MCAG 14/34, MFAC 14/34

Application Guide

High Stability Circulating Current Relay

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1 INTRODUCTION

The application of the MCAG14/34 and MFAC14/34 relays to the protection of machines, power transformers and busbar installations is based on the high impedance differential principle, offering stability for any type of fault occurring outside the protected zone and satisfactory operation for faults within the zone

A high impedance relay is defined as a relay or relay circuit whose voltage setting is not less than the calculated maximum voltage which can appear across its terminals under the assigned maximum through fault current condition.

It can be seen from Figure 1, that during an external fault the through fault current should circulate between the current transformer secondaries. The only current that can flow through the relay circuit is that due to any difference in the current transformer outputs for the same primary current. Magnetic saturation will reduce the output of a current transformer and the most extreme case for stability will be if one current transformer is completely saturated and the other unaffected. This condition can be approached in busbar installations due to the multiplicity of infeeds and extremely high fault level. It is less likely with machines or power transformers due to the limitation of through fault level by the protected unit's impedance, and the fact that the comparison is made between a limited number of current transformers. Differences in current transformer remanent flux can, however, result in asymmetric current transformer saturation with all applications.

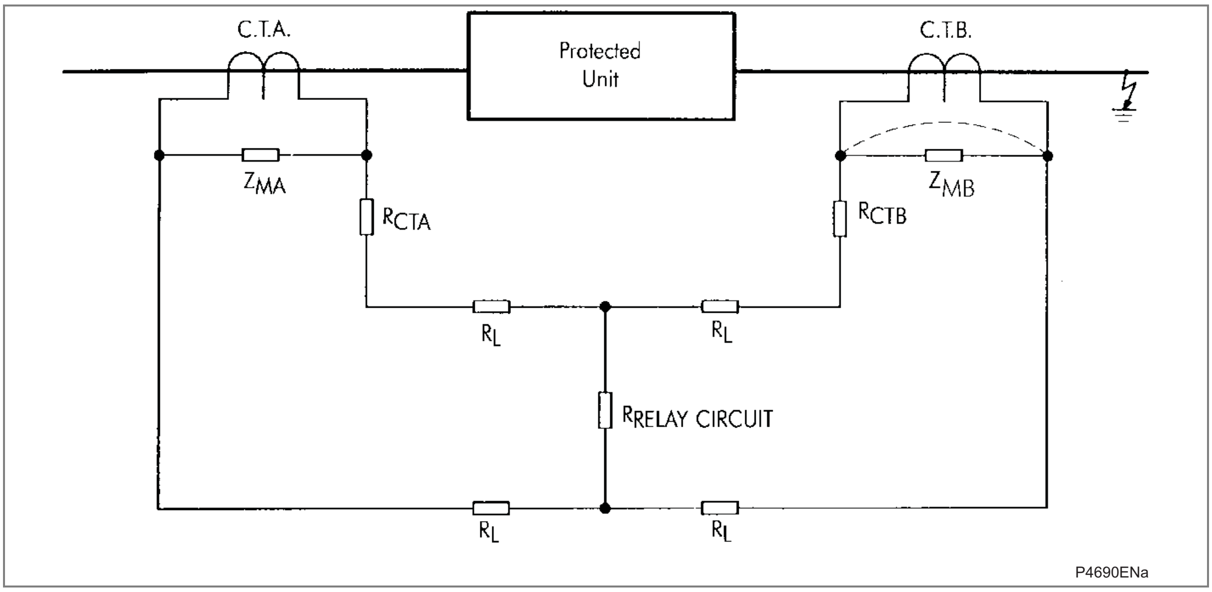

Figure 1: Principle of high impedance protection

Calculations based on the above extreme case for stability have become accepted in lieu of conjunctive scheme testing as being a satisfactory basis for application. At one end the current transformer can be considered fully saturated with its magnetising impedance Z_{MB} short circuited while the current transformer at the other end, being unaffected, delivers its full current output which will then divide between the relay and the saturated current transformer. This division will be in the inverse ratio of $R_{RELAY\ CIRCUIT}$ and $R_{CTB} + 2R_L$ and obviously, if $R_{RELAY\ CIRCUIT}$ is high compared with $R_{CTB} + 2R_L$, the relay will be prevented from undesirable operation, as most of the current will pass through the saturated current transformer.

To achieve stability for external faults, the stability voltage for the protection (V_s) must be determined in accordance with formula 1 for the MCAG and MFAC. The setting will be dependent upon the maximum current transformer secondary current for an external fault (I_f) and also on the highest

loop resistance value between the current transformer common point and any of the current transformers $(R_{CT} + 2R_L)$.

$$Vs > I_f(R_{CT} + 2_{RL}) \qquad \text{——— } 1$$

Where R_{CT} = current transformer secondary winding resistance

R_L = maximum lead resistance from the current transformer to the common point

Note: When high impedance differential protection is applied to motors or reactors, the external fault current will be low. Therefore, the locked rotor current or starting current of the motor, or reactor inrush current, should be used in place of the external fault current.

To ensure satisfactory operation of the relay under internal fault conditions the current transformer kneepoint voltage should not be less than twice the relay voltage setting i.e. $V_K \geq 2V_S$ for the MCAG and MFAC.

The kneepoint voltage of a current transformer marks the upper limit of the roughly linear portion of the secondary winding excitation characteristic and is defined exactly in British practice as that point on the excitation curve where a 10% increase in exciting voltage produces a 50% increase in exciting current.

The current transformers should be of equal ratio, of similar magnetising characteristics and of low reactance construction. In cases where low reactance current transformers are not available and high reactance ones must be used. It is essential to use in the calculations for the voltage setting, the reactance of the current transformer and express the current transformer impedance as a complex number in the form $R_{CT} + jX_{CT}$. It is also necessary to ensure that the exciting impedance of the current transformer is large in comparison with its secondary ohmic impedance at the relay setting voltage.

1.1 The MCAG14/34

The MCAG14/34 is an electromechanical current calibrated relay with setting ranges of:

0.025 - 0.100A

0.050 - 0.200A

0.100 - 0.400A

0.200 - 0.800A

0.250 - 1.00A

0.500 - 2.00A

1.00 - 4.00A

The relay has a fixed burden of approximately 1VA at setting current and its impedance varies with the setting current used. To comply with the definition for a high impedance relay, it is necessary, in most applications, to utilise an externally mounted stabilising resistor in series with the relay coil.

The standard ratings of the stabilising resistors normally supplied with the relay are 470Ω, 220Ω and 47Ω for 0.5A, 1A and 5A current transformer secondary respectively. In applications such as busbar protection, where higher values of stabilising resistor are often required to obtain the desired relay voltage setting, non-standard resistor values can be supplied. The standard resistors are wire wound, continuously adjustable and have a continuous rating of 145W.

1.1.1 Applying the MCAG14/34

The recommended relay current setting for restricted earth fault protection is usually determined by the minimum fault current available for operation of the relay and whenever possible it should not be greater than 30% of the minimum fault level. For busbar protection, it is considered good practice by some utilities to set the minimum primary operating current in excess of the rated load. Thus, if one of the current transformers becomes open circuit the high impedance relay does not mal-operate. The MVTP11/31 (busbar supervision relay) should give an alarm for open circuit conditions but will not stop a mal-operation if the relay is set below rated load.

In the case of the high impedance relay, the operating current is adjustable in discrete steps. The primary operating current $\left(\mathrm{I}_{op}\right)$ will be a function of the current transformer ratio, the relay operating current $\left(\mathrm{I}_r\right)$, the number of current transformers in parallel with a relay element (n) and the magnetising current of each current transformer $\left(\mathrm{I}_e\right)$ at the stability voltage $\left(V_s\right)$. This relationship can be expressed in three ways:

To determine the maximum current transformer magnetising current to achieve a specific primary operating current with a particular relay operating current.

$$\mathrm{I}_e < \frac{1x}{n}\left(\frac{\mathrm{I}_{op}}{CT\ ratio} - \mathrm{I}_r\right)$$

To determine the maximum relay current setting to achieve a specific primary operating current with a given current transformer magnetising current.

$$\mathrm{I}_r < \left(\frac{\mathrm{I}_{op}}{CT\ ratio} - n\mathrm{I}_e\right)$$

To express the protection primary operating current for a particular relay operating current and with a particular level of magnetising current.

$$\mathrm{I}_{op} = \left(CT\ \ ratio\right) x \left(\mathrm{I}_r + n\mathrm{I}_e\right)$$

To achieve the required primary operating current with the current transformers that are used, a current setting $\left(\mathrm{I}_r\right)$ must be selected for the high impedance relay, as detailed in the second expression above. The setting of the stabilising resistor $\left(R_{ST}\right)$ must be calculated in the following manner, where the setting is a function of the relay ohmic impedance at setting $\left(R_r\right)$, the required stability voltage setting $\left(V_s\right)$ and the relay current setting $\left(\mathrm{I}_r\right)$.

$$R_{ST} = \frac{V_s}{I_r} - R_r$$

Note: The MCAG14/34 is a fixed burden relay, therefore the ohmic impedance of the relay will vary with setting. The ohmic impedance $\left(R_r\right)$ of the MCAG14/34 can be calculated using the relay VA burden at current setting (B) and the relay current setting $\left(\mathrm{I}_r\right)$; $R_r = \frac{B}{I_r^2}$

The stabilising resistor supplied is continuously adjustable up to its maximum declared resistance. In some applications, such as generator winding differential protection, the through fault current is low which results in a low stability voltage setting. In many such cases, a negative stabilising resistor value can be obtained from the above formula. This negative result indicates that the relay will be more than stable without a stabilising resistor. When a stabilising resistor is not required, the setting

voltage (V_{SA}) can be calculated using the following formula and the current transformer kneepoint voltage should be at least twice this value.

$$V_{SA} = \frac{B}{I_r}$$

1.1.2 Use of Metrosil nonlinear resistors - MCAG14/34

When the maximum through fault current is limited by the protected circuit impedance, such as in the case of generator differential and power transformer restricted earth fault protection, it is generally found unnecessary to use non-linear voltage limiting resistors (metrosils). However, when the maximum through fault current is high, such as in busbar protection, it is always advisable to use a non-linear resistor (metrosil) across the relay circuit (relay and stabilising resistor).

Metrosils are used to limit the peak voltage developed by the current transformers under internal fault conditions, to a value below the insulation level of the current transformers, relay and interconnecting leads, which are normally able to withstand 3000V peak.

The following formulae should be used to estimate the peak transient voltage that could be produced for an internal fault. The peak voltage produced during an internal fault will be a function of the current transformer kneepoint voltage and the prospective voltage that would be produced for an internal fault if current transformer saturation did not occur. This prospective voltage will be a function of maximum internal fault secondary current, the current transformer ratio, the current transformer secondary winding resistance, the current transformer lead resistance to the common point, the relay lead resistance, the stabilising resistor value and the relay VA burden at relay operating current.

$$V_p = 2\sqrt{2V_K\left(V_f - V_K\right)}$$

$$V_f = I_f\left(R_{CT} + 2R_L + R_{ST} + R_r\right)$$

Where V_p = peak voltage developed by the CT under internal fault conditions

V_K = current transformer knee-point voltage

V_f = maximum voltage that would be produced if CT saturation did not occur

I_f = maximum internal secondary fault current

R_{ct} = current transformer secondary winding resistance

R_L = maximum lead burden from current transformer to relay

R_{ST} = relay stabilising resistor

R_r = Relay ohmic impedance at setting

When the value given by the formulae is greater than 3000V peak, non-linear resistors (metrosils) should be applied. These non-linear resistors (metrosils) are effectively connected across the relay circuit, or phase to neutral of the ac buswires, and serve the purpose of shunting the secondary current output of the current transformer from the relay in order to prevent very high secondary voltages.

These non-linear resistors (metrosils) are externally mounted and take the form of annular discs, of 152mm diameter and approximately 10mm thickness. Their operating characteristics follow the expression:

$$V = CI^{0.25}$$

Where V = instantaneous voltage applied to the non-linear resistor (metrosil)

C = constant of the nonlinear resistor (metrosi)

I = instantaneous current through the non-linear resistor (metrosil)

With a sinusoidal voltage applied across the metrosil, the RMS current would be approximately 0.52x the peak current. This current value can be calculated as follows;

$$\mathrm{I}(rms) = 0.52\left(\frac{Vs(rms)\ x\ \sqrt{2}}{C}\right)^4$$

Where $Vs(rms)$ = rms value of the sinusoidal voltage applied across the metrosil

This is due to the fact that the current waveform through the nonlinear resistor (metrosil) is not sinusoidal but appreciably distorted. For satisfactory application of a non-linear resistor (metrosil), it's characteristic should be such that it complies with the following requirements:

At the relay voltage setting, the nonlinear resistor (metrosil) current should be as low as possible, but no greater than approximately 30mA rms for 1A current transformers and approximately 100mA rms for 5A current transformers.

At the maximum secondary current, the non-linear resistor (metrosil) should limit the voltage to 1500V rms or 2120V peak for 0.25 second. At higher relay voltage settings, it is not always possible to limit the fault voltage to 1500V rms, so higher fault voltages may have to be tolerated.

1.1.3 Applying the MFAC14/34

As the MFAC14/34 is a voltage calibrated relay with setting ranges of 25-175V in 25V steps, 25-325V in 50V steps and 15-185V in 5V steps, it is inherently a high impedance relay requiring no external resistors. Due to the relay circuit impedance always being relatively high, significant voltages can be produced across the current transformers and secondary wiring during an internal fault. To limit the voltage to a value below the insulation level of the current transformers, relay and interconnecting leads, a non-linear resistor (metrosil) is always required and should always be used by connecting in parallel with the relay. Refer to metrosil publication for selection chart).

The operating current is virtually fixed at around 20mA, but there is some slight variation with relay voltage setting as a result of variation in the current drawn by the non-linear resistor (metrosil). The operating current, including the nonlinear resistor (metrosil) current, for the various voltage settings is stated to the right:

The relay effective current setting can be calculated in the same manner as described for the MCAG14/34. For busbar protection, it is considered good practice by some utilities to set the minimum primary operating current in excess of the rated load. Thus, if one of the current transformers becomes open circuit the MFAC14/34 does not mal-operate. The MVTP11/31 (busbar supervision relay) should give an alarm for open circuit conditions but will not stop a mal-operation if the relay is set below rated load. Thus, if the resultant value of I_{op} is too low, it may be increased by the addition of a shunt resistor (RSH) to give a current of:

$$\mathrm{I}_{SH} = \frac{V_S}{R_{SH}}$$

The increased primary operating current with the shunt resistor connected is:

$$\mathrm{I}_{op} = (CT\ ratio)\ x\ (\mathrm{I}_r + n\mathrm{I}_e + I_{SH})$$

Setting range: 25-175V							
Setting Voltage	25	50	75	100	125	150	175
I_r (mA)	19	19	20	23	27	36	53

Setting range: 25-325V							
Setting Voltage	25	75	125	175	225	275	325
I_r (mA)	19	19	20	22	24	31	44

Figures 2 to 8 show how high impedance relays can be applied in a number of different situations.

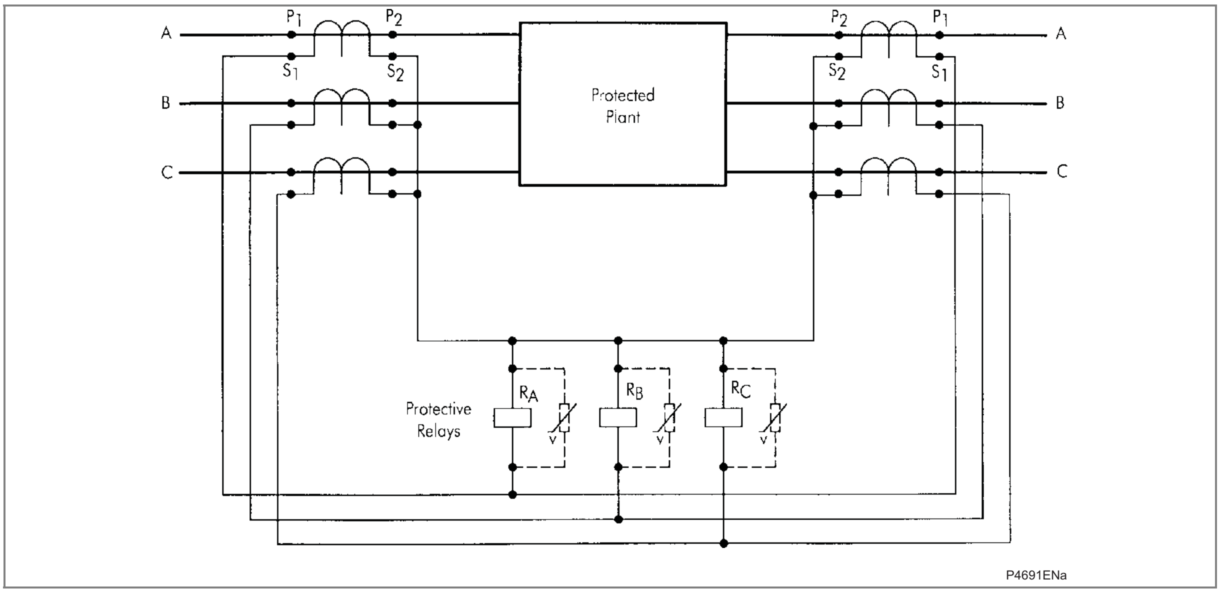

Figure 2: Phase and earth fault differential protection for generators, motors or reactors

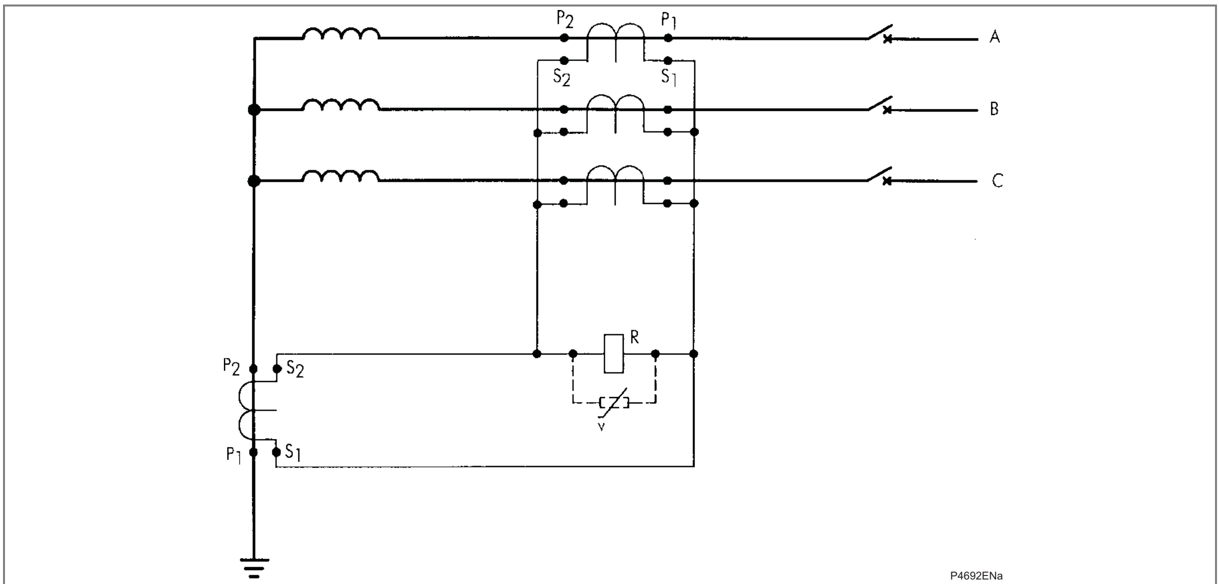

Figure 3: Restricted earth fault protection for a 3 phase, 3 wire system-applicable to star connected generators or power transformer windings

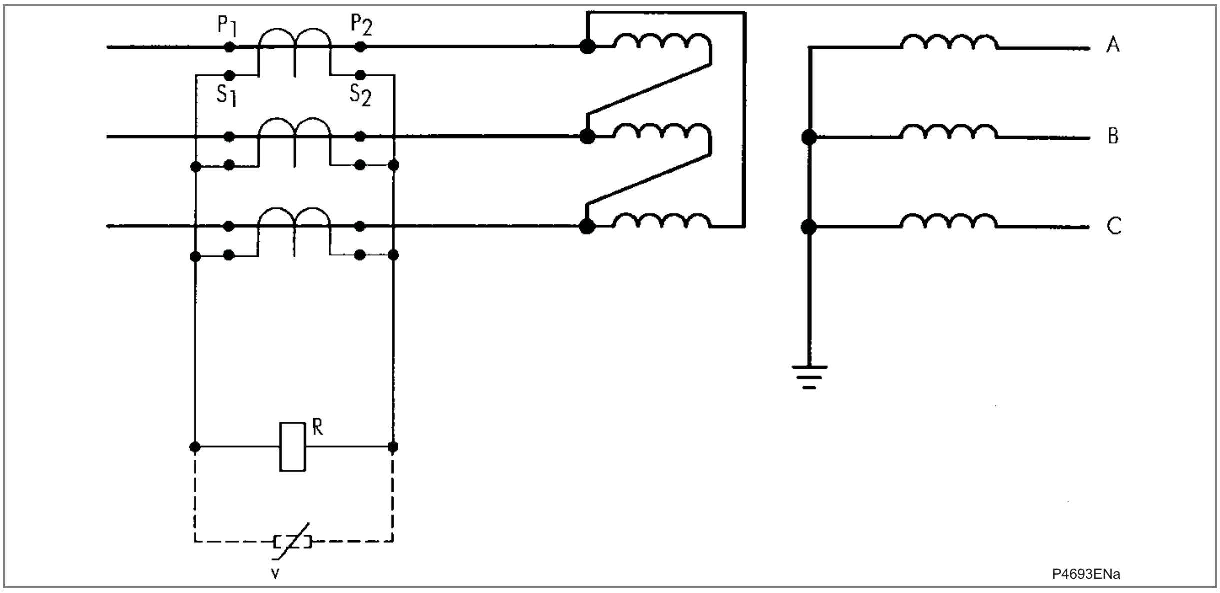

Figure 4: Balanced or restricted earth fault protection for delta winding of a power transformer with supply system earthed

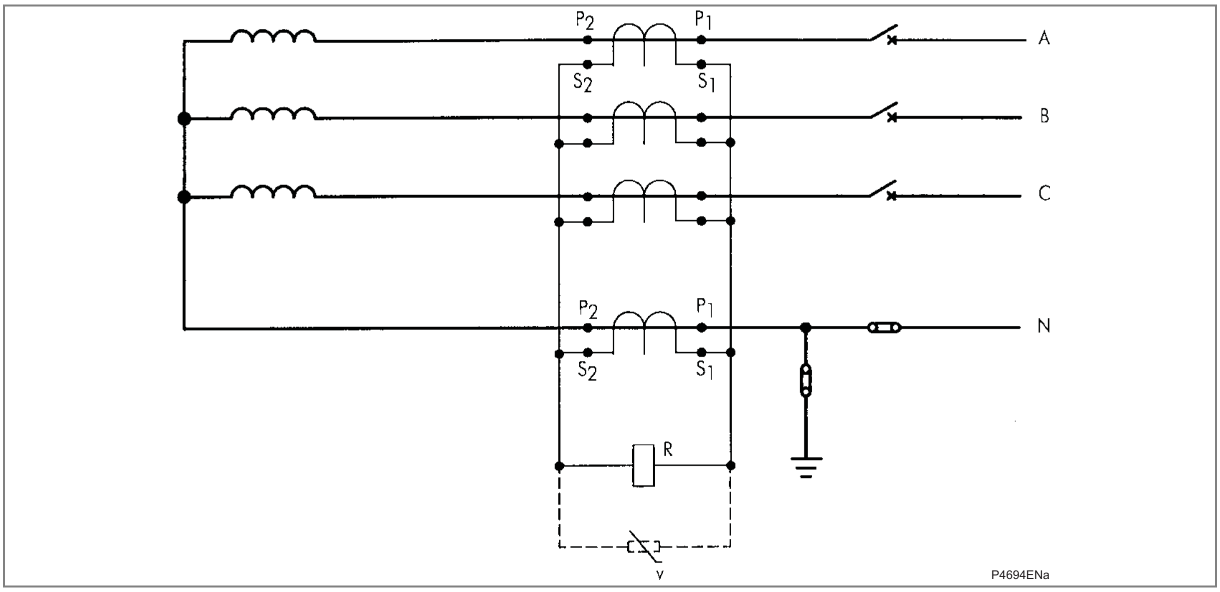

Figure 5: Restricted earth fault protection for 3 phase, 4 wire system-applicable to star connected generators or power transformer windings with neutral earthed at switchgear

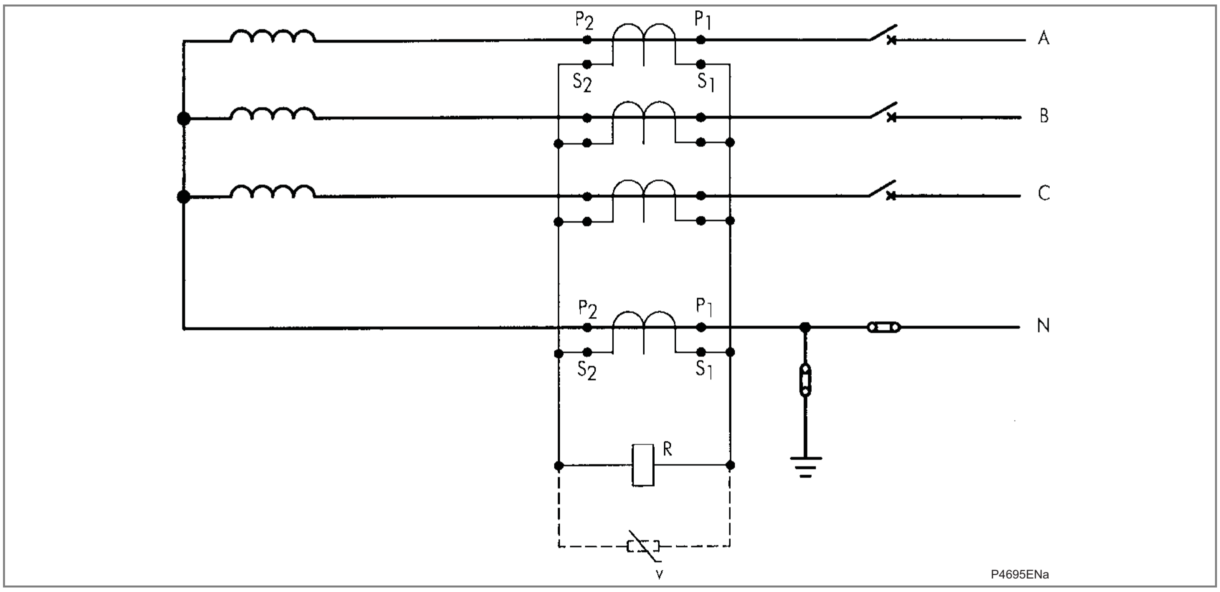

Figure 6: Restricted earth fault protection for 3 phase 4 wire system applicable to star connected generators or power transformer windings earthed directly at the star point

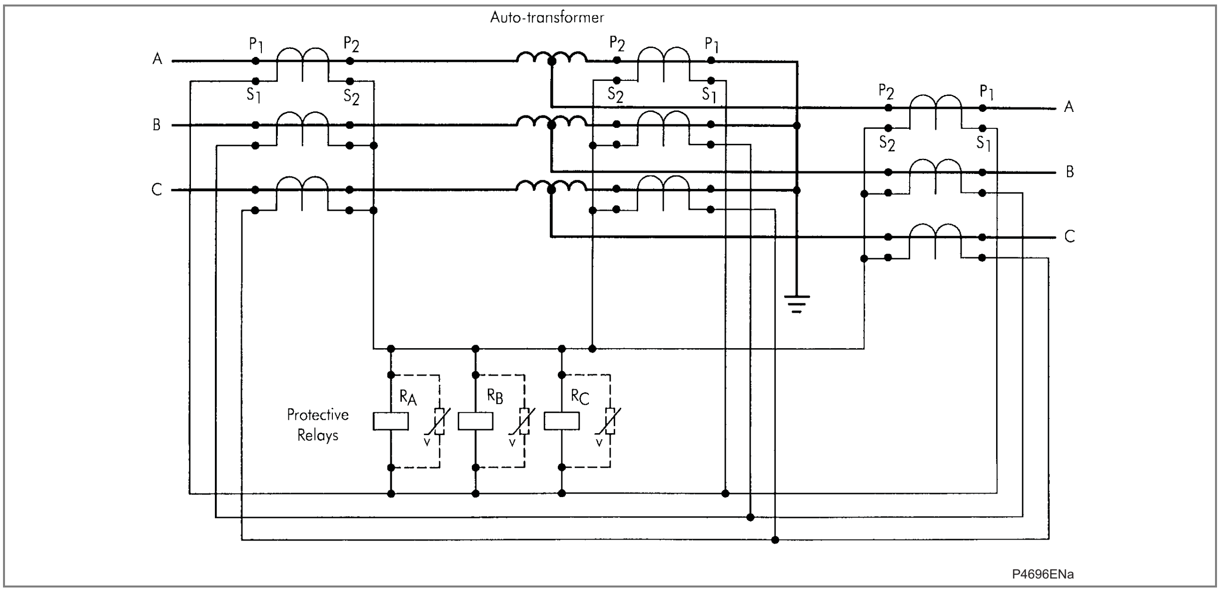

Figure 7: Phase and earth fault differential protection for an auto-transformer with CT's at the neutral star point

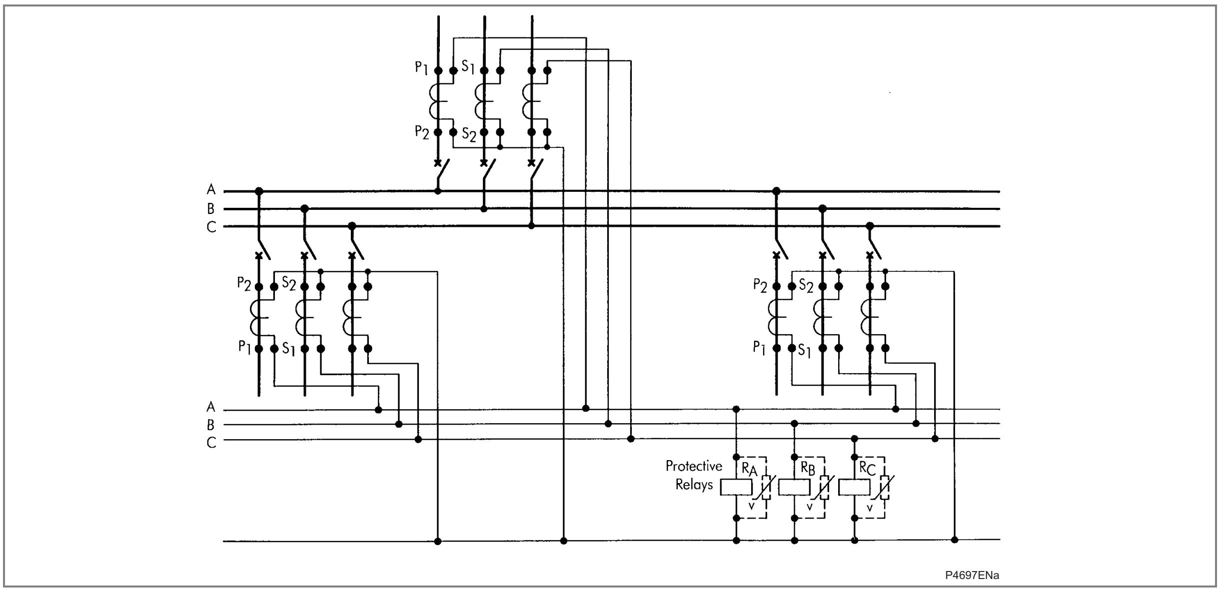

Figure 8: Busbar protection - simple single zone phase and earth fault scheme

2 TYPICAL SETTING EXAMPLES

2.1 Restricted earth fault protection using MFAC14

The correct application of the MFAC14 high impedance relay can best be illustrated by taking the case of the 11000/415V 1000kVA power transformer shown in Figure 9, for which restricted earth fault protection is required on the L.V. winding.

It is assumed that the relay effective setting for a solidly earthed power transformer is approximately 30% of full load current.

2.1.1 Voltage setting

The power transformer full load current.

$$= \frac{1000\ x\ 10^3}{\sqrt{3}\ x\ 415}$$

$$= 1391A$$

Maximum through fault level (ignoring source impedance).

$$= \frac{100MVA}{5\%}\ x\ 1391$$

$$= 27820A$$

Required relay stability voltage (assuming one CT saturated).

$$= I_f\ (R_{CT} + 2R_L)$$

$$= 27820\ x\ \frac{5}{1500}\ (0.3 + 0.08)$$

$$= 35.2V$$

The next highest setting should be selected on the MFAC14, this being 50V.

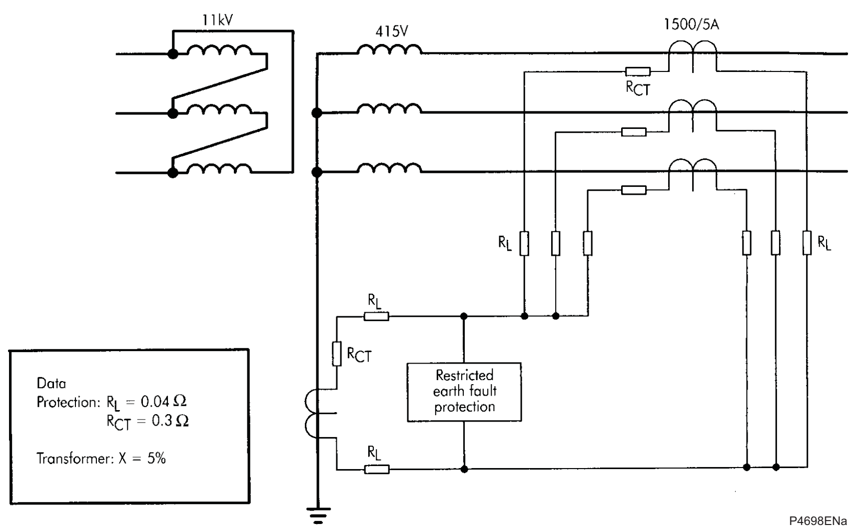

Figure 9: Restricted earth fault protection on a power transformer L.V. winding

2.1.2 Current transformer requirements

The minimum current transformer kneepoint voltage.

$$V_K = 2V_s$$
$$= 2\ x\ 50$$
$$= 100V$$

The exciting current to be drawn by the current transformers at the relay voltage setting, V_s will be:

$$I_e < \frac{I_s - I_r}{n}$$

Where $I_s =$ relay effective setting

$$= \frac{30}{100}\ x\ 1391\ x\ \frac{5}{1500}$$
$$= 1.4A$$

$I_r =$ relay setting

$$= 1A$$

$n =$ number of current transformers in parallel with the relay

$$= 4$$

$$\therefore I_e\ at\ 50V < \frac{1.4 - 0.02}{4}$$
$$< \ 0.345A$$

As previously stated metrosils are always required with an MFAC. The metrosil type is chosen in accordance with the maximum secondary current of 27820 x 5/1500 = 93A.

Therefore the metrosil reference is 600A/S2/P with a constant (C) of 620/740. (Please refer to Metrosil publication for selection chart).

2.2 Restricted earth fault protection using MCAG14

The correct application of the MCAG14 high impedance relay can best be illustrated by taking the case of the 11000/415V 1000kVA power transformer shown in Figure 9, for which restricted earth fault protection is required on the L.V. winding.

2.2.1 Stability voltage

The power transformer full load current.

$$= \frac{1000\ x\ 10^3}{\sqrt{3}\ x\ 415}$$
$$= 1391A$$

Maximum through fault level (ignoring source impedance).

$$= \frac{100MVA}{5\%} \; x \, 1391$$

$$= 27820A$$

Required relay stability voltage (assuming one CT saturated).

$$= I_f \left(R_{CT} + 2R_L \right)$$

$$= 27820 \; x \; \frac{5}{1500} \left(0.3 + 0.08 \right)$$

$$= 35.2V$$

2.2.2 Stabilising resistor

Assuming that the relay effective setting for a solidly earthed power transformer is approximately 30% of full load current, we can therefore, choose a relay current setting of 20% of 5A i.e. 1A. On this basis the required value of stabilising resistor is:

$$R_{ST} = \frac{V_S}{I_r} - \frac{B}{I_r^2}$$

$$= \frac{35.2}{1} - \frac{1}{1^2}$$

$$= 34.2 \, \Omega$$

5A rated MCAG14 relays are supplied with stabilising resistors that are continuously adjustable between 0 and 47Ω. Therefore, a stabilising resistance of 34.2Ω can be set using the standard resistor.

2.2.3 Current transformer requirements

The minimum current transformer kneepoint voltage.

$$V_K = 2V_s$$

$$= 2 \; x \; 35.2$$

$$= 70.4V$$

The exciting current to be drawn by the current transformers at the relay stability voltage, V_s, will be:

$$I_e < \frac{I_s - I_r}{n}$$

Where $I_s =$ relay effective setting

$$= \frac{30}{100} \; x \, 1391 \; x \; \frac{5}{1500}$$

$$= 1.4A$$

$I_r =$ relay setting

$$= 1A$$

n = number of current transformers in parallel with the relay

$$= 4$$

$$\therefore \mathrm{I}_e \; at \; 35.2V < \frac{1.4 - 1}{4}$$

$$< \; 0.1A$$

2.2.4 Metrosil non-linear resistor requirements

If the peak voltage appearing across the relay circuit under maximum internal fault conditions exceeds 3000V peak then a suitable non-linear resistor (metrosil), externally mounted, should be connected across the relay and stabilising resistor, in order to protect the insulation of the current transformers, relay and interconnecting leads. In the present case the peak voltage can be estimated by the formula:

$$V_p = 2\sqrt{2\,V_K\left(V_f - V_K\right)}$$

Where V_K = 70.4V (In practice this should be the actual current transformer kneepoint voltage, obtained from the current transformer magnetisation curve).

$$V_f = \mathrm{I}_f\left(R_{CT} + 2R_L + R_{ST} + R_r\right)$$

$$= 27820 \; x \; \frac{5}{1500} \; x \left(0.3 + 0.08 + 34.2 + 1\right)$$

$$= 92.7 \; x \; 35.58$$

$$= 3298V$$

Therefore substituting these values for V_K and V_f into the main formula, it can be seen that the peak voltage developed by the current transformer is:

$$V_p = 2\sqrt{2\,V_K\left(V_f - V_K\right)}$$

$$= 2\sqrt{2\ x\ 70.4\ x\ \left(3298 - 70.4\right)}$$

$$= 1348V$$

This value is well below the maximum of 3000V peak and therefore no metrosils are required with the relay. I_f on the other hand, the peak voltage V_P given by the formula had been greater than 3000V peak, a non-linear resistor (metrosil) would have to be connected across the relay and the stabilising resistor. The recommended non-linear resistor type would have to be chosen in accordance with the maximum secondary current at the relay.

2.3 Generator winding differential protection using MCAG34

For the vast majority of MCAG14/34 applications (restricted earth fault protection and busbar protection), the aforementioned formulae may be followed without any additional consideration. For MCAG34 generator winding differential applications, which are less common applications, some caution may be necessary in using these formulae alone.

The relatively low level of current that is delivered by a generator to an external fault means that stability of high impedance generator differential protection can easily be achieved with a relatively low protection stability voltage. In many applications, there is no need to utilise stabilising resistors in series with the high impedance relay (indicated by negative stabilising resistor value); the impedance of the relay elements alone will offer more than adequate stability. Where the protection is over stable, literal application of the published CT kneepoint voltage formula by a CT designer would result in the provision of CT`s with extremely low kneepoint voltage, which could result in lack of protection scheme sensitivity and slow relay operation for an internal fault.

The correct application of the MCAG34 when applied as generator winding differential protection is illustrated in Figure 10 which shows a typical application of the MCAG34 relay where the use of the procedure detailed in example 2 would lead to an extremely low kneepoint voltage requirement. This can be avoided by calculation of the kneepoint voltage using the actual value for V_{SA} (setting voltage) rather than the value of V_S required for stability in the event of an external fault.

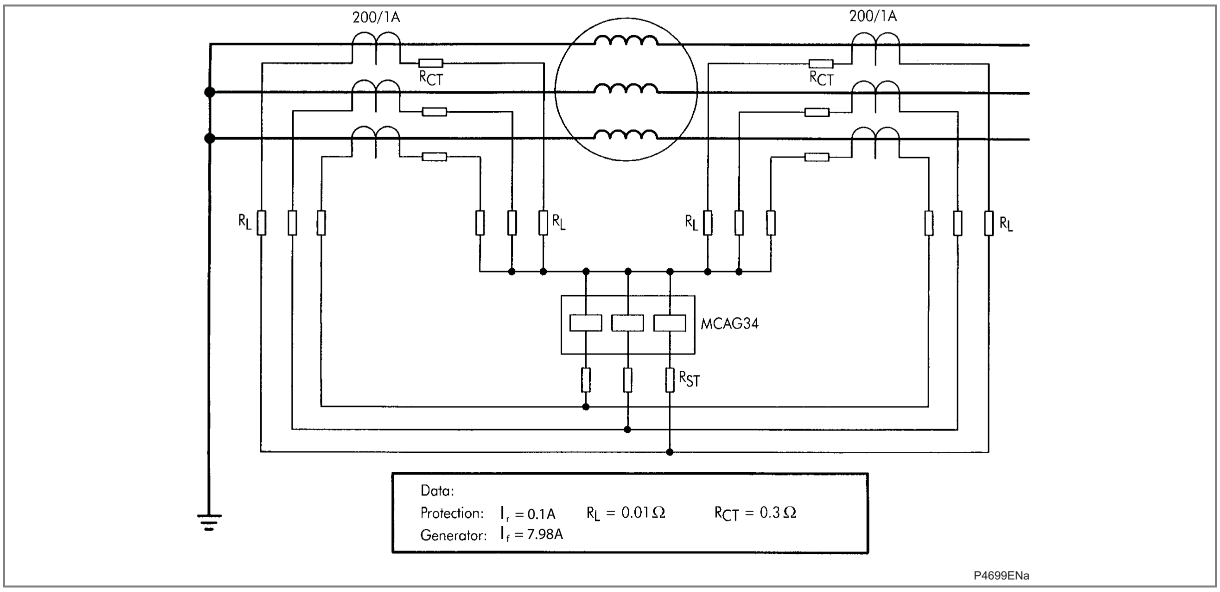

Figure 10: Generator winding differential protection

2.3.1 Stability voltage

The required relay stability voltage (assuming one CT saturated).

$$= I_f \left(R_{CT} + 2R_L\right)$$

$$= 7.98\left(0.3 + 0.02\right)$$

$$= 2.55V$$

Using the standard formula, this would lead to a CT V_K requirement of 2 x 2.55 = 5.1V.

2.3.2 Stabilising resistor

$$R_{ST} = \frac{V_S}{I_r} - \frac{B}{I_r^2}$$

$$= \frac{2.55}{0.1} - \frac{1}{0.1^2}$$

$$= 74.5\,\Omega$$

The negative result indicates that the relay is more than stable without any stabilising resistor. With the relay alone, the actual voltage setting can be calculated as follows:

$$V_{SA} = \frac{B}{I_r}$$

$$= \frac{1}{0.1}$$

$$= 10V$$

Consequently, if the formulae had been literally applied, a CT with a V_K of 5.1V would not have been sufficient to provide correct operation of the relay under fault conditions.

2.3.3 Current transformer requirements

The minimum current transformer kneepoint voltage.

$$\begin{aligned} V_K &= 2V_s \\ &= 2\ x\ 10 \\ &= 20V \end{aligned}$$

The exciting current to be drawn by the current transformers at the relay stability voltage, V_S , will be determined by the maximum tolerable protection primary operating current and is defined by:

$$I_{op} = (CT\ ratio)\ x\ (I_r + nI_e)$$

2.3.4 Metrosil non-linear resistor requirements

If the peak voltage appearing across the relay circuit under maximum internal fault conditions exceeds 3000V peak then a suitable non-linear resistor (metrosil), externally mounted, should be connected across the relay and stabilising resistor, in order to protect the insulation of the current transformers, relay and interconnecting leads.

In this case however the peak voltage will be substantially less than 3000V and so metrosils are not required.

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