Grid Solutions

GE Multilin Technical Note

High-impedance differential protection in the MIB relay

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Foreword

GE Multilin's MIB Differential Protection Relay is a digital, microprocessor-based relay equivalent in function to GE Multilin's PVD high speed, electromechanical differential relay. The MIB has all the advantages of an electromechanical numerical relay, with the added benefits of microprocessor-based relays including communications, configurable logic, as well as events and diagnostics. Both the MIB and PVD have the same high impedance operating principle, with the same limiting criteria of maximum short circuit current calculated from the number of feeders and the calculation of the minimum short circuit current.

Maximum number of feeders

The criterion limiting the number of feeders is the minimum short circuit current available to operate the relay. This is because a portion of the current fault will circulate through the excitation path of the CTs in case of internal faults.

Using the formulas developed for the PVD for 30 feeders, we have:

- Number of breakers: 30
- Maximum breaker interrupting rating: 40000 A
- Cable resistance for longest run: 0.5 ohms at 25°C
- CT ratio: 1200/5

The characteristics for the CT are shown in Figure 2. The value of R_S from this figure is:

$$R_s = 0.0029 \times 240 + 0.113 = 0.809 \text{ ohms} \qquad \textbf{(EQ 1)}$$

The cable resistance for the longest CT run is given at 25°C. If higher operating temperatures are expected, this must be taken into account to determine the maximum expected resistance. Resistance values of wire at 25°C, or at any temperature t_1, may be corrected to any other temperature t_2 as follows:

$$R(\text{at } t_2) = (1 + P_1(t_2 - t_1))R(\text{at } t_1) \qquad \textbf{(EQ 2)}$$

where: R (at t_1) = resistance in ohms at t_1
R (at t_2) = resistance in ohms at t_2
P_1 = temperature coefficient of resistance at t_1

For standard annealed copper, $P_1 = 0.00385$ at $t_1 = 25$ °C, the value of R_L at 50°C is $R_L = 0.548$ ohms.

The CT performance factor must be determined next. First, calculate the following:

$$\frac{(R_s + PR_L)I_F}{E_S N} \qquad \textbf{(EQ 3)}$$

Using $P = 2$ and the knee point $E_S = 300$ V from figure 2, we have:

$$\frac{(R_s + PR_L)I_F}{E_S N} = \frac{(0.809\ \Omega + 2 \times 0.548\ \Omega) \times 40000\ \text{A}}{300\ \text{V} \times 240} = 1.06 \qquad \textbf{(EQ 4)}$$

From the figure below, we have $K = 0.7$ at 1.06.

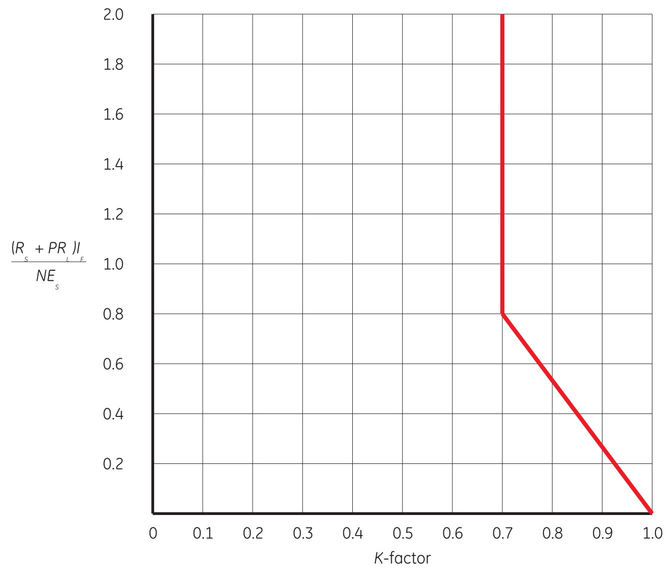

Figure 1: CT factor performance

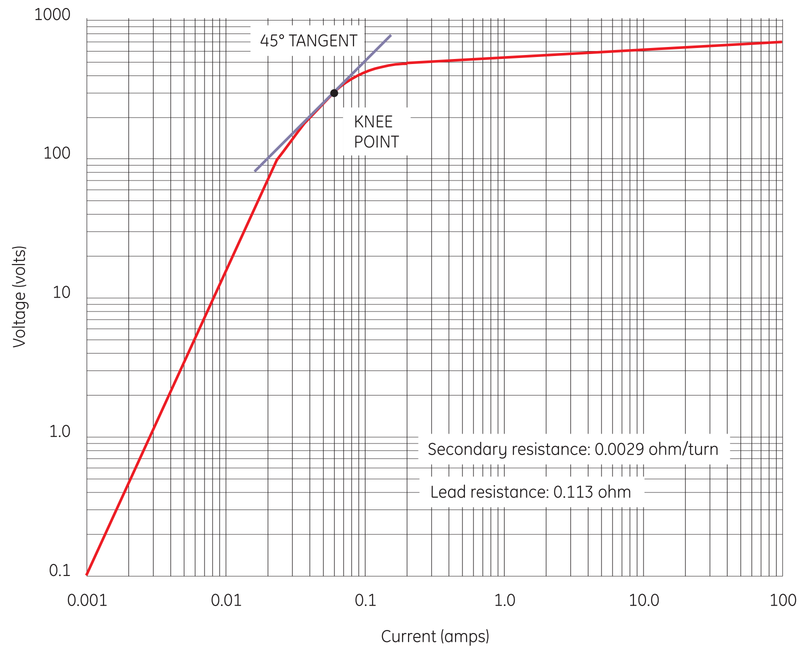

Figure 2: 1250/5 A CT saturation curve

The equation for calculating the I_{pickup} setting, taking CT performance[1] and margin into account, is as follows:

$$I_{pickup} = 1.6K(R_s + PR_L)\frac{I_F}{2000N} \quad \textbf{(EQ 5)}$$

Given our values for K, R_S, P, R_L, and N, we have

$$\begin{aligned} I_{pickup} &= 1.6K(R_s + PR_L)\frac{I_F}{2000N} \\ &= 1.6(0.7)(0.809\Omega + 2 \times 0.548\Omega)\frac{40000\text{ A}}{2000 \times 240} = \frac{355\text{ V}}{2000\Omega} = 177.5\text{ mA} \end{aligned} \quad \textbf{(EQ 6)}$$

If we assume that the maximum internal fault current is 45000 primary amperes (equivalent to 188 secondary amperes), the curve of figure 3 (at 300 V and 188 A) shows that the application is appropriate for either PVD and MIB relays.

1. The CT performance factor is based on bushing CTs from North America. In European applications, the factor used is 1.

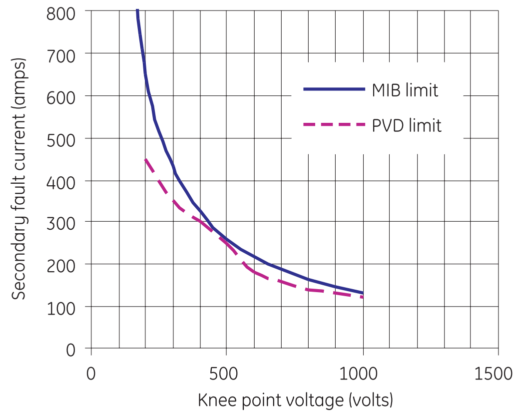

Figure 3: Safe limits of application

The next step is to determine the sensitivity of the relay to internal faults. This may be done using the following equation:

$$I_{min} = \left(\sum_{x=1}^{n} I_x + I_R + I_1 \right) N \quad \textbf{(EQ 7)}$$

where: I_{min} is the minimum internal fault current to trip
n is the numbers of breakers connected to the bus (i.e. CTs per phase)
I is the secondary excitation current of individual CTs at a voltage equal to the 87L pickup
I_R is the current through the MIB unit to pickup the relay
I_1 is the current in the MOV (thyrite) at pickup voltage (pickup current x 2000) [2]
N is the CT ratio

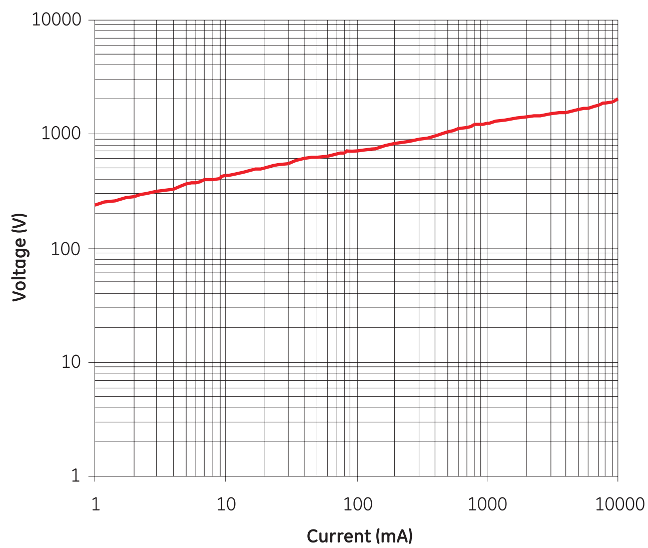

Figure 4: MOV voltage and current characteristics

2. Refer to page 2-9 of the MIB instruction manual, publication number GEK-106426A.

For 30 breakers, the minimum fault current is:

$$I_{min} = \left(\sum_{x=1}^{n} I_x + I_R + I_1\right)N \qquad \textbf{(EQ 8)}$$

$$= (30(0.07\text{ A}) + 0.004\text{ A} + 0.178\text{ A}) \times 240$$

$$= 548\text{ primary amps}$$

Repeating the calculation for 40 breakers, the minimum fault current becomes:

$$I_{min} = \left(\sum_{x=1}^{n} I_x + I_R + I_1\right)N \qquad \textbf{(EQ 9)}$$

$$= (40(0.07\text{ A}) + 0.004\text{ A} + 0.178\text{ A}) \times 240$$

$$= 716\text{ primary amps}$$

Conclusions

As we can see, the main limiting factor in regards to the number of feeders an MIB can support is dictated by the minimum fault current available. In theory, if we have enough short circuit current and a correct CT dimensioning, there is no limitation in the number of feeders.

The other limitation is thermal in nature, driven by the presence of any considerable level of short circuit generated during an internal fault. See the Appendix for details.

The stabilizing resistor and MOV (thyrite) have been designed, on a base case, to support 50000 primary amperes for internal faults with CTs of 1250/5 A, and total operating time of 40 ms (this time is calculated through the sum of the relay, MOV short circuit latching relay, resistor, and MIB current input). If the expected fault current is higher (or lower CT ratios), or the user decides not to use the 86 unit to protect the elements in the differential path, it's recommended that the GE Multilin application team be consulted to analyze the design of the specific application.

In general, one can summarize that the MIB limitations are similar to those of the PVD and their application range is the same.

It is important to note that an application of the PVD requires the use of an external 86 unit (generally a HSA relay model) to protect the internal stabilizing resistors and Thyrites. The GE Multilin HID (external module containing the resistor and Thyrite used within the MIB) module incorporates the 86 unit. In the event that one requires the use of a special HID module without an 86 function, it is required to use an external 86 unit, as is recommended with the PVD scheme.[3]

Finally, to apply the MIB, the following information must be obtained:

- Minimum short circuit current during internal faults
- Maximum short circuit current during internal faults
- Maximum through current during external faults
- CT ratio of all the CTs
- Saturation curve of all CTs
- Secondary CT resistance for all CTs
- Maximum CT secondary loop impedance (resistance of the lead that connect the CT with the relay)
- Number of feeders in the substation

3. Refer to figure 4 of GEK-45405A.

References

1. GE Multilin publication GEK-45405A: Differential Voltage Relays.
2. GE Multilin publication GEK-106426A: MIB Relay

Appendix

Limitation of internal components based on the maximum fault current

One of the limitations imposed on the relay is the maximum fault current that can circulate without damage the relay inputs (*R*), the stabilizing resistor (2 kΩ resistor) and Thyrite.

The specifications of each unit is as follows:

- Relay inputs: 100 A for 1 second
- Stabilizing resistor: 75 watts permanently, 750 watts for 1 second
- Thyrite: 5400 joules (watt-seconds)
- Maximum relay operating time at 60 Hz: 16 ms
- 86 operation time: 22 ms (used to protect the thyrite, resistor and relay input)
- 86 contacts capability: 200 A for 1 second

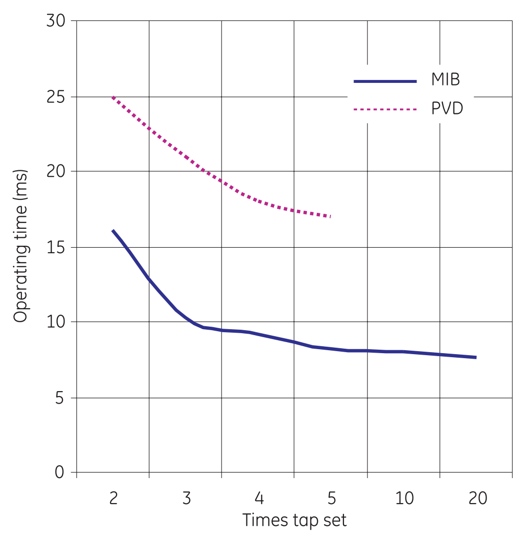

Figure 5: MIB and PVD operating times

The criteria to analyze the capability of each component is as follows:

- Relay input: current during relay operating time + ANSI 86 operating time = 38 ms (we will use 50 ms)
- Thyrite: 50 ms, same as the relay input. The capability is then 108000 watts for 50 ms (this value can be increased to 135000 watts for 40 ms).
- Stabilizing resistor: 50 ms, same as the relay input. The capability is then 15000 watts for 50 ms.

Criteria for calculation (on 60 Hz base)

For calculation (calculation made on 60 Hz base), the following values are assumed:

- Primary current for internal fault: 50000 primary amperes
- CT ratio: 1250/5 A
- Secondary current for calculation: 208 amperes

Because the voltage in the differential circuit saturates all CTs, a large portion of the current circulates through the magnetizing path of the CTs and only a reduced portion circulates through the differential path.

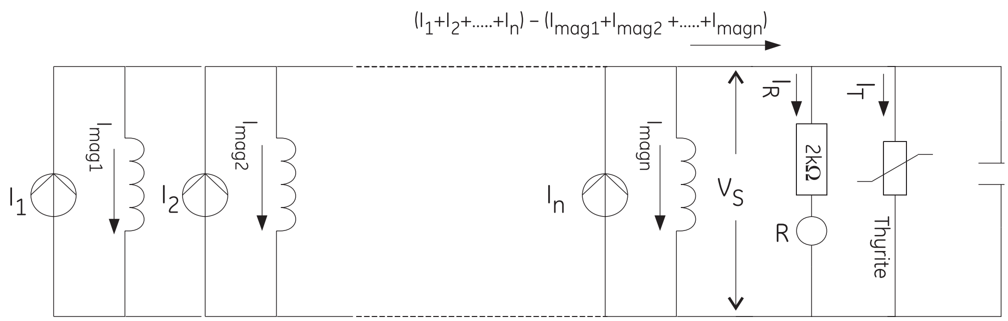

Figure 6: CT equivalent network (current sources)

Although calculation is difficult, and analysis not exact, there are some practical formulas that can be used to evaluate the power dissipated in the resistor and in the Thyrite during internal faults.

The power that can dissipate the resistor can be evaluated as follows.

$$P_R = \frac{\left(1.3\left(V_S^3 \cdot R \cdot I_{F(sec)}\right)^{0.25}\right)^2}{R} \quad \textbf{(EQ 10)}$$

where

$$\begin{aligned} V_S &= 1.6K(R_S + PR_L)\frac{I_F}{N} \\ &= 0.7 \times 1.6 \times (0.809\Omega + 2 \times 0.584\Omega) \times \frac{50000\text{A}}{240} = 445 \text{ volts} \end{aligned} \quad \textbf{(EQ 11)}$$

Therefore:

$$\begin{aligned} P_R &= \frac{\left(1.3\left(V_S^3 \cdot R \cdot I_{F(sec)}\right)^{0.25}\right)^2}{R} \\ &= \frac{\left(\left(445^3 \times 2000 \times 208\right)^{0.25} \times 1.3\right)^2}{2000} = 5116 \text{ watts (1.6 amps)} \end{aligned} \quad \textbf{(EQ 12)}$$

To calculate the power dissipated by the thyrite, we will use following formula:

$$\begin{aligned} P_T &= \frac{4}{\pi} \cdot I_{F(sec)} \cdot V_S \\ &= \frac{4}{\pi} \times 208\text{A} \times 112\text{V} = 118040 \text{ watts} \end{aligned} \quad \textbf{(EQ 13)}$$

We can also check the limits in figure 3 using $I = 208$ A and $V = 445$ V. The values well within the MIB capabilities.