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Performance Analysis of Dynamic Voltage Restorer for Symmetrical and Unsymmetrical Fault Conditions

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Abstract:
Solar grid system are frequently employed, particularly in isolated areas with limited connection to the grid for power. Voltage overshoots, transient response, and steady state errors are the main problems with photovoltaic (PV) systems that sometimes result in grid instability during transitory failures in the network and damage sensitive loads. The PV grid's dependability on irradiations results in the fluctuations of the daily power generated which mismatch the daily demand, this could lead to problems with power quality in a distribution line. In addition, unsymmetrical faults resulting from extreme weather negatively impact the dependability of the grid and power supplies in PV-grid systems exposed to weather. In order to alleviate power quality problems originating from the PV-grid side during severe weather conditions, this study provides a method for improving the stability of microgrids employing dynamic voltage restorers in three-phase grid-connected systems. The most important extreme weather events, such thunderstorms and strong winds, have the potential to generate faults like double or single line-to-ground, lightning strike or impulse transients, power outages, and other faults that affect the stability of the transmission network. The suggested method gives the load symmetrical operating conditions and improves the microgrid's transient stability. The error signal is stabilized and the fault signal is extracted by the control mechanism. In the suggested setup, a PV connected to a DC-Link inverter is driven by a hysteresis-band PWM generator.

Key Word*: Distributed Generation (DG); Dynamic voltage restorers (DVRs); Electricity Network; Hysteresis controller (HC); Maximum Power Point Tracking (MPPT); Voltage Source Inverter (VSI).*

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I. Introduction

Seeing to the environmental impact and matured technologies, solar is penetrating deep into the Electricity Network (EN) [1]. To supply consumers with electricity, power plants and other power sources are connected via electricity grid systems. The grid system consists of transformers, electrical metering devices, overhead lines, subterranean cables, switchyards that join overhead and subterranean cables, and communication and control centers, as well as control systems. Additionally, overhead lines make up the bulk of electrical transmission networks due to their low cost of installation and ease of maintenance [2]. As a result, the weather has a significant impact on how we can access this essential aspect of our lives. Unfavorable weather conditions have the potential to impact both renewable and non-renewable energy generation. The majority of power outages, according to the Climate Central Report, are connected to extreme weather, which is typically brought on by thunderstorms and heavy rain [3]. To maintain the quality of EN, power quality conditioners are connected at various locations.

Dynamic voltage restorers (DVRs), sometimes referred to as series active power filters, are voltage source devices that adjust voltage levels in distribution lines by injecting compensatory voltage to guard against power quality problems such voltage swell and sag or voltage fluctuations [5, 6]. A three-phase inverter is a common component of a three-phase DVR system. In order to extract the error voltage signal and produce gate pulses for the voltage source inverter, DC-Link is connected with an energy storage element, such as a battery, a booster transformer, and an injection of compensation voltage into the distribution line via a controller. At the point of common coupling (PCC), the load side mitigates the supply side's voltage perturbations [7]. Short circuits, single line-to-ground faults, line-to-line faults, double line-to-ground faults, and open conductor faults are examples of unsymmetrical faults [2]. The suggested goal of this study is to minimise unsymmetrical faults by infusing branch mismatch voltages at phases where the fault has occurred in a three-phase system. Unsymmetrical faults cause unbalance voltage and current to flow in the system. Connecting Distributed Generation (DG) to the EN is the conventional method of achieving transient stability at the medium voltage level [8]. To adverse effects of faults, a closed-loop PI-based DVR topology is employed. As required by the grid system, this DVR system can compensate for line voltage faults while the wind turbine continues to operate nominally. For this reason, the researcher has presented an analysis of asymmetric faults under conditions of transient grid faults [9]. Closed-loop DVR control topologies, which were first presented in [6], are not appropriate for compensating for asymmetrical faults because most power system faults are caused by imbalanced voltages.

Therefore, it is important to develop a DVR system that can compensate unsymmetrical voltage faults. A PV integrated DVR system is introduced in this paper to reduce voltage disturbances such as sag, swell and harmonics.

II. PV integrated DVR

DVR is a series active filter connected at the bus where voltage has to be regulated through coupling transformer. In conventional DVR design, 2-level Voltage Source Inverter (VSI) is used as an active filter component whose DC side a battery is connected which draws power from the grid. The PV-DVR system disconnects from the utility grid to assume control of the voltage demand requirement. Consequently, less energy is drawn from the power grid. In order to conduct this transformation on the measured single-phase voltage, the DVR system is run by a single discrete PI controller that uses a single-phase PLL to track the phase angle of the source voltage. The performance of a three-phase DVR system can be enhanced [10,11] by introducing online tracking of the symmetrical network voltage components. In comparison to existing DVR topologies available in the literature, a DVR system architecture is given in this research to reduce symmetrical and unsymmetrical errors in the network. This study describes how to minimise single line-to-ground, double line-to-ground, and three-phase to ground faults by integrating a three-phase DVR system with a photovoltaic system. To extract the error signal, the enhanced two-stage hysteresis control approach is employed. The six VSI pulses that are generated by the hysteresis-band SPWM controller are further driven by this signal. The benefit of the suggested PV-DVR system is that it can reduce asymmetrical voltage problems brought on by unfavourable weather and function as a microgrid in the event that the utility grid experiences a power loss. The schematic of the proposed system is shown in figure 1.

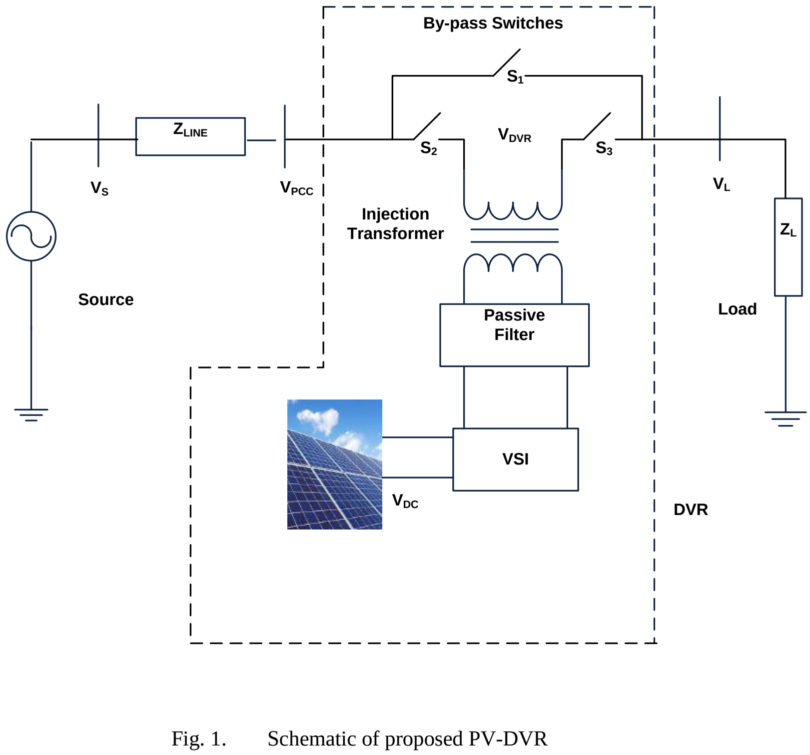

Fig. 1. Schematic of proposed PV-DVR

III. Simulation Model

The system has been designed for 415 V three-phase AC system and the results are obtained in PU. The solar panels are designed using SPR-305E-WHT-D module having 8 parallel and 7 series strings generating DC-output voltage of 600V and 14 KW power. The design parameters for solar is given in table 1. The matlab simulation model of the complete system is shown in figure 3. In the case of a complete power outage from the utility and PV grids, DVR removes any asymmetrical faults and functions as a microgrid. In this setup, an incremental conductance MPPT controller is used to control voltage up to 500 V by connecting a PV array to a booster converter. To feed the PV generated energy into the utility grid, the DC voltage is transformed to an AC voltage level of 415 V. A three-phase full-bridge voltage source inverter with a common DC-link connected by a capacitor serves as the foundation for this DVR setup.

Table no1 : Solar design parameters

Parameters	**Values**
DC-bus voltage	600 V
Max. power per module	305.2 W
Cells per module	96
Open CKT voltage	64.2 V
Short CKT current	5.96 A
Max. Voltage	54.7 V
Max. current	5.58 A
Ideality factor	0.944
Shunt resistance	393.205 Ω
Series resistance	0.374Ω

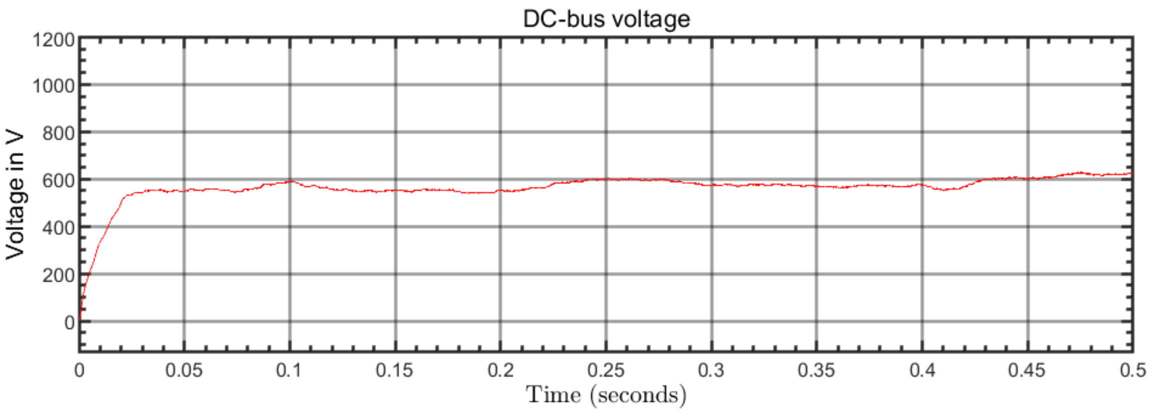

Fig. 2. DC-bus voltage of PV-boost converter

Table no. 2: DVR design parameters

Parameter	**Value**
Utility AC grid	415 V, 50 Hz
3-Phase Coupling transformer	1.5 kVA, 50 Hz, Winding ratio: 1:1
Passive filter	0.1 1Ω, 11mH
Filter: Capacitor	100 µF
Carrier frequency	7 kHz
Voltage source inverter	3 arms; 6 pulses
DC-Link capacitor rating	100 mF,

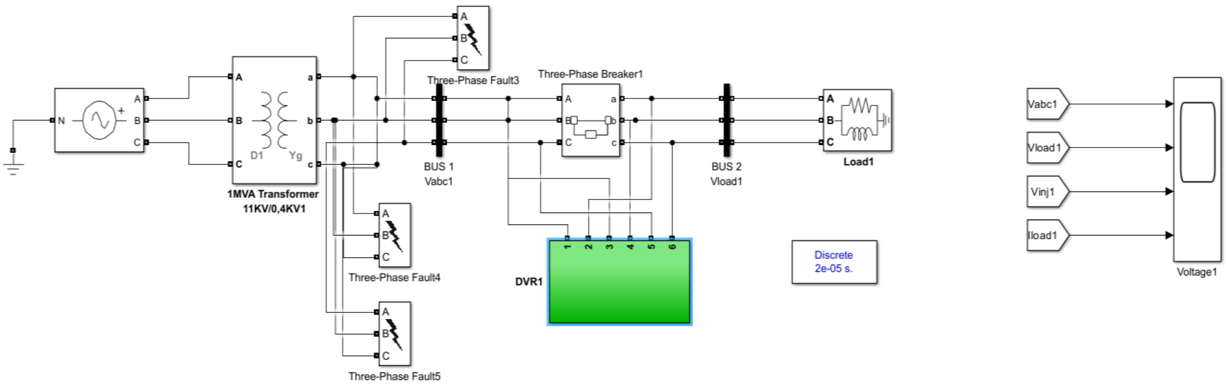

Fig. 3. Simulation model of the proposed DVR

The DVR block consist of three phase universal bridge which acts as a 2-level 6 pulse three arms VSI, whose DC-side is connected to the PV system as shown in figure 4. The voltage controller designed in this paper is hysteresis controller based. Hysteresis controller (HC) is a method for controlling a voltage source inverter in which switching pulses are generated for the inverter by instantaneously comparing the reference current and the grid current. Fig. 5 shows a hysteresis current controller arrangement. It is a non-linear controller loop with hysteresis comparators; to achieve a fixed switching frequency, the controller must be constructed with an adaptive band. Using the knowledge of positive and negative sequence components, a number of control schemes have been devised to provide flexible active and reactive power control during grid breakdowns. The controller might become much more sophisticated, depending on the approach taken. The main benefits of adopting an HC are its simplicity, robustness, and independence of load parameters and good transient response [12, 13]. To analyse the performance of the proposed PV-DVR, the system has been analysed for simultaneous occurrence of L_G fault for the duration of 0.03 -0.07 sec, LL_G fault for the duration of 0.1-0.2 sec and LLL_G fault for the duration of 0.3-0.4 sec at source side. Under this condition the DVR regulates the load voltages and keep it constant irrespective of the symmetrical and unsymmetrical phasor unbalance as shown in figure 6.

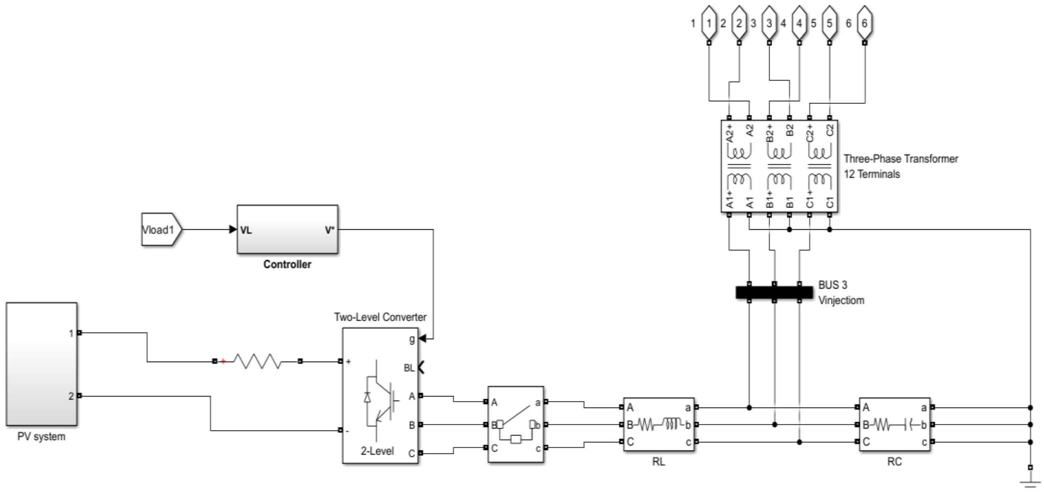

Fig. 4. DVR block

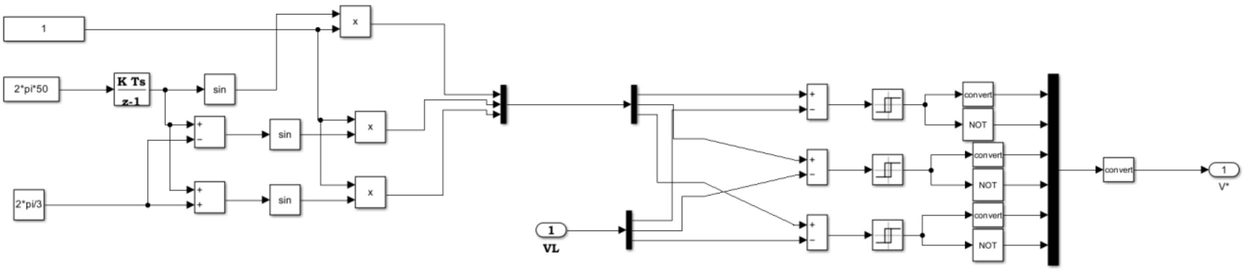

Fig. 5. Proposed hysteresis controller

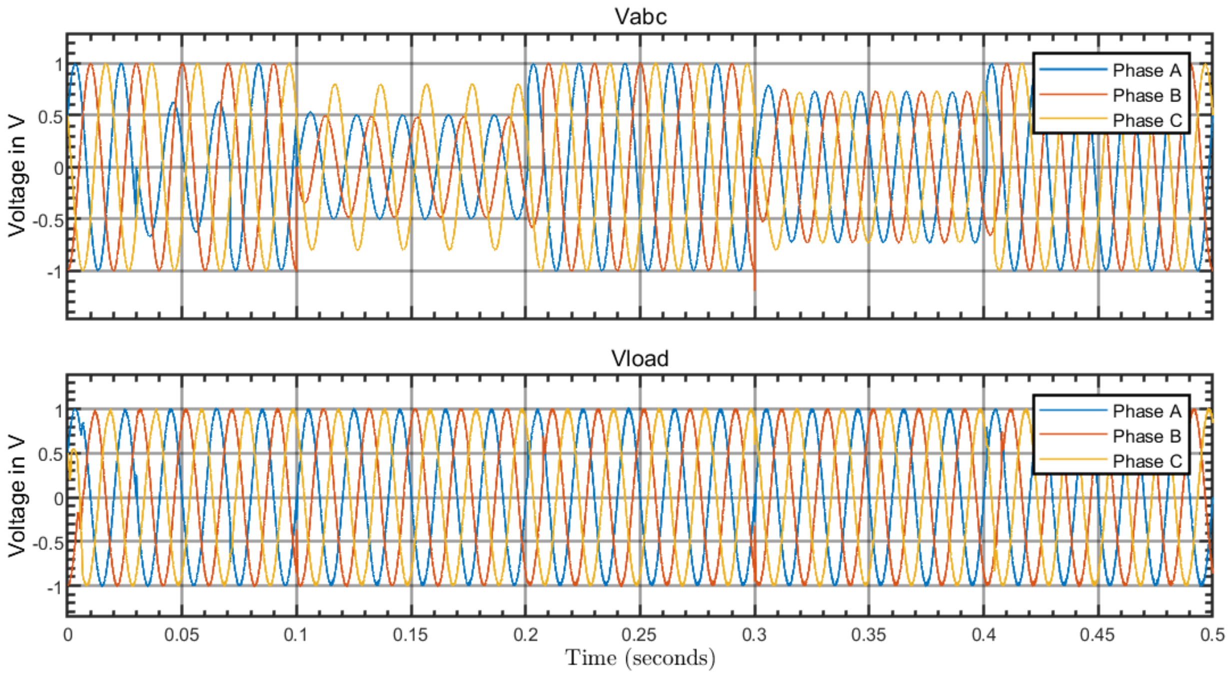

Fig. 6. Three-phase source and load voltage with PV-DVR under the conditions of unsymmetrical and symmetrical faults.

The injected voltage and load current is shown in figure 7. From the waveform of injected voltage it can be seen that during L_G faut, phase A' is shorted and the voltage of same magnitude but in phase opposition is injected to balance the unsymmetrical components of the voltage and current and to regulate the load voltages and current of all the phases. Similarly, for LL_G fault and LLL_G faults, DVR injects the voltage in such a manner so as to not only maintain the constant load side voltage since PV-DVR is connected across the load bus. But, also it maintains the phase symmetry. Hence system stability is retained by the DVR. Also, faults in the system injects harmonics which can affect the performances of the sensitive loads and can also cause frequency instability. DVR also eliminates the harmonics in-order to maintain the sinusoidal voltage at the point of installation.

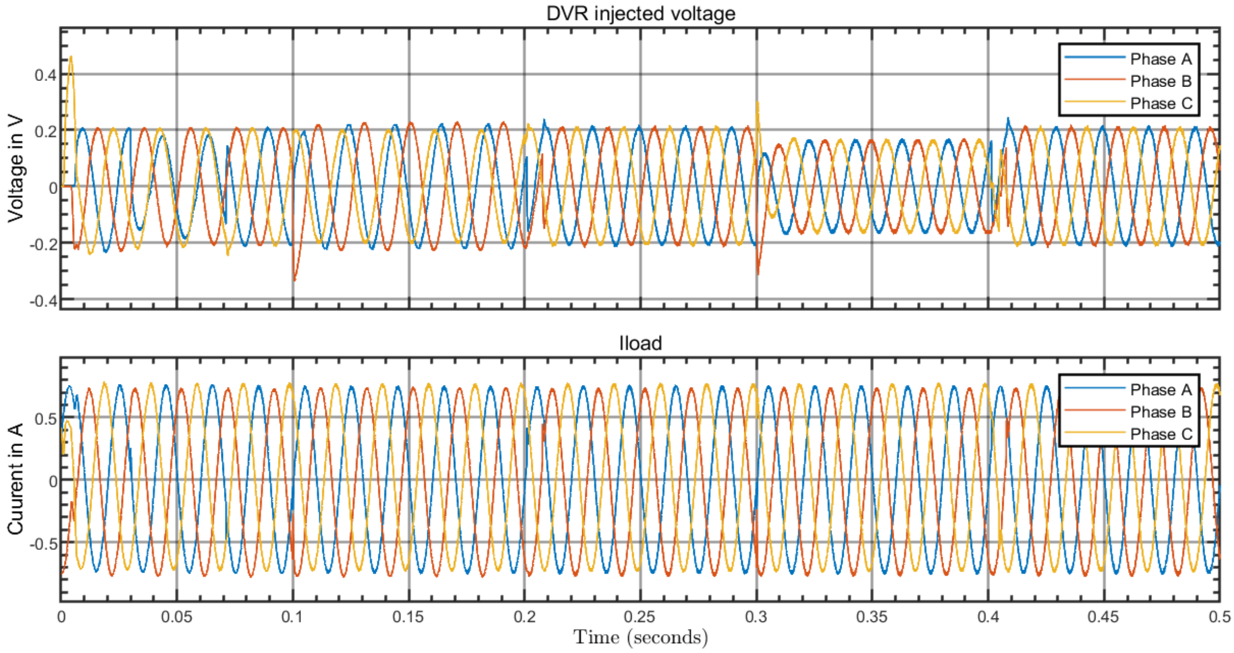

Fig. &. Three-phase injected voltage and laod current with PV-DVR under the conditions of unsymmetrical and symmetrical faults.

IV. Discussion

The quality of supply is not only in terms of voltage stability, but also frequency stability should also be taken care by the compensating device. To confirm the suggested PV-DVR system's dependability in the aforementioned scenarios, the THD is computed. The efficacy of the suggested DVR control system is confirmed by the measured THD of voltages at the load bus before and after compensation under various operating situations. The comparative study of the THD values obtained for source side and load side three phase volatges is displayed in Table 3. It is evident from the findings of the three symmetrical and unsymmetrical fault case studies that, in accordance with IEEE 1159 standards.

Table no 3: Harmonic analysis.

Fault conditions	Source voltage THDs in %			Load Voltage THDs in %		
Phases	Phase A'	Phase B'	Phase C'	Phase A'	Phase B'	Phase C'
L-G fault	7.98	0.01	0.01	3.12	0.5	2.1
LL-G fault	8.46	18.09	0.01	2.6	3.1	0.5
LLL-G fault	8.42	17.32	25.68	3.8	3.5	1.8

V. Conclusion

This study investigates the behaviour of microgrid systems in remote locations when they are subjected to unfavourable weather conditions that result in symmetrical and unsymmetrical voltage faults, which creates problems with power quality. Using a PV-DVR system topology based on a hysteresis voltage management approach that stabilises the error signal, the goal is to improve system stability performance to protect the sensitive load. According to the simulation results, the suggested control strategy with the suitable gate pulses applied improves grid stability and allows the DVR system to function even in the event of a complete power outage or a short circuit fault that arises from the utility grid or the PV grid during inclement weather. The suggested method gives the load symmetrical operating conditions and improves the grid's transient stability. The error signal is stabilised and the fault signal is extracted by the control mechanism. In the suggested setup, a PV-based compensation system connected to a DC-Link inverter is driven by a hysteresis-band PWM generator presents a green solution to power quality problems. Also, harmonic analysis is carried out which presents the THD values in compatible to the IEEE-519 standard even in case of high harmonics at source side.

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