Digital Energy
Multilin

GE Multilin technical note

Neutral voltage unbalance function at grounded wye capacitor banks

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Introduction

The C70 neutral overvoltage unbalance function (ANSI 59NU) compensates for both the system unbalance (V_0), and the bank inherent unbalance using balancing factors k_{AB} and k_{AC}. The operating quantity equation for a perfectly balanced bank ($k_{AB} = k_{AC} = 1$) takes the following familiar simplified form.

$$V_{op} = |V_X - V_0| \quad \textbf{(Eq 1)}$$

In this equation, V_X is a bank neutral point voltage and V_0 is a bus (system voltage) which can either calculated from phase voltages or supplied externally from broken delta VT.

It is preferable to have the bus voltage supplied from a three-phase voltage VT, since the C70 can compensate for bank inherent unbalance by applying balancing coefficients. The auto-setting procedure is available to automatically calculate these coefficients.

For greater sensitivity and security, the relay applies the differential principle with the restraint quantity V_{rest} calculated as follows.

$$V_{rest} = |V_X + V_0| \quad \textbf{(Eq 2)}$$

The neutral overvoltage unbalance element operates if:

$$V_{op} > S \times V_{rest} \quad \textbf{(Eq 3)}$$

Where S is a user-programmable slope factor.

The neutral overvoltage unbalance element can be applied to both ungrounded and grounded capacitor banks. Applying neutral overvoltage unbalance to ungrounded banks appears logical and simple. However, it may not be so obvious for grounded banks. In this case, the banks are grounded through a neutral capacitor with a single-phase VT across the capacitor or grounded through a CT to measure the neutral current or equivalent neutral voltage. This application note attempts to clarify the C70 application for these type of grounded bank configurations.

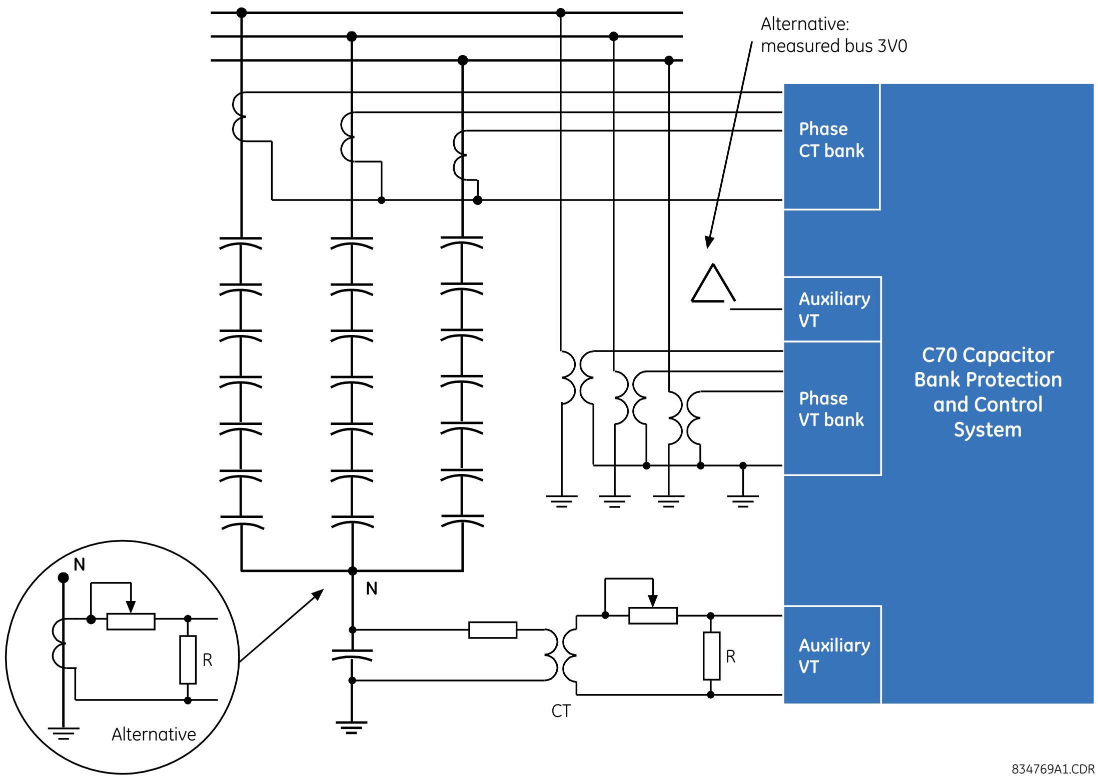
Neutral point voltage equivalent

The following figure depicts two possible grounding arrangements for the capacitor bank.

- Grounded through neutral capacitor.
- Grounded through neutral CT.

In any configuration the value of the resistor *R* has to be chosen so that the voltage which appears at the neutral point (one phase voltage at the bus equals zero) across resistor *R* through the CT/auxiliary VT input matches the bus V_0 value.

Figure 1: Neutral arrangement for grounded wye banks



In the case of neutral CT configuration, it can be achieved by calculating value of the resistor in neutral CT secondary as follows:

$$R = \frac{V_{B(LL)}^2 \times \mathrm{CT_N}}{3 \times S_B \times \mathrm{VT_N}} \qquad \textbf{(Eq 4)}$$

In the above equation:

- $V_{B(LL)}$ is bus phase-to-phase bus voltage (in kV).
- S_B is the bank reactive power rating (in MVA).
- $\mathrm{VT_N}$ is the auxiliary VT input ratio setting, which may be same as bus VT ratio or used to achieve balance if an exact resistor value is not possible.
- $\mathrm{CT_N}$ is the neutral CT ratio.

The voltage derived from the current in the neutral secondary resistor is shifted 90° from the bus V_0 voltage. The relay automatically compensates for this if the **Neutral Voltage Unbalance 1 Ground** setting is programmed as "CTxR (grnd)".

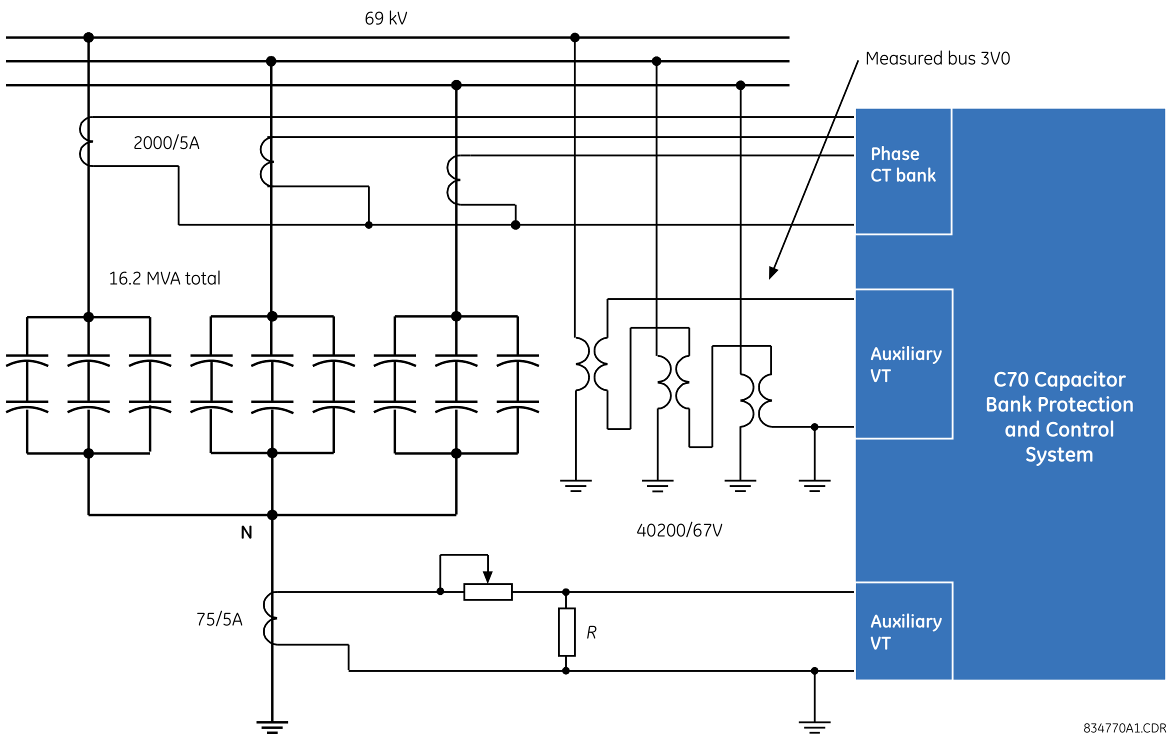
Application example

Consider a capacitor bank with the following ratings.

- Bus phase-to-phase bus voltage $V_{B(LL)}$ = 69 kV.
- Bank reactive power rating S_B = 16.2 MVA.
- 900 kVAR capacitor can rated 19.92 kV.
- Phase VT ratio is 600:1.
- VT secondary = 67 V.
- Neutral CT is 75/5A.

Each capacitor can consists from N = 10 capacitor sections. Two capacitors cans are connected in series (P = 2) and there are three parallel strings (S = 3) in each phase.

Figure 2: Sample bank configuration



General calculations

The nominal current of the capacitor bank is calculated as follows.

$$I_{nom} = \frac{S_B \times 10^3}{\sqrt{3} \times V_{B(LL)}} = \frac{16.2\text{ MVA} \times 10^3}{\sqrt{3} \times 69\text{ V}} = 133.55\text{ A} \qquad \textbf{(Eq 5)}$$

The impedance of the healthy phase capacitors stack is calculated as follows.

$$Z_P = \frac{V_{B(LL)}^2}{S_B} = \frac{(69\text{ V})^2}{16.2\text{ MVA}} = 293.89\ \Omega \qquad \textbf{(Eq 6)}$$

The impedance of the capacitor can is calculated as follows.

$$Z_C = \frac{Z_P \times S}{P} = \frac{293.89\ \Omega \times 3}{2} = 440.84\ \Omega \qquad \textbf{(Eq 7)}$$

The impedance of the capacitor section is calculated as follows.

$$Z_S = \frac{Z_C}{N} = \frac{440.84\ \Omega}{10} = 44.084\ \Omega \quad \textbf{(Eq 8)}$$

From the formula above, the value of resistor R in the neutral CT secondary is estimated as follows.

$$R = \frac{V_{B(LL)}^2 \times \mathrm{CT_N}}{3 \times S_B \times \mathrm{VT_N}} = \frac{(69\ \mathrm{V})^2 \times 15}{3 \times 16.2\ \mathrm{MVA} \times 600} = 2.449\ \Omega \quad \textbf{(Eq 9)}$$

In the above equation, the voltage auxiliary input ratio is assumed same as the phase voltage input ratio.

The calculations of V_N and $V_{0(bus)}$ provide a quick check that the resistor value for one system phase voltage is equal to zero. The V_N value is calculated as follows.

$$V_N = \frac{I_{nom} \times R}{\mathrm{CT_N}} = \frac{133.55\ \mathrm{A} \times 2.449\ \Omega}{15} = 22.131\ \mathrm{V} \quad \textbf{(Eq 10)}$$

The $V_{0(bus)}$ value is calculated as follows.

$$V_{0(bus)} = \frac{(V_{B(LL)} \times 10^3)/(\sqrt{3})}{3 \times \mathrm{VT_{BUS}}} = \frac{69000\ \mathrm{V}/\sqrt{3}}{3 \times 600} = 22.132\ \mathrm{V} \quad \textbf{(Eq 11)}$$

The V_N and $V_{0(bus)}$ values are practically the same.

Unbalance calculations

For a fuseless sample bank as shown above with $S_C = N \times P = 10 \times 2 = 20$ series capacitor sections in one string and $S = 3$ parallel strings, the general equation to calculate ground current for n failed sections is shown below.

$$I_G^n = I_{nom} \times \left(\frac{(S_C - n) \times S + n}{(S_C - n) \times S} - 1\right) \quad \textbf{(Eq 12)}$$

The neutral point secondary voltage with one failed section ($n = 1$) is calculated as follows.

$$V_N^{(n=1)} = I_G^{(n=1)} \times \frac{R}{\mathrm{CT_N}} = 133.55\ \mathrm{A} \times \left(\frac{(20-1) \times 3 + 1}{(20-1) \times 3} - 1\right) \times \frac{2.449\ \Omega}{15} = 0.3825\ \mathrm{V} \quad \textbf{(Eq 13)}$$

This can also be expressed in per-unit values as $V_N^{(n=1)}(\mathrm{pu}) = 0.3825\ \mathrm{V} / 67\ \mathrm{V} = 0.0057$ pu.

The neutral point secondary voltage with two failed sections ($n = 2$) is calculated as follows.

$$V_N^{(n=2)} = I_G^{(n=2)} \times \frac{R}{\mathrm{CT_N}} = 133.55\ \mathrm{A} \times \left(\frac{(20-2) \times 3 + 2}{(20-2) \times 3} - 1\right) \times \frac{2.449\ \Omega}{15} = 0.8076\ \mathrm{V} \quad \textbf{(Eq 14)}$$

This can also be expressed in per-unit values as $V_N^{(n=2)}(\mathrm{pu}) = 0.8076\ \mathrm{V} / 67\ \mathrm{V} = 0.0121$ pu.

The neutral point secondary voltage with three failed sections ($n = 3$) is calculated as follows.

$$V_N^{(n=3)} = I_G^{(n=3)} \times \frac{R}{\mathrm{CT_N}} = 133.55\ \mathrm{A} \times \left(\frac{(20-3) \times 3 + 3}{(20-3) \times 3} - 1\right) \times \frac{2.449\ \Omega}{15} = 1.2826\ \mathrm{V} \quad \textbf{(Eq 15)}$$

This can also be expressed in per-unit values as $V_N^{(n=3)}(\mathrm{pu}) = 1.2826\ \mathrm{V} / 67\ \mathrm{V} = 0.0191$ pu.

From the calculations above, the alarm pickup setting is chosen for the failure of one section as follows.

$$59\mathrm{NU_{alarm}} = 0.9 \times V_N^{(n=1)} = 0.9 \times 0.0057\ \mathrm{pu} = 0.0051\ \mathrm{pu} \quad \textbf{(Eq 16)}$$

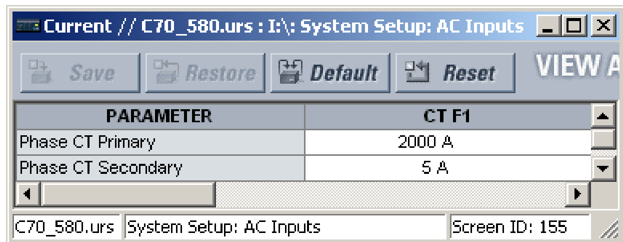
The trip pickup setting is chosen as midway between the second and third capacitor section failures as follows.

$$59NU_{trip} = \frac{V_N^{(n=2)} + V_N^{(n=3)}}{2} = \frac{0.0121\ \text{pu} + 0.0191\ \text{pu}}{2} = 0.0156\ \text{pu} \qquad \textbf{(Eq 17)}$$

Relay configuration

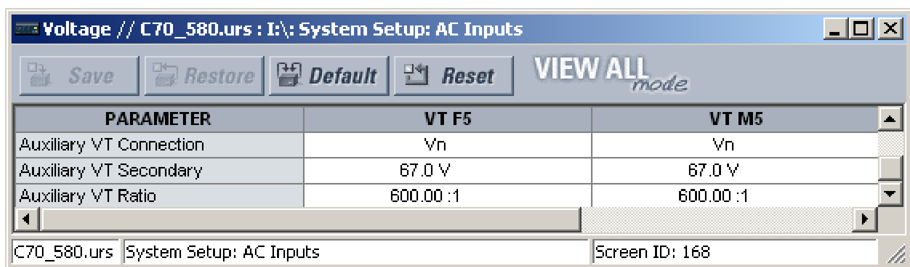
If the external $3V_0$ voltage is brought into the relay, then the C70 model with two VT banks must be ordered to protect capacitor bank according to the application example. One VT bank is sufficient for calculated $3V_0$. For externally brought $3V_0$ and two type L CT/VT modules in the “F” and “M” slots.

Program the following settings in the **System Setup > AC Inputs > Current** menu.



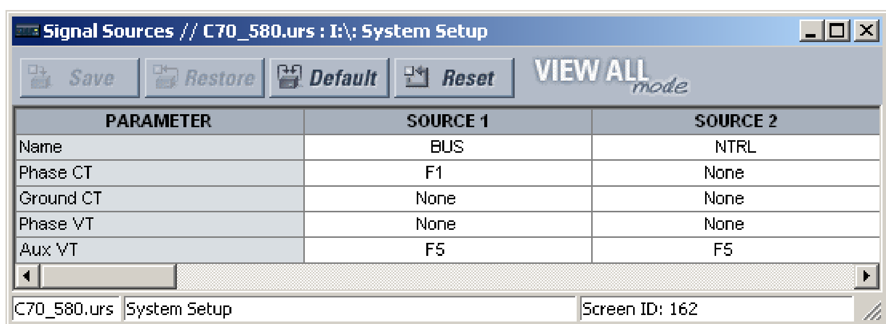
PARAMETER	CT F1
Phase CT Primary	2000 A
Phase CT Secondary	5 A

Program the following settings in the **System Setup > AC Inputs > Voltage** menu.



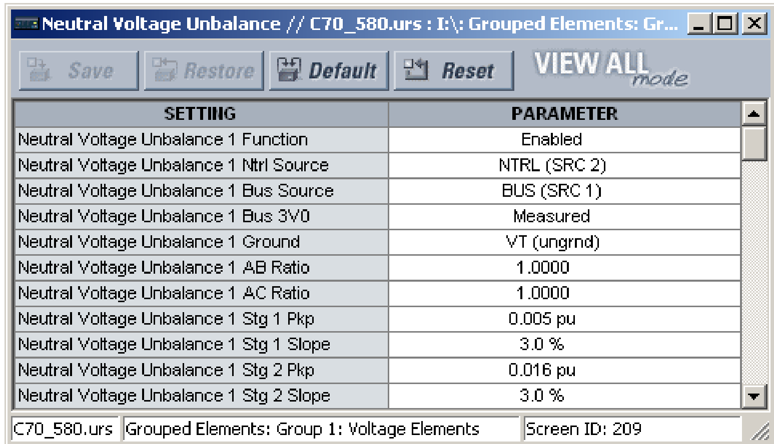
PARAMETER	VT F5	VT M5
Auxiliary VT Connection	Vn	Vn
Auxiliary VT Secondary	67.0 V	67.0 V
Auxiliary VT Ratio	600.00 :1	600.00 :1

Program the following settings in the **System Setup > Signal Sources** menu.



PARAMETER	SOURCE 1	SOURCE 2
Name	BUS	NTRL
Phase CT	F1	None
Ground CT	None	None
Phase VT	None	None
Aux VT	F5	F5

Program the following settings in the **Grouped Elements > Group 1 > Voltage Elements > Neutral Voltage Unbalance** menu.



SETTING	PARAMETER
Neutral Voltage Unbalance 1 Function	Enabled
Neutral Voltage Unbalance 1 Ntrl Source	NTRL (SRC 2)
Neutral Voltage Unbalance 1 Bus Source	BUS (SRC 1)
Neutral Voltage Unbalance 1 Bus 3V0	Measured
Neutral Voltage Unbalance 1 Ground	VT (ungrnd)
Neutral Voltage Unbalance 1 AB Ratio	1.0000
Neutral Voltage Unbalance 1 AC Ratio	1.0000
Neutral Voltage Unbalance 1 Stg 1 Pkp	0.005 pu
Neutral Voltage Unbalance 1 Stg 1 Slope	3.0 %
Neutral Voltage Unbalance 1 Stg 2 Pkp	0.016 pu
Neutral Voltage Unbalance 1 Stg 2 Slope	3.0 %

Appendix

As was mentioned above in the case of neutral CT connections, the value of resistor *R* must be chosen so that the voltage drop across *R* at the neutral point through the CT/auxiliary VT input transformation matches the bus V_0 value for a single phase to ground fault. This *R* value is derived as follows.

If the fault occurs on phase A, then V_0 is calculated as follows.

$$V_0 = \frac{1}{3}(0 + V_B + V_C) = \frac{1}{3}(V_B + V_C) \qquad \textbf{(Eq 18)}$$

The impedance of each leg of bank is calculated as follows.

$$Z = \frac{V_{B(LL)}^2}{S_B} \qquad \textbf{(Eq 19)}$$

The neutral current is calculated as follows.

$$I_N = \frac{V_B + V_C}{V_{B(LL)}^2 / S_B} \qquad \textbf{(Eq 20)}$$

The secondary current in neutral resistor is calculated as follows.

$$I_{N(sec)} = \frac{1}{\mathrm{CT_N}} \times \frac{V_B + V_C}{V_{B(LL)}^2 / S_B} \qquad \textbf{(Eq 21)}$$

The voltage across secondary resistor is calculated as follows.

$$V_{N(sec)} = R \times \frac{1}{\mathrm{CT_N}} \times \frac{V_B + V_C}{V_{B(LL)}^2 / S_B} \qquad \textbf{(Eq 22)}$$

Assume that the voltage setting for the auxiliary VT ratio, $\mathrm{VT_N}$, is set the same as the bus VT ratio. It is desired that following magnitudes are equivalent.

$$\left| \mathrm{VT_N} \times R \times \frac{1}{\mathrm{CT_N}} \times \frac{V_B + V_C}{V_{B(LL)}^2 / S_B} \right| = |V_0| = \left| \frac{1}{3}(V_B + V_C) \right| \qquad \textbf{(Eq 23)}$$

We therefore have:

$$
\begin{aligned}
R \times \frac{1 / \mathrm{CT_N}}{V_{B(LL)}^2 / S_B} &= \frac{1}{3} \\
\Rightarrow R &= \frac{\mathrm{CT_N}}{\mathrm{VT_N}} \times \frac{V_{B(LL)}^2}{3 \times S_B}
\end{aligned}
\qquad \textbf{(Eq 24)}
$$