Inverter-Based versus Synchronous-Based Distributed Generation; Fault Current Limitation and Protection Issues

A.M. Massoud
Member

Qatar University
Doha, Qatar
ahmed.massoud@qu.edu.qa

Shehab Ahmed
Member

Texas A&M University
Doha, Qatar
shehab.ahmed@qatar.tamu.edu

S. J. Finney

B.W. Williams

Strathclyde University, Glasgow, UK
s.finney@eee.strath.ac.uk
barry.williams@eee.strath.ac.uk

Abstract -- **The contribution of distributed generation (DG) to network fault levels depends heavily on the technology employed. In the case of directly connected rotating machines the fault behavior is well established; with synchronous generators contributing higher fault levels than the corresponding induction generators. The contribution of inverter-based distributed generation (IBDG) is the lowest due the capability of this technology to exhibit non over-load characteristics. However the behavior of this generation technology under fault conditions is determined by the employed control methods. In this paper, an investigation of the effect of the DG type on the fault current is investigated. Simulations for case studies have been conducted using Matlab/Simulink.**

Index Terms-- **Distributed generation, Fault Levels, Inverters, Protection.**

I. INTRODUCTION

The connection of distributed generation (DG) onto the low and medium voltage parts of the electricity supply network can result in raised fault levels; resulting in increased stress on network components. This issue has been identified as a potential limit to the level of installed DG that may be integrated into existing networks [1-16]. Fault current limiting (FCL) devices offer a means of managing this issue without the need for extensive network reinforcement.

The contribution of DG to network fault levels will depend heavily on the technology employed [11,13-16]. In the case of directly connected rotating machines, the fault behavior is well established; with synchronous generators contributing higher fault levels than corresponding induction generators. The synchronous generator passes through three stages during faults: subtransient (0-50ms), transient (50ms-1s), and steady state (>1s). The transient and steady state short circuit currents depend on the excitation system. Solid state excitation can be used for controlling and limiting the fault current [14]. In induction generators, the magnetic excitation of the induction generator (IG) is fed from the power system. Short circuiting the induction generator at its terminal causes loss of excitation which results in a collapse of the fault current contribution. Currents decrease to an insignificant value after 100 to 300 ms, thus, IGs do not contribute to the steady state fault current [14].

The contribution of inverter-based distributed generation (IBDG) is the lowest due the capability of this technology to exhibit non over-load characteristics. However the behavior of this generation under fault conditions is determined by the employed control methods. In this paper, an investigation of the effect of DG type on the fault current is presented.

II. INVERTER-BASED DG

A block diagram of three-phase IBDG is shown in Fig. 1. The energy source is connected to the inverter through a conditioning stage (either AC/DC, AC/DC/DC or DC/DC converters). The three phase voltage source inverter is interfaced to the distribution network through an LC filter and transformer. In Fig. 1, reference active and reactive powers are set and reference currents can be extracted from the voltage measurements of the common coupling. A phase locked loop is employed for transforming the three-phase stationary reference frame to two phase synchronously rotating reference one. Proportional-integral control is employed for controlling the currents. Space vector modulation is employed as a pulse width modulation (PWM) technique, as it introduces the lowest total harmonic distortion and increases the inverter gain compared to sinusoidal PWM.

III. THE CHALLENGES TO HIGHLY DISTRIBUTED POWER SYSTEM PROTECTION

The following are challenges to network protection [5,7]:

1. Prevention of automatic reclosing
2. Unsynchronized reclosing
3. Blinding of protection
4. Increased or decreased fault levels
5. Unwanted islanding
6. False tripping of feeders (sympathetic tripping)

Sympathetic tripping [5] occurs when a protective device operates unreasonably during faults. This can be due to the fault contribution of the DG. As shown in Fig. 2, the relay at CB1 and the recloser are not directional. Adequate fault current contribution from the distributed generation would cause an operation in sympathy with CB2 which should

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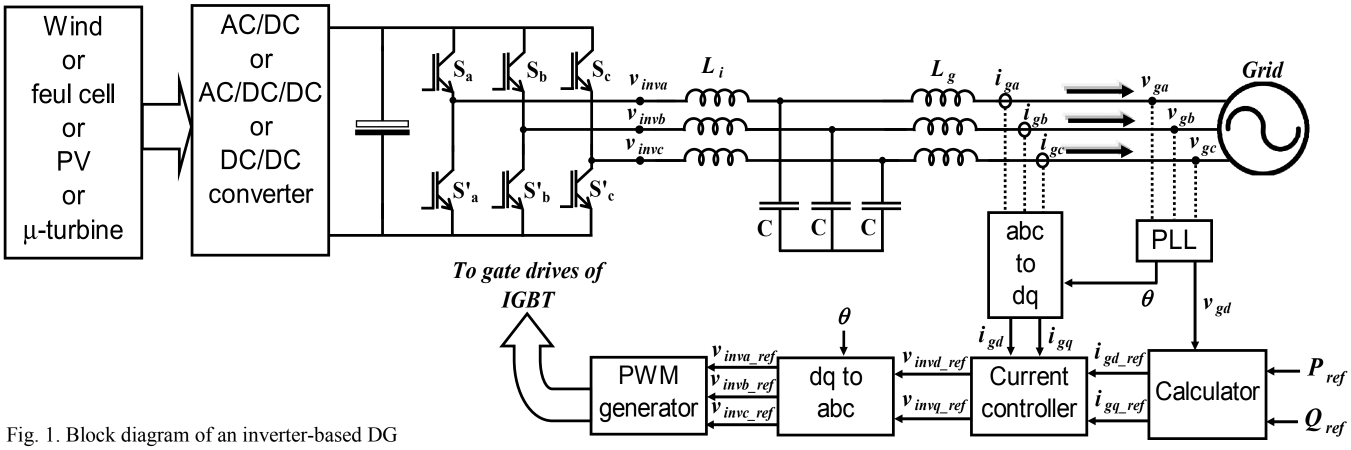

Fig. 1. Block diagram of an inverter-based DG

interrupt the fault first.

It cannot be guaranteed that DG will be disconnected faster than fuse blowing and false tripping. The DG can result in false protection operation [8]. If IBDG is used, these problems can be solved easily. Due to fast dynamic response of IBDG, these problems can be avoided.

From the point of view of fault levels, there are three scenarios in highly distributed power systems:

1. Domination of synchronous and induction generators
2. Domination of IBDG
3. Combination of both 1 and 2

Requirements for Scenario 1

In this scenario excessive short circuit current must be limited by means of FCL devices, provided the contribution from IBDG remains relatively small. These units may be tripped out (dependant on the location and rating) during faults.

Requirements for Scenario 2

In this case the growth in installed capacity is mainly provided by IBDG, such devices have an inherent current limiting capability. Under this scenario IBDG provides a significant part of the installed capacity leading to a fault ride through requirement. The role of specific FCL devices is likely to be minimal.

Requirements for Scenario 3

In the third scenario fault level may be managed through the use of FCL devices and current limited IBDG interfaces. Requirements will depend upon the generation mix. Effective fault level management will depend on the coordination of these technologies.

IV. Recommendations for IBDG

The contribution of the IBDG is limited during faults such that its effect is negligible compared to synchronous generators [14]. There are two scenarios when a fault occurs

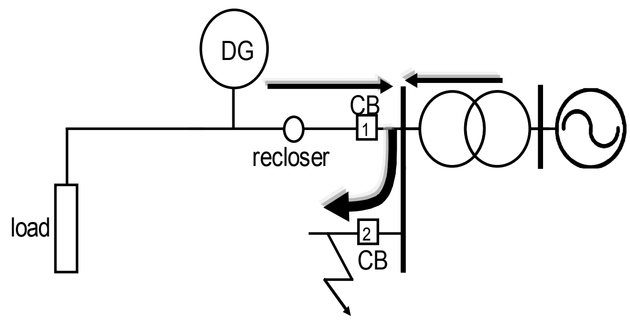

Fig. 2. Sympathetic tripping

(if the IBDG dominates the system):

1. The IBDG continues operation and feeds the fault but the inverter output current is limited avoiding any harm for the inverter switches.
2. When a fault is detected (from the point of view of the inverter), the inverter is tripped out and only the utility feeds the fault and operates with the pre-designed protection devices.

V. Case Studies

Simulation results have been carried out using MATLAB/SIMULINK for four different case studies. In the following four case studies, the IBDG is a three phase inverter with a constant DC voltage (the variation of the DC voltage is neglected).

A. Case (1): high fault current

If the DG is connected to the grid as shown in Fig. 3, it is expected that the fault level increases at the specified fault location after the DG insertion. But when IBDG is used and due to the limited fault current that it can provide (it is assumed here to be 1.5 times the full load current), the problem of high fault current levels disappears.

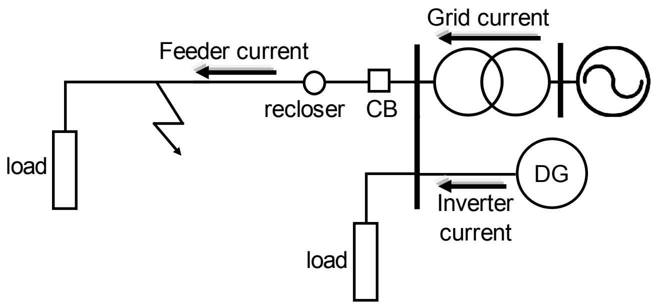

Fig. 3. Case (1): high fault current

The IBDG supplies 10kW and 1kVAR. Fig. 4 shows the simulation results for the case that the IBDG continues supplying the fault current. The fault starts at 0.2s and the CB trips out the feeder at 0.35s. Fig. 5 shows the simulation results for the case when the IBDG detects fault occurrence and clears it (it connects and disconnects respectively). The fault starts at 0.3s and the recloser clears the fault at 0.35s.

B. *Case (2): fault through high impedance*

If the DG is connected to the grid as shown in Fig. 6, it is expected that for a fault through high impedance, the fault level is not sufficient for the CB to trip. Using IBDG, almost all the fault current is supplied from the grid which enables proper CB action.

The IBDG supplies 10kW and 1kVAR. Fig. 7 shows the simulation results for the case when the IBDG continues supplying the fault current. The fault starts at 0.2s and the CB trips out the feeder at 0.35s. Fig. 8 shows the simulation results for the case when the IBDG detects fault occurrence and clearance, and connects and disconnects respectively. The fault starts at 0.3s and the recloser clears the fault at 0.35s.

C. *Case (3): upstream and downstream the fault-connected DG*

If two DGs are connected to the grid as shown in Fig. 9, the fault current sharing among the two DGs and the grid is tricky to calculate. Using IBDG for the two DGs, almost all the fault current is supplied from the grid which enables a proper action of the CB.

The IBDG1 supplies 10kW and 1kVAR while the IBDG2 supplies 10kW and no VAR. Fig. 10 shows the simulation results for the case when IBDG1 (upstream the fault) continues supplying the fault current and IBDG2 (downstream the fault) detects fault occurrence. The fault starts at 0.2s and the CB trips at 0.35s. Fig. 11 shows the simulation results for the same condition in Fig. 10 except that the fault is temporary. Fig. 12 shows the same results as in Fig. 11 except that IBDG1 disconnects.

D. *Case (4): sympathetic tripping*

If the two DGs are connected to the grid as shown in Fig. 13, the fault current passing through feeder (2) for a fault in feeder (1) may cause sympathetic tripping for CB2. Using IBDG for the two DGs, almost all the fault current is supplied from the grid.

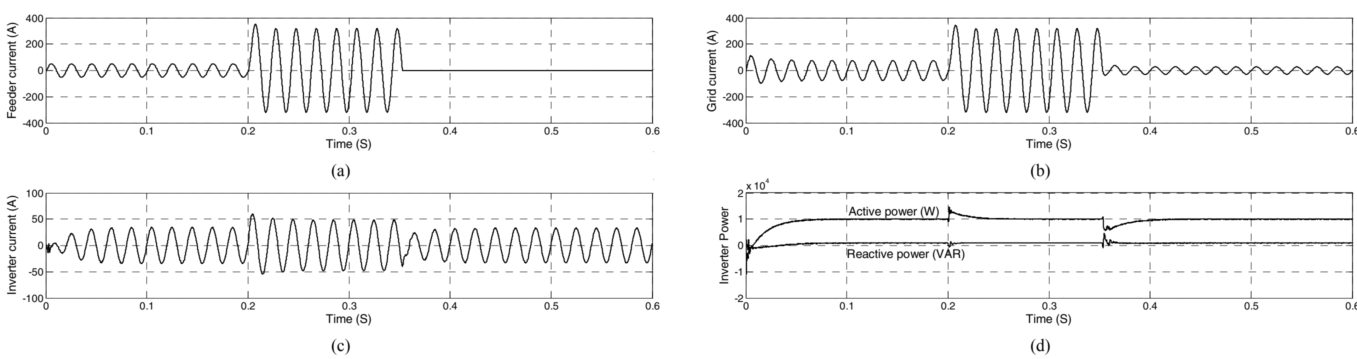

Fig. 4. IBDG continues supplying the fault in case (1)

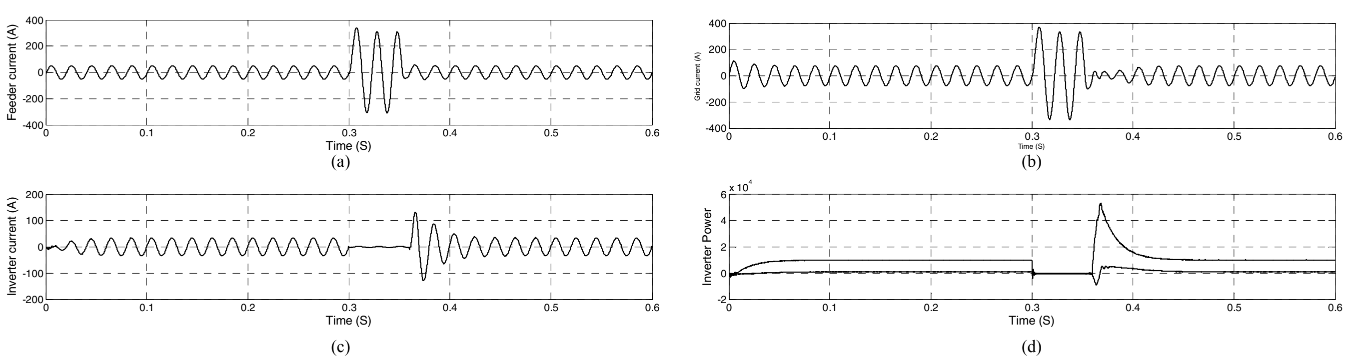

Fig. 5. IBDG disconnects for fault conditions in case (1)

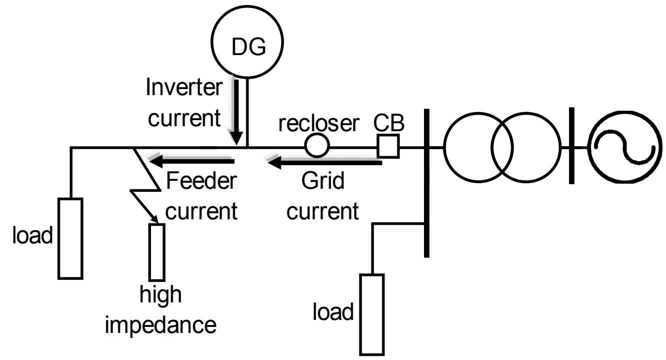

Fig. 6. Case (2): fault through high impedance

IBDG1 supplies 10kW and 1kVAR while IBDG2 supplies 5kW and no VAR. Fig. 14 shows the simulation results for the case that IBDG1 and IBDG2 continue supplying the fault current. The fault starts at 0.2s and is cleared out by the recloser at 0.35s.

VI. Conclusion

The effect of distributed generation during faults on the electric power system has been presented. It is concluded that fault current management solutions must match the generation technologies employed. Where conventional rotating plants dominate, FCL or fast acting circuit breakers are required.

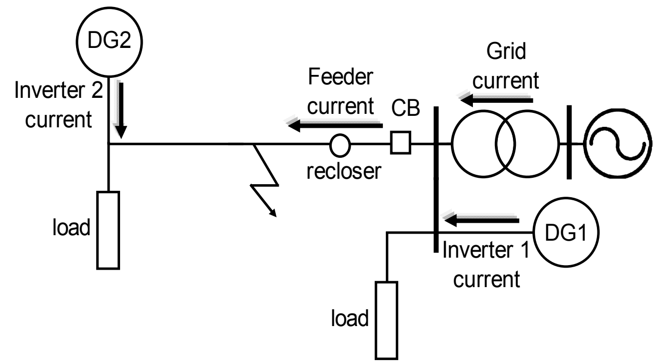

Fig. 9. Case (3): upstream and downstream the fault-connected DG

Many new generation technologies must connect to the grid via inverter interfaces. In such cases, the inverter provides a means of fault current management. The study of IBDG under fault conditions and the development of appropriate control methodologies provide a complimentary development stream to FCL technology development. IBDG case studies supporting this conclusion have been presented in this work.

VII. Acknowledgment

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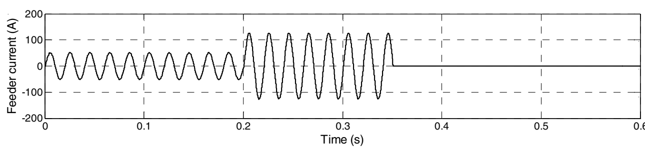

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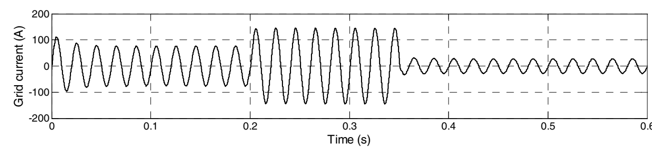

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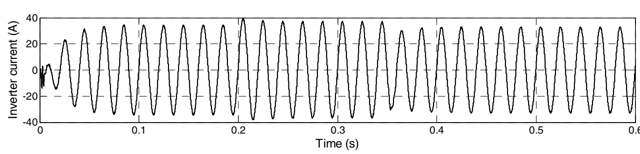

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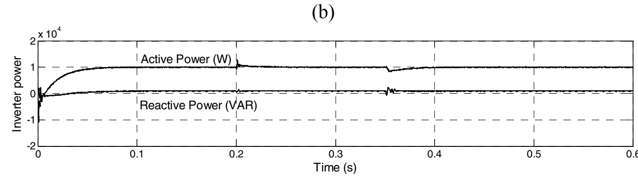
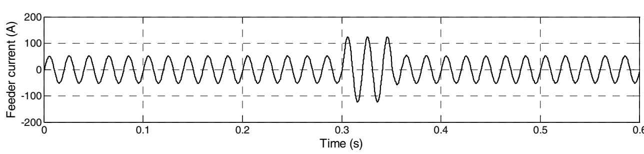


(d)

Fig. 7. IBDG continues supplying the fault in case (2)



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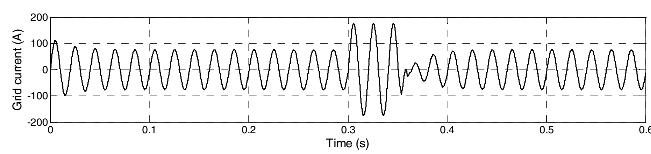

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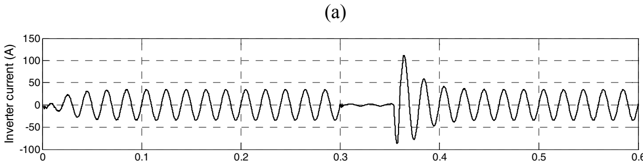

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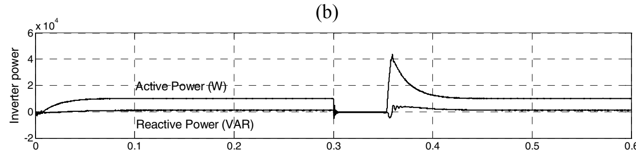

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Fig. 8. IBDG disconnects for fault conditions in case (2)

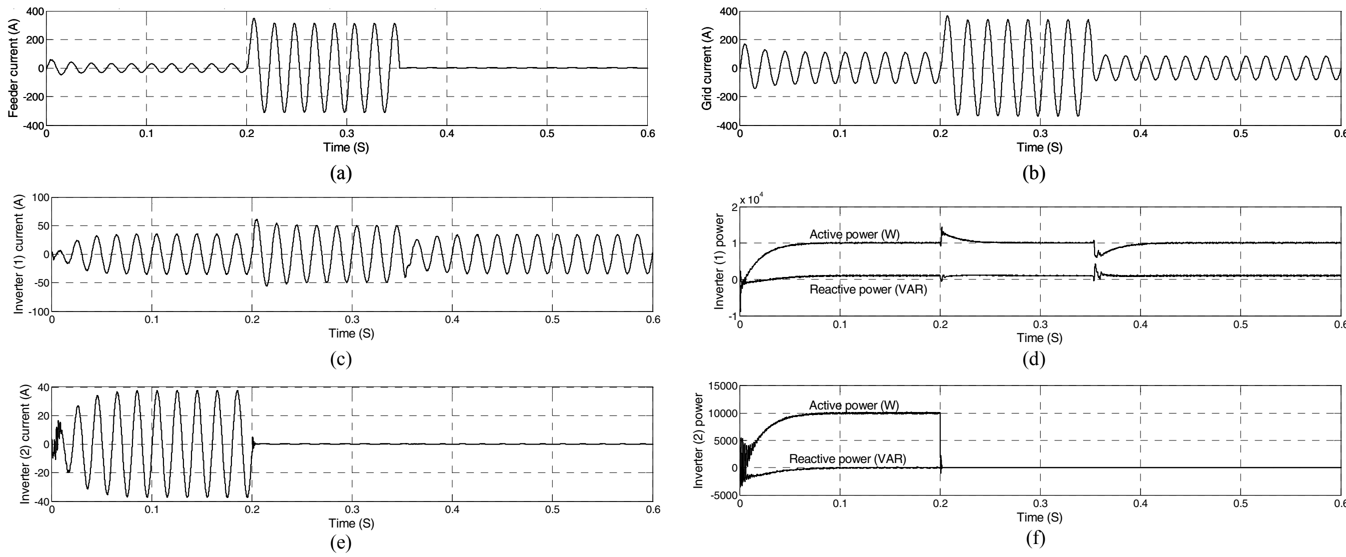

Fig. 10. IBDG1 continues and IBDG2 disconnects (permanent fault) in case (3)

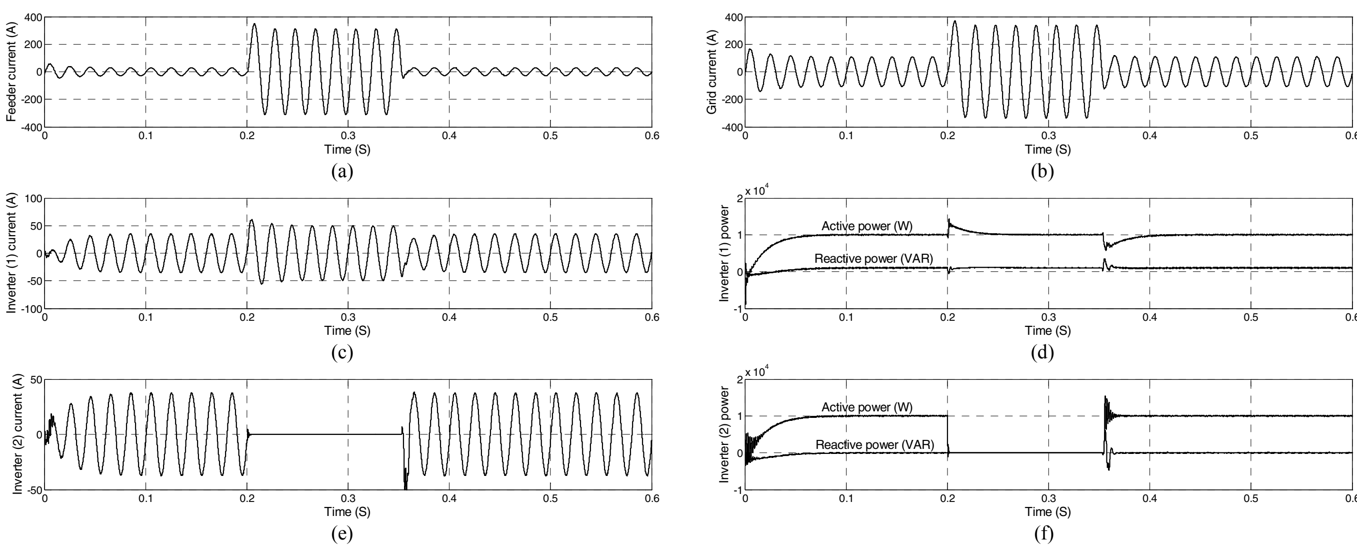

Fig. 11. IBDG1 continues and IBDG2 disconnects (temporary fault) (case (3))

VIII. REFERENCE

[1] R. Chokhawala, G. Castino, "IGBT fault current limiting circuit," *IEEE Industry Applications Magazine*, vol. 1, pp. 30-35, Oct. 1995.

[2] R. C. Dugan, T. E. McDermott, "Distributed generation," *IEEE Industry Applications Magazine*, vol. 8, pp. 30-35, April 2002.

[3] K. Malmedal, P. K. Sen, J. P. Nelson, "Application of out-of-step relaying for small generators in distributed generation," IEEE Trans. Industry Applications, vol. 41, pp. 1506-1514, Dec. 2005.

[4] http://e-collection.ethbib.ethz.ch/ecol-pool/bericht/bericht_424.pdf

[5] Y. Baghzouz, "Voltage Regulation and Overcurrent Protection Issues in Distribution Feeders with Distributed Generation - A Case Study," in *Proc. 2005 Annual Hawaii International Conf.* pp. 66b-66b.

[6] https://archive.ugent.be/retrieve/3284/Renders_paper024.pdf.

[7] M. T. Doyle, "Reviewing the impacts of distributed generation on distribution system protection," in *proc. 2002 IEEE Annual Power Engineering Society Summer Meeting,* pp. 103-105.

[8] S. Chaitusaney, A. Yokoyama, "Impact of protection coordination on sizes of several distributed generation sources," in *Proc. 2005 IEEE Power Engineering Conf.* pp. 669-674.

[9] J. C. Gomez, M. M. Morcos, "Coordination of voltage sag and over current protection in DG systems," *IEEE Trans. Power Delivery*, vol. 20, pp. 214-218, Jan. 2005.

[10] D. M. Vilathgamuwa, P. C. Loh, Y. Li, "Protection of Microgrids During Utility Voltage Sags," *IEEE Trans. Industrial Electronics*, vol. 53, pp. 1427-1436.

[11] N. Nimpitiwan, G. T. Heydt, R. Ayyanar, S. Suryanarayanan, "Fault Current Contribution From Synchronous Machine and Inverter Based Distributed Generators," *IEEE Trans. Power Delivery*, vol. 22, pp. 634-641, Jan. 2007.

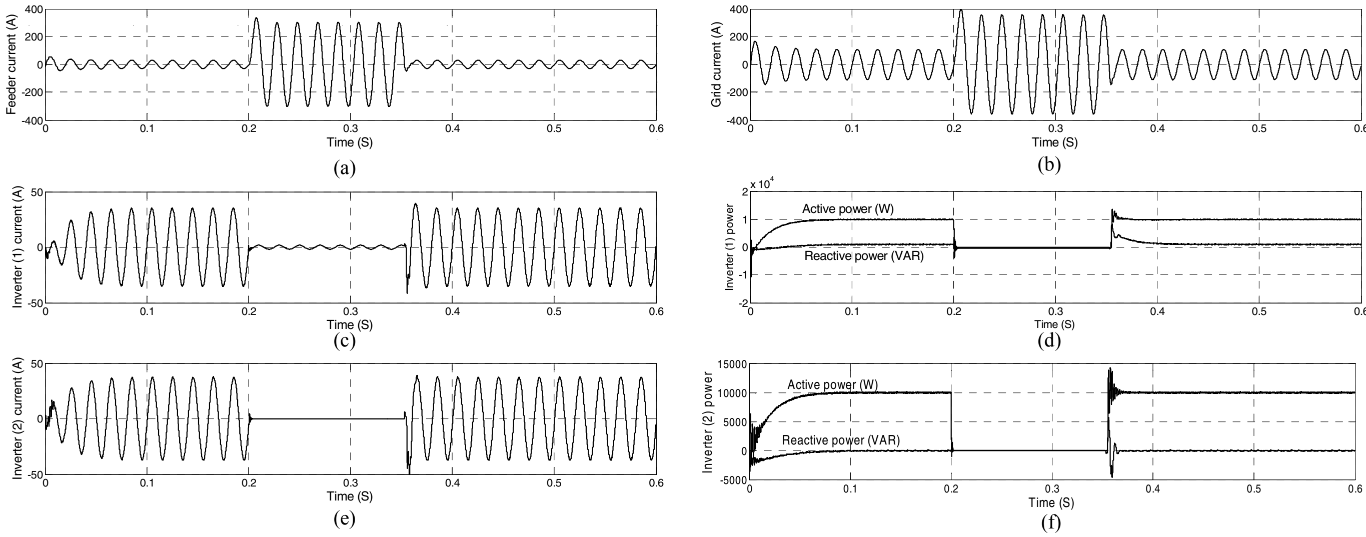

Fig. 12. IBDG1 and IBDG2 disconnect (temporary fault) (case (3))

[12] J. Jager, T. Keil, L. Shang, R. Krebs, "New protection co-ordination methods in the presence of distributed generation," in *Proc. 2004 IEE Developments in Power System Protection Conf.* pp. 319-322.

[13] DTI report "Integration of Additional Microgeneration", (SIAM) CONTRACT NUMBER: DG/CG/00028/REP URN NUMBER: 04/1644 (http://www.berr.gov.uk/files/file15192.pdf)

[14] DTI report "The contribution to distribution network fault levels", CONTRACT NUMBER: DG/CG/00027/00/00, URN NUMBER: 05/1249 http://www.berr.gov.uk/files/file15199.pdf

[15] DTI report "solutions for the connection and operation of distributed generation", K/EL/00303/00/01/REP, URN 03/1195 http://www.ensg.gov.uk/assets/solutions.pdf

[16] DTI report "STABILITY OF NETWORKS WITH, DISTRIBUTED GENERATION AND POWER CONVERTER INTERFACES", Final Report CONTRACT NUMBER: K/EL/00273/REP URN NUMBER: 04/1367 http://www.berr.gov.uk/files/file15188.pdf

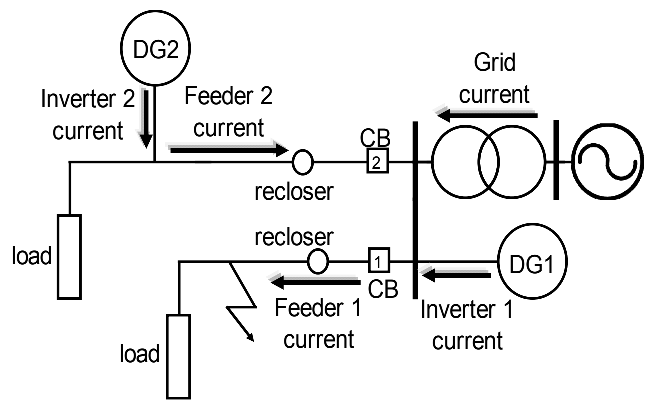

Fig. 13. Case (4): sympathetic tripping

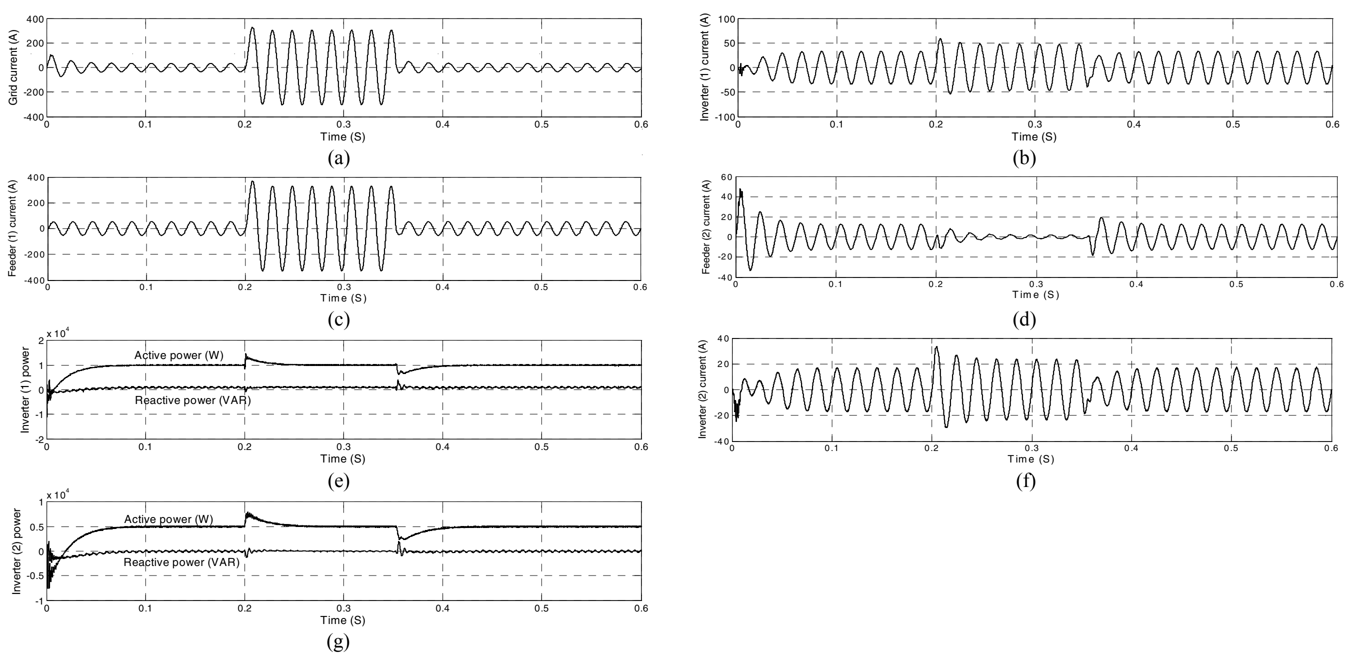

Fig. 14. IBDG1 and IBDG2 continue working (temporary fault) (case (4))