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PHASE FAULT DETECTION DUE TO SWITCHING IN DIRECT INSTANTANEOUS TORQUE CONTROL SWITCHED RELUCTANCE MOTOR DRIVES BASED ON WAVELET

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Abstract

This work describes a technique of detection and identification of switch short circuit fault of IGBT based drive, operating direct instantaneous torque control of switched reluctance motor. The method of detecting fault is based on wavelet decomposition using MATLAB programme. Haar wavelet is chosen as mother wavelet for performing stator current analysis during fault occurrence. When a short circuit fault in an IGBT based inverter occurs, this fault information is revealed in different frequency band obtained after the analysis of stator current using DWT. The spikes present in the 9th level detail witnessed for emerging fault. The instant at which the spikes occur in DWT is reciprocally related to the instant of occurrence of fault. The signal signature obtained in different frequency band using DWT clearly distinguishes a faulty system from a healthy one. The response obtained from DWT testifies that the identification and detection of fault using DWT has immense potential.

Introduction

The advancement in power electronic devices increases the complexity of power system network. The immediate information at the instant of occurrence of fault is always mandatory to maintain the reliability of power system. Fast and accurate assessment of fault allows sufficient protective action to be taken at the time of fault. Restorative measures need to be fascilated immediately after the occurrence of fault. Fault detection and diagnosis of localised events like transient phenomena require robust tool such as wavelet transform. The wavelet transform gives both frequency and time information of the analysed signal [1-4].

For the diagnosis of fault it is required to know which spectral component occurring at what instant of time. Fourier transform provides the information of spectral component present in a signal but there is no time information. STFT suffers from fixed window length. The drawback of Fourier technique is that good localisation for both the frequency and time information of a signal cannot be achieved simultaneously. The most practical power signal is a combination of transient, noise and steady state signal. So STFT or other time frequency technique found to be unfit for analysis. Whereas WT provide a better trade-off in the matter of localisation. In DWT signal is allowed to pass through filters of different cut-off frequency at different scale [5]. Thus it is quite easy to identify and localise transients occurring in a signal.

WT is a capable tool to obtain both time and frequency information. In this work electrical fault signal occurring due to IGBT short circuit fault in the three phase inverter feeding direct instantaneous torque control of switched reluctance motor was analysed using DWT. It testifies from the result that proposed fault detection and diagnosis system have immense capabilities

Wavelet Transform

All Unlike Fourier transform, in wavelet transform the width of the window is varied for the computation of every single spectral component. The mother wavelet is used as a prototype for all the window. The window used is nothing but the dilated/compressed and shifted version of the mother wavelet.

In CWT [6] the signal is analysed by a set of basis function, which relate to oneanother by translation and scaling. The continuous wavelet transform of a signal f(t) can be obtained as

$$CWT(f,a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} f(t)\psi^*(\frac{t-b}{a})dt \qquad (1)$$

Where a is the scaling (dilation) constant and b is the translated constants respectively.

The Discrete wavelet transform of a signal can be obtained as follows:

$$\mathrm{DWT}(f,m,n)=\frac{1}{\sqrt{a_0^m}}\sum_k f(k)\,\psi^*(\frac{t-ka_0^m}{a_0^m})dt \qquad (2)$$

Where a and b in eqn (1) is replaced by a_0^m and ka_0^m respectively.

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DWT employs digital filtering technique to obtain the time scale representation of analysed digital signal. The signal is then passed through filters having different cut-off frequencies at different scale. The signal is passed through a series of high pass filter to obtain the information regarding high frequency content of the signal and it is passed through a series of low pass filter to analyse low frequencies. Thus the signal is decomposed into coarse approximation and detail information.

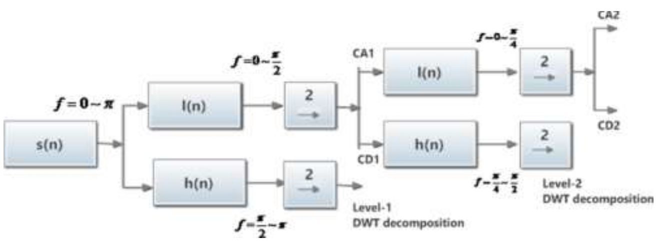


Fig. 1. *Wavelet Packets Decomposition*

The decomposition process uses wavelet function and scaling function which are correlated with high pass and low pass filter respectively.

The technique of decomposition of the signal resulting in different frequency band is explained in Fig. 1. Here f(n) is the original signal . The signal f(n) is passed through high pass filter h(n) and low pass filter l(n). After filtering half of the sample is discarded obeying Nyquist criteria. Now the highest frequency content of the signal is $\frac{\pi}{2}$ radian/second. The signal is then subsampled by 2 and constitute first level of decomposition. This process continues till the signal is decomposed to desired level. The mother wavelet, Haar is used for the analysis it gave better information for the above fault condition.

Description of SRM model

SRM is a singly excited, doubly salient motor. Saliency is present both on the stator and rotor. The stator of the switched reluctance motor contains only excitation winding and rotor is made up of steel lamination without permanent magnet. For the movement of rotor, the phases need to be excited sequentially. Due to saliency in rotor and stator structure, movement of rotor occurs to accuire a minimum reluctance position. The mathematical modeling depicting the dynamics of 6/4, 60 KW SRM comprises of electrical equation for each phase and the equation representing the mechanical systems [7, 8]. Phase voltage supplied to stator act as an electrical input to SRM model. The electrical circuit supplying phase voltage to stator is connected to converter. Due to saliency present in stator and rotor, phase is associated with nonlinear inductance.

The magnetic characteristics of SRM are nonlinear due to saturation and saliency present in stator and rotor. Magnetic flux linkage exhibits a nonlinear relationship with rotor position (θ) and stator current(i) and can be approximated by analytical non linear function [7, 8]as explained below.

$$\psi_p(t) = \psi_p(i,\theta) \qquad (3)$$

The difference of phase voltage and the voltage drop across the stator resistance is time integrated to obtain stator phase voltage.

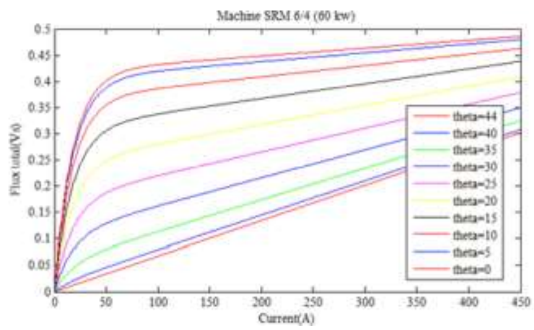


Fig. 2. *Magnetization characteristic of the machine*

$$\psi p(t) = \int_0^t (V_p - R_p I_p) dt \qquad (4)$$

Where $\psi_p(t)$, V_p, R_p, I_p represents the stator flux linkage vector, stator phase voltage vector, stator winding resistance and the stator current vector respectively. Stator current is obtained from magnetization characteristics $\psi(i,\theta)$. The flux linkage (ψ) is a nonlinear function of stator current and rotor position (θ). The stator current $i(\psi,\theta)$ is a nonlinear function and is obtained from the magnetization characteristics $\psi_p(i,\theta)$. The magnetization characteristics are obtained from analytical expressions as shown in Fig. 2. Where θ represents different rotor position in degree during its rotation.

The derivative of machine co-energy obtained is considered as machine electromagnetic torque for any one phase of SRM. Where $w'(i.\theta)$ represent machine co-energy $T_e(i,\theta)$ is the electromagnetic torque.

$$T_e(i,\theta) = \frac{\partial}{\partial\theta} w'(i,\theta) \qquad (5)$$

w' is obtained as follows:

$$w'(i,\theta) = \int_0^i \psi(i,\theta) di \qquad (6)$$

The summation of torque produced by each phase is the electromagnetic torque T_e developed by the machine. The below equation explains the mechanical dynamics of SRM motor.

$$T_e = J\frac{d\omega_m}{dt} + B\omega_m + T_L \quad (7)$$

where T_L, J, ω_m and B represents the load torque, moment of inertia, angular velocity and coefficient of friction respectively.

Direct Instantaneous Torque Control of switched Reluctance Motor

Switched reluctance motor has many advantageous characteristics [9,10] like simplicity in construction, low maintenance cost, ruggedness etc. In industrial field and hybrid electrical vehicle SRM always proved to be a better choice in comparison to induction motor and permanent magnet motor[11,12].

Table 1 Switching strategy of DITC ,three adjacent phases are Ph P-1, Ph P, Ph P+1

Activated Ph P-1	Activated Ph P	Activated Ph P+1	Swiching state S for the Ph P-1	Switching state S for Ph P	Switchng state S for Ph P+1
0	0	0	X	X	X
1	0	0	1/0	X	X
1	1	0	1/0/-1	1/0	X
0	1	0	-1/X	1/0	X
0	1	1	X	1/0/-1	1/0
0	0	1	X	-1/X	1/0

But it always characterises with high torque ripple acoustic noise and vibration [13] due to nonlinear magnetic characteristics.

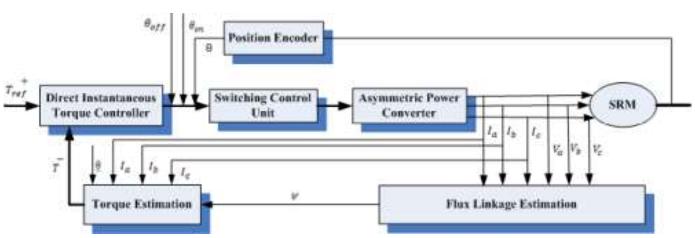


Fig. 3. Torque ripple minimization of SRM using DITC technique

The minimization of torque ripple is always desirable for the application of SRM in the area such as high power servo system[14].

torque ripple acoustic noise and vibration [13] due to nonlinear magnetic characteristics. The minimization of torque ripple is always desirable for the application of SRM in the area such as high power servo system[14].

The advances in power-semiconductor devices make possible the implementation of electronic control technique to reduce the high torque ripple associated with it. Direct instantaneous torque control is one of the control technique proposed by Inderka [15] which successfully minimizes high torque ripple of such drives and provide effective torque control. This method of torque control avoid the use of high precision rotor position sensor. This is a closed loop direct torque control technique to regulate the torque online. The torque is estimated from the terminal quantities readily available for measurement of the analytical model of SRM as explained in section-3.

DITC technique uses a digital torque hysteresis controller to provide switching signal for the activated stator phase.When single phase conduction occur, hysteresis controller regulate the torque of that phase. During the process of phase commutation torque of two adjacent phases is controlled simultaneously by controlling the total torque. The switching plan used in Table-I is implemented to achieve a satisfactory torque commutation. For the time period of active conduction the enable signal is 1. During the process of single phase conduction the switching state S equal to one means that phase is connected to a positive D.C link voltage. Switcing state S equal to zero indicates the phase is freewheeling. Switcing state S equal to -1 indicates a negative D.C link voltage is applied to the phase to demagnetise that phase.

For two phase conduction the phase which was already magnetised switches to zero voltage state. If the incoming power switch short circuit fault. Using DWT necessary fault information are extracted from fault signal.

Wavelet method of fault detection

DITC of SRM was developed in MATLAB environment. Fig. 3 shows the block diagram explaining torque ripple minimization using DITC technique. IGBT short circuit fault is simulated in asynchronous motor power circuit. DWT is used as a tool for the detection and identification of IGBT power switch short circuit fault. Using DWT necessary fault information are extracted from fault signal.

Fig. 4 shows the three phase SRM steady state stator time domain current during healthy mode of operation. Fig. 5 shows 3-phase SRM stator time domain current exhibiting IGBT1 short circuit fault. Because of occurrence of power switch IGBT1 short circuit fault, 3-phase stator current shows a high rise as shown in Fig. 5a-c in order to maintain the required torque of 12 Nm and to track the reference speed.

The short circuit switch fault is simulated at 0.6 sec which leads to increase in stator current. Fig. 5 shows three phase stator current, incorporating short circuit switch fault at 0.6 sec. The fault signal of three phase stator current is decomposed to 9th level of approximation and details using multiresolution signal analysis. The sharp signal variation in the various decomposition level of signal contains the useful fault information. We are using the MATLAB programming environment for the simulation of DITC of SRM and for the application of DWT on the resulting signal. Fig. 6, Fig. 7 and Fig. 8 shows phase-a, phase-b, phase-c stator current respectively decomposed to 9th level of approximation and details using multiresolution signal analysis.

The main goal of this research paper is to identify the short circuit switch fault in power converter. This fault information is obtained from 9th level approximation and detail obtained from multi resolution analysis output of three phase stator current. From the time domain analysis of DWT the healthy system can be easily discriminated from faulty system. It is clearly distinguishable from the detailed level d8 and d9. The fault visible in the low frequency range which is appeared in the approximation level nine (a9). The comparative analysis of different levels of approximation and detail of both the healthy and faulty operating condition shows that the signal is decreased in one frequency region and increased in other frequency region.

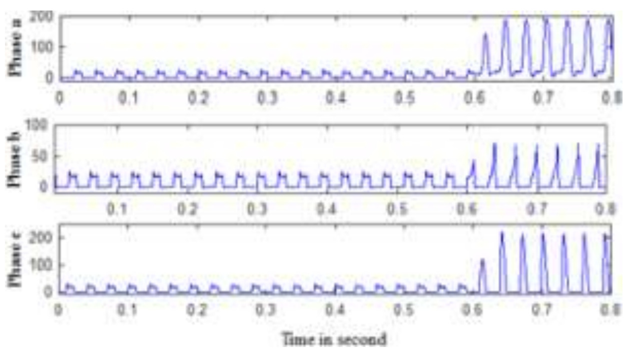


Figure. 5. Stator time domain current of phase a, phase b, phase c exhibiting IGBT1 short circuit faul

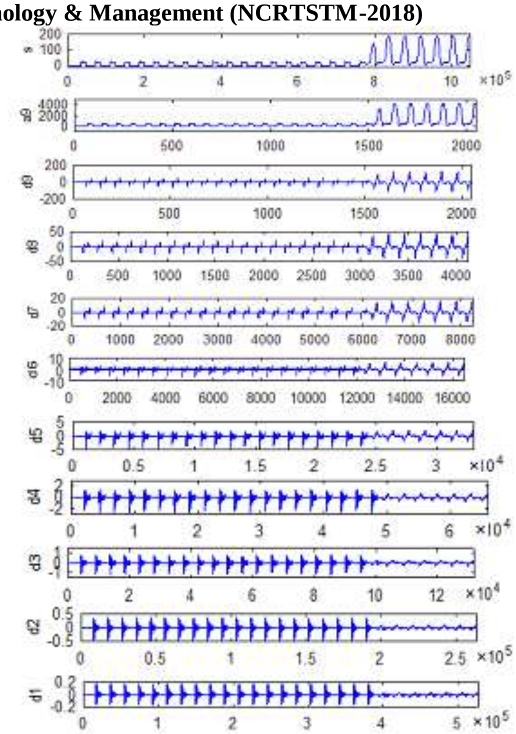
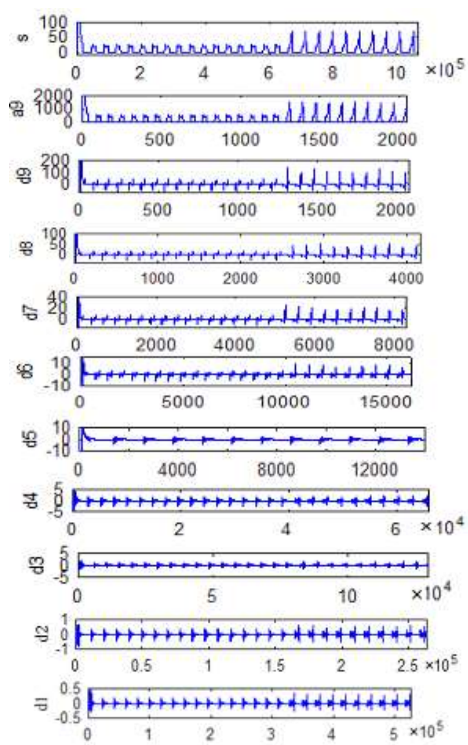


Figure.6 . IGBT1 short circuit fault, Haar wavelet level nine decomposition of stator phase-a current



FFigure.7 . IGBT1 short circuit fault, Haar wavelet level nine decomposition of stator phase-b current

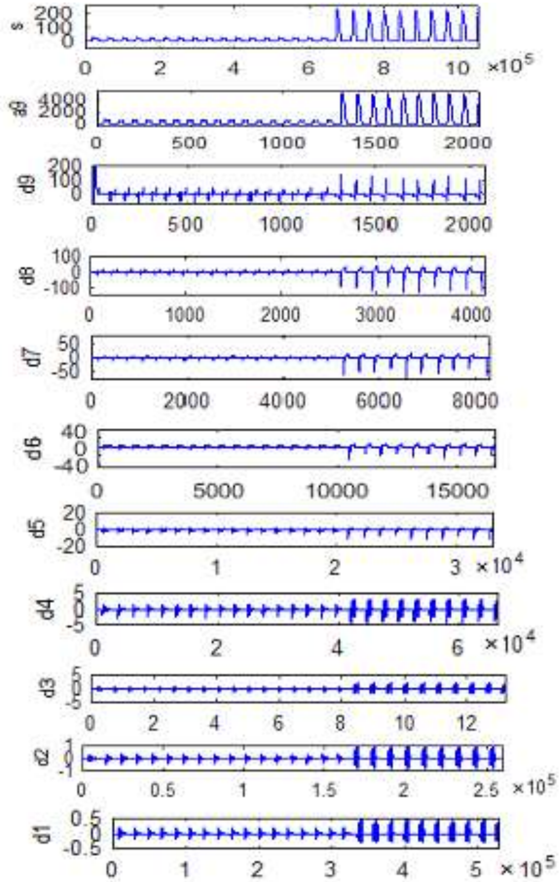


Figure.8 . IGBT1 short circuit fault, Haar wavelet level nine decomposition of stator phase-c current

Conclusion

In this work, stator switching short circuit fault operating as direct instantaneous torque control of switched reluctance motor was decomposed using wavelet transform. The signal is decomposed up to 9th level of approximation and detail. The fault information is clearly visible from8th and 9th detail level analysis. This provides useful information for identifying the fault. The result shows that proposed method of diagnosis of fault has immense capabilities. Future work is to implement it practically using proper hardware set up.

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Appendix

Parameter	Value	Parameter	Value
Power	60 KW	Load torque	12nm
Speed	500 RPM	Aligned inductance	23.62 mH
Stator resistance	0.05 ohm	Unaligned inductance	0.67mH
Inertia	0.05Kg mm	DC link voltage	220V
Friction	0.02Nms	Maximum current	450 A
Stator Pole arc	32 degree	Rotor pole arc	45 degree
No. of rotor pole	4	Maximum flux linkage	0.486mH
No. of stator pole	6	Saturated inductance	0.15mH