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Fault Ride Through Capability Enhancement of Dual-Stage Inverter-Based Grid-Connected PV System

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Abstract: Seeing to the increasing penetration of Photo Voltaic (PV) system into the utility grid, it is required to incorporate new standards for smooth operation of electrical grid.FRT capability incorporation into the PV system is one such grid codes connection requirements. When fault occurs generated power from PV is more than the supplied to the grid. This may increase the voltage across the DC-link capacitor. Due to over-voltage protection of DC-bus PV may get disconnected from the system. The proposed control overcomes this problem that may cause disconnection or damage to the inverter. In the proposed work PV-system is designed using dual converters. The DC-boost converter is incorporated with the Dc-bus voltage control and the inverter controls the ac current output of PV Connected Grid (PVCG). The controller has been so designed so as to absorb the excessive dc-voltage which occurs when the PV generates power but due to grid fault cannot be supplied to the grid. Also it limits excessive ac current, due to current limiting capability. The control designed is capable of providing reactive support and injects current q-axis current to ensure the standard limits of voltage and frequency deviation. The results validates that the FRT capability enhancement of the PVCG can only be accomplished by supplying the reactive demand at the time of fault or dip in the network.

Keywords: PV Connected Grid (PVCG), Photo Voltaic Generation (PVG), Fault (FRT), Phase-Locked Loop (PLL).

I. INTRODUCTION

Photo Voltaic Generation (PVG) has been developed in wide area application as a green energy generation. The installed capacity has reached to its peak. Earlier, PVG required to be disconnecting from the grid as soon as a fault occurred. However in the present scenario of rapid increase of PVG, power systems needs more study for its influence on the operation [1]. At the time of voltage sags PV could boost the grid voltage and can regulate the grid profile. Considering such scenario, the grid connection requirements have been updated [2–4]. The disruption of these plants at the same time of grid disturbances may cause operational and stability problems to the grid and customers. [5]. Hence one of the most promising solutions is Fault Ride Through (FRT) capability that should be met by PV Connected Grid (PVCG) via the PV inverters [6]. Henceforth, it's the need of time to incorporate PV generation capability enhancement to improve stability under the grid condition, for example, framework blames on PV ranch generators [7]. Therefore, in-order to integrate PV system with the grid, the FRT capability control becomes a significant viewpoint with respect to the control framework structure and assembling innovation [8]. The FRT ability demonstrates that the PV inverter need to carry on like conventional coordinated generators to endure voltage hangs coming about because of framework issues or aggravations, remain associated with the force matrix, and convey the predetermined measure of receptive current at the hour of lattice shortcomings, separately [9]. In the ongoing writing, different investigations have been recorded as far as FRT prerequisites in present day matrix code [10].

LVRT, is the ability of PV framework to remain associated in brief times of lower electric system (voltage plunge) as appeared in figure 1.Figure 1(a)presents the disconnection of PVCG from the grid when the depths and durations of voltage dip are below the bold line. For incorporating FRT capability, the controller must keep connected the PVCG under the condition of fault and also it must supply the reactive power in order to recover the grid voltage which is the amount calculated as the ratio of reactive current injected into the grid to rated current as shown in Fig. 1(b). It is required at conveyance level (wind parks, PV frameworks, circulated cogeneration, and so forth.) to forestall a short out at HV or EHV level from causing a broad loss of age. Comparative prerequisites for basic loads, for example, PC frameworks and mechanical procedures are regularly taken care of using an Uninterruptible Power Supply (UPS) or capacitor bank to flexibly make-up power during these occasions. Along with the updates of grid codes, the control techniques of grid-tied PV inverters are required to be upgraded as well because the operation under the low voltage faults is much different from that under the normal conditions. To be specific, the main issues need to be considered include the over current caused by the abrupt voltage drop, the sudden surge of dc-link voltage as a result of the difference between input and output power, the fault detection and the Phase-Locked Loop (PLL) under the low voltage faults. In order to successfully complete the FRT operation, several control methods have been proposed. The most important task of the control to stabilize the operation under the condition of FRT is to inject the required amount of reactive power in order to maintain the voltage sag due to fault. Under such conditions strategies must be designed so that PV system must be capable of ride-through under the condition of fault.

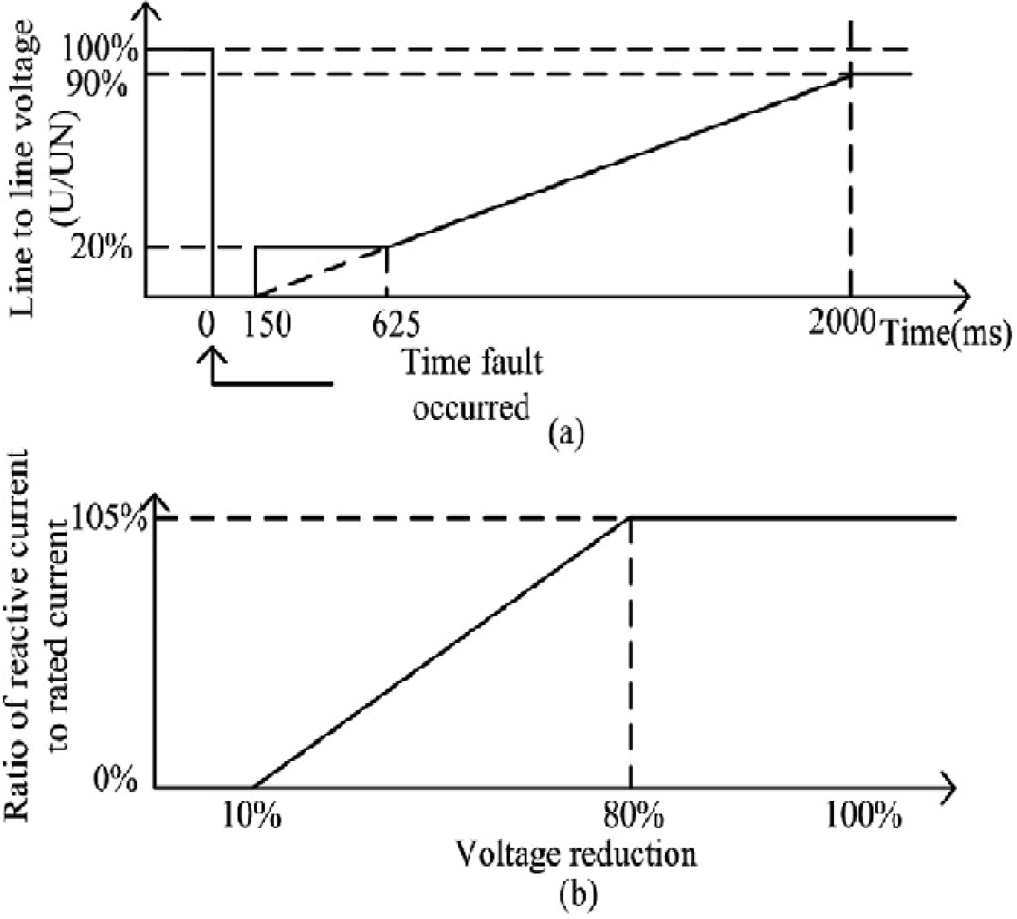

Figure-1. LVRT requirement: (a) Voltage-limit curve to allow disconnection and
(b) Ratio of reactive current to be fed under a voltage dip.

II. FAULT RIDE THRUGH IN PVCG

FRT specify that when voltage dip occurs, the PVCG should remain associated with the network when it works in the association region over the blue curve as shown in the figure 2. To avoid power loss and grid frequency distortion, the PVCG must not be disconnected from the grid for 150 ms when the voltage drops to 0% of the nominal voltage (Vn). Moreover, the voltage should recover 90% from its pre-dip value within 150ms from the occurrence of sag.

In other words, the PV systems must be able to stay in connected to the microgrid for power quality enhancement under grid faults and to enhance voltage profile. The unregulated output power of PV power station under abnormal conditions can be regulated through grid-friendly converters, and the power system reliability can be guaranteed depending on the performance of these power converters. Throughout the years various FRT control methods have been proposed and accustomed related with non-conventional source advancements [8-13].

To fulfill the reactive power demand at the time of fault and to maintain the FRT profile, supplementary control strategies are needed to be incorporate in the control architecture of the grid connected PVCG. This could be within the inverter control system or external circuit incorporation. To improve FRT two prominent controls are widely adopted. Firstly at the time of fault, protection against DC-connect over-voltage and over current at DC-side of the PV inverter which happen in AC side. Another is the infusion of repulsive current, so as to voltage restoration and to help the grid voltage-sag issues.

The stochastic behavior of the PV system may leads to unreliable grid connected operation. A proper DC-voltage regulator may some extent help to stabilize the solar performance. In this work this has been accomplished by Incremental conductance MPPT algorithm. Also for efficient grid integrated operation; the designed inverter must meet the grid code requirements.

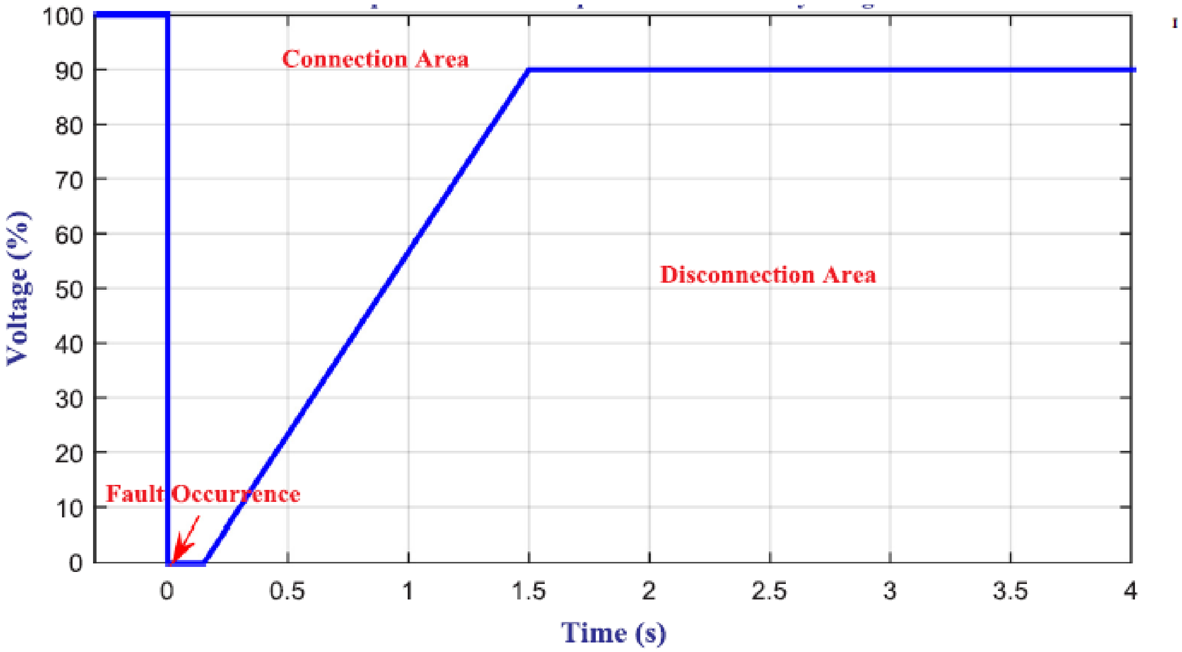

Figure -2. FRT capability curve for PVCG.

III. PROPOSED WORK

The main objective of the work done is to design a control strategy that can control the PVCG output even at grid faults such that the inverter remains connected producing continuous electricity. Also it can absorb excessive energy by balancing the required reactive power under various types of fault to meet grid standards requirements. When contrasted with different techniques, this strategy not just adequately smothers the air conditioner over-current just as the dc-interface over-voltage and secures the inverter during voltage plunge, yet additionally bolster the framework by means of infusion of responsive force. Moreover, when the deficiency is cleared, all qualities will recoup to pre-flaw esteems legitimately. The DC-bus voltage can always be regulated, even in the fault conditions from the DC/AC converter or grid side, thus the fault ride through performance on dc side is enhanced. In this work a continuous DC supply is maintained from PV system at the time of fault at grid side. Also the proposed control scheme is able to support the grid power flow at the time of fault.

The output power of the PV source is affected by the output voltage Vpv given a constant solar irradiation level. In order to maximize the system real power output P, the perturbation is introduced by employing perturb and observe MPPT. The control objective is to design a virtual control input Vref_ peak to make the output voltage Vdc track the Voltage reference Vdc. The controller is designed using abc-dq0 transform and PLL. The design controller has the capability of fault ride through, i.e. it can maintain constant DC output from the solar side when a fault is occur grid. The performance analysis of the proposed system as shown in figure 3, under following three operating mode has been carried out;

1. Under static condition with constant irradiance.
2. Under the condition of voltage sag.
3. Under the condition of grid faults.

The proposed control strategy of the work done is presented in figure 3. Where first stage defines the PVG followed by the boost converter which is designed by properly tuning LC by controlling switching of IGBT. The braking capability is improved by limiting the voltage across $C_{dc.}$ Inverter is designed using three arm universal bridge whose control is so designed so as to limit the current across the PVCG at the time of fault. This is achieved by referencing the grid voltage and current to a predefined values and comparing it with a cut-off values of voltage-current. The control also balances the power demand by calculating the active and reactive power flow at PCC.

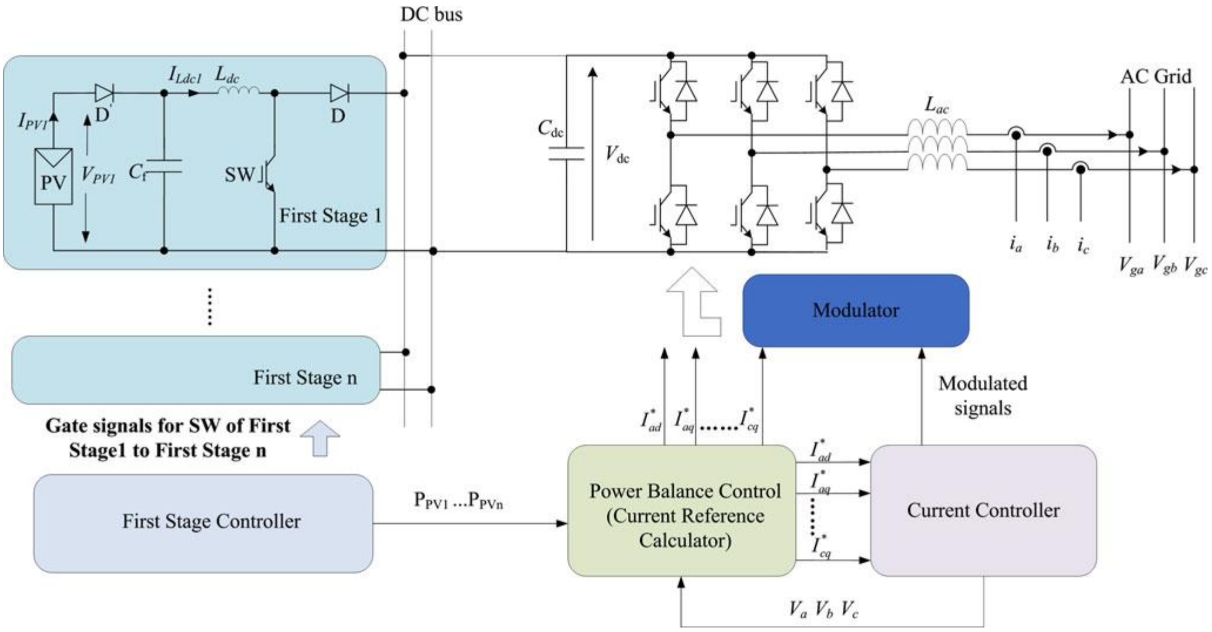

Figure-3. System description of PVCG system with proposed control structure. [9]

IV. SIMULATION RESULT

The system has been designed for software verification in MATLAB 2016a using Simulink tool kit. The complete simulation model of the proposed work is presented in figure 4. The PVG generates 1.5 MW of power with 20 series and 250 parallel strings. The theoretical calculation of power of the PV array is presented in table 1 which could be verified by the figure 5. The parameter selection for the system designed is presented in table 2.

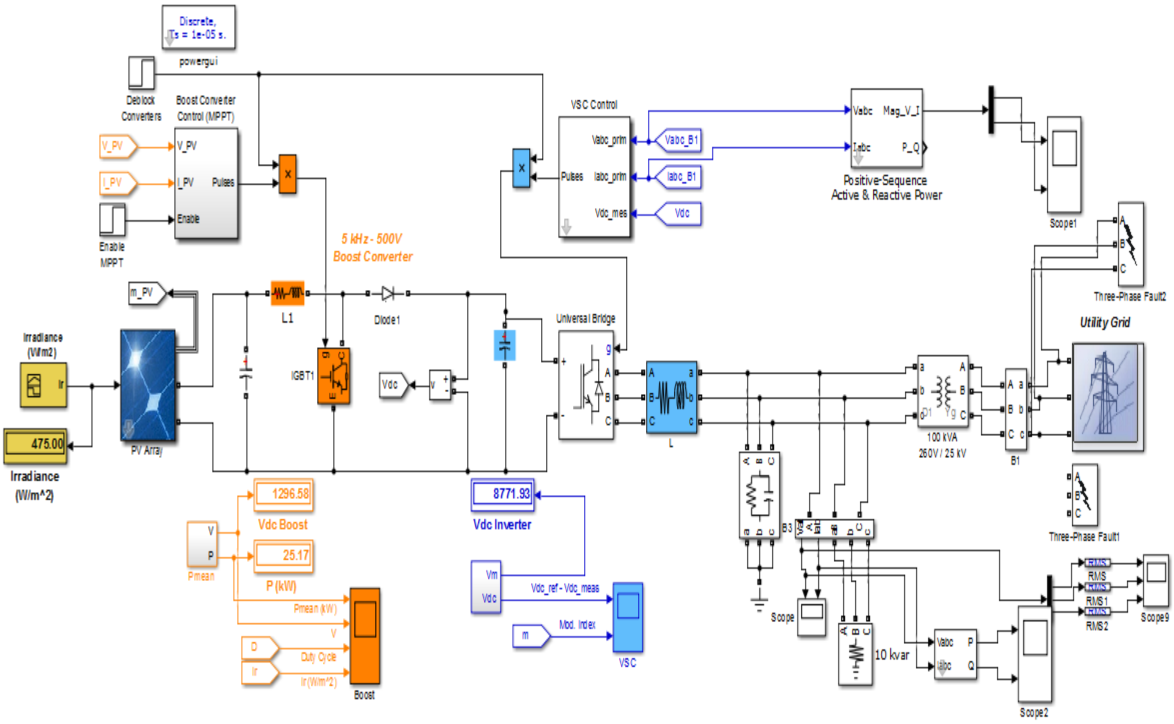

Figure-4. Simulation model of the proposed PVCG system.

The PV array's max optimum operating point can be tracked via different number of tracking methods. Among all, the Increment N' Conductance (IC) technique had been widely utilized due to its low sensor requirement, simplicity and feasibility. The IC is applied in this study. The inverter control is the most important part of proposed PVCG system. In this study, a self-commutated VSI is designed to execute the control optimization purposes. The VSI consists of all basic control requirements for PVCG system to be compatible with technical regulation. The dc-link voltage in dual-stage VSI inverter should have a value in the range of 1000 V. conventional Proportional Integral controller (PI) is adopted to obtain the output from VSI. Fr phase angle and grid voltage synchronization phase Lock loop (PLL) is used in synchronous frame.

Table 1 PV array sizing

Parameters	Value
Cells per module	96
Parallel string Np	250
Series string Ns	20
Maximum voltage (Vmp)	54.7
Maximum current (Imp)	5.58
Output power (Ppv)	1.5MW

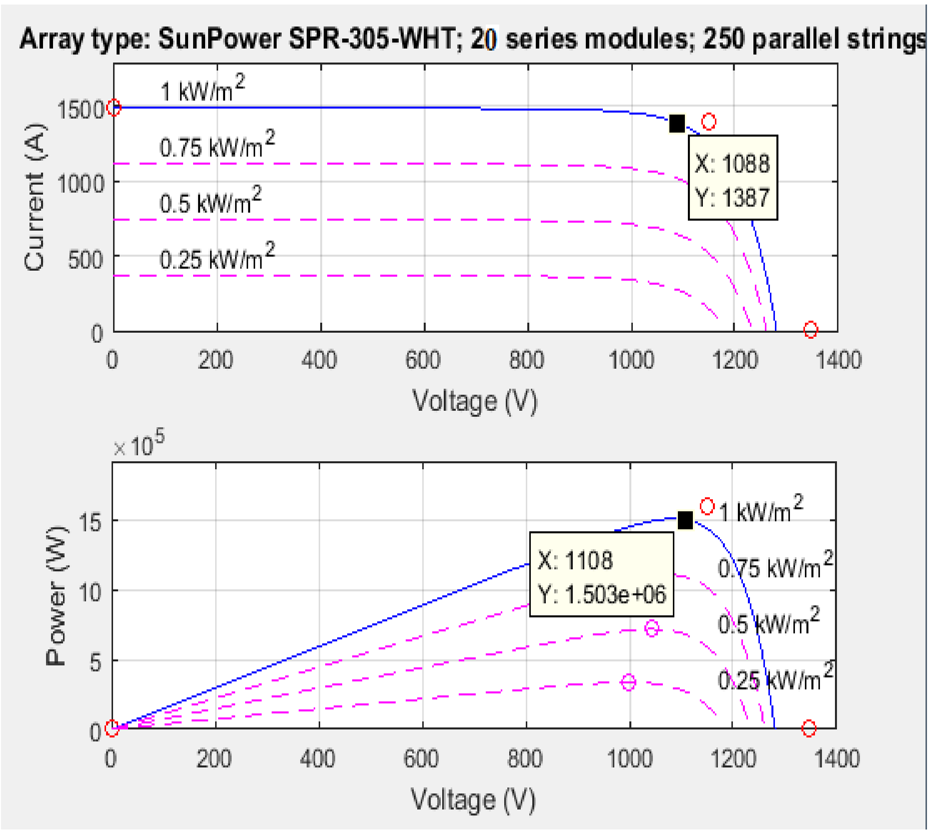

Figure 5 PV-VI characteristics of PV array

Table 2 Parameter selection

Parameter	Values
PV rating	1.5MW
C_{dc}	1000µF
DC converter inductance	3 mH
dc-bus voltage Vdc	1000V
Inverter parameter	
Effective nominal voltage of the utility V_S	415V
Nominal utility grid frequency fS	50Hz

Switching frequency of the converters fch	20khz
inductance of filter	10 mH
Series resistance converter	0.01 ohms
Capacitances of the parallel filters	1500µF
Resistances of the converter filter	0.01 ohms
Gain PI; Ki, Kp	500, 0.04

Under normal operation in PVCG the output voltage and current waveforms are constant and drawing unity power factor as shown in figure 6. The output wave forms are constant and three phase sinusoidal as shown in figure 7. The first problem addressed in this work is three phase (LLL) fault which is presented in figure 8 without the proposed control. After the control is applied the output figure is presented in figure 9 and 10. The respective active and reactive power is presented in figure 11. Fig. 19 shows the response of the inverter FRT control strategy when an unsymmetrical two-line to ground (2LG) fault occurred with voltage dropping to 60% from its nominal value. So, according to the LVRT requirements shown in Fig. 13 with voltage sag of40%, the inverter should support 100% (1p.u) reactive current. From the figures, it is evident that the inverter supported the grid with the required value. Since 100% reactive current is injected to the grid, the active current is zero, resulting in zero active power. When a balanced three-phase voltage sage (70%) occurred at the grid. When the fault is occurred at t=0.3 s, the inverter injected the required amount of active and reactive power according to the standard requirements. As a conclusion, the results show the ability of the proposed inverter FRT control to support the grid and voltage recovery by producing reactive power at different types of faults.

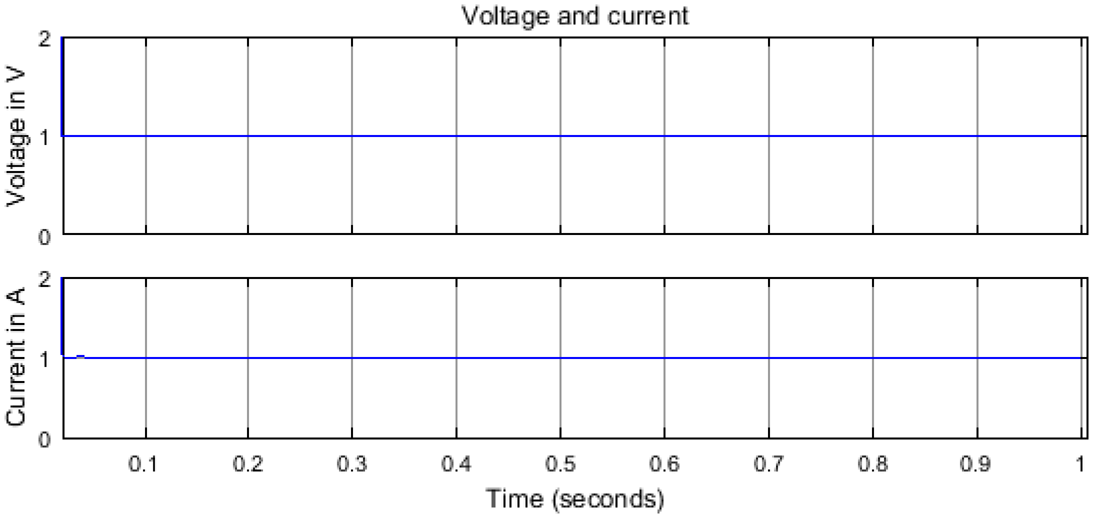

Figure 6 Positive sequence voltage and current at normal operation

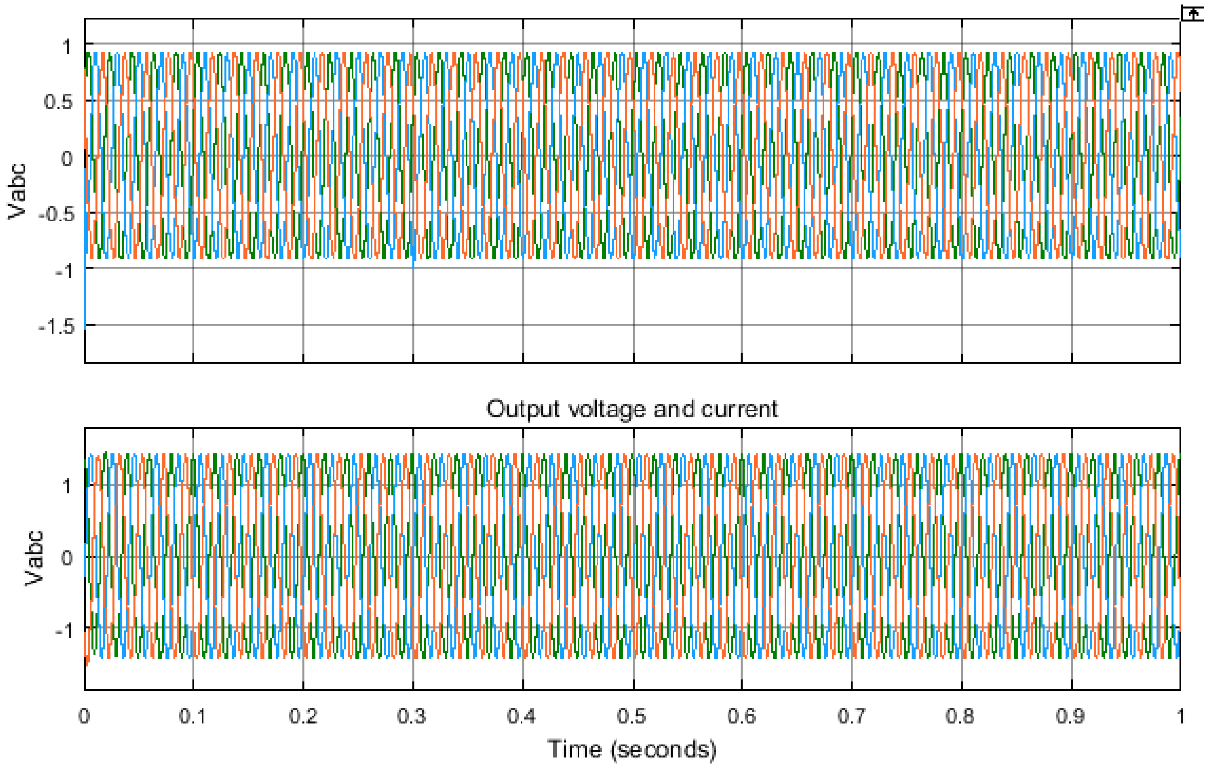

Figure 7 Output voltage and current at PCC for normal operation

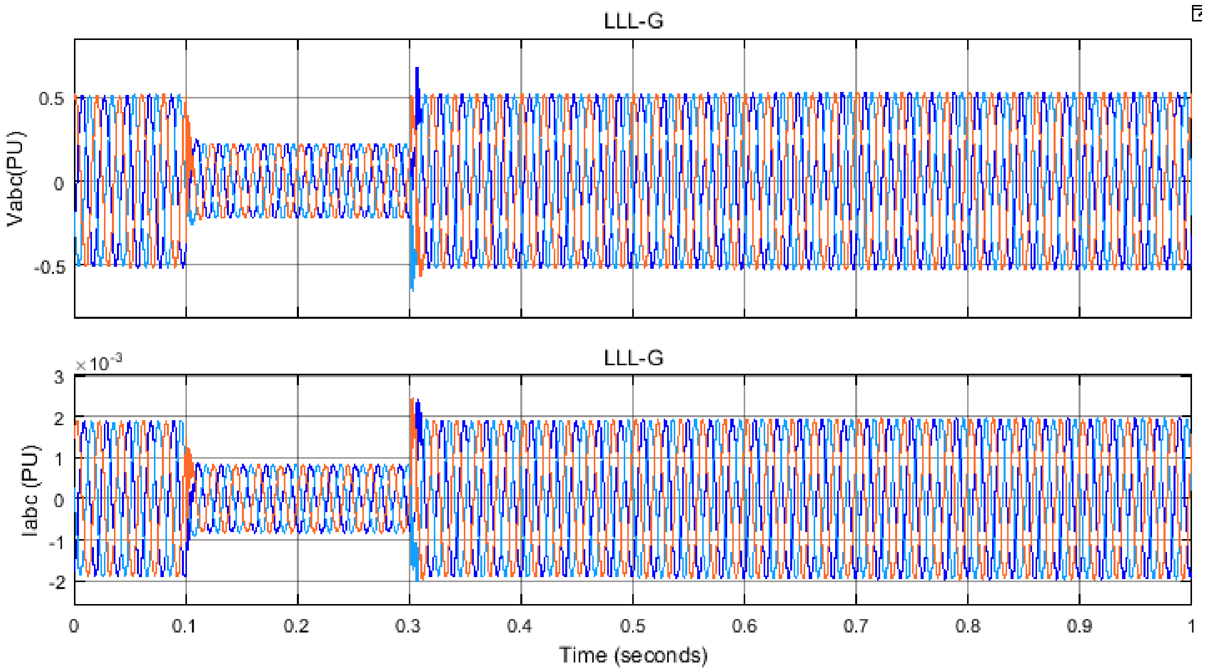

Figure 8 Output voltage and current at PCC for LLL fault

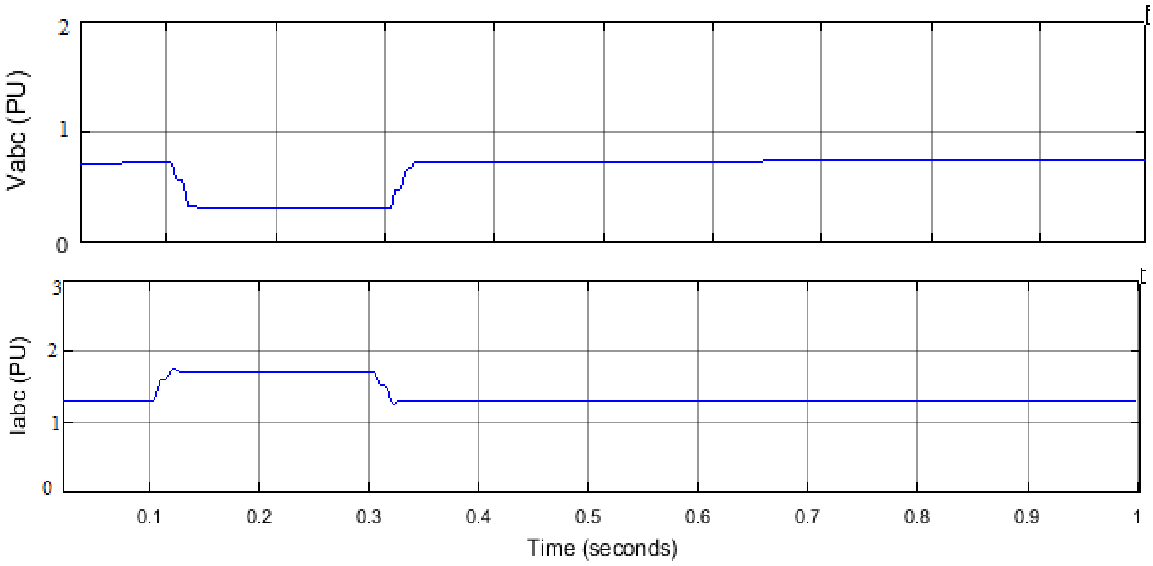

Figure 9 Simulation response of the PVCG when applying 70% (LLL) voltage sag: (a) positive sequence of grid voltage in p.u; and (b) Grid current in p.u.

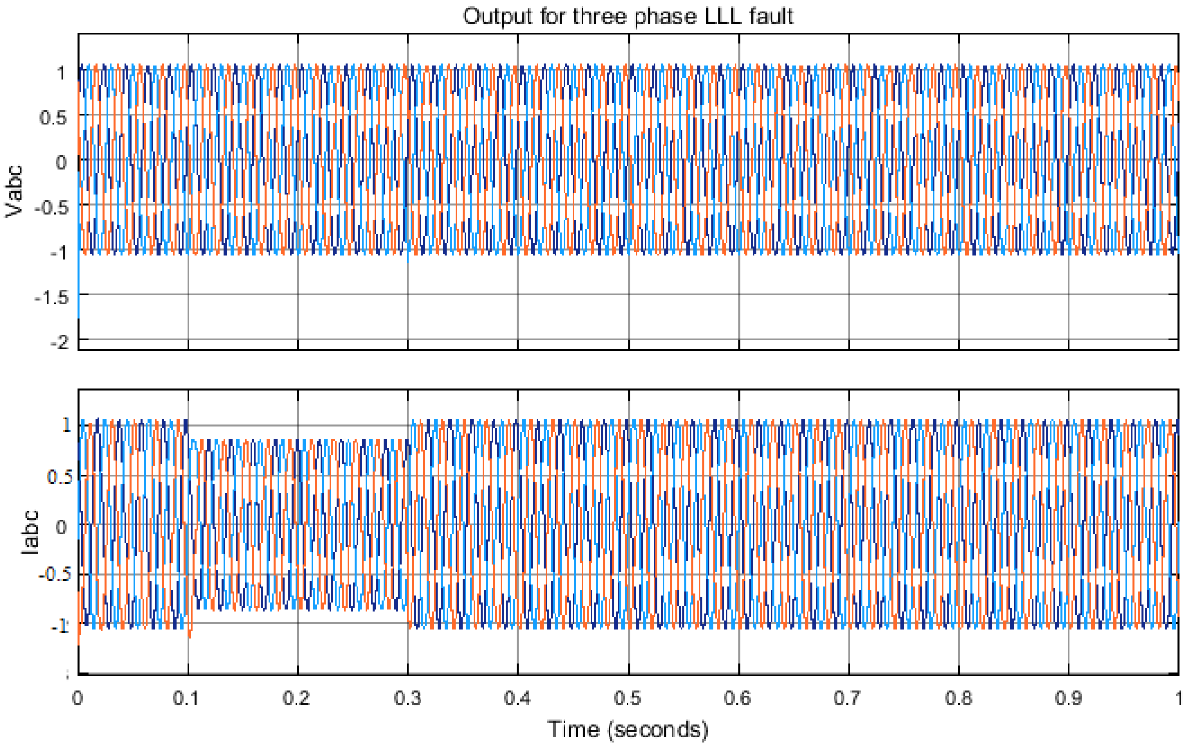

Figure 10 Output voltage and current at grid side for LLL fault after applying proposed control

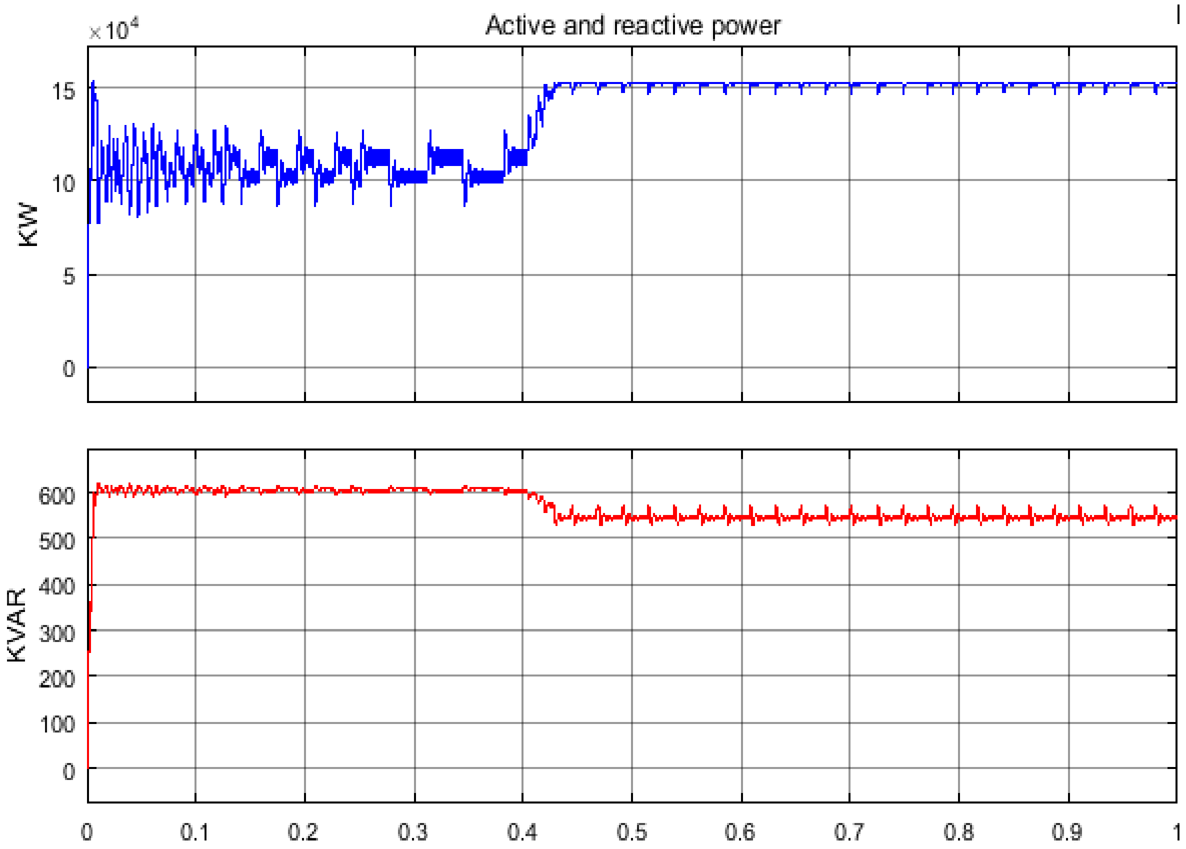

Figure 11 Output voltage and current at grid side for LLL fault after applying proposed control

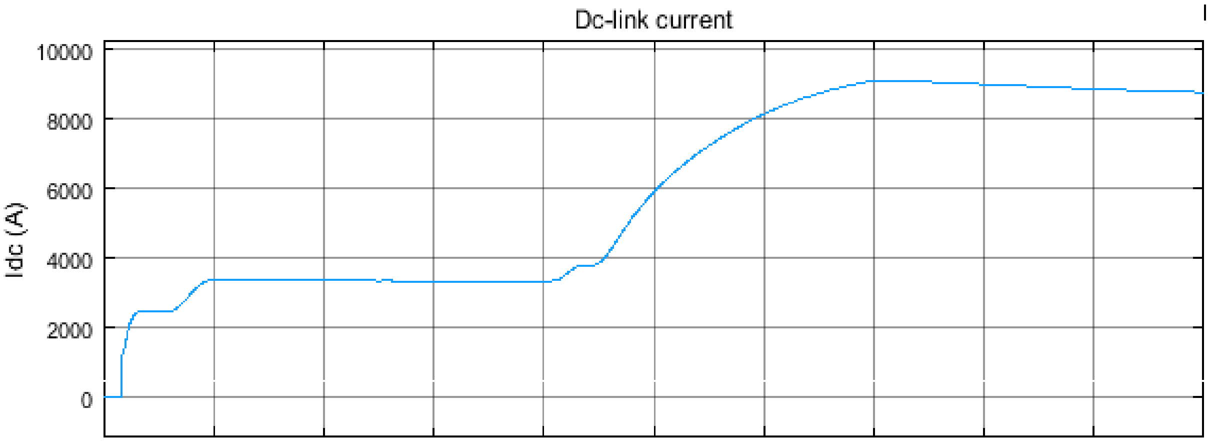

Figure 12 DC-link voltage for voltage sag

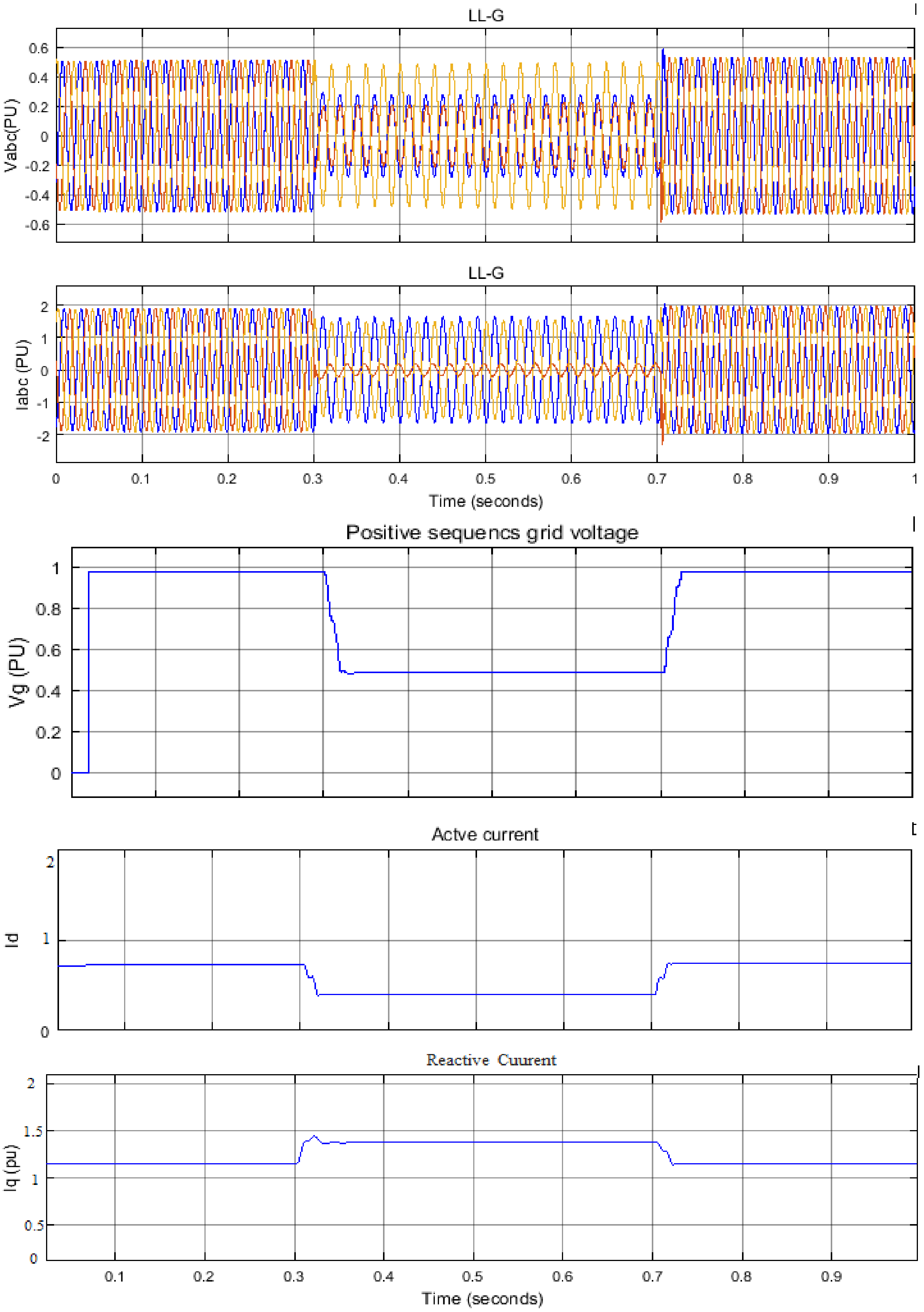

Figure 13 Simulation results of a FRT control strategy with an unsymmetrical 2LG fault

V. CONCLUSION

As per the existing grid requirement, the proposed work focuses on the potential of FRT control strategy of the dual-stage PVPP operating in grid fault conditions. The control strategy proposed enables the PVCG to ride- through all types of grid faults.The effectiveness of the proposed method has been for the three cases, with normal operation, LLL-fault and LL-G fault.It has been observed that the under grid Fault PVG system is able to maintain FRT under unavailability of grid.It can be concluded that the future PVGs can offer some ancillary services forthe grid abnormalities. Inspite of the fact that the performance is dependent on the control strategy and detection method, the proposed control have satisfactory performance concerning sag and fault. The control keep the connectivityof the inverter, protect the system from both over-voltage and over-current.

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