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Intermittent open-circuit fault diagnosis of inverters based on DC-link electromagnetic field signal

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ABSTRACT

For the objective of improving the reliability of converters in electric drives, research on a method for early detection of intermittent open-circuit faults of power valves is reported in this article. Intermittent open circuit condition is the incipient form of power valve open-circuit fault in power converters. Prompt detection of this fault allows for timely remediation of permanent open circuit defects that is a commonly subsequent process. This study introduces an investigation of this fault, which occurs in the voltage source inverter of induction motor drives. Intermittent faults are created through interference with the control pulse of the power valve. Wavelet transform with the Mexican hat mother function is utilized for signal processing. Appropriate ranges of the scale are selected to obtain a high magnitude of the wavelet coefficient at faulty instants. The analysis for the direct current recorded at the DC-link in simulation and the electromagnetic signal measured at the DC-bus of the inverter can be effectively used for the fault diagnosis.

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1. INTRODUCTION

Voltage source inverters are commonly used in variable speed electric drives, high voltage direct current power transmission systems, power electronic interface of renewable energy systems, uninterrupted power supply circuits, and energy storage systems [1]. The inverters are controlled to respond robustly to perform operational tasks such as such as speed, torque, and power control. During the operation, the inverter components affect by various factors such as mechanical, thermal, and electrical, leading to aging and possible damage. Failures mostly happen in the control circuit and inverter power components of variable speed alternating current (AC) power drives [2]. Common classification of the faults in the inverter includes open-circuit and short-circuit faults. The short circuit is a serious failure that comes with an increase in current. Therefore, hardware devices, usually operating on the overcurrent principle, are often integrated into the inverter to quickly detect and isolate the faulty part. Furthermore, this fault can be converted to an open circuit condition by the inverter monitoring circuit [3]. Meanwhile, open-circuit faults are often more difficult to detect. Once the fault occurs, the inverter can continue to operate, but its components are exposed to dangerous electrical and thermal effects. It is the motivation that the open-circuit fault have been attracting much attention in both research and industrial applications [4], [5]. Numerous methods have been proposed for the diagnosis of open-circuit fault that can be categorized into current signatures-based techniques and voltage signatures-based approaches [6], [7]. In study [6], Fourier transform and the wavelet-based multiresolution analysis are applied to processing of electric phase currents from a power inverter. Three rotatory reference systems and arithmetic operations are used for identification of open-circuit faults. The multi-switch open circuit defect can be diagnosed based on the deviation of the average value of the normalized current where the performance of the proposed algorithm does not depend on the load level and speed of the motor [8]. Park's vector method of average current is proposed in [9] so as to detect open-circuit and short-circuit faults in voltage source inverters of AC motor drives. The Park's vector of the current is calculated from the average current supplied to the motor. The fault is detected through monitoring the module and phase angle of the current vector. The trajectory of the stator current in the stationary coordinate system is analyzed in [10] to detect and locate the fault of the two-level voltage source converter. Extended works on the basis of Park's vector method are proposed in [11] for the fault diagnosis of an open-transistor fault in voltage source inverters. Modified normalized direct current and the direct component, which is encountered in faulty phases, are used to calculate a diagnostic variable or a direct component of the line currents for detecting the open circuit of insulated-gate bipolar transistor (IGBT) [11]. Another method proposed for fault diagnosis of voltage source inverter is based on the evaluation of the output current value around zero and the ratio of the average phase current to the average amplitude [12]. Also, a normalized detection variable is introduced to detect the open circuit of the IGBT in the inverter of the AC machine drive [13]. The components in the stationary coordinate system are calculated from stator phase currents. Using low-pass filters, phase angle is calculated, thereby determining the sector. A detection variable is then defined and its average value is computed for fault detection. It is shown that the method owns the ability to detect faults of single IGBT, multiple IGBTs as well as phase open-circuit faults. Furthermore, it does not depend much on the system parameters and operating conditions. Technique based on a phase current waveform is proposed in [14]. In fact, the change of the phase current with respect to time is analyzed to extract the fault feature; and a mathematical integration algorithm is applied to develop a fault-diagnosis method. Transistor and sensor failures can be detected and distinguished through analyzing the current trajectory or estimating the instantaneous wake frequency of the current [15]. In study [7], the variational mode decomposition method combined with correlation coefficients and statistical indicators is applied to diagnosis of IGBTs open-circuit faults in a three-phase inverter. The method has shown advantages in processing noisy signals and avoiding the loss of fault information.

Other methods are those extracted the information from the control system or based on the measurement at the DC-link and inside the converter [5], [16]. The methods based on the measurement at the DC-link offer the capability of monitoring the whole system since all information could be extracted from the DC-bus electromagnetic field signal. In addition, the utilization of the Hall sensor with cost-efficient and contactless has been received much attention.

Machine learning techniques and artificial intelligence applications are also current trends in developing methods for diagnosing open-circuit faults in converters. In study [17], from the current vector trajectory, the authors extracted fault identification features based on changes in adjacent trend line slopes. A neural-network-liked structure for open-circuit fault diagnosis is proposed in [18]. A fixed-period integral mean filter is utilized to smooth sampled discrete current-time pairs that are used for normalizing current and eliminating the singular problem to build the diagnosis function. A spectral analysis method of stator current is proposed in [19] to detect and localize an open circuit of IGBT in the inverter. The combination of signal processing with Hilbert-Huang transform, which extracts the fault feature based on the complete empirical ensemble mode decomposition of three-phase stator currents, and artificial intelligence techniques is made. In study [20], the amplitude of three components including the continuous, fundamental and second order harmonics of the stator current signal is used to characterize the IGBT open-circuit fault. In addition, an artificial neural network model is utilized to locate the faulty IGBT. A fault diagnosis for open-circuit faults in a two-level three-phase voltage source inverter is proposed in [21], in which the root mean square and the correlation coefficient of the motor current are computed to provide feature extraction of fault harmonic for the information of faulty phase. A machine learning model is then applied to detect and localize the fault. Xia and Xu [22] propose a transferrable data-driven fault diagnosis for IGBT open-circuit fault diagnosis in three-phase inverters. The parameter of the learning machine model is calibrated through an adaption process. The advantage of the proposed model is that it can be applied for different systems. Recently, the fuzzy logic method is applied in [4] to discover the fault diagnosis variables with the implementation of the average current Park's vector technique to detect the open-circuit fault in a three-phase cascaded multilevel inverter of permanent magnet synchronous drive.

The common feature of most above-mentioned studies is generally for the detection of permanent open-circuit faults. In order to get effectively condition monitoring of the system, it is necessary to detect abrupt in the early stages. In fact, the open circuit problem of the converter may originate from intermittent malfunctions due to the wiring and material aging, unexpected temperature variation or the PWM control signal to the valves is not executed [4], [23].

In this article, an experimental system is introduced to study the intermittent open circuit fault of the inverter in the induction motor drive. PWM control pulses are interfered to create an intermittent open circuit fault. Wavelets are chosen to analyze the output alternating current signal, direct current signal, and especially the electromagnetic field signal measured at the DC-bus of the drive. The analysis results will show that the magnitude of the coefficient in the 3D analysis of the wavelet can be effectively monitored for the detection of the intermittent open-circuit fault in the power inverter.

The remainder of this article is organized as follows. In section 2, selection analysis and a mathematical description of wavelet transform will be introduced. Simulation and experiment of intermittent defect of the power inverter in an induction motor drive is presented in section 3. In this section, wavelet analysis is carried out for the output AC currents, DC-link current signals in simulation and electromagnetic field signals in experiment. Finally, some conclusions are given in section 4.

2. WAVELET TRANSFORM FOR ANALYSIS OF INTERMITTENT SIGNAL

The intermittent fault is typically caused by the failure of a base drive. The difficulty of detecting the intermittent fault is that the steady state measurements do not contain information about the fault as the system has recovered. Indicating harmonics are possibly found similar to those of an open-circuit fault. However, the changes of the amplitude of harmonic components are strongly dependent on the density of missed pulses. Consequently, the methods using Fourier transform analysis may not be sufficient for the monitoring of intermittent fault [24]. Figure 1 illustrates the spectral of DC-link current under the healthy state and intermittent faulty conditions. It is seen that the faulty spectrum (red dotted line) is a bit different compared to the healthy one (blue solid line). It is also observed that there is no variation in the amplitude of the three first harmonic components as previously demonstrated for the open-circuit fault [5]. In addition, if the data of steady state is used, the spectral in both conditions are identical that there is no indicating frequency to recognize the fault.

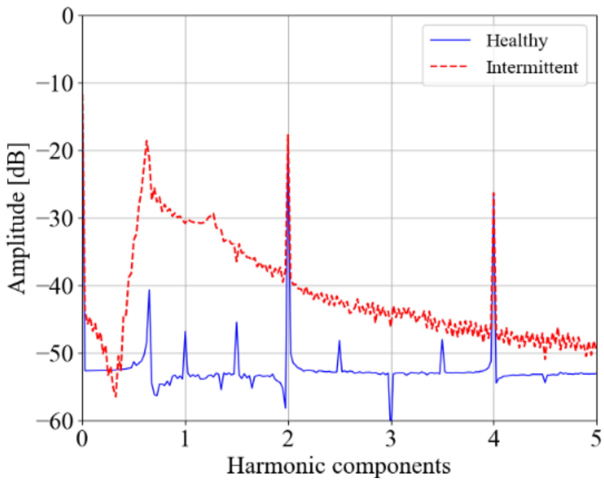


Figure 1. Comparison of DC-link current spectral between healthy and intermittent fault conditions of an IGBT

The wavelet analysis method would be therefore utilized to overcome this shortcoming. Accordingly, the spectrum is calculated for every position when the window is shifted along the signal. The wavelet analysis is appropriate for detecting an abrupt discontinuity of the signals which generated by the intermittent fault [25]. Continuous wavelet transforms are suited for detecting the exact instant signals $s(t)$ that consists of the discontinuities and breakdown points. The coefficient of the transform is calculated by (1) [26]:

$$C_{a,b} = \int_{\Re} s(t) \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) dt \quad (1)$$

where $\psi_{a,b}(x) = \frac{1}{\sqrt{a}} \psi\left(\frac{x-b}{a}\right), a > 0, b \in \Re$ is the associated wavelet family. For instance, the Mexican hat function is given by (2) [25]:

$$\psi(x) = \frac{2}{\sqrt{3}}\pi^{-1/4}(1 - x^2)e^{-x^2/2} \quad (2)$$

For $t \in [k, k+1], s(t) = s(k)$, hence

$$C_{a,b} = \frac{1}{\sqrt{a}}\sum_k s(k) \int_k^{k+1} s(t)\,\psi\left(\frac{t-b}{a}\right) dt \quad (3)$$

or

$$C_{a,b} = \frac{1}{\sqrt{a}}\sum_k s(k) \left(\int_{-\infty}^{k+1} s(t)\,\psi\left(\frac{t-b}{a}\right) dt - \int_{-\infty}^{k} s(t)\,\psi\left(\frac{t-b}{a}\right) dt\right) \quad (4)$$

In fact, the wavelet coefficients $c_{a,b}$ obtained from (4) is the sum of the signal and the scaled wavelet function that is shifted from the value $b = 1$ to the length of signal. The multi-resolution analysis (MRA) algorithm is also a popular technique among many different signal applications of wavelet theory. In which, the signal is decomposed into an approximation coefficient and a detail coefficient at each level, which are obtained by convolving the signal with the low-pass filter and high pass filter respectively. The advantage of this technique is that different high frequency resolutions can be achieved [27]. In the next section, simulations and experiments will be conducted to collect signals. Since then, wavelet analysis has been applied to analyze and detect the fault.

3. RESULTS AND DISCUSSION

3.1. Simulation results

In order to investigate the method used for monitoring intermittent fault, simulation is developed in the following conditions: i) A two-level voltage source inverter is used to supply an induction motor, as illustrated in Figure 2. The parameter of the induction motor is given in Table 1; ii) Scalar control is applied to the power drive, the reference speed is set equal to 1,200 rpm; and iii) The intermittent fault is created by forcing one pulse missed at each faulty instant, t=3, 5, 7, 9 s.

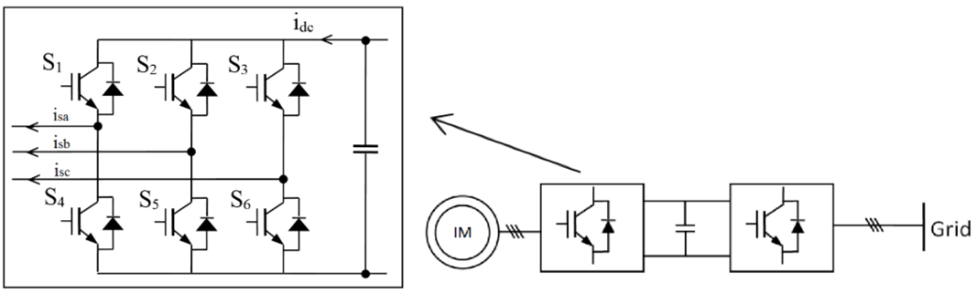


Figure 2. Voltage source inverter-based induction motor drive

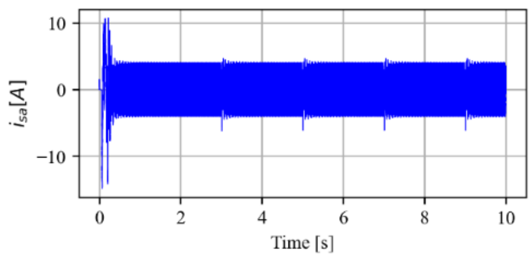
Table 1. Data of induction motor

Nominal values		Model parameters	
Rated power	1,500 W	Stator resistance	3,62 Ω
Rated voltage	400 V	Rotor resistance	3,19 Ω
Rated current	3.35 A	Stator, rotor leakage inductances	0.0184 H
Rated speed	1,430 rpm	Magnetizing leakage inductance	0.3343 H
Number of pole pairs	2	Total inertia coefficient	0.00435 N.m/rad/s^2
Power factor	0.77		

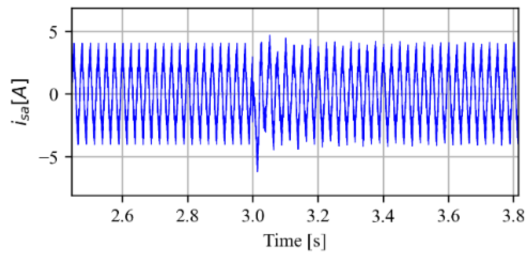
Figure 3 shows the output current of the motor for the power drive. Whole signal simulated in a period of 10 s is shown in Figure 3(a); and a zoom of the signal around the faulty instant at 3 s is depicted in Figure 3(b). It can be seen that the signal shape of the current is slightly distorted at the time of the fault. However, it is instantly restored to normal condition that fast Fourier transform might not be sufficient for the detection of the fault.

In the wavelet analysis, the function of Mexican Hat with the features of gaussian mass spectrometry peaks [28] that offers effective detection and localization of patch will be applied in this study. Following this, the signal of stator current is analyzed to give the continuous wavelet transform coefficients, as depicted in Figure 4. It can be seen that the wavelet coefficient of the output AC current is obtained with increased amplitude at the time of the incident. Analyzing the current signal by different scales suggests that the range from 150 to 200 would be accordingly used to obtain high sudden variation in the magnitude caused by the fault.

Similarly, Figure 5 illustrates the direct current and its 3D wavelet analysis. In Figure 5(a), the distortion can be observed in the signal. Specifically, a little abrupt discontinuity can be viewed at the faulty instants (t=3, 5, 7, 9 s). The wavelet analysis results in Figure 5(b) also show that there is an increase in the magnitude of the wavelet coefficient whenever a pulse is sudden breaking off. It can be recommended by observing the changing in the magnitude with different scales that the range from 50 to 150 would be appropriately applied in order to get a surge of coefficient due to the fault.



(a)



(b)

Figure 3. Simulated output line current, (a) whole signal in 10 s, (b) zoomed signal around t=3 s

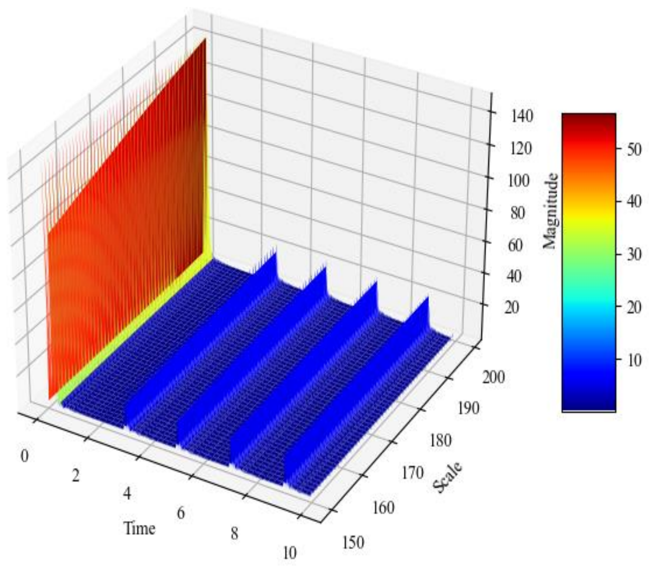
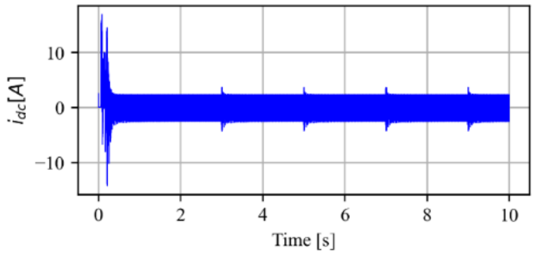
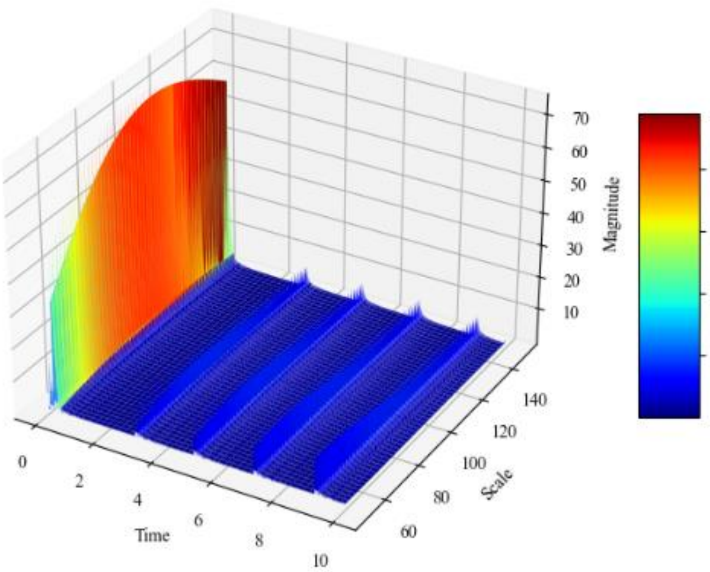


Figure 4. 3D wavelet analysis of simulation output line current



(a)



(b)

Figure 5. Simulation DC-link current signal, (a) whole signal in 10 s, (b) 3D wavelet analysis

To sum up, both the AC current and DC-link current appear with the abrupt discontinuity around the faulty instants. Changes in the waveform of the signal are clearly difficult to detect. However, by analyzing using wavelet transform, along with choosing the appropriate scale range, it is possible to obtain the magnitude variation of the coefficient each time that an intermittent open-circuit fault occurs. In the real operating conditions of the inverter, measurement data can be influenced by many other factors, including noise, which might affect the analysis results. In addition, measuring direct current is challenging due to the geometric structure of the DC-bus. Therefore, in the next section, experiments are conducted with a real inverter to verify the analysis results of the simulation step and suggest the substitution for the DC-link current signal.

3.2. Experiment results

The experiment results and signal analysis of the intermittent fault are provided in this section. The induction motor drive is realized in a test-bed shown in Figure 6. The drive is composed of an induction machine and an inverter, presented in Figure 6(a). In the experiment, an output (stator) current signal is measured and analyzed in order to get the wavelet analysis. Meanwhile, the electromagnetic field is proposed since it can be seen as the image of the DC-link current, which is recorded by using a Hall sensor-based meter, depicted in Figure 6(b).

Figure 7 shows an experimental output line current signal which is recorded in a period of 5 s. The misfiring only occurs at four instants t=6, 7, 8, 9 s as shown in Figure 7(a). It is seen that less variation of signal can be viewed at these instants compared to the simulated current signal. Repeating the analysis for the measured output current data in the time interval [5 s, 10 s] the 3D wavelet of the current can be obtained as shown in Figure 7(b). It is confirmed that the sudden rise of the magnitude can be observed at the faulty instants. Furthermore, the range of scale from 150 to 200 is recommended to be utilized for the analysis.

In Figure 8, the response of magnetic field during the period from t=5 to 10 s can be seen. It is observed that the signal seems to appear without abrupt discontinuity around the faulty instants, as displayed in Figure 8(a). Subsequently, the magnetic field signal is analyzed by using continuous wavelet transform to provide the coefficients in the scale range of (50-150), as shown in Figure 8(b). It is noted this scale range is also chosen for the DC-link current, which is more noised in comparison with the AC current signals.

Obviously, there are abrupt increases in the coefficient at the faulty instants of all selected signals that allows recognizing the fault. The healthy condition measurement will be used to compute the coefficient as reference value to monitor the fault during the service of the inverter. An appropriate range for the coefficient computation with reference to the simulation and experiment analysis using wavelet transform can be determined, i.e. from 50 to 150 for the direct current or electromagnetic field signals. The signal is acquired and analyzed to calculate the coefficient. Following this, the fault alarm can be generated and tripping mechanism to detect the fault can be carried out. To sum up, the application of wavelet analysis to the analysis of magnetic field signal has been illustrated by using continuous wavelet transform. The achieved results have demonstrated their applicability to detect such intermittent fault of the converter based on the magnetic field signal.

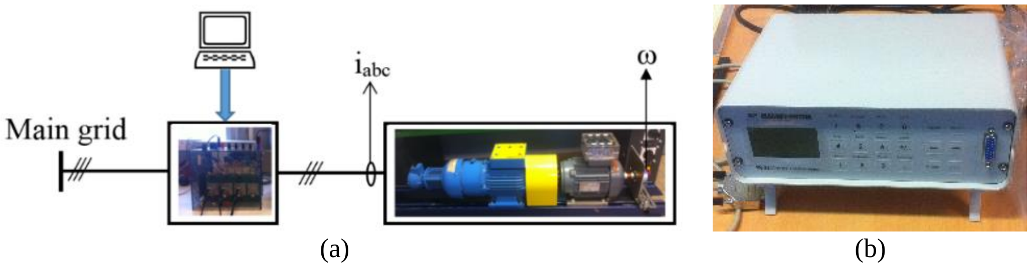


Figure 6. Test system, (a) induction motor drive, (b) magnetic field strength meter FH55

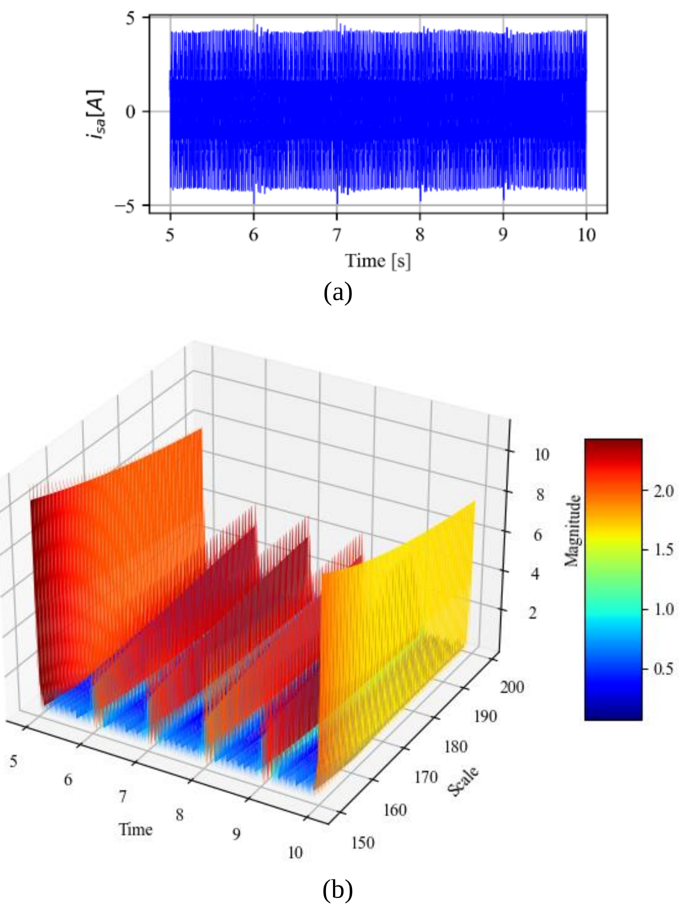
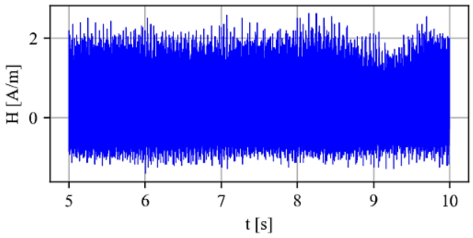
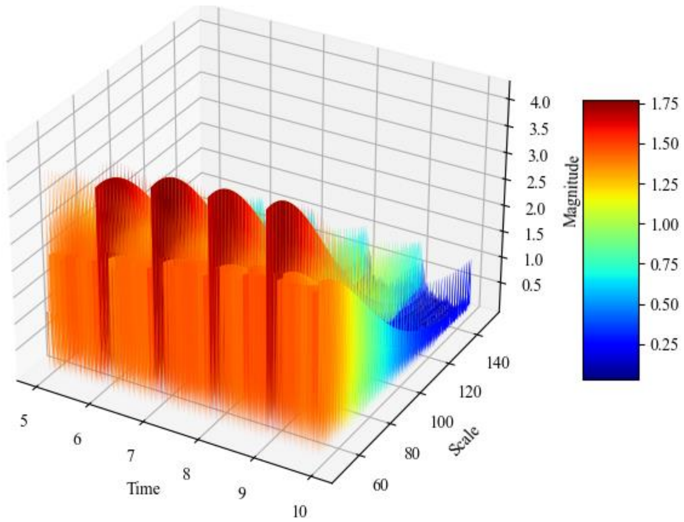


Figure 7. Experimental output line current, (a) whole signal from t=5 to 10 s, (b) 3D wavelet analysis



(a)



(b)

Figure 8. Magnetic field signal, (a) whole signal from t=5 to 10 s, (b) 3D plot of wavelet analysis

4. CONCLUSION

The detection method of intermittent open-circuit fault of the inverter in induction motor drives has been investigated. Intermittent open-circuits are created at arbitrary times by interfering with the control signals sent to the valves. The output alternating current signal of the inverter, direct current and electromagnetic field signals measured at the DC-bus were analyzed using wavelet transform. Simulation and experimental results show that the wavelet coefficient increases dramatically at fault times, allowing timely detection of this type of fault. Furthermore, it should be underlined that processing of the signal with wavelet analysis can be implemented by several software including scientific Python tools. As future research, the combination of wavelet analysis and modern machine learning algorithms enables diagnostic analysis of problems throughout the entire drive.

REFERENCES

[1] A. Ahmed, S. P. Biswas, M. S. Anower, M. R. Islam, S. Mondal, and S. M. Muyeen, “A hybrid PWM technique to improve the performance of voltage source inverters,” *IEEE Access*, vol. 11, pp. 4717–4729, 2023, doi: 10.1109/ACCESS.2023.3235791.

[2] F. W. Fuchs, “Some diagnosis methods for voltage source inverters in variable speed drives with induction machines-a survey,” IEEE, 2003, pp. 1378–1385. doi: 10.1109/IECON.2003.1280259.

[3] B. Wang, X. Feng, and R. Wang, “Open-circuit fault diagnosis for permanent magnet synchronous motor drives based on voltage residual analysis,” *Energies*, vol. 16, no. 15. 2023. doi: 10.3390/en16155722.

[4] N. V. P. Kuraku, Y. He, T. Shi, R. K. Gatla, and R. Yi, “Fuzzy logic based open-circuit fault diagnosis in IGBT for CMLI fed PMSM drive,” *Microelectronics Reliability*, vol. 100–101, p. 113415, 2019, doi: 10.1016/j.microrel.2019.113415.

[5] H. G. Vu and H. Yahoui, “IGBT open-circuit fault detection for voltage source inverters using DC bus magnetic field signal,” *Electrical Engineering*, no. 103, pp. 1691–1700–1691–1700, 2021, doi: 10.1007/s00202-020-01161-w.

[6] J. A. Reyes-Malanche, F. J. Villalobos-Pina, E. Cabal-Yepez, R. Alvarez-Salas, and C. Rodriguez-Donate, “Open-circuit fault diagnosis in power inverters through currents analysis in time domain,” *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–12, 2021, doi: 10.1109/TIM.2021.3082325.

[7] R. Abdelkader, B. D. E. Cherif, A. Bendiabdellah, and A. Kaddour, “An open-circuit faults diagnosis approach for three-phase inverters based on an improved variational mode decomposition, correlation coefficients, and statistical indicators,” *IEEE Transactions on Instrumentation and Measurement*, vol. 71, pp. 1–9, 2022, doi: 10.1109/TIM.2022.3149339.

[8] J. O. Estima and A. J. M. Cardoso, “A new approach for real-time multiple open-circuit fault diagnosis in voltage-source inverters,” *IEEE transactions on industry applications*, vol. 47, no. 6, pp. 2487–2494, 2011, doi: 10.1109/TIA.2011.2168800.

[9] A. M. S. Mendes, A. J. Marques Cardoso, and A. J. M. Cardoso, "Voltage source inverter fault diagnosis in variable speed AC drives, by the average current Park's vector approach," in *IEEE International Electric Machines and Drives Conference. IEMDC'99. Proceedings*, Seattle, WA, USA: IEEE, 1999, pp. 704–706. doi: 10.1109/IEMDC.1999.769220.
[10] T. Orlowska-Kowalska, P, and Sobanski, "Simple diagnostic technique of a single IGBT open-circuit faults for a SVM-VSI vector controlled induction motor drive," *Bulletin of the polish academy of sciences technical sciences*, vol. 63, no. 1, pp. 281–288, 2015, doi: 10.1515/bpasts-2015-0032.
[11] K. Rothenhagen and F. W. Fuchs, "Performance of diagnosis methods for IGBT open circuit faults in three phase voltage source inverters for AC variable speed drives," in *2005 European Conference on Power Electronics and Applications*, Dresden, Germany: IEEE, 2005, pp. 10-pp. doi: 10.1109/EPE.2005.219426.
[12] W. Sleszynski, J. Nieznanski, and A. Cichowski, "Open-transistor fault diagnostics in voltage-source inverters by analyzing the load currents," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 11, pp. 4681–4688, 2009, doi: 10.1109/TIE.2009.2023640.
[13] C. J. Bae, D. C. Lee, and T. H. Nguyen, "Detection and identification of multiple IGBT open-circuit faults in PWM inverters for AC machine drives," *IET Power Electronics*, vol. 12, no. 4, pp. 923–931, 2019, doi: 10.1049/iet-pel.2018.5188.
[14] S. Cheng *et al.*, "An open-circuit fault-diagnosis method for inverters based on phase current," *Transportation Safety and Environment*, vol. 2, no. 2, pp. 148–160, 2020, doi: 10.1093/tse/tdaa008.
[15] 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, 1998, doi: 10.1109/28.739017.
[16] I. Abari *et al.*, "Fault detection methods for three-level NPC inverter based on DC-bus electromagnetic signatures," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 7, pp. 5224–5236, 2017, doi: 10.1109/TIE.2017.2777378.
[17] X. Sun, N. Diao, C. Song, Y. Qiu, and X. Zhao, "An open-circuit fault diagnosis method based on adjacent trend line relationship of current vector trajectory for motor drive inverter," *Machines*, vol. 11, no. 10. 2023. doi: 10.3390/machines11100928.
[18] C. Song, X. Zhao, X. Sun, N. Diao, and J. Zhao, "Fast in-loop single-tube open-circuit fault diagnosis for voltage source inverter based on duality of current-time pairs," *IEEE Transactions on Industrial Electronics*, vol. 70, no. 9, pp. 9572–9581, 2023, doi: 10.1109/TIE.2022.3212398.
[19] B. D. E. Cherif, A. Bendiabdellah, and M. Tabbakh, "An automatic diagnosis of an inverter IGBT open-circuit fault based on HHT-ANN," *Electric Power Components and Systems*, vol. 48, no. 6–7, pp. 589–602, 2020, doi: 10.1080/15325008.2020.1793835.
[20] B. D. E. Cherif, S. Seninete, M. Defdaf, and F. Berrabah, "Diagnosis of three-phase two-level voltage inverter under open-circuit fault of an IGBT," in *Artificial Intelligence and Heuristics for Smart Energy Efficiency in Smart Cities: Case Study: Tipasa, Algeria*, Springer, 2022, pp. 674–681. doi: 10.1007/978-3-030-92038-8_67.
[21] B. D. E. Cherif, M. Chouai, S. Seninete, and A. Bendiabdellah, "Machine-learning-based diagnosis of an inverter-fed induction motor," *IEEE Latin America Transactions*, vol. 20, no. 6, pp. 901–911, 2022, doi: 10.1109/TLA.2022.9757372.
[22] Y. Xia and Y. Xu, "A transferrable data-driven method for IGBT open-circuit fault diagnosis in three-phase inverters," *IEEE Transactions on Power Electronics*, vol. 36, no. 12, pp. 13478–13488, 2021, doi: 10.1109/TPEL.2021.3088889.
[23] R. Isermann, "Model-based fault detection and diagnosis - status and applications," *IFAC Proceedings Volumes*, vol. 37, no. 6, pp. 49–60, 2004, doi: 10.1016/S1474-6670(17)32149-3.
[24] B. Lu and S. K. Sharma, "A literature review of IGBT fault diagnostic and protection methods for power inverters," *Industry Applications, IEEE Transactions on*, vol. 45, no. 5, pp. 1770–1777, 2009, doi: 10.1109/TIA.2009.2027535.
[25] I. Daubechies, *Ten lectures on wavelets*, vol. 61. SIAM, 1992.
[26] O. Rioul and M. Vetterli, "Wavelets and signal processing," *IEEE signal processing magazine*, vol. 8, no. 4, pp. 14–38, 1991, doi: 10.1109/79.91217.
[27] S. G. Mallat, "A theory for multiresolution signal decomposition: the wavelet representation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 11, no. 7, pp. 674–693, 1989, doi: 10.1109/34.192463.
[28] Y. Zheng, R. Fan, C. Qiu, Z. Liu, and D. Tian, "An improved algorithm for peak detection in mass spectra based on continuous wavelet transform," *International Journal of Mass Spectrometry*, vol. 409, pp. 53–58, 2016, doi: 10.1016/j.ijms.2016.09.020.

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