with renewable-energy inverter-based generators: A review," Electronics, vol. 10, no. 2, pp. 1–27, Jan. 2021, doi: 10.3390/electronics10020115.

[4] Y. Jani, S. Savaliya, V. Solanki, and A. Mahavidyalaya, "A review on dynamic voltage restorer (DVR) to improve power quality," Int. J. Eng. Sci. Res. Technol., vol. 3, no. 2, pp. 1–5, 2014.

[5] S. Jothibasu and M. K. Mishra, "A control scheme for storageless DVR based on characterization of voltage sags," IEEE Trans. Power Del., vol. 29, no. 5, pp. 2261–2269, Oct. 2014, doi: 10.1109/TPWRD.2014.2316598.

[6] F. K. de Araújo Lima, J. M. Guerrero, F. L. Tofoli, C. G. C. Branco, and J. L. Dantas, "Fast and accurate voltage sag detection algorithm," Int. J. Electr. Power Energy Syst., vol. 135, Feb. 2022, Art. no. 107516, doi: 10.1016/j.ijepes.2021.107516.

[7] S. F. Al-Gahtani, A. B. Barnawi, H. Z. Azazi, S. M. Irshad, J. K. Bhutto, H. M. Majahar, and E. Z. M. Salem, "A new technique implemented in synchronous reference frame for DVR control under severe sag and swell conditions," IEEE Access, vol. 10, pp. 25565–25579, 2022, doi: 10.1109/ACCESS.2022.3151919.

[8] S. Suraya and K. S. R. Anjaneyulu, "SRF controlled DVR for compensation of balanced and unbalanced voltage disturbances," Int. J. Electr. Eng. Technol., vol. 7, no. 3, pp. 73–92, 2016.

[9] E. A. Al-Ammar, A. Ul-Haq, A. Iqbal, M. Jalal, and A. Anjum, "SRF based versatile control technique for DVR to mitigate voltage sag problem in distribution system," Ain Shams Eng. J., vol. 11, no. 1, pp. 99–108, Mar. 2020, doi: 10.1016/j.asej.2019.09.001.

[10] S. Nawaz, N. Jhajharia, and T. Manglani, "Reduction of distribution losses by combined effect of feeder reconfiguration and optimal capacitor placement," Int. J. Recent Res. Rev., vol. 2, pp. 30–38, Jun. 2012.

[11] R. O. Bawazir and N. S. Cetin, "Comprehensive overview of optimizing PV-DG allocation in power system and solar energy resource potential assessments," Energy Rep., vol. 6, pp. 173–208, Nov. 2020, doi: 10.1016/j.egyr.2019.12.010. [12] M. Farhadi-Kangarlu, E. Babaei, and F. Blaabjerg, "A comprehensive review of dynamic voltage restorers," Int. J. Electr. Power Energy Syst., vol. 92, pp. 136–155, Nov. 2017, doi: 10.1016/j.ijepes.2017. 04.013.

[13] C. Zhan, "Dynamic voltage restorer with battery energy storage for voltage dip mitigation," in Proc. 8th Int. Conf. Power Electron. Variable Speed Drives, 2000, pp. 360–365, doi: 10.1049/cp:20000273.

[14] G. S. Chawda, A. G. Shaik, O. P. Mahela, S. Padmanaban, and J. B. Holm-Nielsen, "Comprehensive review of distributed facts control algorithms for power quality enhancement in utility grid with renewable energy penetration," IEEE Access, vol. 8, pp. 107614–107634, 2020, doi: 10.1109/ACCESS.2020.3000931.

[15] T. Bhattacharjee, M. Jamil, and A. Jana, "Design of SPWM based three phase inverter model," in Proc. Technol. Smart-City Energy Secur. Power (ICSESP), Mar. 2018, pp. 1–6, doi: 10.1109/ICSESP.2018. 8376696.

[16] N. Abas, S. Dilshad, A. Khalid, M. S. Saleem, and N. Khan, "Power quality improvement using dynamic voltage restorer," IEEE Access, vol. 8, pp. 164325–164339, 2020, doi: 10.1109/ACCESS.2020. 3022477.

[17] J. Afonso, C. Couto, and J. Martins, "Active filters with control based on the P-Q theory," IEEE Ind. Electron. Soc. Newslett., vol. 47, no. 3, pp. 5–10, Sep. 2000. [Online]. Available: http://hdl.handle.net/1822/1921

[18] A. Eltamaly, Y. Sayed, A.-H. Ahmed, and A. A. Elghaffar, "Mitigation voltage sag using DVR with power distribution networks for enhancing the power system quality," Int. J. Electr. Eng. Appl. Sci., vol. 1, no. October, pp. 2600–7495, 2018.

[19] J. Han, X. Kong, P. Li, Z. Zhang, and X. Yin, "A novel low voltage ride through strategy for cascaded power electronic transformer," Protection Control Modern Power Syst., vol. 4, no. 1, pp. 1–12, Dec. 2019, doi: 10.1186/s41601-019-0137-1.

[20] A. H. Soomro, A. S. Larik, M. A. Mahar, A. A. Sahito, A. M. Soomro, and G. S. Kaloi, "Dynamic voltage restorer—A comprehensive review," Energy Rep., vol. 7, pp. 6786–6805, Nov. 2021, doi: 10.1016/j.egyr.2021.09.004.

[21] A. Mortezaei, C. Lute, M. G. Simoes, F. P. Marafao, and A. Boglia, “PQ, DQ and CPT control methods for shunt active compensators—A comparative study,” in Proc. IEEE Energy Convers. Congr. Exposit. (ECCE), Sep. 2014, pp. 2994–3001, doi: 10.1109/ECCE.2014. 6953807.