Failure Prognosis for Permanent Magnet AC Drives Based on Wavelet Analysis

Wesley G. Zanardelli, Elias G. Strangas, and Selin Aviyente

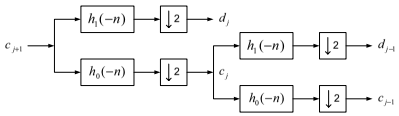
zanardel@egr.msu.edu strangas@egr.msu.edu aviyente@egr.msu.edu

•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

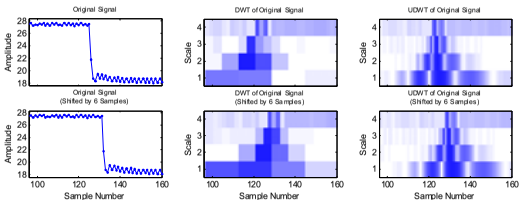
•Discrete Wavelet Transform (DWT)

- •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

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

- •Categorization of $\mathbf{x}_i$ 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

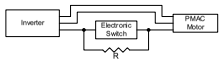
$$D_l(\mathbf{x}) = \max_{l \neq j}[D_1(\mathbf{x}),\cdots,D_K(\mathbf{x})]$$

$$\boldsymbol{\alpha}_j(i+1) = \boldsymbol{\alpha}_j(i) + a\mathbf{x}_i \qquad \boldsymbol{\alpha}_l(i+1) = \boldsymbol{\alpha}_l(i) - a\mathbf{x}_i$$

- •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

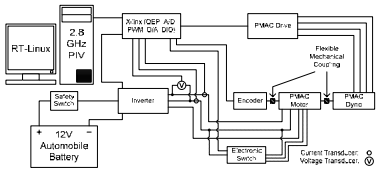


- •Turn-to-Phase Short (5 and 10ms)
  - •Insulation failure in the stator windings of the motor
  - •A normally open switch is added between a winding and its corresponding phase

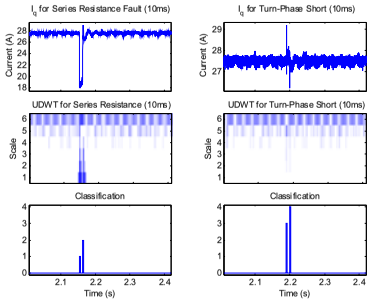
•Analysis Methods

- •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