Introduction

The Multilin 869 motor protection relay provides a patented algorithm to detect rotor bar failure. The broken rotor bar feature includes the following:

- Increased accuracy in the detection of cracked or broken rotor bars during the motor running state by an enhanced power-based coherent demodulation technique. The combination of a voltage and current signature provides more accurate detection, compared to a typical current-based algorithm.

- Enhanced security of detection, with the broken rotor bar function automatically blocked during decaying voltage, low motor load, high current balance, motor starting etc. to ensure false alarms are minimized.
Fundamentals of Broken Rotor Bar Detection

Under healthy rotor conditions, the slip frequency \( s \cdot f_s \) will be the only current in the rotor. A broken rotor bar (BRB) creates an asymmetry in the rotor circuit, which in turn creates a negative rotating magnetic field at slip frequency \(-s \cdot f_s\) in the rotor, as shown in Figure 1.

![Figure 1: Rotor bar anomaly, and resultant induced rotor fault signature in stator currents](image)

This negative slip frequency component in the rotor creates the \( f_s \cdot (1-2s) \) component in the stator. This causes electromagnetic torque and speed oscillation at twice the slip frequency, resulting in \( f_s \cdot (1+2s) \) and other harmonics in the stator current at \( f_s \cdot (1\pm 2k\cdot s) \), where \( k \) is an integer and \( s \) is the slip.

The spectral components due to broken rotor bars can be expressed as: \( f_b = (1 \pm 2s) \cdot f_1 \). The lower component is due to broken bars, and upper one is due to a related speed oscillation. Since the broken rotor bar disturbances are of an “impulse nature” (not a pure sine wave), the broken rotor bar spectral components can be expressed more accurately as:

\[
 f_b = (1 \pm 2k\cdot s) \cdot f_1, \text{ where } k = 1, 2, 3...
\]

The amplitude of harmonic spectral components due to rotor bar defects, where \( k \geq 2 \), are dependent on the geometry of the fault. Their amplitude is significantly lower than the “main” sidebar component, and can be ignored in this analysis.

Advantages of Patented Power-Coherent Demodulation

Rotor bar defects in an induction motor cause modulation of the stator current; the impact on the stator current can be determined by analysis in the frequency domain. This approach to detecting rotor bar failure is also referred as Motor Current Signature Analysis (MCSA).

In the 869 relay, two different modes are combined to detect broken rotor bar components:

1. Current based FFT mode: If voltage is not available or the voltage magnitude is lower than the MOTOR VOLTAGE SUPERVISION setting value, the broken rotor bar detection algorithm analyses the frequency spectrum from current samples only to detect the broken rotor bar component.

2. Power Coherent Demodulation mode: This advanced technique uses multiplication of voltage and current samples, thereby shifting the fundamental frequency to DC and the fault frequency lower, and closer to the DC value, to detect the broken rotor bar component. This method is used when voltage is available and is higher than the MOTOR VOLTAGE SUPERVISION setting value.

Figure 2 shows Stator current in the time domain (top) and frequency domain (FFT spectrum, bottom) during a broken rotor bar event. It can be observed that the envelope of the stator current waveform is heavily modulated.
with the broken rotor frequency present at nearly ±5.7 Hz with respect to the fundamental frequency.

![Figure 1: Stator Current Waveform](image)

![Figure 2: Stator Current During a Broken Rotor Bar Event](image)

**Figure 2** Stator current during a broken rotor bar event

The patented power-based coherent demodulation method is based on the multiplication of the current signal with the supply fundamental frequency signal, which is readily available in the voltage signal. Hence, for coherent demodulation, the current signal is multiplied by the corresponding phase or line voltage signal $V_a \cdot I_a$. This approach allows an increase in contrast between fault signatures by shifting the fault characteristic frequency closer to the DC frequency in the spectrum.

The resultant power coherent demodulation signal from the multiplication of the stator current (from Figure 2) and voltage is shown in the Figure 3.

Comparison of two figures shows that the power-coherent demodulation method helps to clearly identify the fault component by moving the fundamental (i.e. supply frequency value) to DC. The fundamental 50Hz component in Figure 3 is at 0 Hz (DC) and small fault components at (50-5.7=) 44.3Hz and (50+5.7=) 56Hz are now combined with higher magnitude at 5.7 Hz. Power coherent demodulation creates a clear distinction between the fault signature and supply frequency, and consistently provides a measurable fault component.
Thus the power-based coherent demodulation method enhances sensitivity as well as security and confidence in the measurement of a broken rotor bar. Therefore, it is possible to detect early evolution of broken rotor bars as compared to conventional current-based method.

**Setting Guidelines**

The following figure is the Broken Rotor Bar setting screen as it appears in 8 Series setup software program:

The setting “Start of BRB offset” defines the beginning of the frequency range, where the spectral component is searched, while “End of BRB offset” defines the end of the frequency range, where the spectral component is searched.

The following guidelines are used to configure the Multilin 869 setpoints:

**Function**

The selection of Alarm, Latched Alarm or Configurable enables the Broken Rotor Bar function.
**Start of BRB Offset**
This setting defines the beginning of the frequency range where the spectral component due to a rotor bar failure is searched.

\[
\text{Start of BRB Offset (fstart\_offset)} = 2s*f1 - \max(0.3, \min(2s*f1 - 0.4, 1.0))
\]

where: 
- \( f1 \) = system frequency 
- \( s \) = the motor slip at full load 
- \( \max \) = returns the largest of its arguments 
- \( \min \) = returns the smallest of its arguments

**Calculation Example.**
When the full load slip is 0.01 at 60 Hz, 
\[
f_{\text{start\_offset}} = 2s*f1 - \max(0.3, \min(2s*f1 - 0.4, 1.0))
\]
Set point “Start of BRB offset” = \( 2 \times 0.01 \times 60 - \max(0.3, \min(2 \times 0.01 \times 60 - 0.4, 1.0)) \)  
\[
= 1.2 - \max(0.3, \min(0.8, 1.0))
\]
\[
= 1.2 - 0.8 = 0.40 \text{ Hz, for a 60 Hz power system.}
\]

**Set point “End of BRB offset”:**
This setting defines the end of the frequency range where the spectral component due to a rotor bar failure is searched.

\[
\text{End of BRB Offset (fend\_offset)} = 2s*f1 + \max(0.3, \min(2s*f1 - 0.4, 1.0))
\]

**Calculation Example.**
When the full load slip is 0.01 at 60 Hz,  
\[
\text{Set point “End of BRB offset”} = 2 \times 0.01 \times 60 + \max(0.3, \min(2 \times 0.01 \times 60 - 0.4, 1.0))
\]
\[
= 1.2 + \max(0.3, \min(0.8, 1.0))
\]
\[
= 1.2 + 0.8 = 2.00 \text{ Hz, for a 60 Hz power system.}
\]

**Start Block Delay**
This setting specifies the time for which the broken rotor bar detection algorithm is blocked after the motor status has changed from “Stopped” to “Running”. This ensures that the broken rotor bar element is active only when the motor is running.
Typically, this can be set to 60 s.

**Minimum Motor Load**
The Broken Rotor Bar detection algorithm cannot reliably determine the BRB spectral component when a motor is lightly loaded. This setting is used to block the data acquisition of the Broken Rotor Bar detection function, as long as the motor load is below this setting.
Typically, this can be set to 0.70 xFLA, which means that if motor load is below 0.7 xFLA, BRB detection is blocked to pass, and then automatically enabled once the load is above 0.7 xFLA.

**Maximum Load Deviation**
The Broken Rotor Bar detection algorithm cannot reliably determine the BRB spectral component when the motor load varies significantly. This setting is used to block the data acquisition of the Broken Rotor Bar detection function, as long as the standard deviation of the motor load is above this setting.
Typically, this can be set to 0.10 xFLA, which means that if load variations are above 0.1xFLA, the BRB detection is blocked for the duration, and then automatically enabled once the load stabilizes.

**Maximum Motor Load**
The Broken Rotor Bar detection algorithm cannot reliably determine the BRB spectral component during motor unbalance situations. This setting is used to block the data acquisition of the Broken Rotor Bar detection function, as
long as the current unbalance is above this setting. Typically, this can be set to 15%, which means if there is a motor unbalance above 15%, the BRB detection will be blocked for the duration, and then automatically enabled once the current stabilizes.

**Motor Voltage Supervision**

There are two different BRB algorithms that run in 869 relay depending upon the "MOTOR VOLTAGE SUPERVISION" setting. This setting is used to switch the detection technique from power-based coherent demodulation to current-based FFT detection when the minimum of the three phase-to-phase voltages falls below the configured value. This voltage is expressed as a percentage of the Setpoints > System > Motor > Motor Nameplate Voltage setting. This setting is hidden for non-voltage order code devices. Typically, this setting can be set to 50%.

**Pickup**

The “Component Level” shown in the 8 Series setup software under Metering > Motor > Broken Rotor Bar shows the dB level magnitude main side bands with respect to fundamental magnitude. The “Component Frequency” shows the frequency at which one of the main side bands has been detected. As shown in Error! Reference source not found., the commissioning engineer identifies the component level of the healthy rotor during 869 installation, and then configures the Broken Rotor Bar Pickup level setting to be around 15 dB above it this value. For example, if the component level for a healthy rotor is read as -70dB (shown in Error! Reference source not found.), then the Broken Rotor Bar pickup level should be set at around -60 dB to detect a cracked rotor, -55dB to detect one broken rotor bar, and so on.

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Level</td>
<td>-70.0 dB</td>
<td></td>
</tr>
<tr>
<td>Component Frequency</td>
<td>56.7 Hz</td>
<td></td>
</tr>
<tr>
<td>Motor load at BRB Calculation</td>
<td>0.80</td>
<td>x FLA</td>
</tr>
<tr>
<td>Load Dev. at BRB Calculation</td>
<td>0.01</td>
<td>x FLA</td>
</tr>
<tr>
<td>Time of BRB Calculation</td>
<td>09/02/17 05:43:35</td>
<td></td>
</tr>
<tr>
<td>Maximum Component Level</td>
<td>-70.0 dB</td>
<td></td>
</tr>
<tr>
<td>Maximum Component Freq</td>
<td>56.7 Hz</td>
<td></td>
</tr>
<tr>
<td>Motor load at BRB Maximum</td>
<td>0.80</td>
<td>x FLA</td>
</tr>
<tr>
<td>Load Dev. at BRB Maximum</td>
<td>0.01</td>
<td>x FLA</td>
</tr>
<tr>
<td>Time of Maximum BRB</td>
<td>09/02/17 02:23:44</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5 Multilin 869 Metering screen
Broken Rotor Bar Testing

Testing the 869 relay settings

The test case settings described in this section are for a system frequency of 60 Hz and motor slip of 0.1%, therefore component frequencies are very close to each other and the fundamental and main side band frequencies are also very close.

1. Calculate the Start of BRB Offset and End of BRB Offset, as discussed above:

   **Start of BRB Offset:**
   \[ f_{\text{start\_offset}} = 2 \times s \times f_1 - \max(0.3, \min(2 \times s \times f_1 - 0.4, 1.0)) \]
   \[ = 2 \times 0.001 \times 60 - \max(0.3, \min(2 \times 0.001 \times 60 - 0.4, 1.0)) \]
   \[ = 0.12 - \max(0.3, \min(0.12-0.4, 1.0)) \]
   \[ = 0.12 - \max(0.3, -0.28) = 0.12 - 0.3 = -0.18 \text{ Hz} \]

   **End of BRB Offset:**
   \[ f_{\text{end\_offset}} = 2 \times s \times f_1 + \max(0.3, \min(2 \times s \times f_1 - 0.4, 1.0)) \]
   \[ = 2 \times 0.001 \times 60 + \max(0.3, \min(2 \times 0.001 \times 60 - 0.4, 1.0)) \]
   \[ = 0.12 + \max(0.3, \min(0.12-0.4, 1.0)) \]
   \[ = 0.12 + \max(0.3, -0.28) = 0.12 + 0.3 = 0.42 \text{ Hz} \]

2. Configure the Broken Rotor Bar setting as shown:

3. Inject the following current value in the phase A current terminal of the relay:
   
   System frequency = 60Hz,
   
   Fundamental = 0.80 pu @ 60.00Hz,
   
   lower main side band signal = 0.010 pu @ 59.88,
   
   upper main side band signal = 0.010 pu @ 60.12Hz

   **Note:** Make sure that the “Motor Load” value under Metering > Motor > Motor load is > 0.50 x FLA
4. With current injection continuing, browse to the screen Metering> Motor> Broken Rotor Bar in the software and record the Component level and Component frequency:

<table>
<thead>
<tr>
<th>Expected BRB Component level</th>
<th>Actual BRB Component level</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>-38 dB</td>
<td>-38.3 dB</td>
<td>Pass</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected BRB Component frequency</th>
<th>Actual BRB Component frequency</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.88 or 60.12 Hz</td>
<td>60.1 Hz</td>
<td>Pass</td>
</tr>
</tbody>
</table>

5. Since the metered value (-38.3 dB here) is greater than the pickup setting (-40 dB), the following events can be seen:
   a. On the front panel, the “Pickup” LED can be seen glowing and the “Alarm” LED can been seen flashing
   b. The target message shows “BRB ALARM OP” message
   c. “BRB ALARM PKP” & “BRB ALARM OP” events are logged in the event recorder

Test on a motor with known broken rotor bar

At a motor workshop, the broken rotor bar detection test has been performed on a motor with name plate details of 415V, 26 A and 50 Hz.

During the test, settings in the 869 relay were configured as shown below:

![Figure 7 Test BRB settings, actual motor](image)

The result is shown below where -50.8 dB represents the condition of potential BRB condition,

![Figure 8 Test BRB metering settings, actual motor](image)
Summary

A proprietary algorithm combining current-based frequency analysis and power-coherent demodulation provides accurate broken rotor bar detection, paired with effective blocking of the function to minimize false alarms in the 8 Series Multilin 869 relay. This document describes the BRB algorithm, and gives guidelines for configuring the 869 relay, including a test example.

For further assistance

For product support, contact the information and call center as follows:
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