GE
Grid Solutions

Multilin 8 Series

869 Stator Inter-turn Fault Detection

Application Note

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Overview

If stator inter-turn faults are not properly detected, the fault current causes severe localized heating and the fault rapidly spreads to a larger section of the winding, consequently resulting in a sequential phase-to-ground or phase-to-phase fault. If the fault is detected at its early stage, machine shutdown can be planned and accurate repair actions may be taken, such as re-winding. If preventative maintenance does not take place, once the fault propagates and the motor is forced out of service, a huge downtime is needed to replace the motor. The 869 motor protection system provides advanced detection of stator inter-turn faults using sequence components. The 869 stator inter-turn fault detection algorithm can help detect an inter-turn fault before it evolves to insulation breakdown, minimizing unplanned system downtime.

This application note first discusses the 869 methodology used to detect stator inter-turn faults and then discusses setting recommendations to properly program the protection element.

Stator inter-turn fault detection algorithm

The steady-state sequence component equation in matrix form is given as:

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{pp} & Z_{pn} \\ Z_{np} & Z_{nn} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Where

V_1/V_2 = positive/negative sequence voltages

I_1/I_2 = positive/negative sequence currents

Z_{pp}/Z_{nn} = positive/negative sequence impedances

Z_{np}/Z_{pn} = cross-coupled negative-to-positive/positive-to-negative sequence impedances

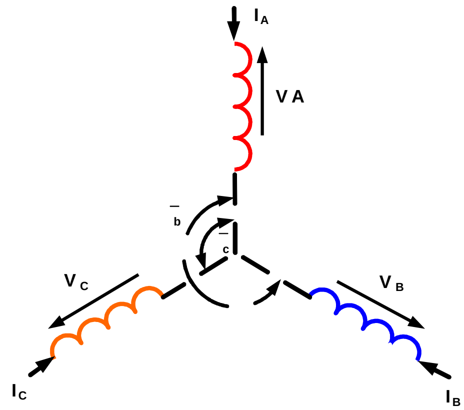

Figure 1: Stator winding with stator inter-turn fault on phase A

For an ideal, perfectly symmetrical machine, the off-diagonal elements of the matrix above are zero, signifying a decoupled positive and negative sequence component circuit for the induction machine. The normalized cross-coupled impedance (the ratio of Z_{np} to Z_{pp}) is the key operating signal that can effectively detect a stator inter-turn fault. From the matrix above, the ratio of Z_{np} to Z_{pp} can be computed as:

$$\frac{Z_{np}}{Z_{pp}} = \frac{V_2 - Z_{nn} I_2}{V_1}$$

However, in practice the situation is not ideal, and due to inherent asymmetry in the machine the Z_{pn} and Z_{np} values are small non-zero quantities. When an inter-turn fault occurs, the asymmetry in the system is further aggravated which results in an increase in these cross-coupling terms. The inherent asymmetry in the machine at the time of commissioning and without a stator inter-turn fault is represented as:

$$Z_{UBbase} = \left(\frac{Z_{np}}{Z_{pp}} \right) \text{at 0 inter - turn fault}$$

The 869 Stator inter-turn fault algorithm learns (in the learning phase) the unbalance impedance (Z_{UBbase}) due to inherent asymmetry in the machine and compensates for this asymmetry using the following fault monitoring operating condition:

$$OP = \frac{Z_{np}}{Z_{pp}} - Z_{UBbase}$$

During monitoring (in the monitoring phase) of the stator inter-turn fault, the ratio of Z_{np} to Z_{pp} equals zero, while it is greater than zero during inter-turn fault conditions.

Having compensated for the inherent asymmetry feature, the operating threshold level can be programmed to a near-zero level to detect even the small percentage of the shorted turns.

Features of the 869 stator inter-turn fault algorithm

- Novel cross-coupled impedance-based inter-turn fault detection (patent protected)
- Load independent algorithm: Since the equation does not involves the positive sequence current that essentially is the load current, the parameters of interest remain the same under different load conditions.
- Robustness to System unbalance: Any supply voltage unbalance gives rise to a negative sequence component in voltage. This causes an increase in the negative sequence current distinct from the negative sequence current resulting from an inter-turn fault. The equation compensates for the effect of voltage unbalance, and responds only to the latter current.
- Machine independent: The parameter Z_{np} is machine dependent, i.e. it depends on power, voltage, pole and frequency rating of the machine. However, once it is normalized with respect its own base impedance (Z_{pp}) the ratio is independent of the machine rating. This enables the setting of a uniform threshold across all machine ratings.
- Algorithm insensitive to measurement error, with novel compensation
- Model-based normalized Z_{nn} estimation
- Unified threshold for machines of different power ratings

Setting Guidelines

This section explains Stator Inter-turn Fault element setpoints and provide guidelines to properly program the 869 Stator inter-turn Fault element.

Setpoints\Monitoring\Stator Inter-Turn Fault		
Item Name	Value	Unit
Function	Disabled	
Neg Seq Imp Autoset	Auto	
Neg Seq Impedance	10.00	ohms
Pickup Stage 1	0.100	
Pickup Delay Stage 1	0.00	s
Pickup Stage 2	0.600	
Pickup Delay Stage 2	1.00	s
Dropout Delay	0.00	s
Learn Turn Fault Data	No	
Block	Off	
Relays	Do Not Operate	
Events	Enabled	
Targets	Self-Reset	
Turn Flt		

NEG SEQ IMP AUTOSET

The stator inter-turn fault algorithm requires negative sequence impedance (Z_{nn}), which can be manually programmed or calculated automatically by the relay.

In case Z_{nn} is not available, the 869 uses the heuristic method of approximating this impedance value based on the motor ratings available in the motor nameplate data – Voltage (rms, L-L), Power (HP) and Poles. For the 869 relay to automatically approximate the Znn value, setpoint "Neg Seq Imp Autoset" must be set to Auto.

When the setpoint "Neg Seq Imp Autoset" is set to Manual, user manually programs the negative sequence impedance (Z_{nn}) under setpoint 'NEG SEQ IMPEDANCE', as explained below.

NEG SEQ IMPEDANCE

This setting is only visible when setpoint 'Neg Seq Imp Autoset' is set to Manual. This setting defines the negative sequence impedance Z_{nn} calculated or obtained by the user. Z_{nn} can be obtained directly from the motor manufacturer or can be calculated from motor parameters.

From the equivalent circuit model of the motor, having stator/rotor resistances (Rs/Rr) and inductances (Ls/Lr), mutual inductance (Lm) and rated slip (s), the following relationship can be used to calculate Z_{nn}:

$$Z_{nn} = (R_s + jX_s) + \frac{jX_m\left(\frac{R_r}{2-s} + jX_r\right)}{\frac{R_r}{2-s} + j(X_r + X_m)}$$

The parameters used in the equation above can be obtained from the motor data sheet provided with the motor by the manufacturer.

PICKUP STAGE 1(2)

869 Stator inter-turn element operates when the OP quantity exceeds the corresponding program pickup level defined by the setpoints Pickup Stage 1 and Pickup Stage 2. These settings specify the pickup threshold ratio between Znp and Zpp averaged over 100 msec. There is no unit to the pickup setting.

As mentioned earlier, the 869 Stator inter-turn fault algorithm compensates unbalance impedance (Z_{UBbase}) due to inherent asymmetry in the machine from the operating quantity 'OP' as defined by the below relation.

$$OP = \frac{Z_{np}}{Z_{pp}} - Z_{UBbase}$$

Having compensation of the inherent asymmetry(Z_{UBbase}), threshold levels (setpoint names "Pickup Stage 1" and "Pickup Stage 2") can be programmed to a near zero level in order to detect even the small percentage of shorted turns in the early stages of an inter-turn fault.

Actual value of the 'Operating Quantity', averaged over the window of 100msec, can be seen under metering values of the Stator Inter-turn Fault (path: Metering\Motor\Stator Inter-Turn Fault). Having compensation of the inherent asymmetry(Z_{UBbase}), under no inter-turn fault condition the operating quantity equals zero, as shown in the screen-shot of metering values below.

Actual value 'Max. Operating Quantity' represents the maximum of the operating quantity during the window of 100msec.

Metering\Motor\Stator Inter-Turn Fault		
Item Name	Value	Unit
Operating Quantity	0.000	
Learned Unbal Z	0.020	
Time of Learned Unbal Z Calc	31/07/17 11:08:00	
Max. Operating Quantity	0.000	
Max. Learned Unbal Z	0.020	
Turn Flt		

The parameter Z_{np} is machine dependent, i.e. it depends on the power, voltage, pole and frequency rating of the machine. However, once it is normalized with respect its own base impedance (Z_{pp}), the ratio is independent of the machine rating. This allows for a uniform threshold setting across all machine ratings. The following figure shows the machine independency of the algorithm, proven analytically. It can be observed from the figure that the level of Z_{np}/Z_{pp} for similar fault conditions is predicted to be in the same zone.

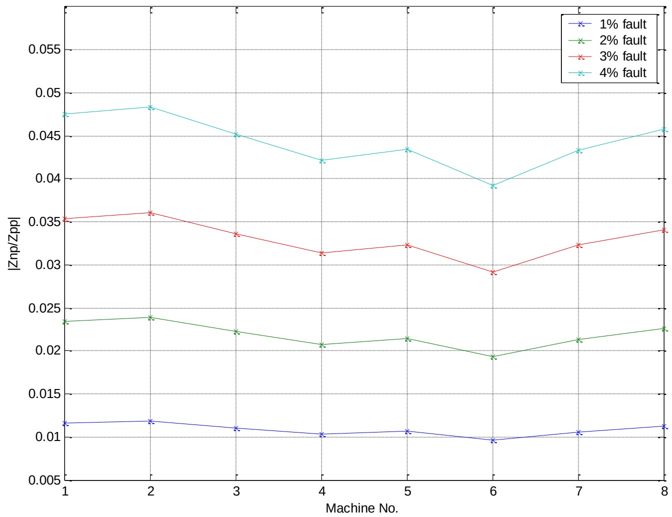

Figure 2: Simulation results of machine independent of algorithm

And thus, pickup threshold can be determined from the curve below.

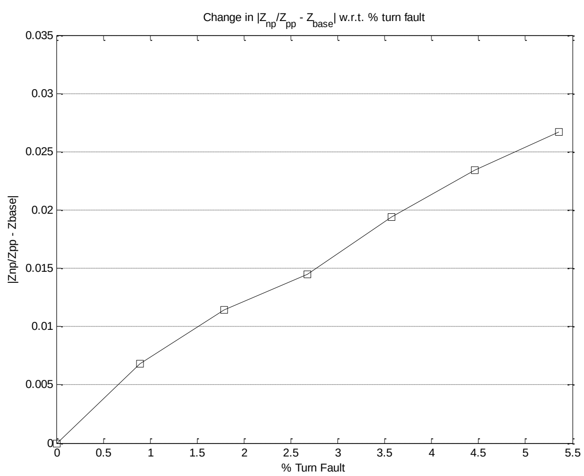

Figure 3: Experimental results of a change in Znp/Zpp norm with an increase in total turn fault

For instance, in order to detect 3% (of total winding turns) length of shorted-turns, user must program Pickup Stage 1(2) equal to 0.015, as suggested by Figure 3.

PICKUP DELAY STAGE 1(2)

These settings provide selection for pickup time delay used to delay the operation of the protection.

LEARN TURN FAULT DATA

The 869 relay learns the Z_{UBbase} (unbalance due to inherent asymmetry in the machine) for a given setup of CTs, PTs and machine rating. The learning phase can be initiated if any of the following conditions is true:

1. The setpoint "Learn Turn Fault Data" is set to Yes
2. Negative sequence impedance is changed manually
3. Negative sequence impedance is changed automatically by the relay due to any change in motor ratings (voltage, HP, poles).

Under any of the conditions listed above, the 869 stator inter-turn fault algorithm goes into a learning phase.

Once the 869 Stator inter-turn algorithm goes into the learning phase, the monitoring phase algorithm is suspended while the learning algorithm acquires a new set of Z_{UBbase} values. The monitoring phase remains disabled until Z_{UBbase} is calculated, at which point the monitoring phase resumes using the newly determined values.

Once the learning phase is complete, the monitoring phase runs continuously, checking for the operating signal, and alarms whenever it exceeds the programmed pickup level.

Actual value of the learned unbalance impedance (Z_{UBbase}) 'Learned Unbal Z' averaged over the window of 100msec, can be seen under metering values of Stator Inter-turn Fault, as shown in the screen-shot of metering values below.

Actual value 'Max. Learned Unbal Z' represents the maximum value of the learned unbalance impedance during the window of 100msec. Whereas 'Time of Learned Unbal Z Calc' represents the time when learning phase has finished the calculation of last averaged Unbalance Base Impedance (Z_{UBbase}).

Metering\Motor\Stator Inter-Turn Fault

Item Name	Value	Unit
Operating Quantity	0.000	
Learned Unbal Z	0.020	
Time of Learned Unbal Z Calc	31/07/17 11:08:00	
Max. Operating Quantity	0.000	
Max. Learned Unbal Z	0.022	

Turn Flt

Summary

Using the innovative inter-turn fault algorithm, an 869 relay can be used to detect stator inter-turn faults before serious damage occurs. Compensation of unbalance impedance due to any inherent asymmetry from the operating quantity makes this element sensitive to even a small number of shorted turns. This document has provided guidelines to properly program the element settings.

For further assistance

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

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