Condition Monitoring of Motor-Driven Systems

NREL Wind Turbine Condition Monitoring Workshop – 8 October 2009

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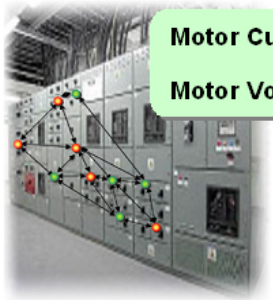
Outline

- Overall methodology
- Motor diagnostic and prognostic algorithms
  - Rotor speed detection
  - Winding temperature estimation
  - Shaft misalignment
  - Broken rotor bar detection
  - Pump cavitation
  - Bearing fault detection
- Extensions to wind

Overall Condition Monitoring Methodology

Only motor voltages and currents are used.



Motor Control Center

(Motor Terminals, meter, Starter, Breaker, Drive, etc.)

Motor Currents

Motor Voltages

Energy Efficiency and Fault Prognostic Algorithms

Parameter Identification

- Speed Estimator
- Stator Resistance Estimator

Motor Nameplate Information

Power, Energy & Efficiency

- Power Analysis
- Harmonics Analysis
- Motor Efficiency
- Energy Usage

Motor / Load Fault Diagnosis

- Bearing fault
- Shaft Misalignment
- Winding Insulation
- Broken Rotor Bar
- Thermal Faults
- Load Faults

- Energy Usage Evaluation
- Motor Efficiency
- Equipment Wellness

- System Identification
- Pattern Recognition
- Intelligent Methods
- Statistical & Stochastical Process
- Digital Signal Processing
- Motor Modeling & Analysis

Inferential Data Processing Techniques

Inferential, nonintrusive, continuous!

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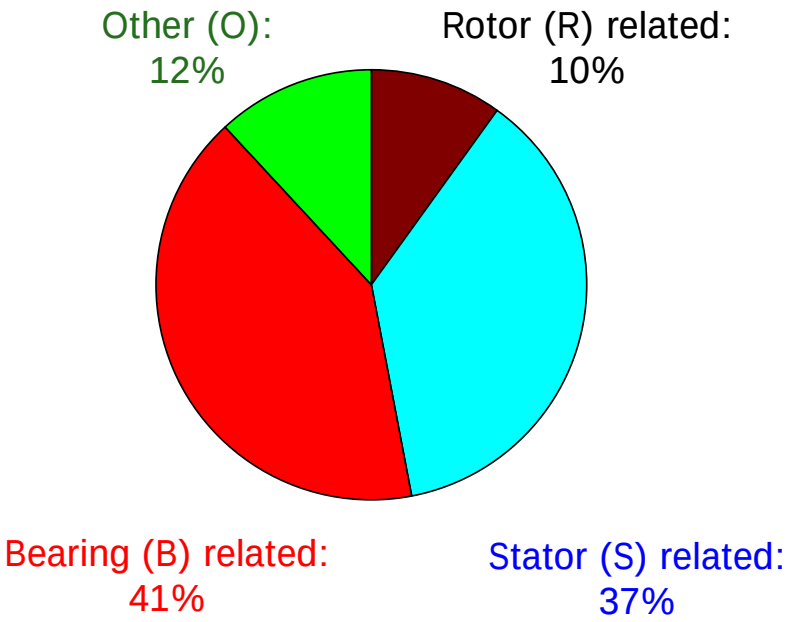
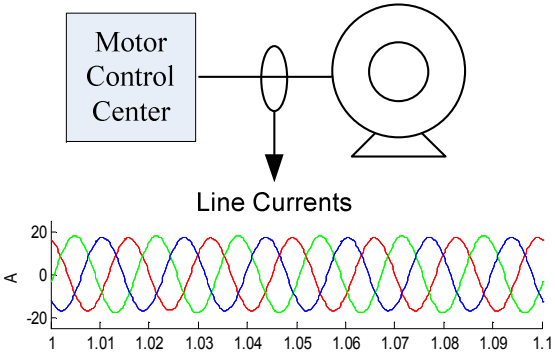
Motor CBM Algorithm Summary

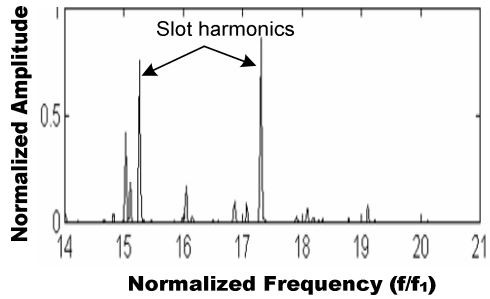
- Rotor Speed Detection (R)
- Shaft Misalignment (R, B)
- Broken Rotor Bar Detection (R, B)
- Pump Cavitation (O)
- Winding Temperature Estimate (S)
- Bearing Fault Detection (B)
- Shaft Torque Estimate (R)
- Power Metering (O)
- Motor Efficiency (O)
- Stator Winding Insulation Faults (S)
- Power Quality (O)
- Harmonics Analysis Algorithms (O)

Motor Fault distribution



Sensorless Rotor Speed Estimation





Rotor Slot Harmonics

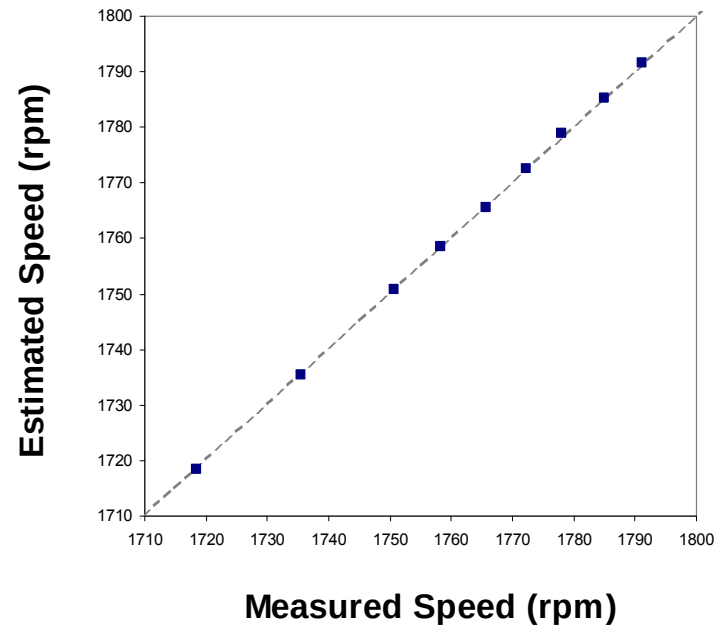
$$f_{seh}$$

$$f_{seh} = f_1\left[(kR + n_d)\frac{1-s}{p/2} + n_w\right]$$

Slip s and rotor speed ω_r

→ *Sensorless, low-cost, and accurate !*

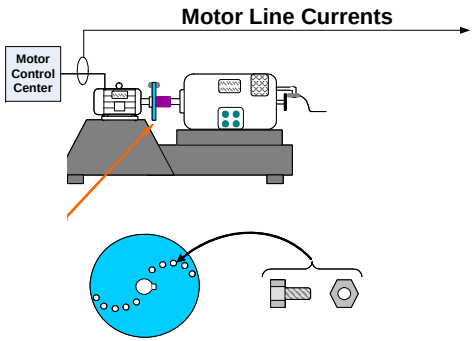
Motor current spectrum analysis

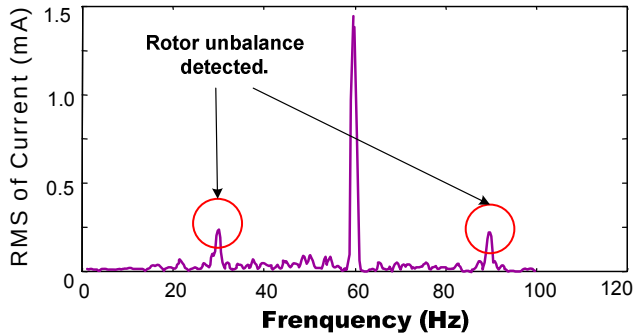


Estimation error less than 1%.

Rotor Eccentricity and Misalignment Detection

Detection of Rotor Eccentricity

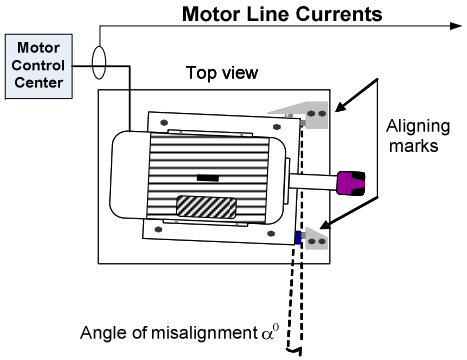


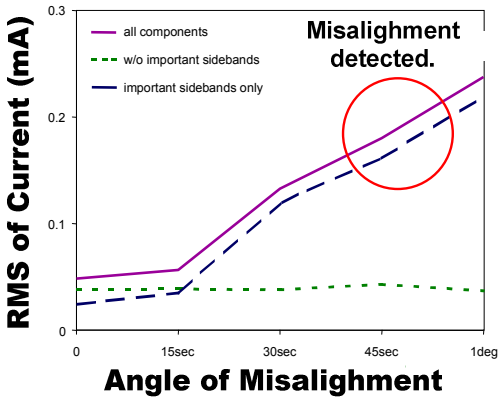


Similar Motor Faults:

- Air-gap eccentricities
- Load torque oscillation
- Rotor unbalances
- Shaft misalignment
- Broken rotor bar

Detection of Shaft Misalignment



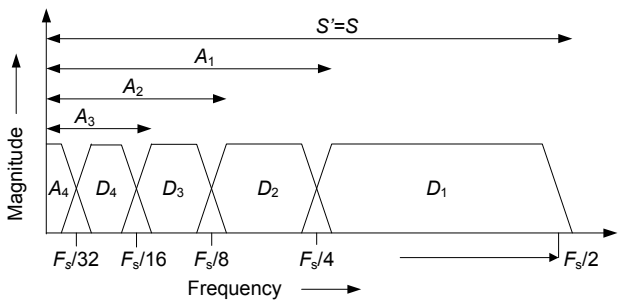


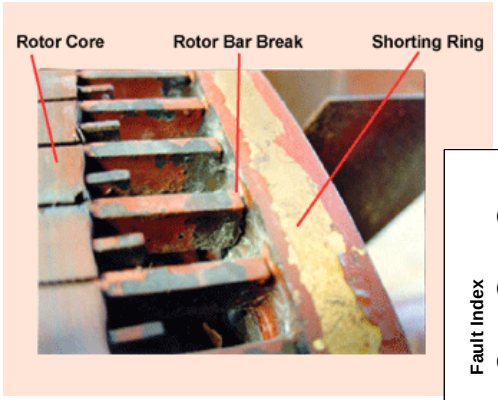
Motor faults can be detected using only stator voltages and currents

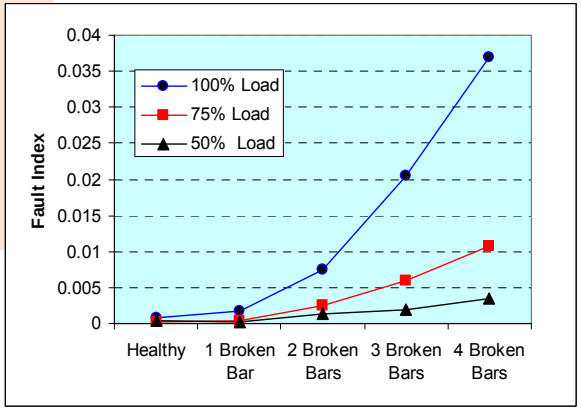
Rotor Fault (Broken Rotor Bar) Detection

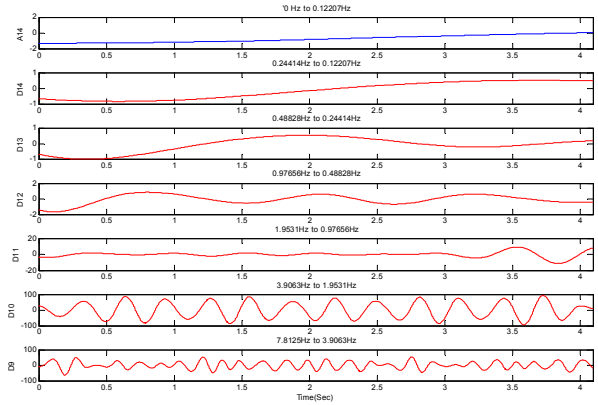
Wavelets – time/frequency domain multi-resolution analysis

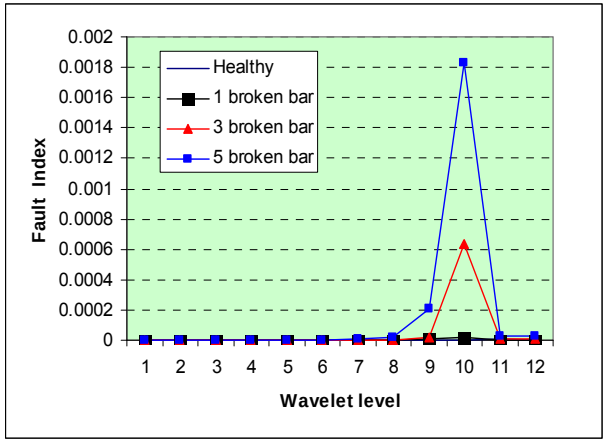
- **Algorithm is based on advanced wavelets analysis**
- **Detect developing rotor fault (crack/broken bar, end ring)**











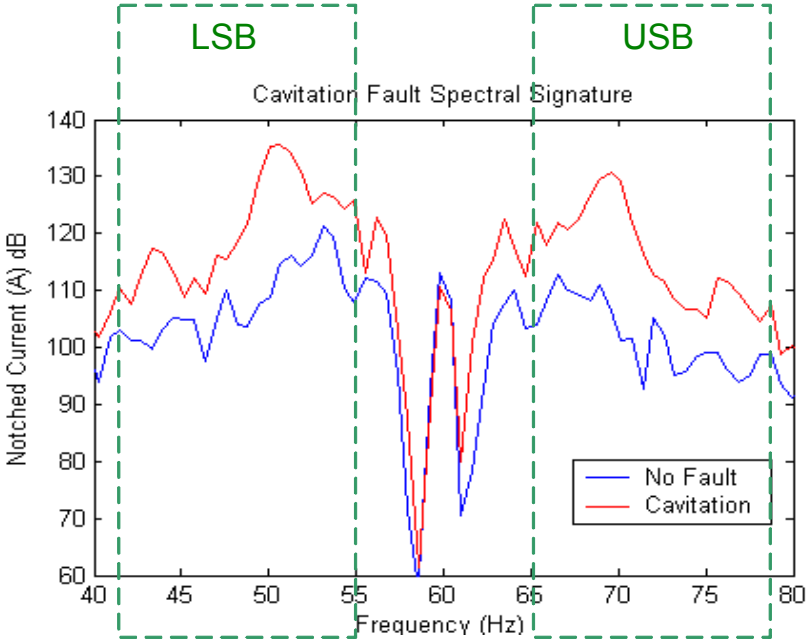
Pump Cavitation Detection

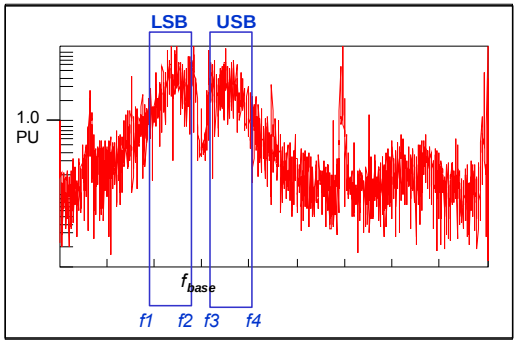
- Fluid vaporizes when the pressure becomes to low, forming cavities that violently collapse causing damage to the impeller

- When pump cavitation occurs, the spectral energy of the current in the “lower side-band” (LSB) and “upper side-band” (USB) increase accordingly.

- Detection of cavitation monitoring average LS USB magnitude.

- For example:
  - LSB: 25-55 Hz
  - USB: 65-85 Hz



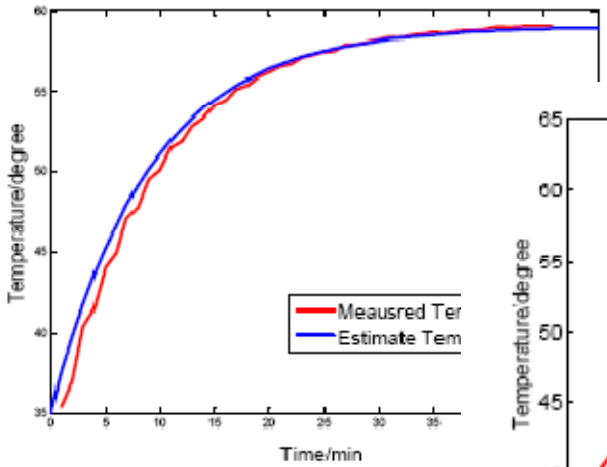


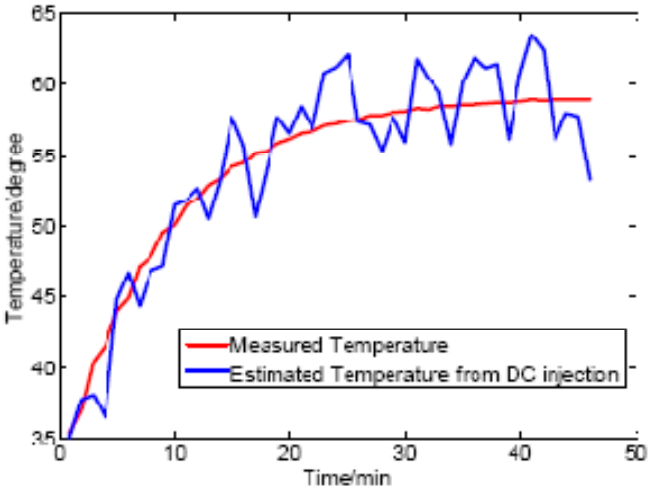
Winding Resistance/Temperature Estimation

- 37% of motor failures are caused by stator insulation breakdown ⇒ thermal overloading is one of the major causes
- Signal Injection-Based R_S (and Temperature) Estimation
- Inject signal in the stator → R_S estimate and Temperature estimate

Soft-starter

Drive





Estimation error less than 3%.

DC is injected every 1 minutes for a short period (0.5 sec)

→ *Sensorless, low-cost, and accurate !*

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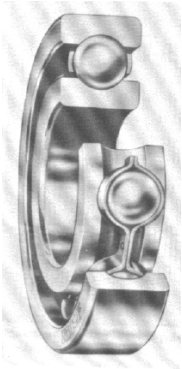
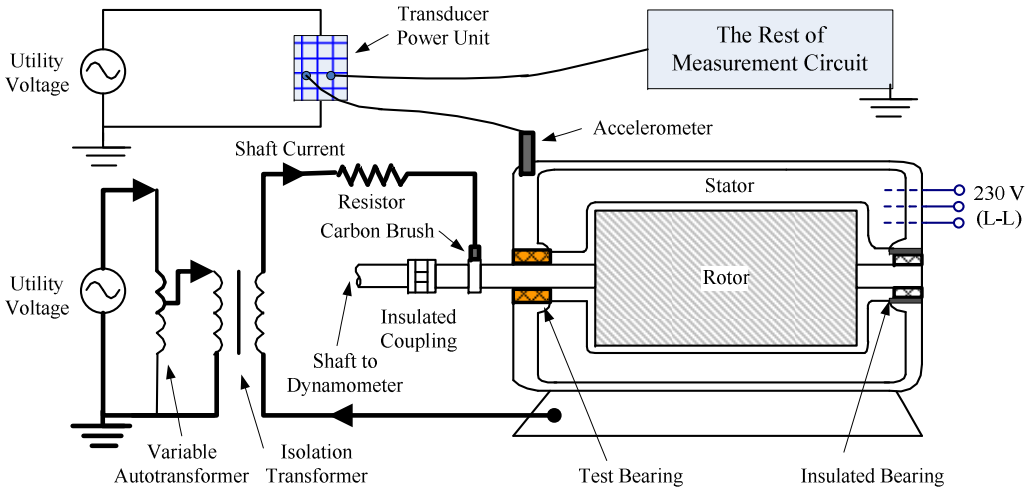
Bearing Fault Detection

- Bearing faults account for over 40% of all induction motor faults.
- Bearing faults classification
  - Single-point defects
    - Characteristic fault frequencies
  - Generalized roughness
    - More realistic of incipient faults
    - Difficult to detect for current monitoring

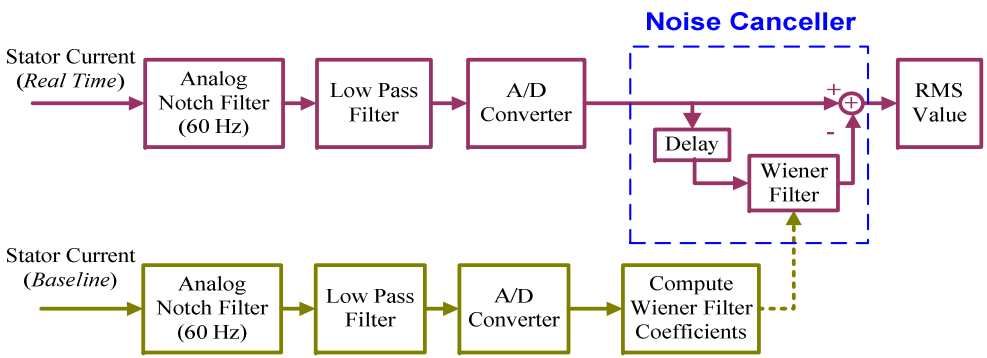


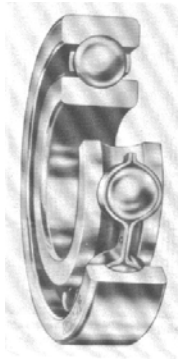
- Bearing Test Setup

  Accelerate bearing wearing process to <100 hours

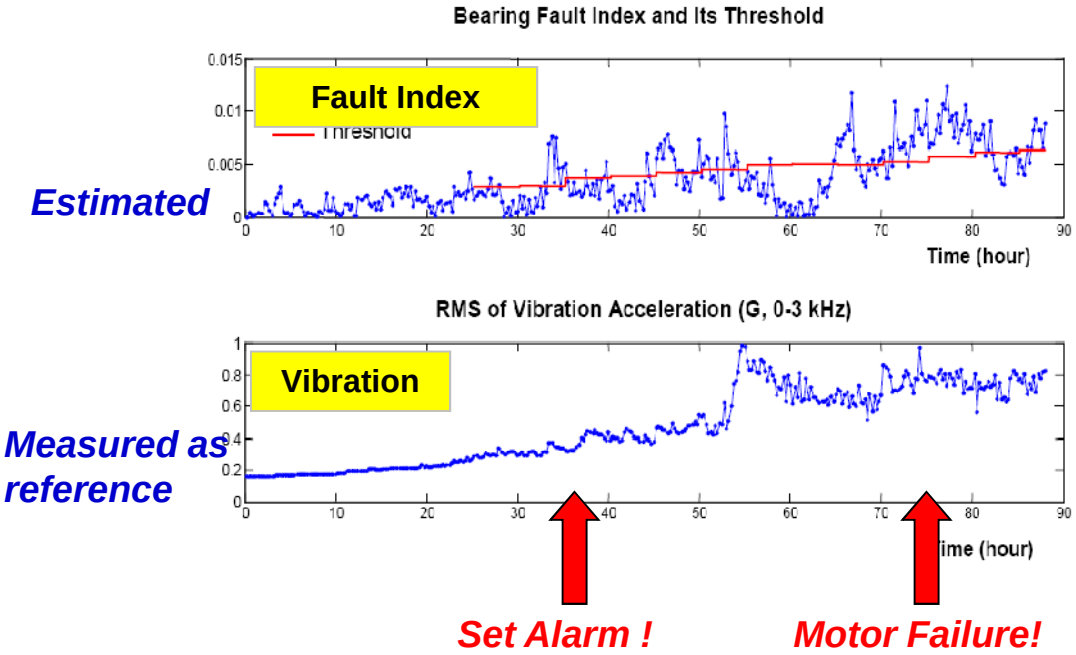


Bearing Fault Detection Algorithm using Noise-Cancellation





- Effective to detect incipient and developing bearing faults (before bearing breaks)
- Noise canceller adaptively eliminates correlated harmonic components, leaving uncorrelated frequency content as bearing fault index
- **None of the following are required:**
  - Machine parameters
  - Bearing dimensions
  - Nameplate values
  - High-resolution spectra analyzer.



Extensions to Wind

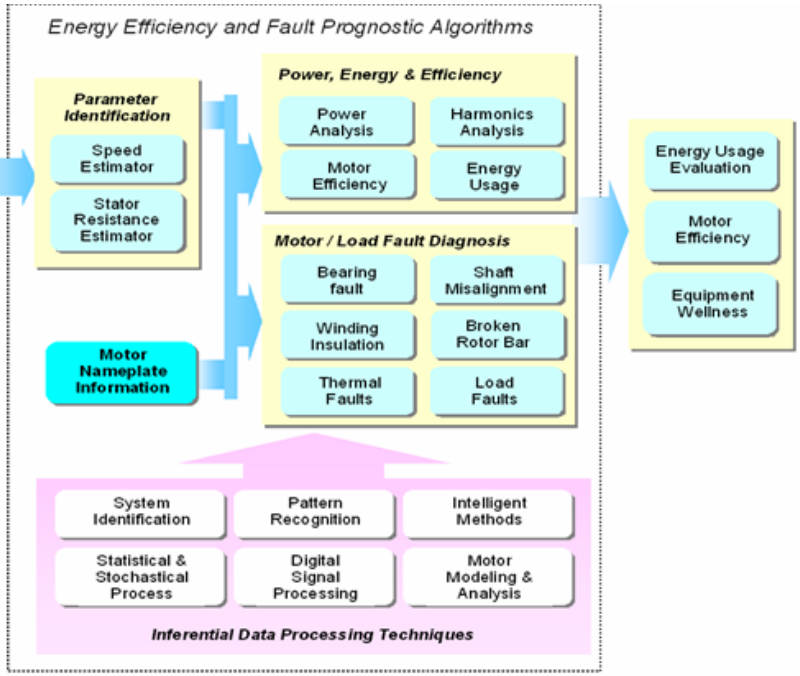
- Motor Current Signature Analysis technology may be possible for *induction* generator CBM
- Low cost complement to sensor-based CBM technologies (vibration, fluid condition, etc)
- Reliable – no sensors to fail!

Motor Currents

Motor Voltages

Motor Control Center

(Motor Terminals, meter, Starter, Breaker, Drive, etc.)



Nonintrusive, continuous, inferential

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Technical Challenges of Wind Application

- What is special about wind turbine CBM?
  - Variable speed and variable torque load
  - Time-varying and unsteady loads (wind gust)
  - Relative low shaft speed
- Unsteady wind load blurs the diagnostic signatures matured for other applications. Most existing CBM methods cannot be directly applied due to dynamic load.
- Adaptation of motor current spectral analysis (MCSA) techniques towards time-varying or time-frequency representations holds promise
- Scalability – How well do these CBM methods developed for relatively small motors (< 200 HP) scale-up to the large turbine generators?

Questions?

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