An Innovative Photovoltaic Solar Fed TransZSI-DVR for Grid-Connected PV Systems to Improve Power Quality

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***Abstract*— In order to enhance the power quality of off-grid photovoltaic (PV) systems, a novel solar PV fed Dynamic Voltage Restorer (DVR) based on Trans-Z-source Inverter (TransZSI) is proposed in this paper. The DVR is a power electronic compensator that is used to adjust the voltage disturbance by injecting the desired voltage into the Point of Common Coupling (PCC). With the exceptional benefits of buck/boost, a wider range of voltage boost gain, fewer passive components, and reduced voltage stress, TransZSI is offered as a replacement for standard VSI in the proposed DVR. In order to reduce the injected voltage harmonics and achieve accurate voltage disturbance mitigation and efficient detection, a hybrid Unit Vector Template with Maximum Constant Boost Control (UVTMCBC) method is suggested for TransZSI-DVR. We've examined the suggested TransZSI-DVR with UVT-MCBC's performance in the presence of swell, interruption, severe sag, and minor sag with harmonics. The comparison analyses and simulation outcomes demonstrate the superiority of the suggested TransZSI-DVR over the conventional ZSI-DVR and VSI-DVR. The PV system's TransZSI-DVR has reduced voltage sag, swell, and interruption. Additionally, it has enhanced the power quality of the output voltage of the PV system as well as the injected voltage to the PCC.**

***Keywords* — PV, DVR, TransZSI, voltage sag, voltage transient, THD.**

I. INTRODUCTION

Future power systems will have a significant penetration of solar PV and wind power systems due to environmental concerns and the growth towards a sustainable society. The pattern is in favour of phasing out coal and fossil fuels and increasing renewable energy. Since sunlight is one of the most plentiful and accessible energy supplies on Earth, photovoltaic systems have seen a notable bias among renewable energy sources [1]. However, a number of variables, including temperature, soiling, clouds, solar radiation, and so on, can affect how well PV systems work. As a result, voltage sag—one of the most frequent yet serious power quality problems—occurs when the PV output voltage is reduced. Power quality problems including sags, swells, and interruptions have gotten worse in the modern power system due to an increase in sensitive and important loads. Significant losses arise from these power quality problems, including diminished producer competitiveness, decreased efficiency, higher production and maintenance costs, lower product quality, shorter equipment lifespans, production disruptions, and energy losses. Possessing superior power Thus, thus manufacturing company can benefit economically and save a significant amount of money by obtaining highquality power.

An ideal power supply with no noise, a sinusoidal waveform, and constant availability, and voltage and frequency tolerances is produced by high power quality. The most significant power quality problems are defined as shortduration voltage changes, which include voltage sags, swells, and interruptions.

Voltage sag is defined by IEEE standard 1159 as a decline in the Root Mean Square (RMS) voltage (0.1~0.9pu of normal voltage) lasting 0.5 cycles-1min. Large loads, such as motors, are frequently started improperly and generate sags. Voltage sags in grid-connected photovoltaic systems are mostly caused by partial shadowing conditions. A voltage swell is also defined as an increase in the RMS voltage (1.1–1.8pu of nominal value) that occurs simultaneously with a voltage sag.

The main sources of swells are shutting off huge loads and starting and stopping large capacitors. There are numerous ways to protect sensitive and important loads from the effects of such voltage changes. Using specialised power devices, often known as devices built on power converters, is the most sensible and efficient option. Out of all of them, the Dynamic Voltage Restorer (DVR) is the most effective tool for reducing voltage dips, surges, and interruptions. The DVR is in standby mode while the PCC is in good condition and is connected in series between the load and source sides. The DVR controller senses the supply voltage's duration and magnitude once it deviates from its nominal value. It then injects the appropriate voltage into the PCC in accordance with the findings. Three single phase injection/coupling transformers, an LC filter, a voltage source inverter (VSI), and a DC storage unit make up a DVR.

In the DVR configuration, the VSI has historically been used. In, simulation for voltage sag and voltage swell scenarios is carried out, and the DVR system's performance based on the VSI is examined. The load requires a balanced and consistent voltage, which the DVR system can readily handle and maintain. Despite being frequently utilised in DVR configuration, the VSI has certain drawbacks. It requires a DC/DC boost converter because it is a buck converter. Additionally, the semiconductors in each leg must not be turned on simultaneously to prevent shoot-through (ST), which could harm the inverter bridge. It should be noted that the ST is caused by short-circuiting the supply by simultaneously turning on both switches in the 1', 2', or all 3' legs. Similar to VSI, CSI requires a buck converter and at least one of the upper or lower semiconductors to be turned on.

II LITERATURE SURVEY

In the last few years renewable energies have experienced one of the largest growth areas in percentage of over 30 % per year, compared with the growth of coal and lignite energy. The goal of the European Community (the EU) is to reach 20 % in 2020, but the EU-27 energy is only 17 % of world energy. The US, with 22 % of energy share, has adopted similar goals under the pressure of public opinion concerned by environmental problems and in order to overcome the economic crisis. However, the policies of Asia and Pacific countries, with 35 % of energy share, will probably be more important in the future energy scenario. In fact, countries like China and India require continuously more energy (China energy share has increased 1 point every year from 2000). The need for more energy of the emerging countries and the environmental concerns of the US and the EU increases the importance of renewable energy sources in the future energy scenario [1].

The global concern with power quality is increasing due to the penetration of renewable energy (RE) sources to cater the energy demands and meet de-carbonization targets. Power quality (PQ) disturbances are found to be more predominant with RE penetration due to the variable outputs and interfacing converters. There is a need to recognize and mitigate PQ disturbances to supply clean power to the consumer. This paper presents a critical review of techniques used for detection and classification PQ disturbances in the utility grid with renewable energy penetration. The broad perspective of this review paper is to provide various concepts utilized for extraction of the features to detect and classify the PQ disturbances even in the noisy environment [2].

Rapid industrialization and its automation on the globe demands increased generation of electrical energy with more reliability and quality. Renewable energy (RE) sources are considered as a green form of energy and extensively used as an alternative source of energy for conventional energy sources to meet the increased demand for electrical power. However, these sources, when integrated to the utility grid, pose challenges in maintaining the power quality (PQ) and stability of the power system network. This is due to the unpredictable and variable nature of generation by these sources. The distributed flexible AC transmission system (DFACTS) devices such as distributed static compensator (DSTATCOM) and dynamic voltage restorer (DVR) play an active role in mitigating PQ issues associated with RE penetration. The performance of DFACTS devices is mostly dependent on the type of control algorithms employed for switching of these devices [3].

Power quality is a pressing concern and of the utmost importance for advanced and high-tech equipment in particular, whose performance relies heavily on the supply’s quality. Power quality issues like voltage sags/swells, harmonics, interruptions, etc. are defined as any deviations in current, voltage, or frequency that result in end-use equipment damage or failure. Sensitive loads like medical equipment in hospitals and health clinics, schools, prisons, etc. malfunction for the outages and interruptions, thereby causing substantial economic losses. For enhancing power quality, custom power devices (CPDs) are recommended, among which the Dynamic Voltage Restorer (DVR) is considered as the best and costeffective solution [4].

Super capacitor as the energy storage device for the DVR to compensate voltage sag, voltage swell and harmonics due to addition of nonlinear load in the distribution line. Based on this topology, DVR consist of super capacitor, z source inverter and injection transformer. Super capacitor produces the necessary dc voltage which is given as the input voltage to the z-source inverter; provide the necessary injecting voltage, which has to be restored. In addition, it also consists of PI controller which provides the necessary control signals for the z source inverter [5].

The grid-connected PV system in partial shading conditions through the three-level SVM inverter and compensation of inverter output voltage sag caused by the partial shading using the dynamic voltage restorer (DVR). A function per time and the amount of radiation has been used to create the partial shading condition in the photovoltaic system. The advantages of three-level SVM inverter include the complete region detection method even in the boundary points between two regions through boundary lines equations and complete online solution of those equations. Also the reduction of total harmonic distortion (THD) through the switching table is appropriate. The results show that in the partial shading conditions the three-level SVM inverter decreased THD in the presence or absence of DVR [6]. This research activity is aimed at introducing a comprehensive review of these different modulation schemes employed for the three-phase impedance source inverters, which is enhanced with a comparative assessment. In this paper, different modulation schemes are classified and reviewed, introducing an important benchmark in order to identify the basic differences between these modulation schemes. In other words, from this paper, the concept of classifying the different modulation schemes and the mandatory equations to implement each scheme can easily be drawn [7].

The dynamic voltage restorer has been gaining acceptance as an effective device for voltage sag compensation. The compensation capability of a dynamic voltage restore (DVR) depends primarily on the maximum voltage injection ability and the amount of stored energy available within the restorer. A new topology based on Zsource inverter for the DVR is proposed in order to enhance the voltage restoration property of the device. Z-source impedance network along with shoot through capability of the proposed inverter would ensure a constant dc-voltage across the dc-link despite dwindling voltage in the storage devices connected in the dc-link during the process of voltage compensation. Even when the dc-link energy is supplied through a shunt connected auxiliary supply, the voltage rating of the shunt converter, shunt transformer and the dc-link capacitor can be kept smaller with the proposed topology [8]. The dynamic voltage restorer, with its excellent dynamic capabilities, when installed between the supply and a critical load feeder, can compensate for voltage sag/swells, restoring line voltage to its nominal value within few milliseconds and hence avoiding any power disruption to the load. A new topology based on Z-source inverter is presented in order to enhance the voltage restoration property of dynamic voltage restorer. Z-source inverter would ensure a constant DC voltage across the DC-link during the process of voltage compensation [9].

The power quality requirement is one of the major issues for power companies and their customers. The analysis of power disturbance characteristics and finding solution to the power quality problems have resulted in an increased interest for power quality. The most concerning disturbances affecting the quality of the power in the distribution system are voltage sag/swell. The DVR is used to mitigate the voltage sag/swell on sensitive load. In this paper Z-source inverter (ZSI) based DVR is proposed to enhance the voltage restoration property of the system. The ZSI uses an LC impedance grid to couple power source to inverter circuit and prepares the possibility of voltage buck and boost by short circuiting the inverter legs. Additionally a fuzzy logic control scheme for Z-source inverter based DVR is proposed to obtain desired injecting voltage [10].

The Dynamic Voltage Restorer (DVR) using Z-Source Inverter. Voltage sag is a crucial power quality problem faced by the utility industry which has resulted in increased attention. The DVR is a series power quality conditioning device used to eliminate the voltage disturbance. The DVR compensates the voltage disturbances by injecting the voltage of suitable magnitude and phase in series with the line. The compensation capability of a dynamic voltage restorer primarily depends on the maximum voltage injection ability and the amount of stored energy available within the restorer. The topology is proposed in this paper in order to enhance the voltage restoration property of the device. A constant dc-link is ensured during sag compensation by having an X-shaped impedance network with inherent shoot-through capability [11].

III. PROPOSED WORK

There exist numerous techniques to mitigate the effects of voltage fluctuations on delicate and vital loads. The majority Using gadgets that are constructed using power converters— also known as custom power devices—is an effective and sensible option. Out of all of them, the Dynamic Voltage Restorer (DVR) is the most effective tool for reducing voltage dips, spikes, and disruptions. Under normal circumstances, the DVR is in standby mode and is connected in series with the PCC between the source and load sides. The DVR controller senses the amount and duration of the supply voltage and then injects the desired voltage to the PCC in accordance with the change in supply voltage above or below its nominal value. Three single-phase injection/coupling transformers, an LC filter, a voltage source inverter (VSI), and a DC storage unit make up a DVR.

In the DVR configuration, the VSI has historically been used, simulation for voltage sag and voltage swell scenarios is carried out, and the DVR system's performance based on the VSI is examined. The load requires a balanced and consistent voltage, which the DVR system can readily handle and maintain. The VSI has certain drawbacks even though it is frequently used in DVR configuration. It requires a DC/DC boost converter because it is a buck converter. Additionally, the semiconductors in each leg must not be turned on simultaneously to prevent shoot-through (ST), which could harm the inverter bridge. It should be noted that the ST is caused by short-circuiting the supply by simultaneously turning on both switches in the 1ϕ, 2ϰ, or all 3ϕ legs. A buck converter is required for Current Source Inverters (CSI), just like for VSIs, and at least one upper or lower semiconductor must be turned on.

In order to overcome the aforementioned constraints, the ZSI (Impedance Source Inverter) has been suggested. In addition to connecting the main circuit to the load side, the ZSI uses an X-shaped impedance circuit with two capacitors and two inductors to provide important advantages that the CSI and VSI do not. The AC output voltage in the ZSI can be any value between, and it is independent of the DC input voltage. As a result, the ZSI has a larger voltage gain range and functions as a buck and boost converter concurrently. Therefore, it is a great idea to use ZSI in the DVR arrangement instead of VSI. There have been studies on ZSI-DVR arrangement. ZSIDVR, which employed a multi-loop controller, was introduced. The findings demonstrated that the suggested DVR made use of ZSI's buck/boost advantages to utilise energy storage while ultimately adjusting for sag. Nevertheless, sag was the sole voltage disruption that was examined in this article. Additionally, the conventional Pulsewidth Modulation (PWM) was used. Analogous research was conducted , wherein simple and effective open-loop sag/swell and closed swell controllers were examined. The investigation of ZSI-DVR with a fuzzy controller was carried, and the simulation results demonstrated that the suggested ZSI-DVR optimised by the fuzzy controller performed better. In order to enhance ZSI-DVR's ride-through capabilities, wind turbines are suggested as renewable energy sources in. However, the wind turbine's rectifier and wind generator may raise the cost and complexity of the DVR. In order to generate ZSI's DC voltage, a super capacitor-based ZSI-DVR with energy storage was presented.

Super capacitors have a very slow discharge rate and a quick charging rate Modified topologies were presented to reduce the voltage stress and boost the voltage-gain of ZSIs. Based on such altered ZSI arrangements, some research has been conducted recently to improve DVR's performance. In order to reduce the voltage THD, cascaded multilayer ZSI for DVR was presented. An incorporated EZSI-based DVR was introduced to reduce balanced and unbalanced voltage sags brought on by various problems. The outcomes demonstrated how inexpensive and easy to implement the suggested DVR is. A new DVR based on LCCT-ZSI was unveiled in [20] and has a greater voltage gain capability. On the other hand, swell and interruption performance evaluation and THD analysis were disregarded. In contrast to ZSI-DVR, YSI-based DVR with Fuel Cell was investigated, and the THD was decreased with the aid of the fuzzy controller.

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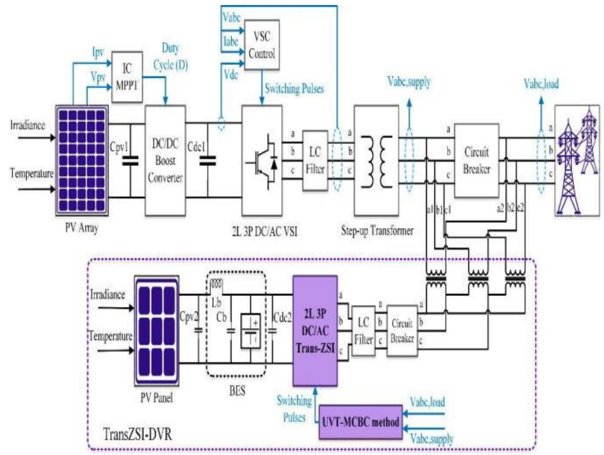

Fig 1 Architecture of Proposed System

TransZSI, which includes an impedance network consisting of a transformer and a capacitor, has outperformed the other modified ZSI designs. TransZSI achieves a larger voltage gain than ZSI due to the transformer's turns ratio. Additionally, fewer passive components mean lower costs and longer lifespan and dependability for the inverter. This paper attempts to provide an integration of PV panel and batteries in a new PV fed DVR setup based on TransZSI. This will assist with the problems with energy harvesting in photovoltaic panels and battery energy reserves. A hybrid unit vector template (UVT) with an MCBC method (UVTMCBC) is proposed herein to increase the efficacy of the DVR controller and offer an accurate detection method and efficient compensation for voltage sags, swells, and interruptions. Every voltage disturbance's precise start and stop points may be found using the UVT, which can subsequently create voltage load references for the modulation unit.

The modulation unit in this article is based on the modified Simple and Maximum Boost Control (MCB) approach, which is derived from the standard MCBC method (SBC and MBC). But there are drawbacks to both the SBC and MBC approaches. The output voltage can only be increased so far using the SBC approach. Voltage stress increases as the ST rises because the modulation index falls. The output voltage level is increased in the MBC technique by using all zero states as ST states.

This technique reduces voltage stress and increases voltage gain, but it also causes low-frequency current ripples. This implies that the passive parts are higher the lower the output frequency. Such restrictions can be addressed via the MCBC approach. The ST duty ratio in the MCBC technique stays constant, providing the remarkable advantages of a greater voltage gain range and the absence of low-frequency ripples. As a result, the UVT-MCBC is able to precisely identify voltage disturbances, inject the appropriate voltage in accordance with lower harmonics, and effectively offset them. The noteworthy contributions of this study are listed below:

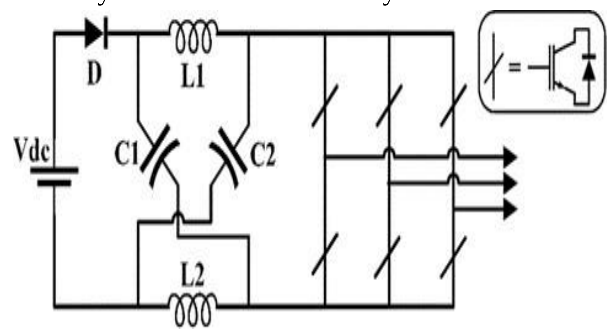

Fig.2 The ZSI basic circuit topology.

The suggested TransZSI-DVR configuration is displayed in Fig. 1. In order to detect and correct for voltage disturbances such as sags, swells, and interruptions, the DVR in this figure is linked in series with the PCC on the supply side (in this case, the output of a grid-connected PV system).

The PV array, MPPT controller, boost converter, DC/AC VSI, filter, 3ϕ transformer, and distribution network that the PV array is attached to are all part of the PV system. The DVR is in standby mode in typical circumstances. The DVR detects voltage sags, swells, and interruptions and injects the appropriate voltage into the PCC according on the magnitude and duration of the voltage disturbances. The PV panel, Battery Energy Storage (BES), TransZSI, UVT-MCBC controller, LC filter, and three single-phase injection transformers are all part of the DVR.

The DVR's energy storage delivers the required energy when there is a voltage disruption on the supply side. A Battery Energy Storage (BES) or a DC-link capacitor can be used as the energy storage device. Because the BES has a larger store capacity than the capacitor, it is more commonly utilized.

This article suggests merging the BES with the PV panel for the TransZSI-DVR. One way that solar energy helps is by reducing the energy limitations of the batteries. Recharging the BES with solar power provides DVR with a practical choice. PV panels' intermittent problem is solved with batteries. This integration meets the requirements for resolving the issues with battery energy reserves and energy capture in photovoltaic panels.

IV. RESULT AND DISCUSSION

The suggested PV fed TransZSI-DVR configuration's performance evaluation is simulated in this section, and the results are compared to the outcomes of conventional VSIDVR and ZSI-DVR configurations, which employ VSI and ZSI, respectively. Subsections that follow illustrate three distinct VSI-DVR, ZSI-DVR, and the suggested TransZSIDVR scenarios. Due to partial shadowing conditions at 250 W m^2 of solar irradiation in the PV system, there is a severe sag as the initial voltage disturbance. The second voltage anomaly is a small one. Slump with relation to harmonics. This is also a result of settings with partial shadowing at 500 W/m2 of solar radiation. Swell, a third-volt disturbance, is nearly always the result of a sudden drop in load, such as when a big motor is shut off. An interruption is the final type of voltage disruption. Interruptions are typically caused by faults. The output voltage of the PV system is always the supply voltage.

Finally, the simulation's output could be examined and used to modify the system's architecture or the DVR's management scheme. The simulation may, for instance, show that the DVR is injecting too much voltage into the system or that it is not responding to voltage disturbances fast enough. On the basis of these discoveries, modifications could be made to enhance system functionality and guarantee that it complies with the necessary power quality standards.

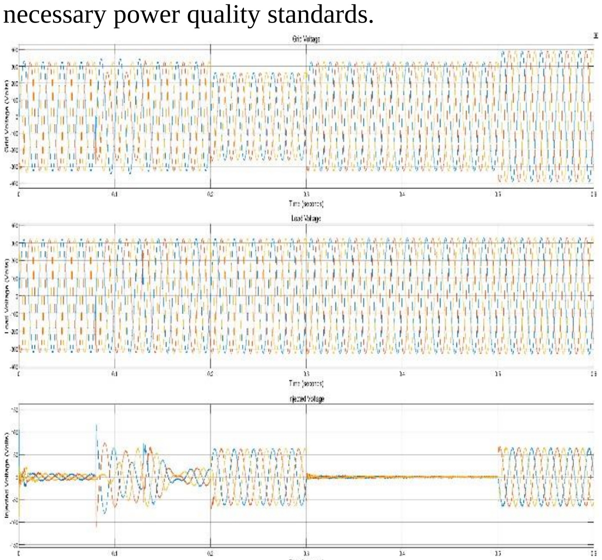

Fig 3*:* Supply, injected, and load voltage waveforms (upper, middle, and lower, respectively) in the PV fed TransZSI-DVR.

V. CONCLUSION

In this work, a new PV fed Trans ZSI-DVR has been presented to enhance the power quality of PV systems. Compared to traditional VSI-DVR and ZSI configurations, the proposed Trans-ZSIDVR brings significant benefits like being a buckand boost converter simultaneously, fewer passive components, broader voltage gain, and lower voltage stress on switches. The theoretical analysis and simulation results have significantly substantiated the performance of the proposed TransZSI-DVR in terms of sufficient compensation for sag/swell/interruption, The scopes for future research will be many some of which could be as follows. Research into modified DVR control methods to improve the power quality of injected voltage to the PCC in terms of its magnitude, harmonics, and also accurate detection of start/stop point of the voltage disturbance better than before. Another research spot would be the configuration of the inverter used in the DVR to reduce the cost, weight, and volume of the inverter, thereby decreasing the overall DVR cost. Last but not least, The stability of the proposed DVR system can be also studied, especially for remote areas where the stability of power is important.

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