GE
Grid Solutions

Multilin 8 Series

869 Broken Rotor Bar Detection

Application Note

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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 ($s \cdot fs$) 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 ($- s \cdot fs$) in the rotor, as shown in Figure 1.

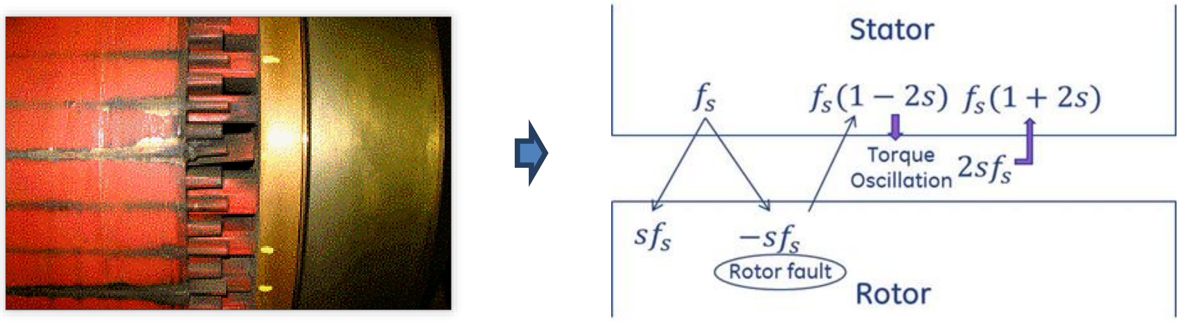


Figure 1: Rotor bar anomaly, and resultant induced rotor fault signature in stator currents

This negative slip frequency component in the rotor creates the $fs \cdot (1\text{-}2\cdot s)$ component in the stator. This causes electromagnetic torque and speed oscillation at twice the slip frequency, resulting in $fs \cdot (1+2\cdot s)$ and other harmonics in the stator current at $fs \cdot (1\pm 2\cdot k\cdot s)$, 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:

$$f_s = (1 \pm 2\cdot k\cdot s) \cdot f_1, \text{ where } k = 1,2,3...$$

The amplitude of harmonic spectral components due to rotor bar defects, where k >= 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.

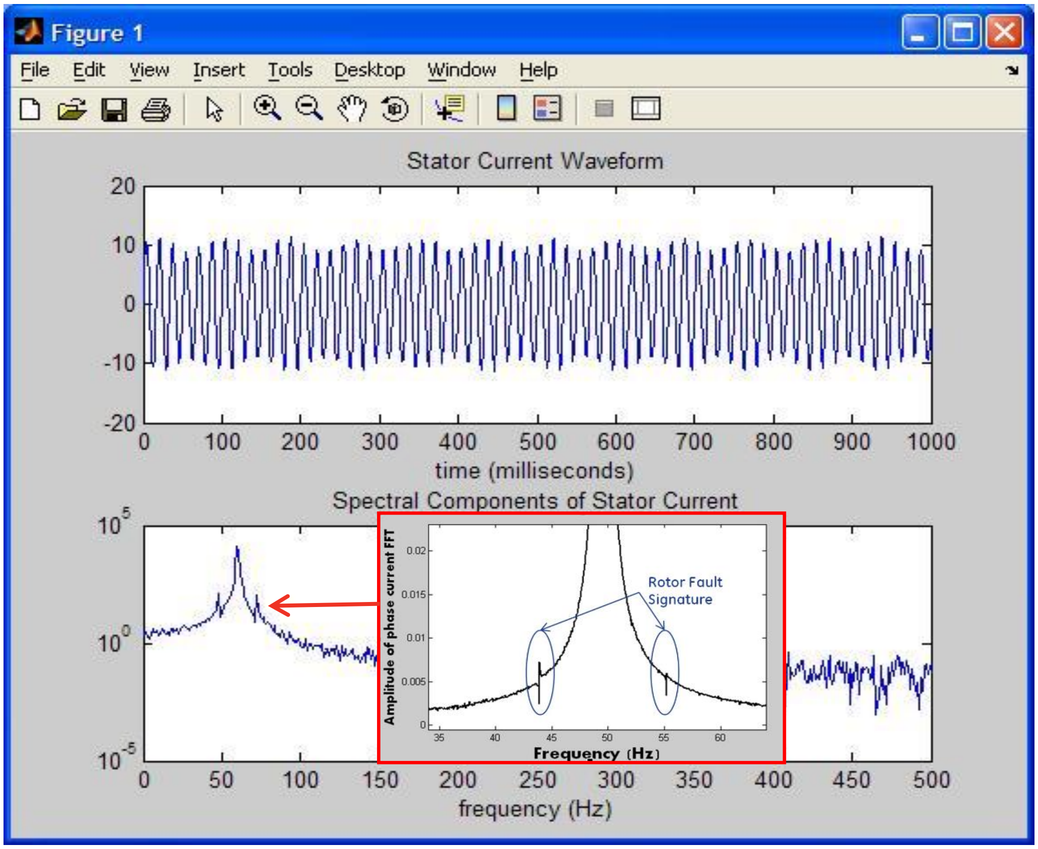


Figure 2 Stator current during a broken rotor bar event

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 Va·Ia. 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 distiction between the fault signature and supply frequency, and consistenly provides a measurable fault component.

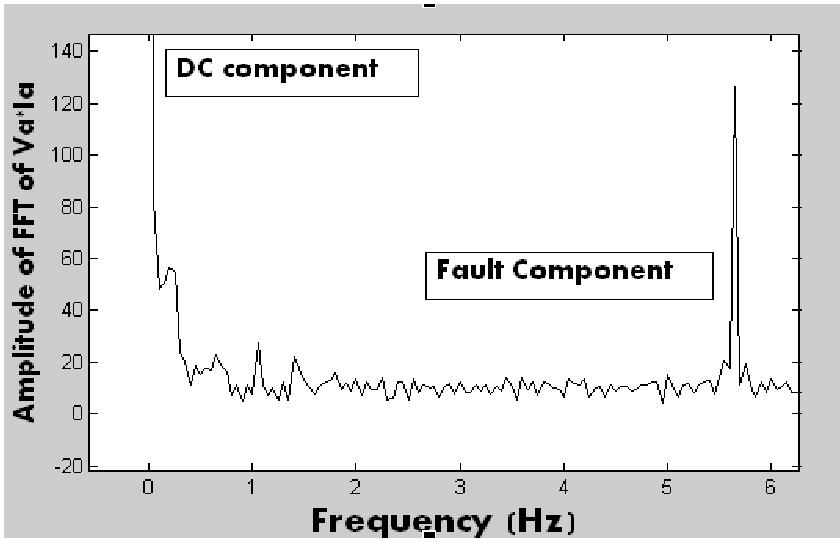
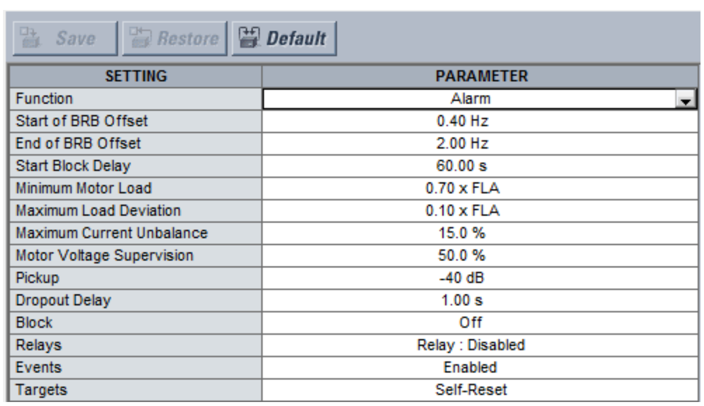


Figure 3 Resultant power coherent demodulation signal during BRB

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 the EnerVista 8 Series Setup software program:



Save Restore Default

SETTING	PARAMETER
Function	Alarm
Start of BRB Offset	0.40 Hz
End of BRB Offset	2.00 Hz
Start Block Delay	60.00 s
Minimum Motor Load	0.70 x FLA
Maximum Load Deviation	0.10 x FLA
Maximum Current Unbalance	15.0 %
Motor Voltage Supervision	50.0 %
Pickup	-40 dB
Dropout Delay	1.00 s
Block	Off
Relays	Relay : Disabled
Events	Enabled
Targets	Self-Reset

Figure 4 Multilin 869 setting screen

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.

Start of BRB Offset (fstart_offset) = 2*s* f1 – max(0.3, min(2*s* 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,

fstart_offset = 2*s* f1 – max(0.3, min(2*s* f1 – 0.4, 1.0))

Set point "Start of BRB offset" = 2*0.01*60 – max(0.3, min(2*0.01*60 – 0.4, 1.0))

= 1.2- max(0.3, min(0.8,1.0))

=1.2 - 0.8 = 0.40 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.

End of BRB Offset (fstart_offset) = 2*s* f1 + max(0.3, min(2*s* f1 – 0.4, 1.0))

Calculation Example,

When the full load slip is 0.01 at 60 Hz ,

Set point "End of BRB offset" = 2*0.01*60 + max(0.3, min(2*0.01*60 – 0.4, 1.0))

= 1.2 + max (0.3, min (0.8,1.0)

= 1.2 + 0.8 = 2.00 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 EnerVista 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 the following figure, 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 below), 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.

Metering\Motor\Broken Rotor Bar

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

BRB

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 :

   fstart_offset = 2*s* f1 – max(0.3, min(2*s* f1 – 0.4, 1.0))

   = 2 * 0.001* 60 – max (0.3, min (2 * 0.001* 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 Hz

   End of BRB offset:

   fend_offset = 2*s* f1 + max(0.3, min(2*s* f1 – 0.4, 1.0))

   = 2 * 0.001* 60 + max (0.3, min (2 * 0.001* 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 Hz

2. Configure the Broken Rotor Bar setting as shown:

SETTING	PARAMETER
Function	Alarm
Start of BRB Offset	-0.18 Hz
End of BRB Offset	0.42 Hz
Start Block Delay	5.00 s
Minimum Motor Load	0.50 x FLA
Maximum Load Deviation	1.00 x FLA
Maximum Current Unbalance	100.0 %
Motor Voltage Supervision	50.0 %
Pickup	-40 dB
Dropout Delay	1.00 s
Block	Off
Relays	Relay : Disabled
Events	Enabled
Targets	Self-Reset

Figure 6 BRB test settings

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:

Expected BRB Component level	Actual BRB Component level	Results
-38 dB	-38.3 dB	Pass

Expected BRB Component frequency	Actual BRB Component frequency	Results
59.88 or 60.12 Hz	60.1 Hz	Pass

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:

SETTING	PARAMETER
Function	Alarm
Start of BRB Offset	0.00 Hz
End of BRB Offset	11.99 Hz
Start Block Delay	10.00 s
Minimum Motor Load	0.50 x FLA
Maximum Load Deviation	0.10 x FLA
Maximum Current Unbalance	15.0 %
Motor Voltage Supervision	50.0 %
Pickup	-54 dB
Dropout Delay	1.00 s
Block	Off
Relays	Relay : 2-4
Events	Enabled
Targets	Latched

SETTING	PARAMETER
Component Level	-50.8 dB
Component Frequency	58.68 Hz
Motor load at BRB Calculation	0.79 x FLA
Load Dev. at BRB Calculation	0.01 x FLA
Time of BRB Calculation	01/01/08 01:43:35
Maximum Component Level	-28.0 dB
Maximum Component Freq	49.98 Hz
Motor load at BRB Maximum	0.73 x FLA
Load Dev. at BRB Maximum	0.04 x FLA
Time of Maximum BRB	01/01/08 00:41:18

SETTING	PARAMETER
Motor Full Load Amps (FLA)	20 A
Motor Overload Factor	1.00
Motor Nameplate Voltage	415 V
Emergency Restart	Off
Number of Starts to Learn	3
Load Average Calc. Period	15 min
Switching Device Type	Breaker
Motor Load Filter Interval	0 cycles

Figure 7 Test BRB settings, actual motor

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

SETTING	PARAMETER
Component Level	-50.8 dB
Component Frequency	58.68 Hz
Motor load at BRB Calculation	0.79 x FLA
Load Dev. at BRB Calculation	0.01 x FLA
Time of BRB Calculation	01/01/08 01:43:35
Maximum Component Level	-28.0 dB
Maximum Component Freq	49.98 Hz
Motor load at BRB Maximum	0.73 x FLA
Load Dev. at BRB Maximum	0.04 x FLA
Time of Maximum BRB	01/01/08 00:41:18

Figure 8 Test BRB metering settings, actual motor

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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