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# Grid Fault Ride Through Capability of Voltage Controlled Inverters for Photovoltaic Applications

Islam Abdelraouf[1], Sobhy Abdelkader[2], Mohamed Saeed[3]

1 Electrical Engineer at north delta electricity distribution company, Egypt
2 Electrical Power Engineering Department, E-JUST, Egypt
3 Dept. of Electrical Engineering, Faculty of Engineering, Mansoura University, Egypt

## Abstract:

Fault ride through (FRT) capability is one of the challenges faced in today's large-scale grid photovoltaic (PV) power system.
Solar PV systems are designed to disconnect, and remain offline for 5 mints when tripped by loss of grid voltage. However, The PV system, by itself, cannot differentiate between transient and sustained grid voltage loss. It behaves in the same manner in the two cases, i.e., disconnect, stay offline for five minutes and then makes re-connection trial. Staying offline for five minutes unnecessarily wastes considerable amount of clean energy from the PV, may affect the power balance of the grid and many other adverse effects of service discontinuity
This paper presents a new control strategy for grid FRT capability of a large grid connected PV System to increase the stability and reliability of the PV system, in which a photovoltaic inverter can be controlled to pass transient faults. Our strategy is to control the inverter so that it disconnects from the grid when the current exceeds a specific value for a specific time otherwise, it still connected and ride-through the faults to ensure continuous output power under transient fault conditions. A case study of a 100 KW PV power system simulated to ensure the proposed control. The results show the ability of the proposed control method to manage various types of grid faults. A case study of a 100 KW PV power system simulated to ensure the proposed control. The results show the ability of the proposed control method to manage various types of grid faults.

**Keywords**: fault ride through, PV, inverter control, protection.

## 1. Introduction

Solar power has become one of the most famous sources of renewable energy, and we need not only to produce power, but also to protect the system, and increase the reliability.
A control strategy was used to ride-through the voltage drops (voltage sag) based on positive/negative sequence droop control for grid-interactive MGs with inductive/resistive, Complex line impedance has also been proposed [1-5]. A new control strategy proposed for on-grid PV systems where the dc-dc converter controller controls the dc bus voltage [6]. By proposing a comprehensive design predictive control system, the incorporation of solar power into utility with grid (FRT) capability was explored [7-9]. A control system using Direct current link voltage for a dc-dc converter has proposed to increase LVRT performance of the two-stage on-grid PV inverter [10]. A control system designed to increase the (FRT) capability by measuring both the DC chopper and the current boundary based on the reactive power needed at fault time [11-14]. There are many topologies for PV power converters, for example single-stage conversion Fig.1, two-stage conversion Fig.2, with transformer, transformer less and more, but, all these topologies need an inverter to be connected to the utility and some standards must be met in order to perform this connection.

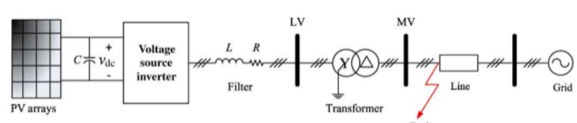


Fig.1. A single-stage GCPPP diagram.

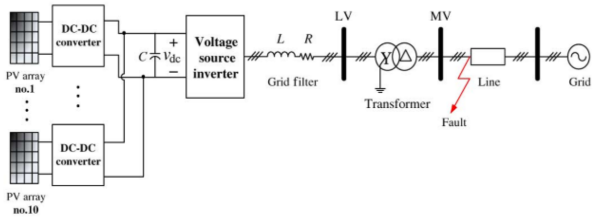


Fig. 2. Two-stage GCPPP conversion diagram.

One of these requirements is about the short circuit (S.C) faults. After a S.C fault occurs the inverter disconnects from the utility for protection, and takes some time to reconnect again, the problem is if the S.C fault is a temporary fault, then the inverter should not disconnect from the utility, the power sent to the utility stay constant as the fault happens, but the current can raise to dangerous values. For that reason, the converter is equipped with a protective control system to disconnect and prevent damage. This Single-stage control strategy conversion presented in [12-16]

There are many PV inverter topologies. Using a low frequency (LF) transformer, standard grid PV inverters are prepared to increase input voltage as shown in Fig.3 (a). LF-transformer is separated galvanically from the grid to the PV array. The DC-AC inverter accomplishes MPPT and provides the grid with low current distortion. The weight of the inverter is not small, its volume is large, and the output is poor however, Inverter output can be improved by 2 percent by connecting a high frequency (HF) transformer [17] and remove the LF-transformer as shown in Fig.3 (b). The Phase-shifted dc-dc converter performs MPPT features and provides galvanic isolation as well. To ensure that distribution transformers are not saturated, the DC sent to the grid should be checked. The efficiency increased by 2 percent more by transformer-less inverters shown in Fig.3 (c) [18]. A simple H-bridge inverter or a Neutral-Point Clamped (NPC) inverter could be used as a dc-ac unit as shown in Fig.3 (d), the boost converter is usually used in transformer-less inverters to control the voltage of the PV array. The paired NPC inverter does not have dc injection and achieves a wide range of MPPT [17-18].

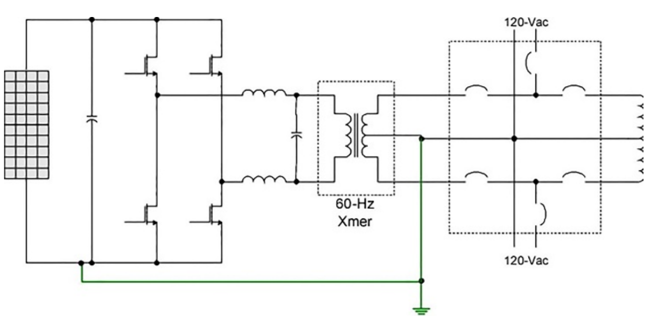


Fig. 3 (a) PV inverter with LF-transformer

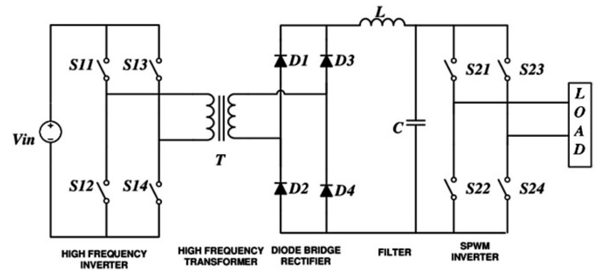


Fig.3 (b) PV inverter with HF-transformer

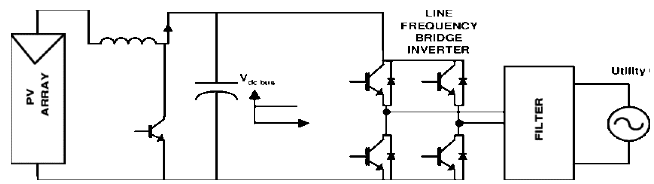


Fig.3 (c) Transformer-less inverter

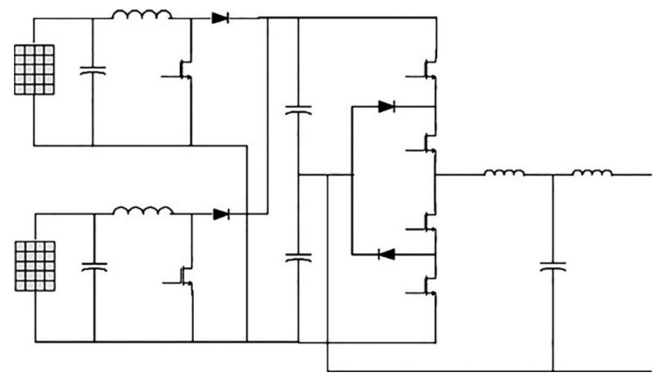

Fig.3 (d) Neutral-Point-Clamped (NPC) inverter

The inverter's overall efficiency depends on the MPPT performance material and efficiency of dc-ac conversion. In low irradiation situations, MPPT efficiency is usually lower because the power curve is much flatter and it's not easy to know the true maximum power point. The voltage ripple will affect the monitoring and decrease the output of MPPT.

The efficiency of DC-AC inverters depends mostly on the topologies and pulse width modulation (PWM) schemes selected.

This paper proposes a new control strategy for the two-stage conversion in on-grid PV power system that allow the inverter in Large Solar PV plants to Stay connected to the utility under temporary faults (transient faults), and to disconnect under permeant faults.

## 2. Proposed system

A MATLAB/ SIMULINK model shown in Fig.4 Represented a Grid connected 100 KW PV station. The model consists of a 100 KW PV panels with open circuit voltage of 330V connected to the grid through a boost maximum power point tracker, a three phase inverter synchronized with the grid at 250V, a transmission line model and step up transformers to step up the PV voltage to the grid level. The model equipped with a maximum power control circuit to control the DC-DC converter, control function to synchronize the inverter with the grid and the control protection circuit to protect the system in case of faults.

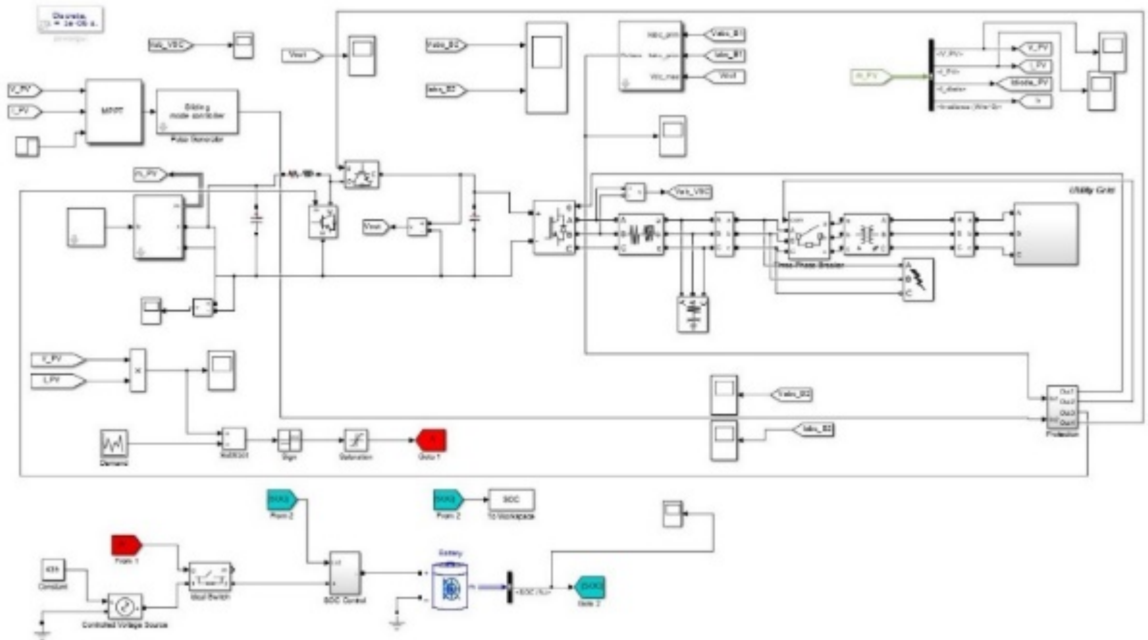


Fig. 4. Simulink Model for 100 KW Grid Connected PV System

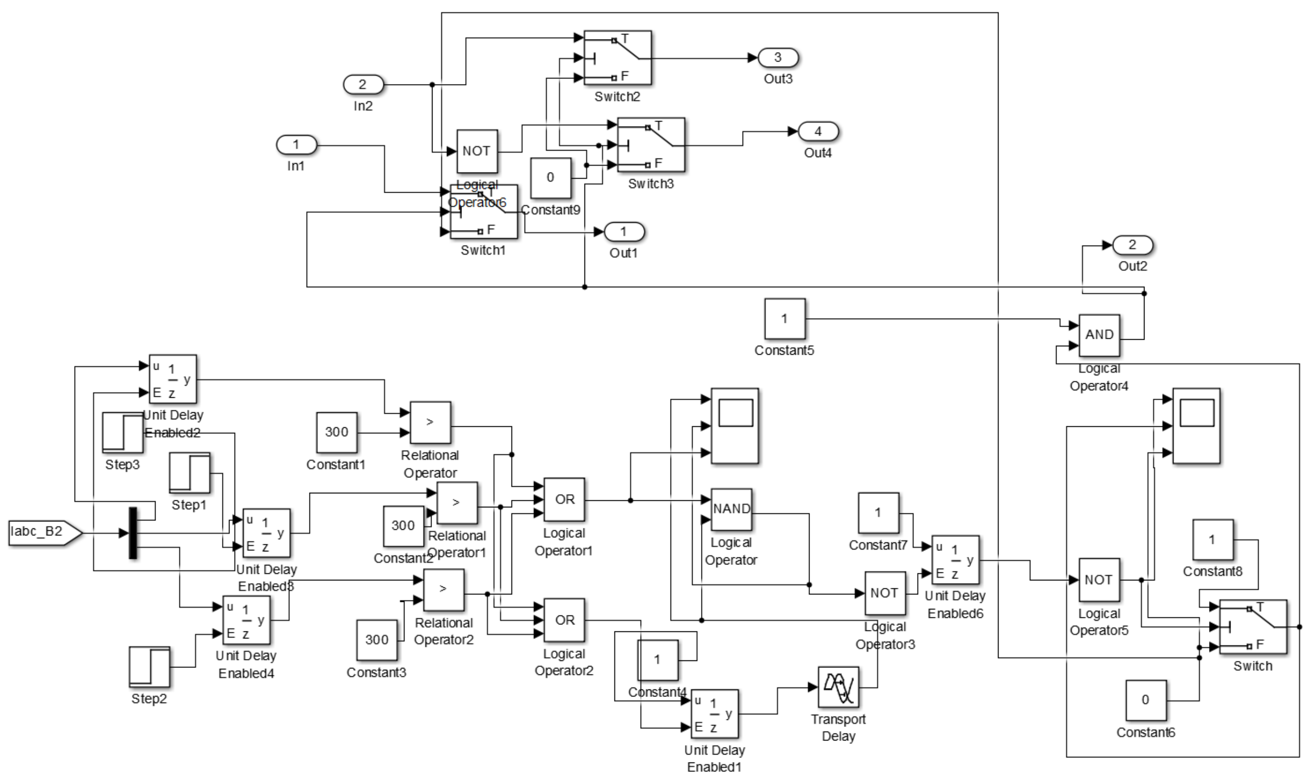


Fig.5 the protection control circuit

A control circuit is proposed as shown in Fig.5 is used to control the inverter, the dc-dc converter and isolate the PV system from the grid. The control circuit measures the three-line currents to detect any type of faults and detect if it a temporary fault or permanent one. In case of temporary faults, the control circuit keeps feeding the fault from the PV station and from the grid until the fault will finish which take very small time. On the other hand, for permanent faults, the control circuit isolate the PV system from the grid and disconnect the inverter and the tracker at the same time.
Therefore, we can control the inverter to disconnect from the grid when the current exceeds a specific value for a specific time. In addition, isolate the system from the grid, otherwise they stay connected, for example if the temporary fault is less than 0.5 sec then we have two cases
Case1 if the fault duration time is less than 0.5 sec (temporary fault)
Case2 if the fault duration time is more than 0.5 sec (permanent fault)
The proposed controller applied to 100 KW grid connected PV system to validate its applicability and effectiveness in ride through the temporary faults in the two case at different types of faults.

# 3. Case Studies

## 3.1. Case1: temporary phase to phase fault phase to phase fault

A phase-to-phase fault (phase (a) and phase (b)) applied on the grid line side for 0.3 sec from 1.3 to 1.6 sec. When the fault occurs, the line voltage decreased from 260 V to 220V as shown in Fig.6, and the current increased from 160 A to more than 600 A as shown in Fig.7. The PV voltage and current became unstable and rises from 240 V to 280 V as shown in Fig.8 and from 260 A to 287 A as shown in Fig.9. Then after the fault clearing, all values restored to its normal values; in this case, the control circuit did not disconnect the inverter from the grid because the fault duration was less than 0.5 sec. that means it was a temporary fault.

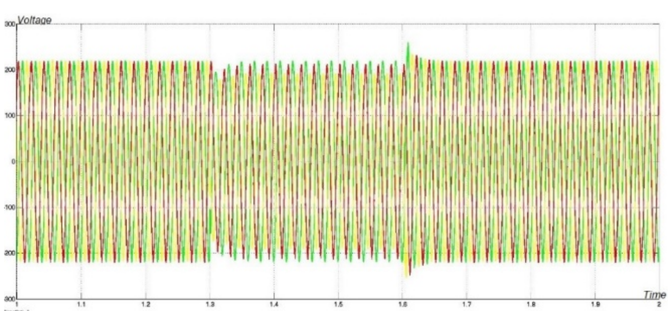


Fig. 6 (case 1-line voltage at grid side)

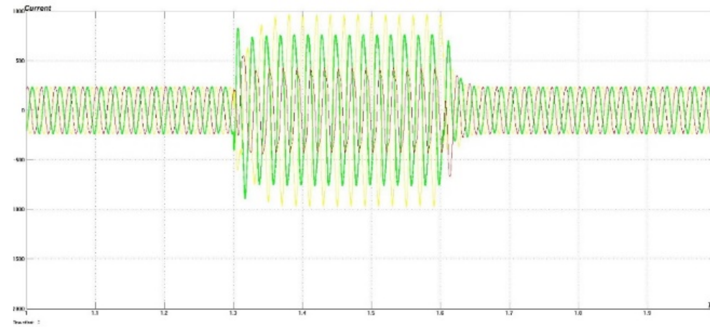


Fig. 7 (case 1 line current at grid side)

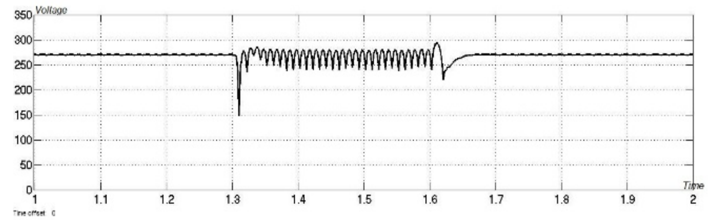


Fig. 8 (case 1 PV voltage at PV side)

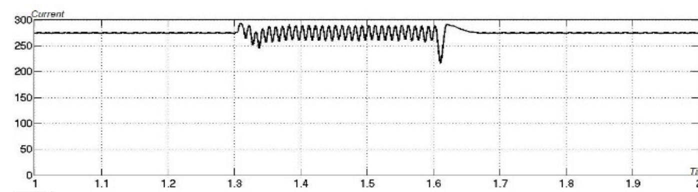


Fig. 9 (case 1 PV current at PV side)

## 3.2. Case:2 permanent phase to phase fault

A phase-to-phase fault (phase (a) and phase (b)) applied on the grid line side for 0.7 sec from 1.3 to 2 sec. When the fault occurred, the grid side-line voltage decreed from 260 V (RMS) to 220 V (RMS) for 0.5 sec from 1.3 to 1.8 sec, Then the inverter was disconnected, and the voltage became zero as shown in Fig.10. The current increased from 160 A (RMS) to more than 600 A (RMS) for 0.5 sec from 1.3 to 1.8 sec, then the inverter disconnected, and the current became zero as shown in Fig.11. The PV voltage was unstable and rises from 240 V to 280 V from 1.3 to 1.8 sec, and then it became open circuit voltage as shown in Fig.12. The PV current was unstable and rises from 260 A to 287 A from 1.3 to 1.8 sec, then it became zero as shown in Fig.13. In this case, the control circuit disconnected the inverter, the DC-DC converter, and the circuit breaker between the inverter and the grid; because the fault time was more than 0.5 (the pre-defined value) sec that means it was a permanent fault.

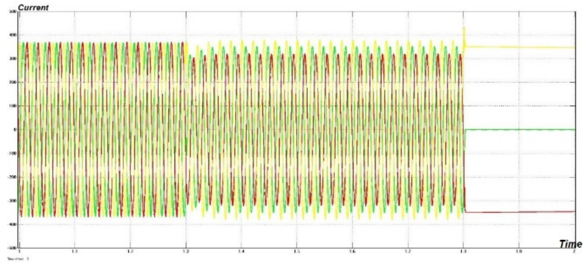

Fig.10 (case 2-line voltage at grid side)

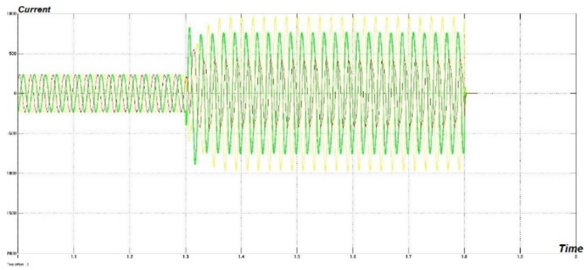

Fig. 11. (Case 2 line current at grid side)

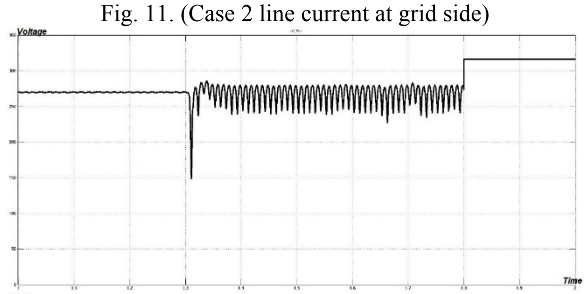

Fig. 12 (case 2 PV voltage at PV side)

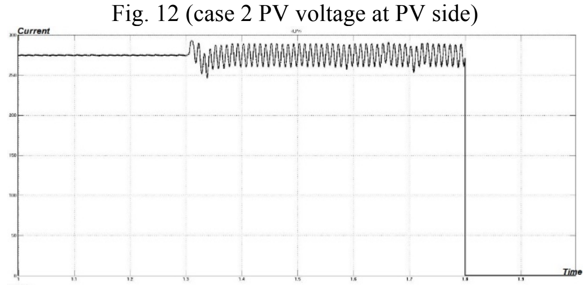

Fig. 13 (case 2 PV current at PV side)

### 3.3. **Case**:3 **permanent phase to ground fault**

A phase to ground fault (phase (c) to ground) simulated on the grid line side for 0.7 secs from 1.3 to 2 sec. When the fault occurred, the grid side line voltage phase a and phase b increased from 220 V (L-G) line to ground to 350 V (L-G) for 0.5 sec from 1.3 to 1.8 sec and phase c voltage decreased from 220 (L-G) to 10 V. The inverter disconnected and the voltage became zero as shown in Fig.14. Phase a and b current slightly decreased from 230 A to 225 A and phase c current increased from 230 A to 280 A for 0.5 sec from 1.3 to 1.8 sec, then the inverter disconnected, and the current becomes zero as shown in Fig.15. The PV voltage was almost stable due to the small fault current, and then it rises to open circuit voltage as shown in Fig.16. The PV current became zero as shown in Fig.17.

In this case, the proposed control circuit isolated the permanent fault effectively.

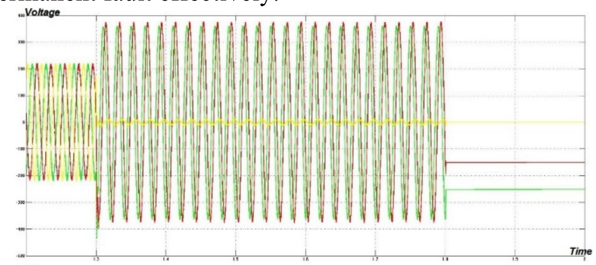

Fig. 14 (case 3 line voltage at grid side)

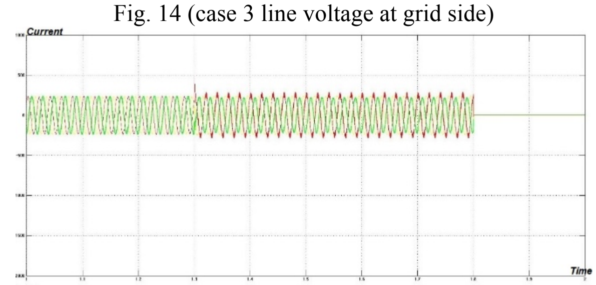

Fig. 15 (case 3 line current at grid side)

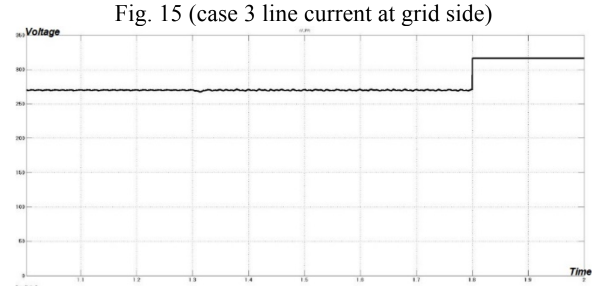

Fig. 16 (case 3 PV voltage at PV side)

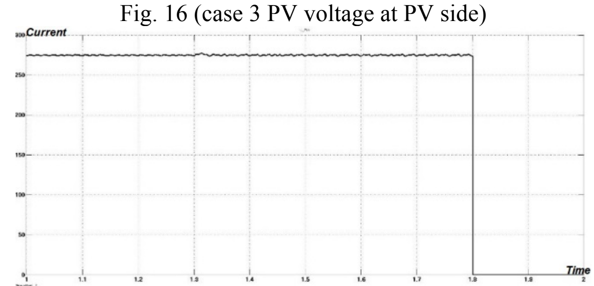

Fig. 17 (case 3 PV current at PV side)

Other types of faults were tested, and the controller ride through the temporary faults and disconnect the permanent faults. As the controller based on the overcurrent protection, it detects both the line to line and line to ground faults.

## 4. Conclusion

Much of the previous research has focused on the protection of solar power plants, but few have focused on reliability, which is intended to continue feeding in case of transient faults. This paper proposed a control circuit to control the operation of a solar cell system inverter, which can ride through the transient faults.

Solar PV systems designed to disconnect and remain offline for five mints when tripped by loss of grid voltage. However, traditional solar systems cannot differentiate between transient and sustained grid voltage loss. It behaves in the same manner in the two cases, i.e., disconnect, stay offline for 5 minutes and then makes re-connection trial. Staying offline for 5 minutes unnecessarily wastes considerable amount of clean energy from the PV, may affect the power balance of the grid and many other adverse effects of service discontinuity. When a fault occurs and persists for more than 0.5 seconds (the pre-defined value), it immediately disconnects the inverter and the converter (in the case of two stage conversion) and disconnect the grid side breaker.

Three different types of faults applied to test the system and the results proved the success of the proposed control circuit to avoid the disconnection of the solar system in the case of transient faults and isolate the faults in the case of permanent ones.

# 5. References


[1] Alvaro L, et al., "low voltage ride through Strategies for SCIG Wind Turbines in Distributed Power Generation Systems", 2008 IEEE Power Electronics Specialists Conference, Rhodes, 2008, pp. 2333-2339.

[2] Gustavo M, et al., " Photovoltaic Inverters with Fault Ride-Through Capability ", IEEE International Symposium on Industrial Electronics, PP 549:553, July 5-8, 2009

[3] Yongheng Y, Frede B, et al., " Power control flexibilities for grid-connected multi-functional photovoltaic inverters ", IET Renewable Power Generation, VOL 10, Number 4, PP 1:10,2016.

[4] Zhao, et al. "Low-Voltage Ride-Through Operation of Power Converters in Grid-Interactive Micro grids by Using Negative-Sequence Droop Control ", IEEE Transactions on Power Electronics, VOL 32, Number 4, PP 3128:3142, Apr 2017

[5] Jorge L, et al. " Control Strategy to Maximize the Power Capability of PV Three-Phase Inverters During Voltage Sags", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL 31, Number 4, PP 1:11, 2015.

[6] Yeqin W, and Beibei R, "Fault Ride-Through Enhancement for Grid-Tied PV Systems with Robust Control" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS", VOL 65, Number 3, PP: 2302-2312, MARCH 2018

[7] Adel M, et al.,"Robust Model Predictive Control for Photovoltaic Inverter System with Grid Fault Ride-Through Capability", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL 65, Number 3, PP 2302:2312, MARCH 2018

[8] Rajiv K. Varma, Ehsan M. Siavashi," PV-STATCOM: A New Smart Inverter for Voltage Control in Distribution Systems", IEEE TRANSACTIONS ON SUSTAINABLE ENERGY, VOL 9, Number 4, PP 1681:1691, OCTOBER 2018

[9] MITCHELL E, et al., "Computationally Efficient Distributed Predictive Controller for Cascaded access Multilevel Impedance Source Inverter with LVRT Capability", IEEE Access, VOL 7, PP 35731:35742, publication March 12, 2019, date of current version April 2, 2019

[10] S. Raja Mohamed, et al., "DC-Link Voltage Control of a Grid-Connected Solar Photovoltaic System for Fault Ride-Through Capability Enhancement", MDPI, VOL.9, Number 5, PP 952:979, March 2019.

[11] Ronald N, et al., " Low Voltage Ride through Control Capability of a Large Grid Connected PV System Combining DC Chopper and Current Limiting Techniques", Journal of Power and Energy Engineering, PP 62:79, January 2019

[12] M. Mirhosseini, J. Pou, and V. G. Agelidis, "Single-stage inverter-based grid-connected photovoltaic power plant with ride-through capability over different types of grid faults," in Proc. Annu. Conf. IEEE Ind. Electron. Soc. (IECON), PP 8008–8013, Nov. 2013.

[13] "Technical Guideline: Generating Plants Connected to the Medium-Voltage Network BDEW Bundesverband der Energie- und Wasserwirtschaft e.V." in, Berlin, Germany, 2008.

[14] "Renewables 2016: Global status report (GRS)", 2016, [online] Available: http://www.ren21.net/.

[15] "Technical regulation 3.2.2 for PV power plants with a power output above 11 kW", 2015.

[16] Q. Li, P. Wolfs, "A review of the single-phase photovoltaic module integrated converter topologies with three different DC link configurations", IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL 23, Number 3, PP 1320-1333, May 2008.

[17] X. Yuan, Y. Zhang, "Status and Opportunities of Photovoltaic Inverters in Grid-Tied and Micro-Grid Systems", 2006 CES/IEEE 5th International Power Electronics and Motion Control Conference, China , PP 1-4, February 2009.

[18] B. Kavya Santhoshi, et al., "Critical Review of PV Grid-Tied Inverters", Energies, Vol 12, 2019.