

Failure Prognosis for Permanent Magnet AC Drives Based on Wavelet Analysis

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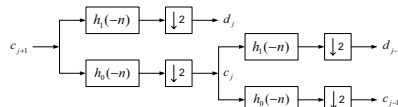
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Objectives

- Detection of non-catastrophic faults in Permanent Magnet AC machines which lead to reduced life and eventually failure
- Stator Faults
 - Insulation failures
 - Resistance changes

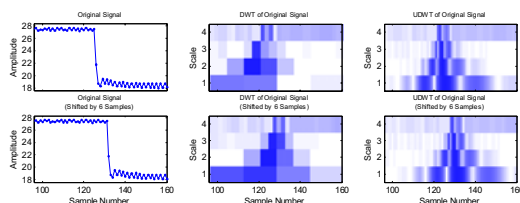
Discrete Wavelet Transform (DWT)

- Wavelets have finite energy concentrated around a point which helps to localize irregularities in a signal
- Can give a sparse representation of a fault
- Can choose different basis functions (mother wavelets) to achieve the best results for a specific application
- Coefficients can be realized using a filter bank
- FIR filter coefficients h_1 and h_0 based on the scaling and wavelet functions



Undecimated Discrete Wavelet Transform (UDWT)

- Shift-invariant representation of the DWT
- Realized using the "Algorithme à Trous", which omits downsampling and inserts zeros between filter coefficients at each successive scale



Linear Discriminant Analysis

$$D_k(\mathbf{x}) = x_1\alpha_{1k} + x_2\alpha_{2k} + \dots + x_N\alpha_{Nk} + \alpha_{N+1,k} \quad k = 1, 2, \dots, K$$

- Categorization of \mathbf{x}_j into j

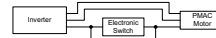
$$D_j(\mathbf{x}) > D_k(\mathbf{x}) \quad \text{for every } k \neq j$$
- Iterative training procedure for the weighting coefficients makes adjustments to α_j and α_l following an initial guess, where

$$D_l(\mathbf{x}) = \max_{j \neq l} [D_j(\mathbf{x}), \dots, D_K(\mathbf{x})]$$

$$\alpha_j(i+1) = \alpha_j(i) + ax_i \quad \alpha_l(i+1) = \alpha_l(i) - ax_i$$
- and a is a gain constant

Faults Explored

- Series Resistance (5 and 10ms)
 - Intermittent increased series contact resistance
 - A normally closed switch and a resistance in parallel are added in series with one of the motor phases
- Turn-to-Phase Short (5 and 10ms)
 - Insulation failure in the stator windings of the motor
 - A normally open switch is added between a winding and its corresponding phase

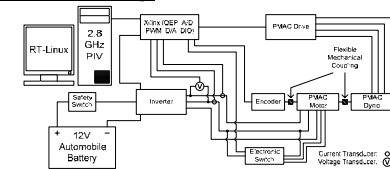


Analysis Methods

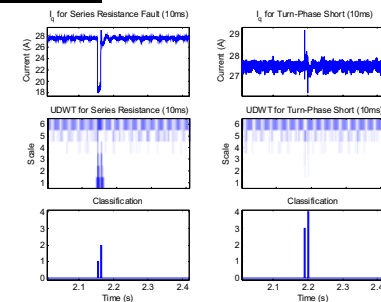
- Field oriented currents are used since the fundamental electrical frequency is not present
- UDWT applied to measured q-axis current
- Daubechies D4 wavelet used
- Decomposition performed for 6 scales
- Inception and clearing of faults are identified separately
- Detection Algorithm
 - A threshold is applied to the weighted energy of the UDWT at each time instant
 - Threshold is set to 40% greater than the largest observed on healthy motors
- Classification Algorithm

- Linear discriminant analysis applied to the 64 samples beginning 8 samples prior to where detection occurred

Experimental Setup



Typical Results



Algorithm Performance

Test Description	Number of False Detections	Fault Inception Total / Detected / Classified Correctly	Fault Clearing Total / Detected / Classified Correctly
Healthy	0	0 / 0 / 0	0 / 0 / 0
Series Resistance (5ms)	0	2 / 2 / 2	2 / 2 / 2
Series Resistance (10ms)	0	2 / 2 / 2	2 / 2 / 2
Turn-to-Phase Short (5ms)	0	2 / 1 / 1	2 / 2 / 2
Turn-to-Phase Short (10ms)	0	2 / 2 / 2	2 / 2 / 2

Conclusions

- Detection and classification of machine faults which manifest themselves in the stator current is achieved
- Data from an exhaustive set of operating conditions is necessary to develop a robust algorithm