ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2009 (841-851)
VOLUME : 9
NUMBER : 1

OPEN SWITCH FAULTS DETECTION AND LOCALIZATION ALGORITHM FOR THREE PHASE SHUNT ACTIVE POWER FILTER BASED ON TWO LEVEL VOLTAGE SOURCE INVERTER IN MAIN POWER SUPPLY CONSTANT AND VARIABLE FREQUENCY CONDITIONS

Tarak BENSLIMANE[1] **Thameur ABDELKRIM**[2]

[1]University of Boumerdes, Algeria
[2]Renewable Energies Applied Research Unit, Ghardaïa, Algeria
bens082002@yahoo.fr, tameur2@yahoo.fr

Abstract

This paper proposes an open switch faults detection and localization algorithm for shunt three phase active filter topology. It mainly details converter configuration and examines a simple and reliable optimised fault diagnosis method. The converter topology is based on classical three-leg active power filter topology. A new fault diagnosis method is proposed, based on classical currents measurements. It includes combinatory logic to analyse and validate error signals. A Hysteresis Control is applied before and after fault detection, which avoids any controller reconfiguration. Simulation results obtained with Matlab/Simulink/Plecs tools prove the effectiveness of this method.

Keywords: *Active power filter, fault detection, two level there phase voltage source inverter, current mean value, zero harmonic component.*

1. INTRODUCTION

The reliability of power electronic equipments becomes extremely important in general in industrial applications. The fault mode behaviour of static converters, protection and fault tolerant control of voltage source inverter systems has been covered in a large number of papers. Most of them are focused on induction motor drive applications.

Received Date: 12.12.2007
Accepted Date: 05.01.2009

D. Kastha and B. K. Bose considered various fault modes of a voltage source PWM inverter system for induction motor drive [1]. They have studied rectifier diode short circuit, inverter transistor base driver open and inverter transistor short-circuit conditions. However, they do not propose to reconfigure the inverter topology.
C. Thybo was interested in fault tolerant control of induction motor drive applications using analytical redundancy, providing solutions to most frequent occurring faults [2].

E. R. C. Da Silva and al investigated fault detection of open-switch damage in voltage source PWM motor drive systems [3]. They mainly focused on detection and identification of the power switch in which the fault has occurred. In another paper, they investigated the utilization of a two-leg based topology when one of the inverter legs is lost. Then the machine operates with only two stator windings [4]. They proposed to modify PWM control to allow continuous free operation of the drive.

More recently, E. R. C. Da Silva and al have studied fault tolerant active power filter system [5], [6]. They proposed to reconfigure power converter and PWM control and examined a fault identification algorithm.

This present paper deals with open switch faults detection and localization in shunt active three-phase filter based on two level voltage source inverter controlled by current Hysteresis controllers. The proposed method is simple and reliable. It needs no more than active filter current sensors and display interface indicating the open faulty power switch.

First, an inverter based on standard three-phase power structure is presented. Fault diagnosis is detailed. Then, shunt active filter hysteresis control is presented for three-leg structures. Finally, simulation results illustrating fault diagnosis and localization developed in the present paper are presented.

2. SYSTEM DESCRIPTION

Figure 1 presents a classical three-leg shunt active power system. It is composed of a grid (e_{si} for i = {1, 2, 3}), a non-linear load, a voltage source converter. The load is a three phase balanced inductance Ls with three phase thyristor (or diode) rectifier feeding a series (R, L) DC load. The grid is supposed to be balanced with the same series resistance R_{cc} and inductance L_{cc} for each phase. The static converter is a voltage source inverter with the same series inductance L_f for each phase.

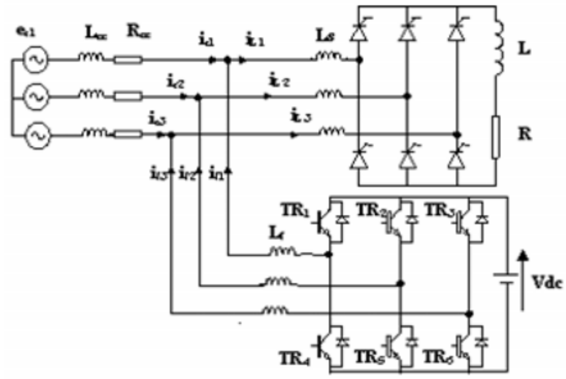


Fig.1 Classical three-leg shunt active filter topology.

The output currents of the shunt active filter are controlled by Hysteresis controllers to provide reactive power and harmonic currents generated by the non-linear load to ensure filtering.
Several faulty cases can occur: power switch or power switch driver can be faulty. In each case, it results in the following models:
- A switch is closed instead of being normally open. It results in a short-circuit of the DC voltage source, increasing DC current of the inverter. To isolate the faulty switch as fast as possible, one can use fuses.
- A switch is open instead of being normally closed. It results in an open phase. The filter may continue injecting currents to the power supply. These currents don't cause any prompt risk because they are at the same range level as the case of no-fault condition.

However, the filter in this case is polluting more the power supply instead of elimination of harmonic currents of non-linear load. This case is considered in this paper.

3. ACTIVE FILTER CONTROL

Figure 2 presents a block diagram of the proposed control system. The major advantage of this control principle is its simplicity and easiness to be implemented. The task of this control is to determine the current harmonic references to be generated by the active filter.
They are defined using classical active and reactive power method proposed by Akagi [7].

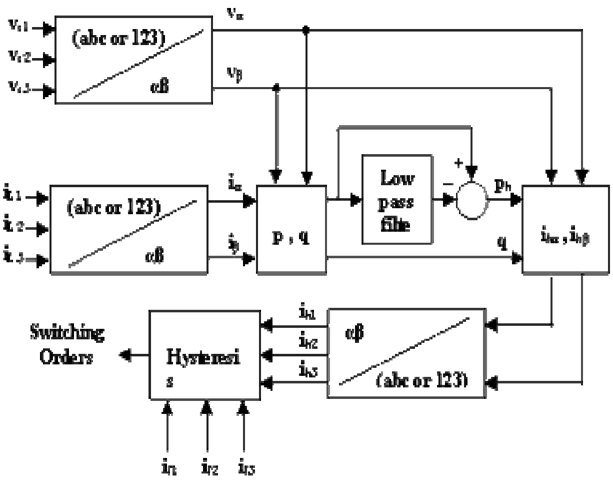


Fig. 2 Block diagram of the control system.

By supposing that the main power supply voltages are sinusoidal, current harmonic references will be calculated like indicated in [8].
(α, β) voltage components at connexion point of active filter (v_α, v_β) and currents (i_α, i_β) are defined by the classical Concordia transformation:

$$\begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} vs1 \\ vs2 \\ vs3 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} iL1 \\ iL2 \\ iL3 \end{bmatrix} \quad (2)$$

The instantaneous real and imaginary powers, noted by p and q, are calculated by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (3)$$

These powers are then filtered by high-pass filters, which gives ph and qh and the harmonic components of the currents will be:

$$\begin{bmatrix} ih1 \\ ih2 \\ ih3 \end{bmatrix} = \sqrt{3/2} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} ph \\ qh \end{bmatrix} \quad (4)$$

4. FAULT DIAGNOSIS METHOD

This section presents simulation results obtained with Matlab simulator for the proposed fault detection algorithm.
General simulation parameters are given in the appendix. These parameters are chosen to reduce THD of main source currents below 5%.
Fault detection is based on the calculation of zero harmonic component (mean value, dc offset) included in the active filter currents. A change in active filter current waveform is

defined as the instant at which a sudden increase or decrease is observed in the DC offset component of the current. A change is considered to have occurred in the active filter current DC offset component of the current exceeds or falls below a given band (figure 3, figure 4, figure 5 and figure 6).

If the open circuit faulty transistor is one of the upper transistors of the inverter based active filter, the current of the phase linked to that leg will have a negative DC component and the two other phases currents will have a positive ones (figure 4, figure 6).

If the open circuit faulty transistor is one of the lower transistors of the inverter, the current of the phase linked to that leg will have a positive DC component and the two other phases currents will have a negative ones (figure 5).

The open switch fault detection algorithm is developed to identify the faulty device as classified in Table 1.

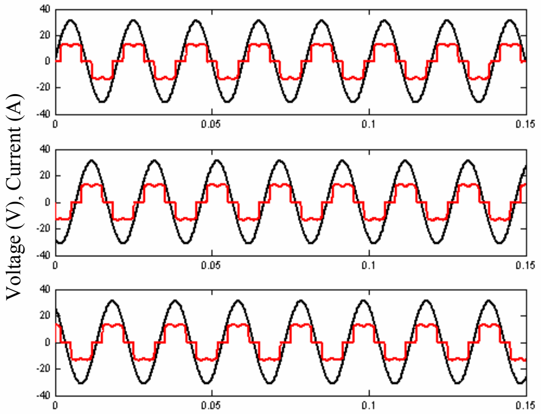
Table 1 DC current Offset polarity corresponding to faulty open circuit transistor

Faulty Device	DC Current Offset Polarity		
	Phase1	Phase2	Phase3
TR_1	negative	positive	positive
TR_2	positive	negative	positive
TR_3	positive	positive	negative
TR_4	positive	negative	negative
TR_5	negative	positive	negative
TR_6	negative	negative	positive

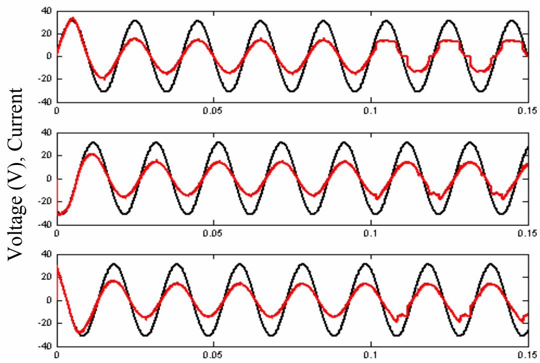
4.1. Constant known frequency of power supply voltage

Mean value calculator computes the mean value of input signal (filter current) over running window of one cycle of the specified lowest harmonic component. Even if the filter current contains a small fundamental component as the lowest harmonic component, its frequency will define the filter currents mean value calculating window. In this case of constant grid frequency, 50 Hz was considered.

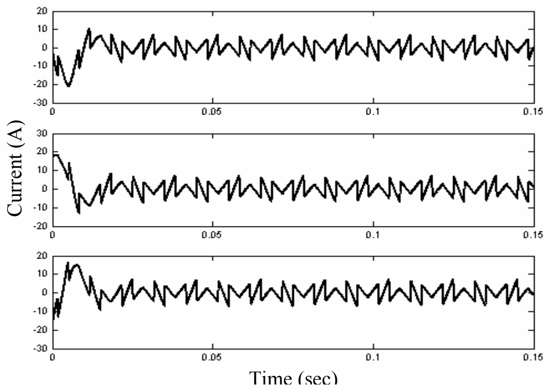
For the first cycle of simulation, the output is held constant to the value specified by the parameter initial input (DC Component = 0 A).



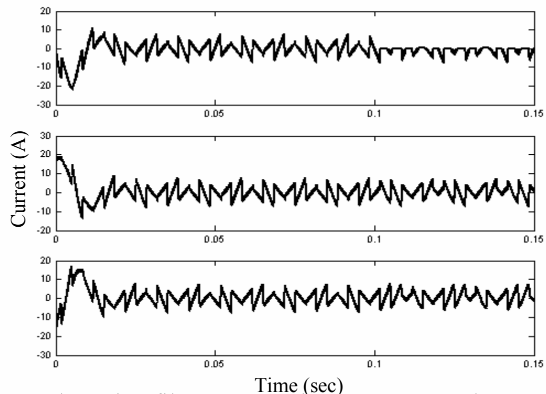
a. Main phases voltage instantaneous values / 10, Rectifier phases currents instantaneous values



b. Main phases voltage instantaneous values / 10, main source phases currents instantaneous values before and after TR1 open fault condition

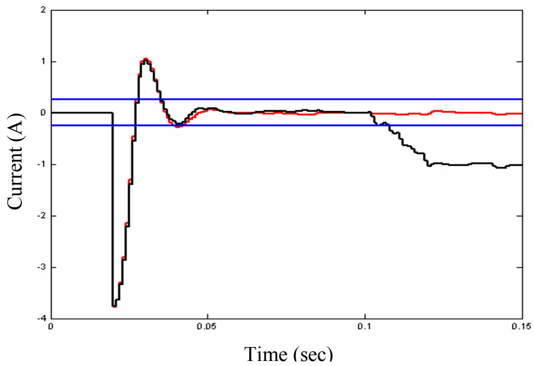


c. Harmonic identified currents instantaneous values

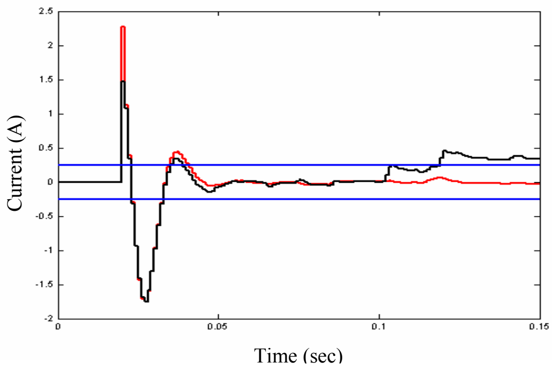


d. Active filter currents instantaneous values before and after TR1 open fault condition From the top to the Bottom if1, if2, if3

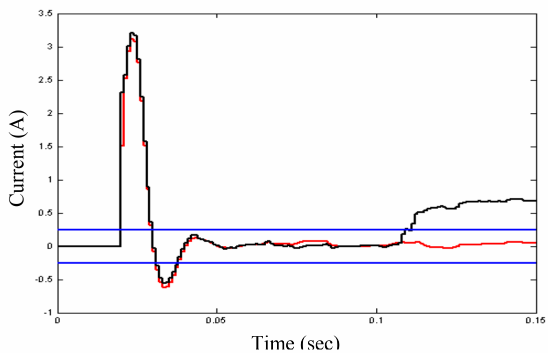
Fig. 3 Simulation results of active power filtering before and after TR1 open fault condition (instantaneous main source phase voltages and currents, non linear load currents and active filter currents with their references).



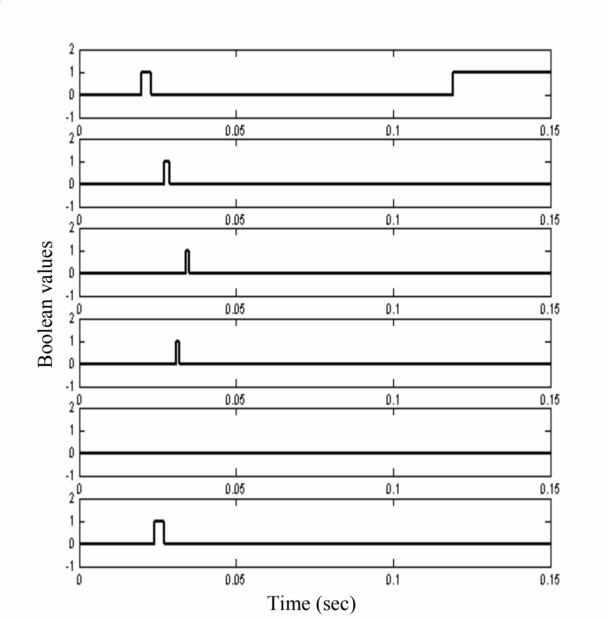
a. Phase 1 Active filter current with its reference mean values if1refmean (red), if1mean (black) with DC band +/- 0.25A (blue) before and after TR1 open fault condition



b. Phase 2 Active filter current with its reference mean values if2refmean (red), if2mean (black) with DC band +/- 0.25A (blue) before and after TR1 open fault condition

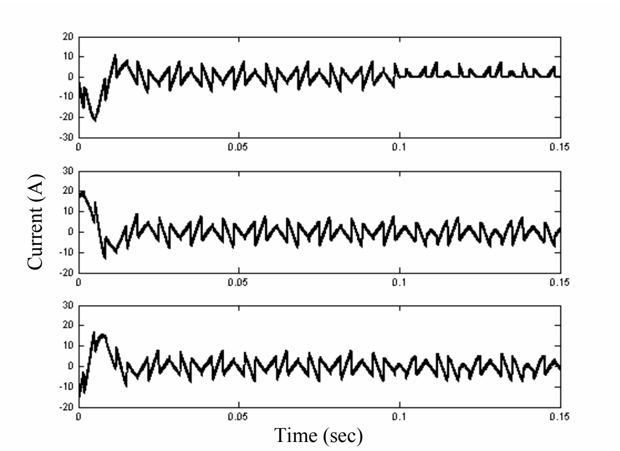


c. Phase 3 Active filter current with its reference mean values if3refmean (red), if3mean (black) with DC band +/- 0.25A (blue) before and after TR1 open fault condition

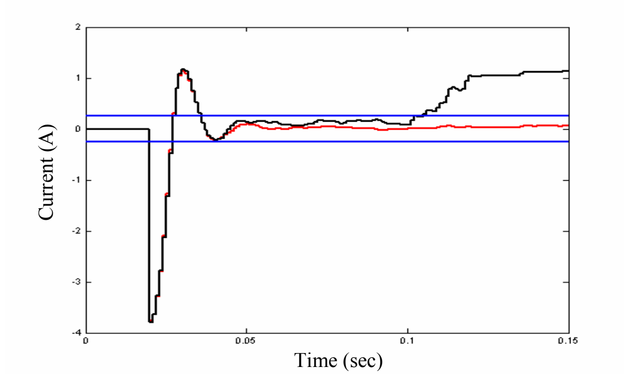


d. Boolean Outputs of Open switch fault detection algorithm before and after TR1 open switch fault From the top to the bottom TR1, TR2, TR3, TR4, TR5, TR6

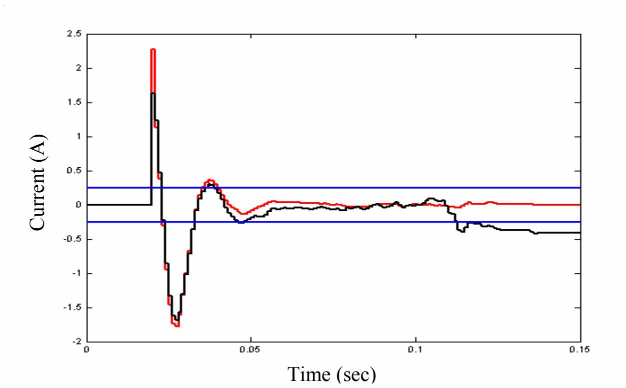
Fig. 4 Simulation results of open switch fault identification system before and after TR1 open fault condition (active filter currents mean values with their references mean values, Boolean outputs of diagnostic system).



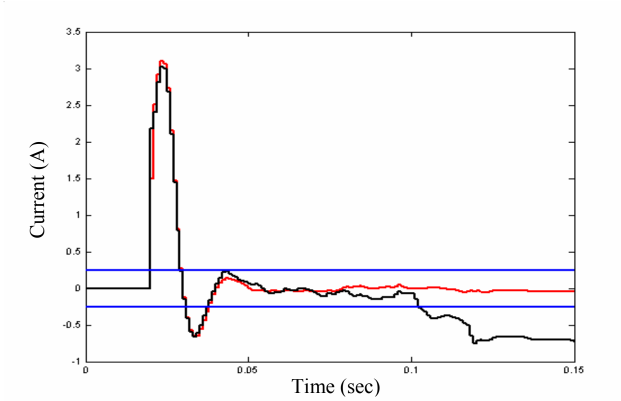
a. Active filter currents instantaneous values From the top to the Bottom if1, if2, if3



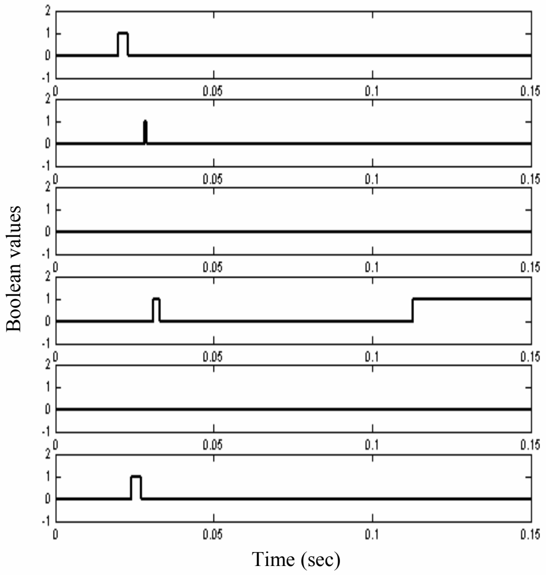
b. Phase 1 Active filter current with its reference mean values if1refmean (red), if1mean (black) with DC band +/- 0.25A (blue)



c. Phase 2 Active filter current with its reference mean values if2refmean (red), if2mean (black) with DC band +/- 0.25A (blue)

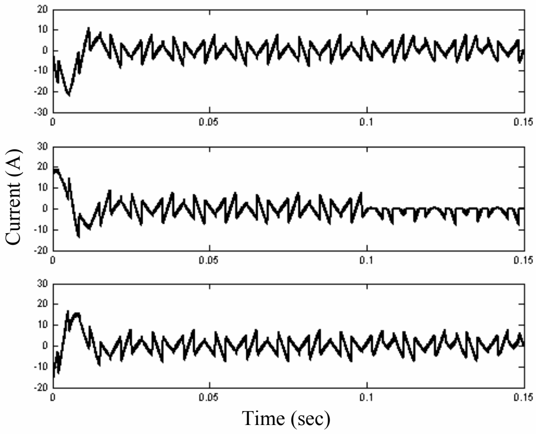


d. Phase 3 Active filter current with its reference mean values if3refmean (red), if3mean (black) with DC band +/- 0.25A (blue)

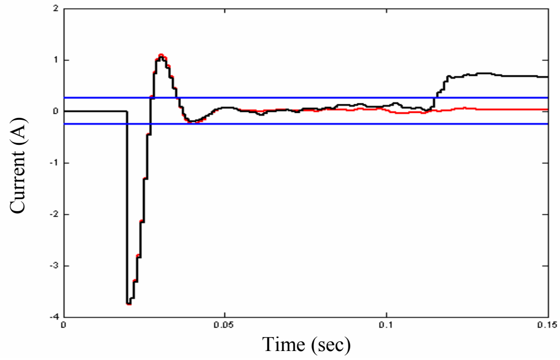


e. Boolean Outputs of Open switch fault detection algorithm before and after TR4 open switch fault From the top to the bottom TR1, TR2, TR3, TR4, TR5, TR6

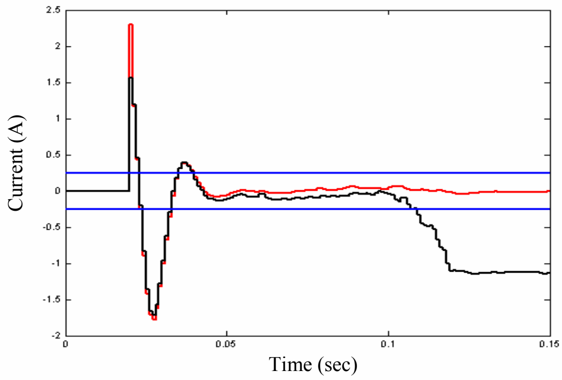
Fig. 5 Simulation results of open switch fault identification system before and after TR4 open fault condition (active filter currents with their mean values and their references mean values, Boolean outputs of diagnostic system).



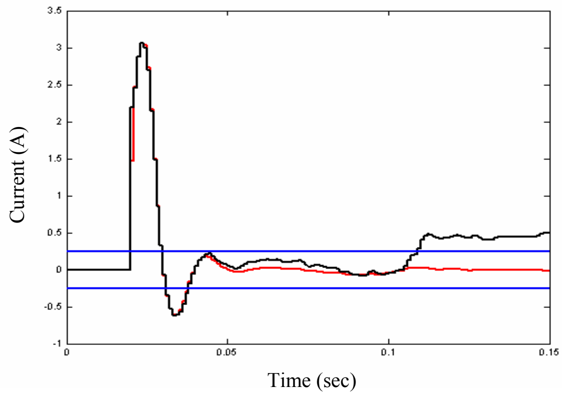
a. Active filter currents instantaneous values From the top to the Bottom if1, if2, if3



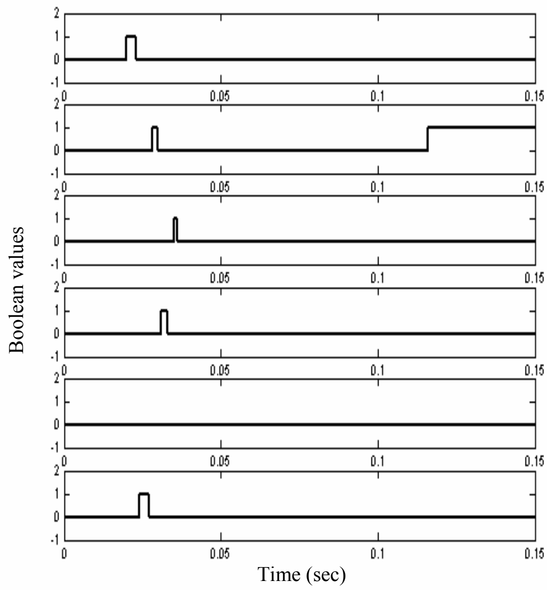
b. Phase 1 Active filter current with its reference mean values if1refmean (red), if1mean (black) with DC band +/- 0.25A (blue)



c. Phase 2 Active filter current with its reference mean values if2refmean (red), if2mean (black) with DC band +/- 0.25A (blue)



d. Phase 3 Active filter current with its reference mean values if3refmean (red), if3mean (black) with DC band +/- 0.25A (blue)



e. Boolean Outputs of Open switch fault detection algorithm before and after TR2 open switch fault From the top to the bottom TR1, TR2, TR3, TR4, TR5, TR6

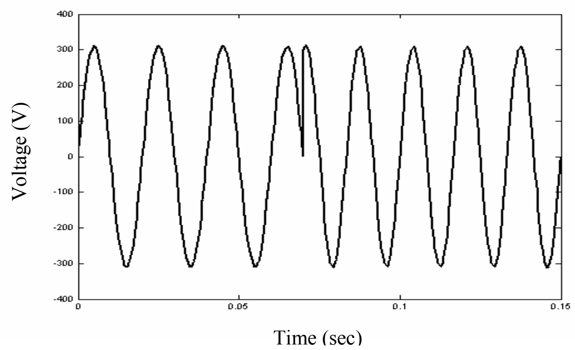
Fig. 6 Simulation results of open switch fault identification system before and after TR2 open fault condition (active filter currents with their mean values and their references mean values, Boolean outputs of diagnostic system).

4.2. Variable frequency of power supply voltage (TR1 open fault condition)

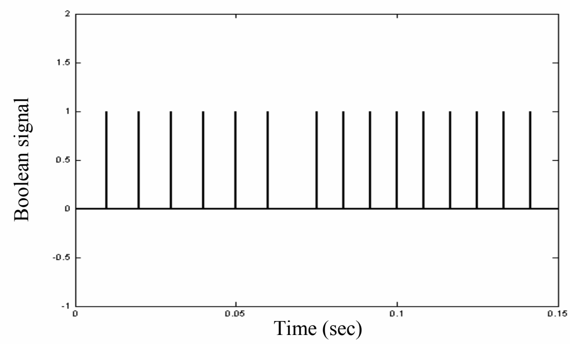
Mean value calculator computes the mean value of input signal (filter current) over running window of one cycle of the specified lowest harmonic component. Even if the filter current contains a small fundamental component as the lowest harmonic component, its frequency will define the filter currents mean value calculating window. In case of a power grid of variable frequency, it must be measured.

Power supply voltage frequency measurement

Frequency of power supply voltage was realised basing on voltage zero crossing detection. Time between to successive zero crossing signals constitutes a half cycle (period) of power supply voltage. This former frequency will be deduced by doubling this time and getting its inverse (1/T) value. Figure 7 shows the first phase of main power supply with two different frequencies (50 Hz before t = 0.07 seconds and 60 Hz after that).

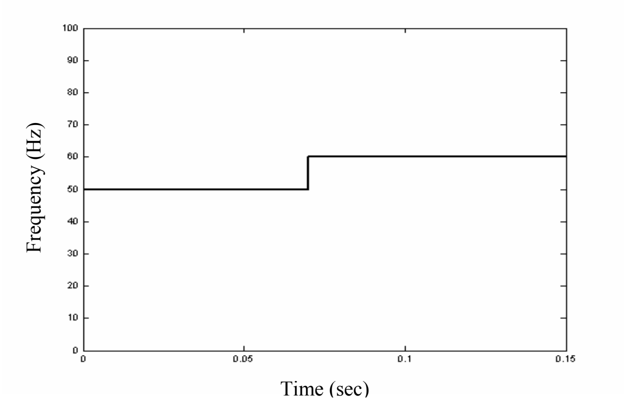


a. Main first phase voltage instantaneous values

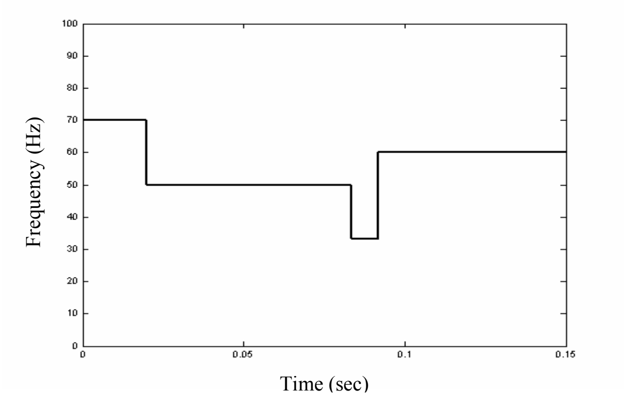


b. Main first phase voltage zero crossing signals

Fig. 7 Main first phase voltage instantaneous values with its zero crossing signals (active filter currents mean values with their references mean values, Boolean outputs of diagnostic system).

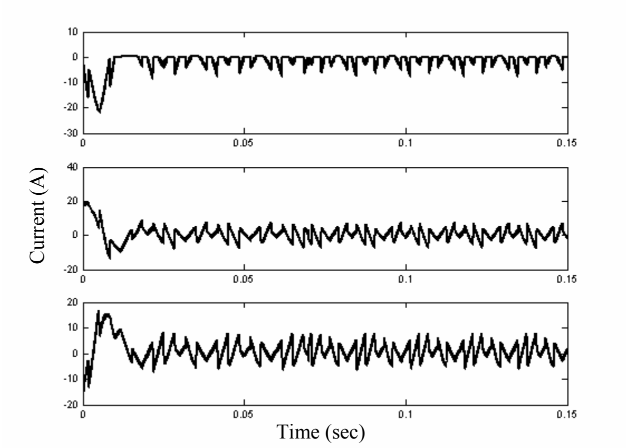


a. Main first phase voltage real frequency

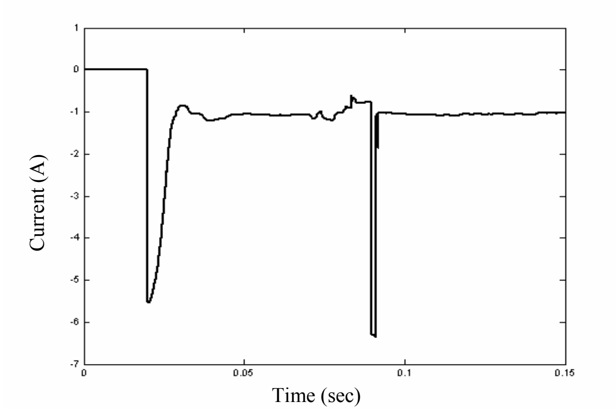


b. Main first phase voltage measured frequency

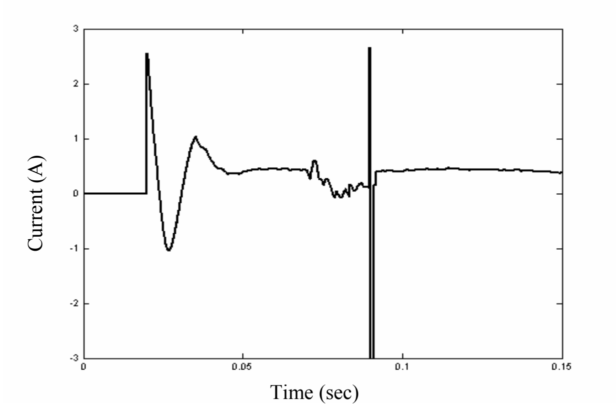
Fig. 8 Main first phase voltage real frequency and measured frequency.



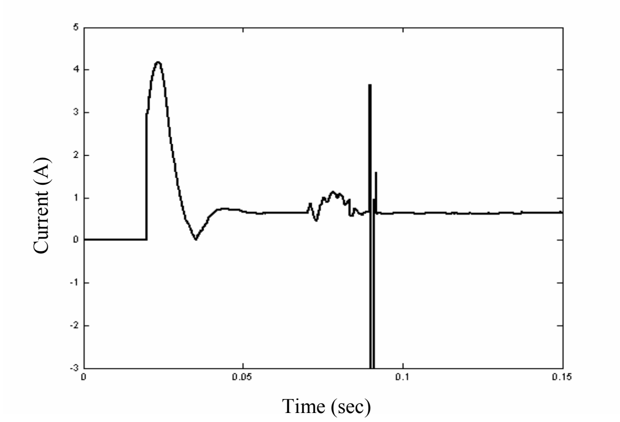
a. Active filter currents instantaneous values From the top to the Bottom if1, if2, if3



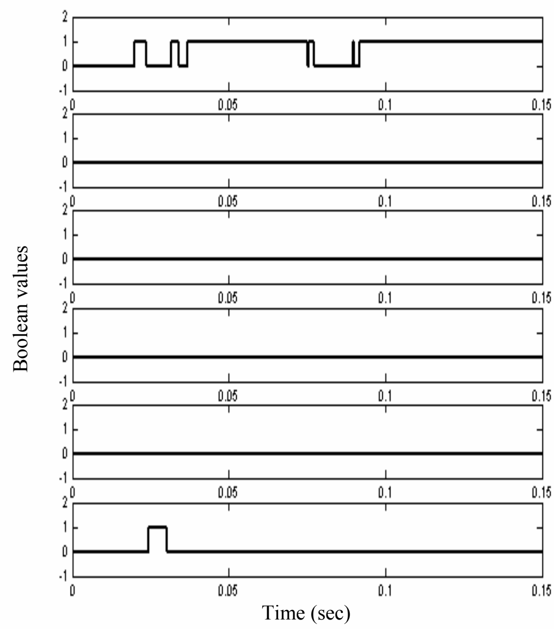
b. Phase 1 Active filter current mean value



c. Phase 2 Active filter current mean value



d. Phase 3 Active filter current mean value



e. Boolean Outputs of Open switch fault detection algorithm with TR1 open switch fault and main power supply frequency variation
From the top to the bottom TR1, TR2, TR3, TR4, TR5, TR6

Fig. 9 Simulation results of open switch fault identification system with TR1 open fault condition and main power supply frequency variation (active filter currents with their mean values, Boolean outputs of diagnostic system).

Figure 3, figure 4, figure 5 and figure 6 present results in an open switch fault cases (fault of respectively TR1, TR4 and TR2), introduced at t = 0.1 s. In this case, power main supply was supposed known and invariable or at least lightly variable around 50 Hz.

Figure 7, figure 8 and figure 9 present results in an open switch fault case (fault of TR1), introduced at t = 0.07 s. In this case, power main supply was supposed unknown and variable (50 Hz, 60 Hz). In this case, main power supply frequency was calculated basing on main power voltage zero crossing detection method. The calculated frequency was quietly superposed on its reference after a half cycle transient time.

Even the delay time due to the transfer from safe operating steady state to fault operating steady state of active filter and the delay time of main power frequency calculation as well as time of active filter currents mean values calculation; these results show that the proposed fault detection algorithm is reliable and efficient not only in open switch fault detection but also in localising the faulty switch even in main power supply variable frequency condition.

5. CONCLUSION

In this paper, it is presented a simple, reliable and efficient open switch faults detection and localization in shunt active three-phase filter based on two level voltage source inverter controlled by current Hysteresis controllers.

The semi conductor open fault detection method is robust to semi conductors switching and includes combinatory logic to perform reliability.

Simulation results demonstrate that when optimising active filter parameters, the zero harmonic component strategy can be used with robustness to detect and localize the open faulty switch in active filter inverter.

REFERENCES

[1] Kastha, D.; Bose, B.K., 'Investigation of fault modes of voltage-fed inverter system for induction motor drive', IEEE Transactions on Industry Applications, Vol. 30, Issue 4, July-Aug. 1994 pp. 1028 . 1038.

[2] Thybo, C., 'Fault-tolerant control of

induction motor drive applications', American Control Conference, 2001. Proceedings of the 2001, Vol. 4, 25-27 June 2001, pp. 2621 . 2622.

[3] *De Araujo Ribeiro, R.L.; Jacobina, C.B.; da Silva, E.R.C.; Lima, A.M.N.,*'Fault detection of open-switch damage in voltage-fed PWM motor drive systems', IEEE Transactions on Power Electronics, Vol. 18 , Issue: 2 , March 2003, pp. 587 . 593.

[4] Beltrao de Rossiter Correa, M.; Brandao Jacobina, C.; Cabral da Silva, E.R.; Nogueira Lima, A.M., 'An induction motor drive system with improved fault tolerance', IEEE Transactions on Industry Applications, Vol. 37, Issue 3, May-June 2001, pp. 873 . 879.

[5] *Jacobina, C.B.; Correa, M.B.R.; Pinheiro, R.F.; Lima, A.M.N.; da Silva,* 'Improved fault tolerance of active power filter system', *E.R.C.,* Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual, Vol. 3, 17-21 June 2001.

[6] *Jacobina, C.B.; Pinheiro, R.F.; de R. Correa, M.B.; Lima, A.M.N.; da Silva,* 'Control of a three-phase four-wire active filter operating with an open phase', *E.R.C.,* Industry Applications Conference, 2001. Thirty-Sixth IAS Annual Meeting. Conference Record of the 2001 IEEE, Vol.: 1, 30 Sept.-4 Oct. 2001.

[7] *H. Akagi, Y. Kanazawa, A. Nabae*, 'Generalized theory of the instantaneous reactive power filter', Proceeding International power electronics conference. Tokyo, Japan, PP. 1375-1386, 1983.

[8] T. Benslimane, K. Aliouane, 'A new optimized SVPWM Technique Control for Autonomous Parallel Active Filter' 11th International Conference on Harmonics and Quality of Power 2004 NEW YORK , USA, Published in IEEE Xplore, IEEE Transactions on Automatic Control, pp 112-116.

Appendix

Simulation parameters are:

- Main source Grid: 220V, Rcc = 0.0148 Ohm, Lcc = 0.175 mH, 50 Hz.
- Non-linear load: R = 40 Ohm, L = 2 mH, Ls = 0.2 mH.
- Active filter: Vdc = 700 V, Lf = 5 mH, Currents regulators Hysteresis band = +/- 0.5 A.

Biography

BENSLIMANE TARAK received his Eng. Degree in Electrical Engineering in 2001 from University Centre of Bechar in Algeria. He received his Master Degree in Electrical Engineering in 2004 from Military Polytechnic School of Algiers in Algeria. Currently, he is PhD candidate in the University of Boumerdes in Algeria. His research interests are power quality and electrical drives control and diagnostic besides renewable energies.

ABDELKRIM THAMEUR received his Engineer degree in Electromechanics in 2001 from University of Boumerdes in Algeria. He received his Magister Degree in Electrical Engineering in 2004 from Military Polytechnic School of Algiers in Algeria. Currently, he is PhD candidate in the Polytechnic National School, Algeria.

In 2005, he joined the Applied Research Unit on Renewable Energies in Ghardaïa, Algeria. His research interests are power quality, electrical drives control and renewable energies.