A Generalized Current Trajectory Based Fault Diagnostic Method for Three-Phase Two-Level Inverters

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Abstract

Inverters play a vital role in the distributed generated energy systems. Hence, the reliability of the entire distributed energy system depends on the consistent and continuous operation of the inverter. Consequently, to maintain a reliable operation, effective condition monitoring and fault diagnostic schemes have to be incorporated. In this paper, a method based on current trajectory is analyzed for the fault detection and diagnosis of open-switch faults in three-phase two-level voltage source inverters (VSI). The current trajectory-based method of fault diagnosis has been already presented literature for the identification and localization of open-switch fault in the three-phase two-level VSI. The main drawback of the existing current trajectory method is that the fault diagnosis and detection is dependent on the phase currents selected to plot the current trajectories. Therefore, in this paper, a generalization is proposed for the fault diagnosis and diagnosis based on the

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current trajectory, which make the method independent of the selection of the phase current used to plot the current trajectory. The validity and effectiveness of the proposed generalization is verified by simulation and experiments in a laboratory prototype of three-phase two-level VSI.

Keywords: Three-phase two-level inverter, gate-open circuit fault, current trajectory, fault detection, fault diagnosis.

1 Introduction

Inverters play a crucial role in the conversion and integration of electrical energy in distributed generations in grid-connected and stand-alone modes [1, 2]. Now a days, inverters are employed in distributed energy systems in applications such as solar PV systems, wind energy systems, V2G/G2V modes of electric vehicles, reactive power control, motor drives, etc. [3–7]. All these applications are highly dependent on the consistent and continuous working of the inverter. However, the inevitable power semiconductors in the inverters makes the applications more probable to faults. It is reported in [8] that about 80% of the faults in the power converters is due to the power semiconductor switch faults. In order to make the applications employing inverters, an effective fault diagnostic schemes have to be incorporated to improve the overall reliability and to reduce the influence of the power semiconductor faults. The leading causes of inverter faults are open-circuit (OC) and short-circuit (SC) faults [9]. Out of these two faults, SC fault is the most critical fault. Now a day all the inverter fed applications are equipped with the SC fault mitigation techniques as a standard. In contrast, the OC fault may remain unnoticed in the inverter system, and operating under such faulty condition may result in other cascading failures and serious consequences. This fault mainly happens due to the gate circuit failures or connection cut-off [9, 10]. Therefore, this work focuses on the most commonly occurring single-switch OC fault diagnostic schemes in the three-phase two-level inverters.

Fault detection and diagnosis (FDD) in three-phase two-level Voltage Source Inverter (VSI) has been a vibrant research field from the starting of the 1990s, and since then, several FDD schemes have been introduced. Various methods have been presented for the FDD such as method based on rule-based expert system [11, 12]; methods based on current trajectory [13–18]; methods based on phase currents such as Park's vector [19], simple DC current method [20] and reference current errors [21]; methods based on inverter output voltage [22, 23]; methods based on control theory such as bond graph [24], Extended Kalman Filter [25] and non-linear PI observers [26]. In addition, a number of methods of based on artificial intelligence such as wavelet-adaptive neuro-fuzzy inference system [27], wavelet-neural network method and wavelet-fuzzy algorithm [28, 29] also have been introduced. In spite of the extensive research work in this area, the recent publications show that FDD in three phase two-level VSI is still an active and potential area of research [30, 31].

Out of the various methods of fault diagnosis presented, one of the stimulating diagnostic schemes is the method based on the current trajectory of the inverter currents [13–18]. In [13], Concordia transformation is used to convert the three-phase current to the two-phase system. Then the slope of the current trajectory of the two-phase system is calculated and used to detect and locate the fault. Implementation of this method on a pulse width modulation (PWM) current-controlled inductor motor drive with the aid of real-time controller is reported in [14]. A different approach of this method is covered in [15], where, the current trajectory of stator current space phasor with respect to stator reference frame is used for the FDD. It is also reported that the current trajectory patterns obtained by methods based on 3D current trajectory mass center [16] and principle component analysis and mean value [17] also confirm the possibility of switch fault diagnosis in two-level inverters. Another method based on the current trajectory of any ‘two’ phase current is presented in [18]. The main drawback of this method is that the FDD is dependent on the phase currents selected to plot the current trajectories.

The current trajectory-based method of fault diagnosis is an effective method of diagnostic method for the identification and localization of open-switch fault in the three-phase two-level VSIs [13–18]. Some these methods need transformation to other domains [13–15]; and few methods need advanced plotting techniques such as 3D current trajectory [16]. All these methods require ‘three’ phase currents and transformation, which call for higher number of current sensors and computational requirement. On the other hand, the method methos presented in [18] need only ‘two’ current sensors and no transformation. However, this method depends on the selection of phase currents to plot the current trajectory. Therefore, in this paper, a generalization is proposed for the fault diagnosis and diagnosis based on the current trajectory presented in [18], which make the method independent of the selection of the phase current used to plot the current trajectory. The validity and effectiveness of the proposed generalization is verified by simulation and experiments in the three-phase two-level VSI. The contents of the paper are as follows: in Section 2, the modulation, simulation and experimental setup of three-phase two-level VSI is explained. The open-switch fault is analyzed in Section 3. Sections 4 and 5 describes the FDD based on current trajectory and the proposed generalization. Finally, the conclusions are given in Section 6.

2 Three-Phase Two-Level Voltage Source Inverter

A typical structure of the three-phase two-level VSI power circuit is shown in Figure 1. It consists of six power semiconductors switches. The upper switches are denoted by T_1, T_3 and T_5, while, the lower switches are denoted by T_2, T_4 and T_6, respectively. The inverter is supplied from a fixed DC-link voltage (V_{dc}) obtained from a three-phase rectifier or DC power source or Solar Panels.

2.1 Modulation Scheme of Three-phase Two-level Inverter

Various modulation techniques such as modulation techniques such as sinusoidal pulse width modulation (SPWM), space vector modulation (SVM) and selective harmonic elimination (SHE) are presented for the modulation three-phase two-level inverters. Among these, the SPWM is the most widely used modulation method in two-level VSI, which is used in this case. In this method, the gate signals are generated based on the comparison of the three sinusoidal reference signals (v_{ra}, v_{rb}, v_{rc}) and a triangular carrier signal (v_t),

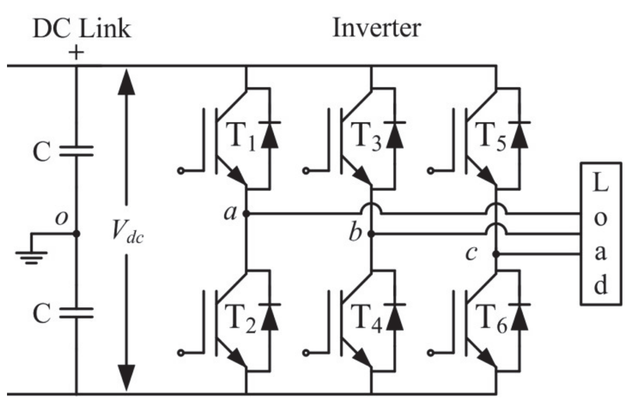


Figure 1 Three-phase two-level VSI topology.

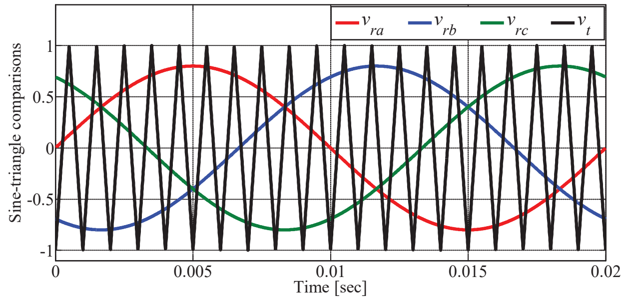


Figure 2 SPWM modulation of three-phase two-level VSI.

Table 1 Parameters of three-phase two-level inverter

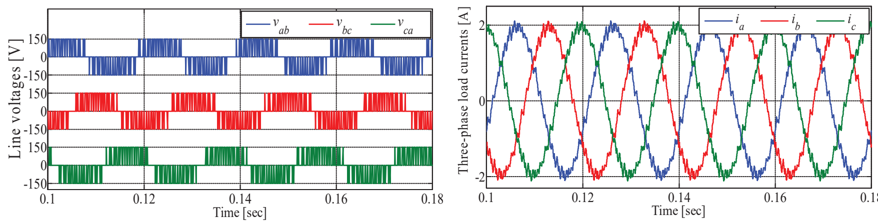
Parameter	Value
DC-link voltage (V_{dc})	150V
Rated current (RMS)	5A
DC-Link Capacitors (C)	2200MFD
Fundamental frequency	50 Hz
Triangular carrier frequency	1 kHz
Modulation index	0.8
RL-Load	R = 35 Ohm, L = 10 mH

as tabulated in Table 1. Typical SPWM waveform with three reference signals of 50 Hz and the triangular carrier signal of 1 kHz with a modulation index of 0.8 is illustrated in Figure 2.

2.2 Simulation and Experimental Setup of Three-phase Two-level Inverter

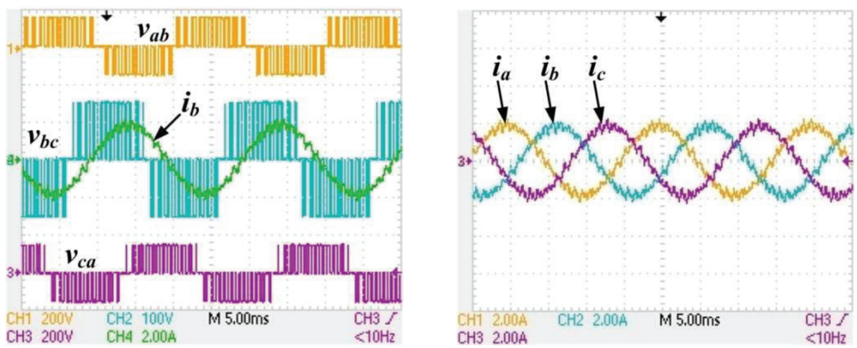
A simulation model of a three-phase two-level VSI has been realized using MATLAB/Simulink block set. Similarly, the three-phase two-level VSI configuration shown in Figure 1 has been fabricated in the laboratory. The three-phase two-level VSI is developed using six FGA15N120 IGBTs. The SPWM scheme is implemented using a microcontroller, and the PWM gate pulses have been given to respective switches using TLP250 gate driver ICs. A three-phase star connected RL-load is connected to the output terminals. This load condition is set to maintain the peak current values to 2A. The parameters of the inverter are indicated Table 1.

The simulation results of line voltages (v_{ab}, v_{bc}, v_{ca}) and the three-phase currents (i_a, i_b, i_c) with an RL-load of R = 35 Ohm and L = 15 mH are shown in Figure 3. Similarly, the experimental waveforms of line voltages



(a) (b)

Figure 3 Simulation results: (a) line voltages (b) three phase currents.



(a) (b)

Figure 4 Experimental results: (a) line voltages and b-phase current (b) three-phase load currents.

(v_{ab}, v_{bc}, v_{ca}) along with b-phase current (i_b) and three-phase load currents (i_a, i_b, i_c) are shown in Figure 4(a) and (b), respectively.

3 Gate Open-Circuit Fault in Three-Phase Two-Level VSI

In this work, gate open-circuit fault in one of the power switches of the three-phase two-level VSI at a time is considered, as the chances for multiple switch faults are rare. The simulation model and experimental setup discussed in Section-1 are used to undertake the gate-open circuit fault study. The fault has been intentionally introduced into the properly working inverter in simulation and experiments by removing the gate pulse, resulting in gate-open circuit fault.

The results of an upper-leg switch is analysed first. The gate-open circuit fault has been introduced to the upper-leg switch 'T_3' switch in simulation

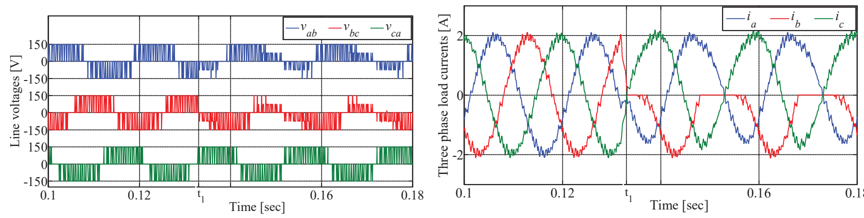


Figure 5 Simulation results with faulty upper switch T_3: (a) line voltages (b) three-phase load currents.

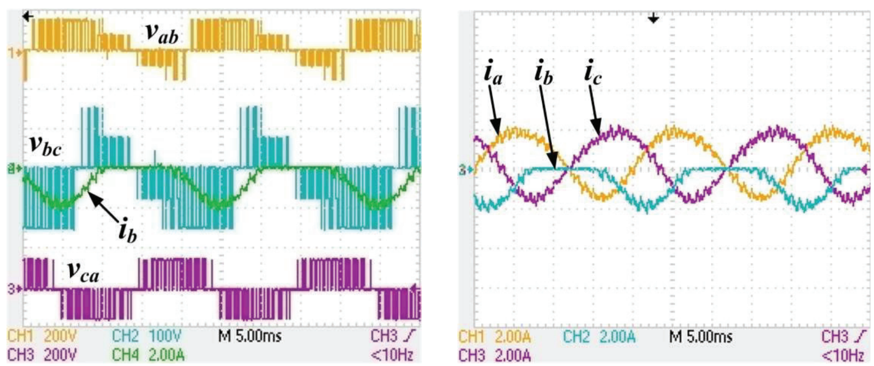
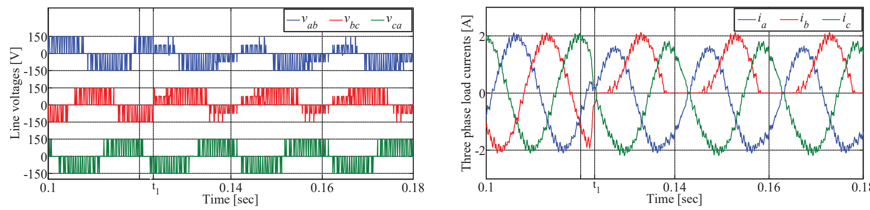


Figure 6 Experimental results with faulty upper switch T_3: (a) line voltages and b-phase current (b) three-phase load current.

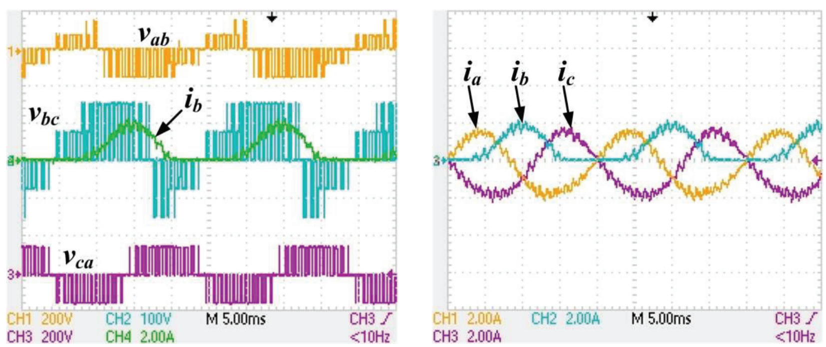
by removing the gate pulse at the instant 't_1', and the three-phase line voltages (v_{ab}, v_{bc}, v_{ca}) and three-phase load current (i_a, i_b, i_c) during the fault are illustrated in Figure 5. Similarly, the fault has been introduced in the experimental setup. The experimental waveforms of three-phase line voltages (v_{ab}, v_{bc}, v_{ca}) along with b-phase current (i_b) and the three-phase current waveforms (i_a, i_b, i_c) under fault condition is illustrated in Figure 6.

Similarly, the gate-open circuit fault has been introduced to the lower-leg switch 'T_4' switch in simulation by removing the gate pulse at the instant 't_1', and the three-phase line voltages (v_{ab}, v_{bc}, v_{ca}) and three-phase load current (i_a, i_b, i_c) during the fault are illustrated in Figure 7. Similarly, the fault has been introduced in the experimental setup. The experimental waveforms of three-phase line voltages (v_{ab}, v_{bc}, v_{ca}) along with b-phase current (i_b) and the three-phase current waveforms (i_a, i_b, i_c) under fault condition is illustrated in Figure 8.



(a) (b)

Figure 7 Simulation results with fault in the lower switch T4: (a) line voltages (b) three phase load currents.



(a) (b)

Figure 8 Experimental results with fault in the lower switch T4: (a) line voltages and b-phase current (b) thee-phase load currents.

Similar procedure is carried out in other upper and lower switches and it is observed that, when an upper switch is faulty, the positive half cycle of the corresponding phase current vanishes as illustrated in Figures 5 and 6. When a lower switch is faulty, the negative half cycle of the corresponding phase current vanishes, as illustrated in Figures 7 and 8. In the case of line voltages, it is observed that the fault occurrence in any switch in a particular inverter-leg affects only the line voltages associated with that inverter-leg in which fault has occurred.

4 FDD Based on Current Trajectory in Three-Phase Two-Level VSI

As it is clear from the literature, the current trajectories of the three-phase currents also can be used for the FDD [13–18]. In this section, current

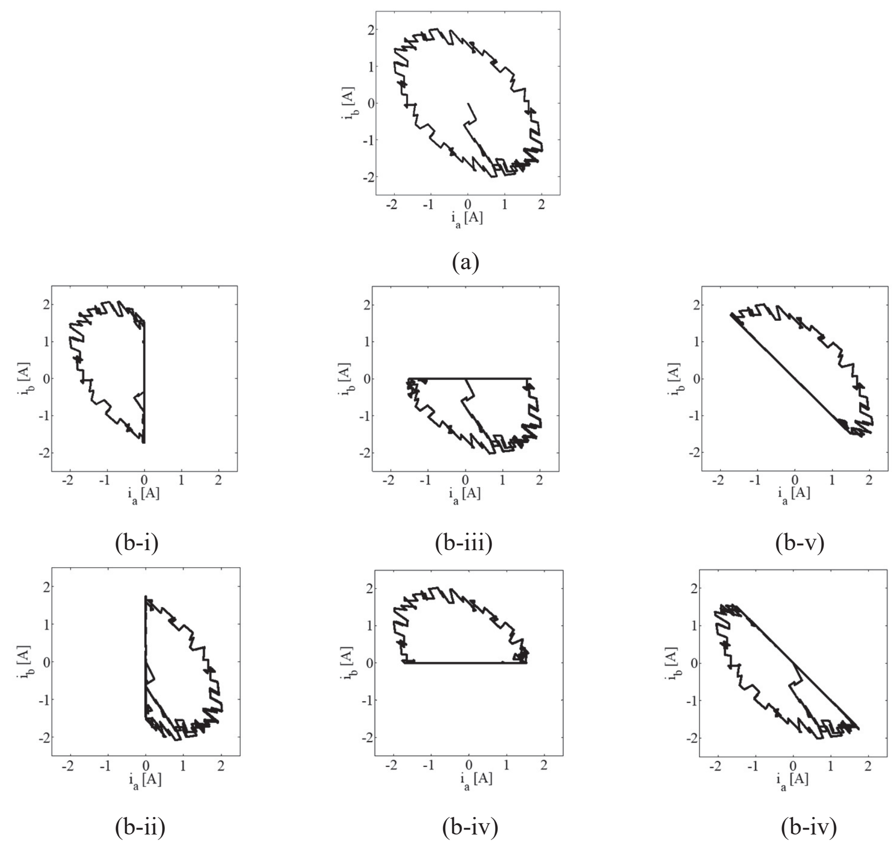


Figure 9 Simulation of current trajectory of i_a vs i_b: (a) all switches under normal condition (b) fault condition in switches (i) T_1 (ii) T_2 (iii) T_3 (iv) T_4 (v) T_5 (vi) T_6.

trajectories formed by the combinations of different currents such as i_a vs i_b, i_b vs i_c and i_c vs i_a are investigated in detail. The trajectory of the currents i_a and i_b are plotted in XY-mode in simulation. The trajectory under normal operation is shown in Figure 9(a). Now, current trajectories are plotted with the fault in each of the six power switches, and the resultant current trajectories are illustrated in Figure 9(b–i)–(b–vi). Also, the trajectory of the currents i_b and i_c under the healthy condition is depicted in Figure 10(a) and with fault conditions are shown in Figure 11(b–i)–(b–vi). A similar approach is carried out in the case of currents i_c and i_a, the current trajectory under normal operation is shown in Figure 11(a), and the faulty condition are illustrated in Figure 11(b–i)–(b–vi).

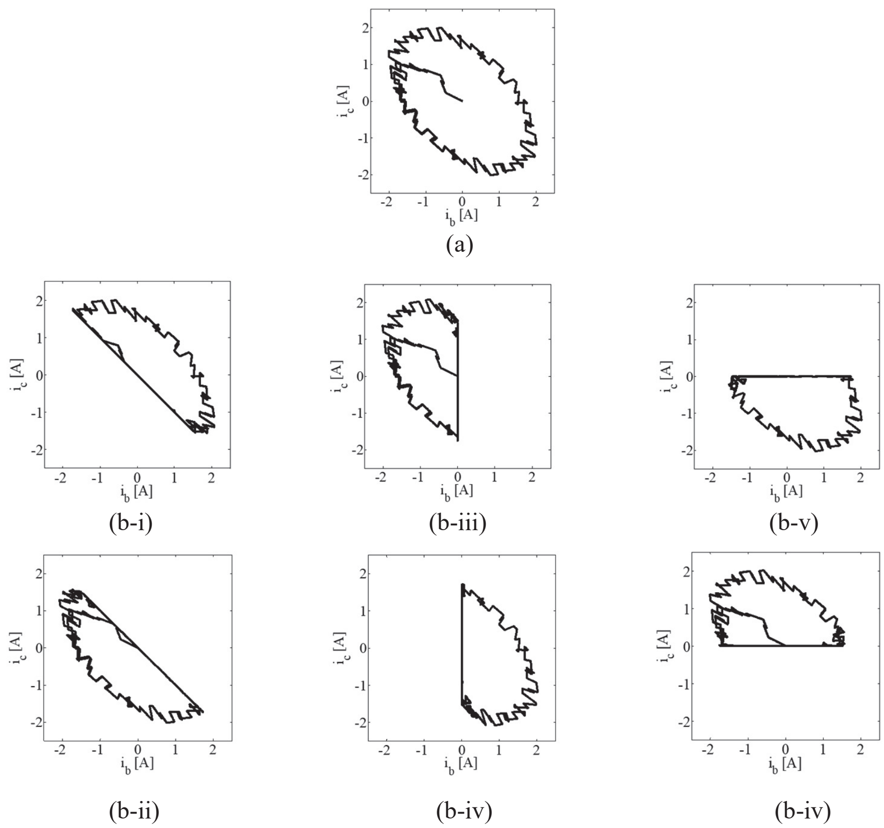


Figure 10 Simulation of current trajectory of i_b vs i_c: (a) all switches under normal condition (b) fault condition in switches (i) T_1 (ii) T_2 (iii) T_3 (iv) T_4 (v) T_5 (vi) T_6.

The current trajectories of phase currents i_b and i_c from the experiments are plotted in the XY-mode of the DSO. The trajectory under normal operation is shown in Figure 12(a). Now, current trajectories are plotted with the fault in each of the six power switches, and the resultant current trajectories are illustrated in Figure 12(b–i)–(b–vi). Similarly, other combinations of the current trajectories are also plotted. It is found that, they are exactly matching with the simulation results.

It is observed that, the current trajectories remain the same for healthy operation in all three current combinations. Furthermore, the current trajectories follow a unique pattern for each switch under fault conditions,

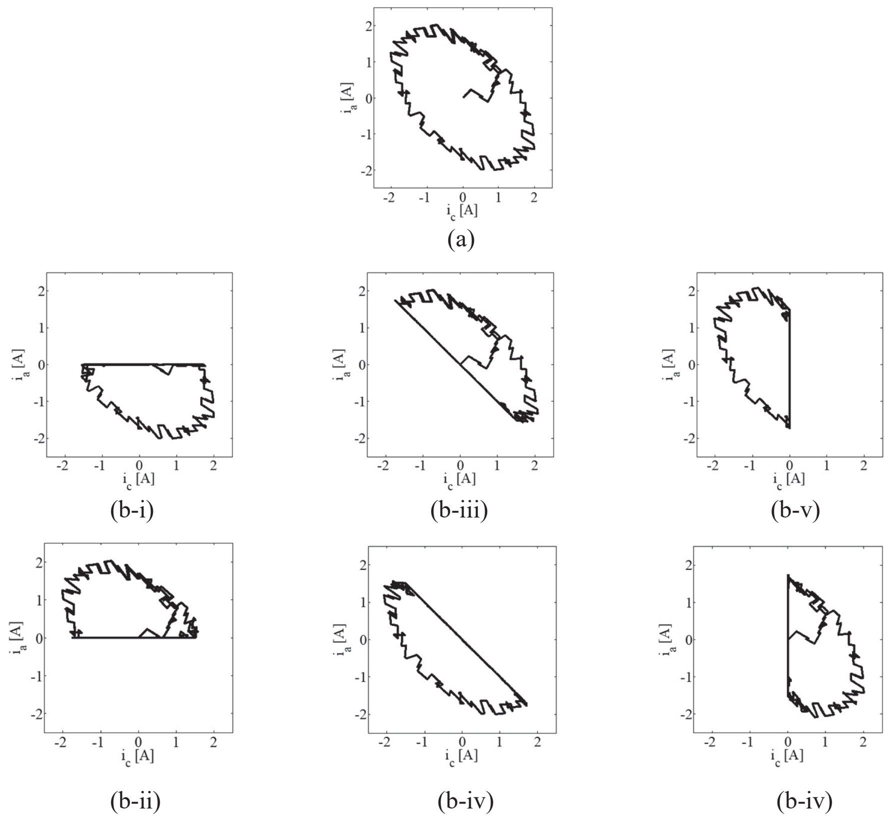
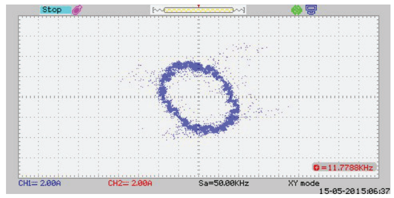
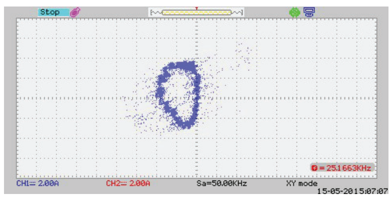


Figure 11 Simulation of current trajectory of i_c vs i_a: (a) all switches under normal condition (b) fault condition in switches (i) T_1 (ii) T_2 (iii) T_3 (iv) T_4 (v) T_5 (vi) T_6.

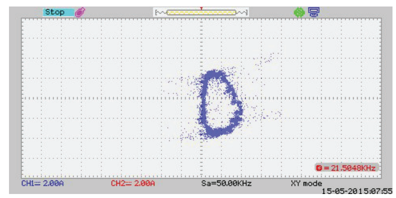
and based on the current trajectory pattern, the faulty power switch can be identified. However, the trajectories under faulty conditions are dependent on the choice of phase current selected for the plot. For instance, the trajectory with switch T_1 fault is different in i_a vs i_b, i_b vs i_c and i_c vs i_a plots as shown in Figures 9(b–i), 10(b–i), and 11(b–i). In order to make this method independent of the phase current selected to plot the current trajectory, a generalization between the various current trajectories and the power switches has to be established. Hence, a generalized FDD based on current trajectory is proposed.



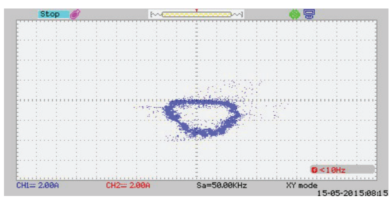
(a)



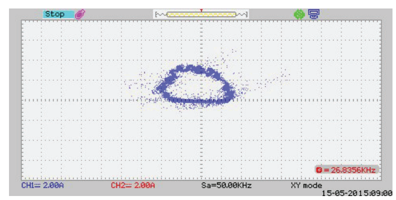
(b-i)



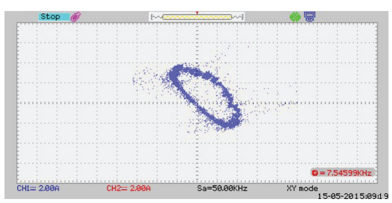
(b-ii)



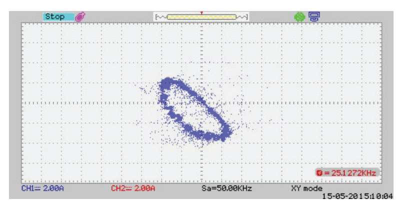
(b-iii)



(b-iv)



(b-v)



(b-vi)

Figure 12 Experimental results of current trajectory of i_a vs i_b: (a) all switches under normal condition (b) fault condition in switches (i) T_1 (ii) T_2 (iii) T_3 (iv) T_4 (v) T_5 (vi) T_6.

5 Generalized FDD Based on Current Trajectory

A generalized approach to correlate the current trajectory obtained and power switch under faulty condition is developed based on the trajectory of i_a vs i_b illustrated in Figure 12(b–i) to (b–vi), as the reference. For a generalized approach three variables x, y and z are assumed. The relationship between

Table 2 Fault inference with generalized current trajectory method

Current Trajectory	Fault Inference
i_x vs i_y plot matches with Figure 12(a)	No-fault condition
i_x vs i_y plot matches with Figure 12(b–i)	upper-leg switch in the phase represented by '*x*'
i_x vs i_y plot matches with Figure 12(b–ii)	lower-leg switch in the phase represented by '*x*'
i_x vs i_y plot matches with Figure 12(b–iii)	upper-leg switch in the phase represented by 'y'
i_x vs i_y plot matches with Figure 12(b–iv)	lower-leg switch in the phase represented by 'y'
i_x vs i_y plot matches with Figure 12(b–v)	upper-leg switch in the phase represented by 'z'
i_x vs i_y plot matches with Figure 12(b–vi)	lower-leg switch in the phase represented by 'z'

these variables are as given below,

$$\begin{array}{c} If\ x = a;\ then\ y = b\ and\ z = c \\ or \\ If\ x = b;\ then\ y = c\ and\ z = a \\ or \\ If\ x = c;\ then\ y = a\ and\ z = b \end{array} \tag{1}$$

The generalization is summarized in Table 2. This approach clearly identifies the faulty switch based on the current trajectory and the knowledge of the phase current selected to plot the trajectory.

If the i_x vs i_y plot gives a current trajectory as shown Figure 12(b–i), then the fault has occurred in the upper-leg switch in the phase represented by '*x*'. If the i_x vs i_y plot gives a current trajectory as shown Figure 12(b–ii), then the fault has occurred in the lower-leg switch in the phase represented by '*x*'. A similar approach is applicable to all other switches as well.

5.1 Valuation of Generalized Current Trajectory Method

The generalized FDD method has certain advantages compared to existing methods. This method requires only 'two' phase currents for the current trajectory compared to other methods using three currents; thereby reducing the number of current sensors and signal conditioning requirements. Also, there is no need of transformation of the currents to any domain or frames.

Table 3 Comparison of proposed generalized method with existing methods

FDD Methods	Need of Transformation	Number of Current Sensing Required
Based on Concordia transformation [13, 14]	Park's transformation	Three-phase currents
Based on stator current space phasors [15]	Stator current space phasor with respect to stator reference frame	Three-phase currents
3D current trajectory [16, 17]	Not required	Three-phase currents
Current trajectory based on phase currents [18]	Not required	'Any two' phase currents; method **dependant** on the phase currents selected for the plot
Proposed generalized method	Not required	'Any two' phase currents; method **independent** on the phase currents selected for the plot

The comparison of the proposed method with existing methods is indicated in Table 3. However, it is found that the current trajectory method is only effective in a heuristic level of fault diagnosis, because the realization of this method requires additional technique such as image processing or pattern recognition or contour detection algorithms with data acquisition systems.

6 Conclusion

The gate open-circuit fault diagnosis based on the current trajectory is analysed in this manuscript, with the aim of improving the continuous and reliable operation of three-phase two-level VSIs. Based on the analysis of the various current trajectories plotted between the inverter output phase currents. A generalized current trajectory-based fault diagnostic scheme in three-phase two-level VSI is proposed. This scheme requires only 'two' of the phase currents to be sensed for the fault detection, without any transformation to other frames or domains. It can be inferred that this method is very effective in a heuristic level of fault detection and diagnosis in three-phase two-level VSIs. Moreover, as a future scope, the real-time or the online fault detection and diagnosis can be developed, by plotting the current trajectories in a digital platform using data acquisition system, and the realising the proposed method with the aid of image processing techniques. Further, the online method shall be extended towards the implementation of the fault tolerant operations in three-phase level VSIs.

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References

[1] Atinkut Bayu, Degarege Anteneh, Baseem Khan, 'Grid Integration of Hybrid Energy System for Distribution Network', Distributed Generation & Alternative Energy Journal, Vol. 37, Iss. 3, pp. 537–556, 2022. DOI: 10.13052/10.13052/dgaej2156-3306.3738

[2] Sanjeev K. Nayak, D.N. Gaonkar, 'Performance Study of Distributed Generation System in Grid Connected/Isolated Modes', Distributed Generation & Alternative Energy Journal, Vol. 29, No. 1, pp. 61–80, 2014. https://www.journal.riverpublishers.com/index.php/DGAEJ/article/view/1159

[3] P. K. Chamarthi, M. S. El Moursi, V. Khadkikar, K. H. A. Hosani and T. H. M. El-Fouly, "Novel Step-Up Transformerless Inverter Topology for 1-Φ Grid-Connected Photovoltaic System," in IEEE Transactions on Industry Applications, vol. 57, no. 3, pp. 2801–2815, May–June 2021. DOI: 10.1109/TIA.2021.3066141

[4] M. M. Amin and O. A. Mohammed, "Development of High-Performance Grid-Connected Wind Energy Conversion System for Optimum Utilization of Variable Speed Wind Turbines," in IEEE Transactions on Sustainable Energy, vol. 2, no. 3, pp. 235–245, July 2011. DOI: 10.1109/TSTE.2011.2150251

[5] S. Liu, D. Xin, L. Yang, J. Li and L. Wang, "A Hierarchical V2G/G2V Energy Management System for Electric-Drive-Reconstructed Onboard Converter," in IEEE Access, vol. 8, pp. 198201–198213, 2020. DOI: 10.1109/ACCESS.2020.3034968

[6] R. K. Varma and M. Akbari, "Simultaneous Fast Frequency Control and Power Oscillation Damping by Utilizing PV Solar System as PV-STATCOM," in IEEE Transactions on Sustainable Energy, vol. 11, no. 1, pp. 415–425, Jan. 2020. DOI: 10.1109/TSTE.2019.2892943

[7] D. R. Farrakhov, F. R. Ismagilov, V. Y. Vavilov, I. I. Urazbakhtin, I. A. Kunsbaev and E. Rubtsov, "Development of a control system for a linear electric drive based on a two-level inverter," 2021 International

Conference on Electrotechnical Complexes and Systems (ICOECS), 2021. DOI: 10.1109/ICOECS52783.2021.9657216

[8] S. Yang, D. Xiang, A. Bryant, P. Mawby, L. Ran and P. Tavner, "Condition Monitoring for Device Reliability in Power Electronic Converters: A Review," in IEEE Transactions on Power Electronics, vol. 25, no. 11, pp. 2734–2752, Nov. 2010. DOI: 10.1109/TPEL.2010.2049377

[9] N. B. Y. Gorla, S. Kolluri, M. Chai and S. K. Panda, "A Novel Open-Circuit Fault Detection and Localization Scheme for Cascaded H-Bridge Stage of a Three-Stage Solid-State Transformer," in IEEE Transactions on Power Electronics, vol. 36, no. 8, pp. 8713–8729, Aug. 2021. DOI: 10.1109/TPEL.2019.2918148

[10] Raj, N., Kale, T., Anand, A., G, J., & George, S., "Switch fault detection and diagnosis in space vector modulated cascaded H-bridge multilevel inverter", in International Journal of Electronics, vol. 105, no. 12, pp. 1977–1992, 2018. DOI: 10.1080/00207217.2018.1494327

[11] K. Debebe, V. Rajagopalan and T. S. Sankar, "Expert systems for fault diagnosis of VSI fed AC drives," Conference Record of the 1991 IEEE Industry Applications Society Annual Meeting, Dearborn, MI, USA, pp. 368–373, 1991. DOI: 10.1109/IAS.1991.178181

[12] R. Peuget, S. Courtine and J. P. Rognon, "Fault detection and isolation on a PWM inverter by knowledge-based model," in IEEE Transactions on Industry Applications, vol. 34, no. 6, pp. 1318–1326, Nov/Dec 1998. DOI: 10.1109/28.739017

[13] R. Peuget, S. Courtine and J. P. Rognon, "Fault detection and isolation on a PWM inverter by knowledge-based model," in IEEE Transactions on Industry Applications, vol. 34, no. 6, pp. 1318–1326, Nov/Dec 1998. DOI: 10.1109/28.739017

[14] P. Gilreath and B. N. Singh, "A New Centroid Based Fault Detection Method for 3-Phase Inverter-Fed Induction Motors," 2005 IEEE 36th Power Electronics Specialists Conference, Recife, pp. 2664–2669, 2005. DOI: 10.1109/PESC.2005.1582009

[15] C. Kral and K. Kafka, "Power electronics monitoring for a controlled voltage source inverter drive with induction machines," 2000 IEEE 31st Annual Power Electronics Specialists Conference. Conference Proceedings (Cat. No.00CH37018), Galway, vol. 1, pp. 213–217, 2000. DOI: 10.1109/PESC.2000.878841

[16] V. Fernão Pires, T. G. Amaral and J. F. Martins, "Fault detection and diagnosis of voltage source inverter using the 3D current trajectory mass

center," 2012 IEEE International Conference on Industrial Technology, Athens, pp. 737–742, 2012. DOI: 10.1109/ICIT.2012.6210026

[17] J. F. Martins, V. F. Pires, C. Lima and A. J. Pires, "Fault detection and diagnosis of grid-connected power inverters using PCA and current mean value," IECON 2012 – 38th Annual Conference on IEEE Industrial Electronics Society, Montreal, QC, pp. 5185–5190, 2012. DOI: 10.1109/IECON.2012.6388972

[18] Nithin Raj, Jose Mathew, G. Jagadanand, Saly George, "Open-transistor Fault Detection and Diagnosis Based on Current Trajectory in a Two-level Voltage Source Inverter", Elsevier Procedia Technology, Vol. 25, pp. 669–675, 2016. DOI: 10.1016/j.protcy.2016.08.159

[19] A. M. S. Mendes and A. J. Marques Cardoso, "Voltage source inverter fault diagnosis in variable speed AC drives, by the average current Park's vector approach," Electric Machines and Drives, 1999. International Conference IEMD '99, Seattle, WA, pp. 704–706, 1999. DOI: 10.1109/IEMDC.1999.769220

[20] K. Rothenhagen and F. W. Fuchs, "Performance of diagnosis methods for IGBT open circuit faults in voltage source active rectifiers," 2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No.04CH37551), vol. 6, pp. 4348–4354, 2004. DOI: 10.1109/PESC.2004.1354769

[21] J. O. Estima and A. J. Marques Cardoso, "A New Algorithm for Real-Time Multiple Open-Circuit Fault Diagnosis in Voltage-Fed PWM Motor Drives by the Reference Current Errors," in IEEE Transactions on Industrial Electronics, vol. 60, no. 8, pp. 3496–3505, Aug. 2013. DOI: 10.1109/TIE.2012.2188877

[22] M. Trabelsi, M. Boussak, and M.Gossa, "PWM-Switching pattern-based diagnosis scheme for single and multiple open-switch damages in VSI-fed induction motor drives," In ISA Transactions, vol. 51, no. 2, pp. 333–344, Mar. 2012. DOI: 10.1016/j.isatra.2011.10.012

[23] O. S. Yu, N. J. Park and D. S. Hyun, "A Novel Fault Detection Scheme for Voltage Fed PWM Inverter," IECON 2006 – 32nd Annual Conference on IEEE Industrial Electronics, Paris, pp. 2654–2659, 2006. DOI: 10.1109/IECON.2006.347541

[24] B. M. Gonzalez-Contreras, J. L. Rullan-Lara, L. G. Vela-Valdes and A. S. Claudio, "Modelling, Simulation and Fault Diagnosis of the Three-Phase Inverter Using Bond Graph," 2007 IEEE International Symposium on Industrial Electronics, Vigo, pp. 130–135, 2007. DOI: 10.1109/ISIE.2007.4374586

[25] D. Luo and S. M. Seong, “EKF-based fault detection and isolation for PMSM driver inverter,” 2014 14th International Conference on Control, Automation and Systems (ICCAS 2014), Seoul, pp. 1152–1157, 2014. DOI: 10.1109/ICCAS.2014.6987733

[26] D. R. Espinoza-Trejo, D. U. Campos-Delgado, E. Barcenas and F. J. Martinez-Lopez, “Robust fault diagnosis scheme for open-circuit faults in voltage source inverters feeding induction motors by using non-linear proportional-integral observers,” in IET Power Electronics, vol. 5, no. 7, pp. 1204–1216, August 2012. DOI: 10.10z49/iet-pel.2011.0309

[27] M. A. Awadallah and M. M. Morcos, “Diagnosis of switch open-circuit fault in PM brushless DC motor drives,” Large Engineering Systems Conference on Power Engineering, 2003, 2003, pp. 69–73. DOI: 10.110 9/LESCPE.2003.1204682

[28] F. Charfi, F. Sellami and K. Al-Haddad, “Fault Diagnostic in Power System Using Wavelet Transforms and Neural Networks,” 2006 IEEE International Symposium on Industrial Electronics, Montreal, Que., 2006, pp. 1143–1148. DOI: 10.1109/ISIE.2006.295798

[29] M. R. Mamat, M. Rizon and M.S. Khanniche, “Fault Detection of 3-Phase VSI using Wavelet-Fuzzy Algorithm,” American Journal of Applied Sciences, vol. 3, no. 1, pp. 1642–1648, 2006. DOI: 10.3844/ajassp.2006.1642.1648

[30] Li, Kd., Chen, Cy., Chen, Tf. et al. A new approach for on-line open-circuit fault diagnosis of inverters based on current trajectory. J. Cent. South Univ. 26, pp. 743–758, 2019. DOI: 10.1007/s11771-019-4044-4

[31] M. Tousizadeh, H. S. Che and N. Abd Rahim, “Current Trajectory-Based Fault Detection and Fault Tolerant Control for Three-phase Induction Drives,” 2021 22nd IEEE International Conference on Industrial Technology (ICIT), pp. 1341–1347, 2021. DOI: 10.1109/ICIT4657 3.2021.9453527

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