USE OF RESISTIVE VOLTAGE DIVIDERS FOR TRANSFORMER TERTIARY GROUND DETECTION

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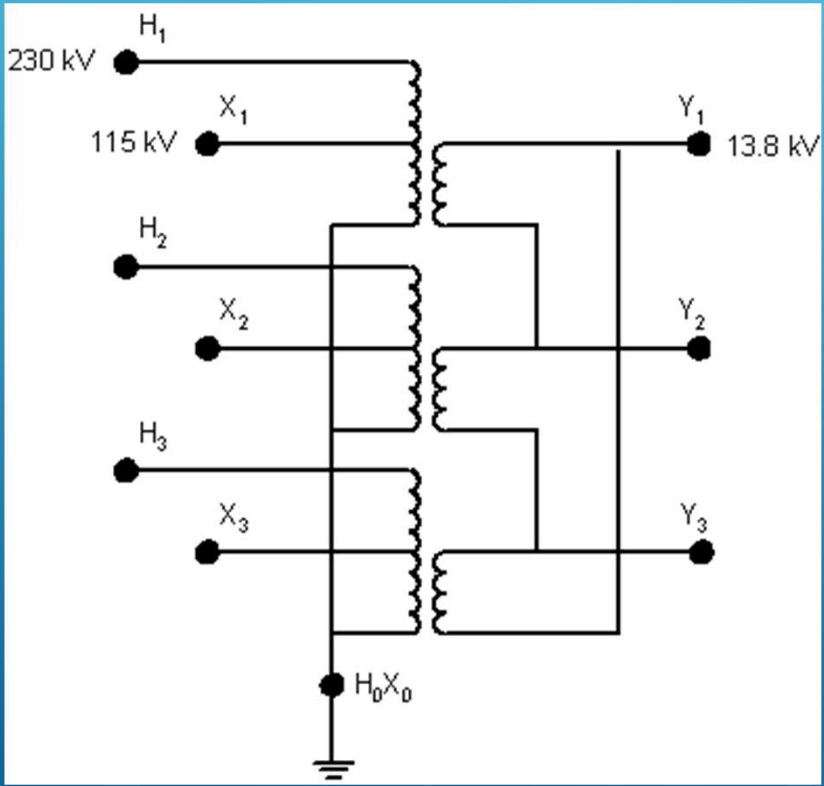
TYPICAL 3-WINDING AUTO TRANSFORMER BANK



Delta winding: supplies station service power

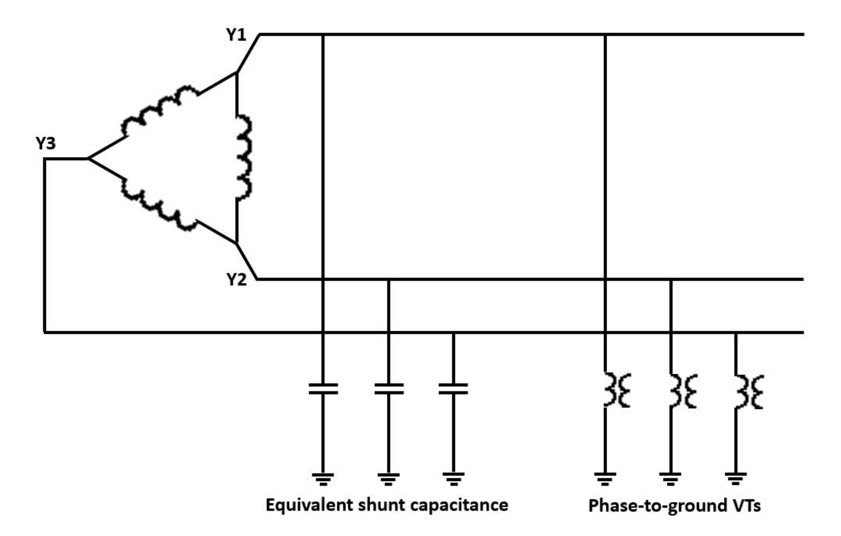
Objective: to be able to detect a phase-to-ground fault on the delta-side

Phase-to-ground fault

- the delta-winding phase-to-ground voltages on the unfaulted phases increase by a factor of √3 causing insulation stress that can lead to failure
- a phase-to-ground fault has caused a lightning arrestor to fail

Insulation rating: phase-to-ground voltage

GROUND FAULTS ON DELTA-SIDE NETWORK

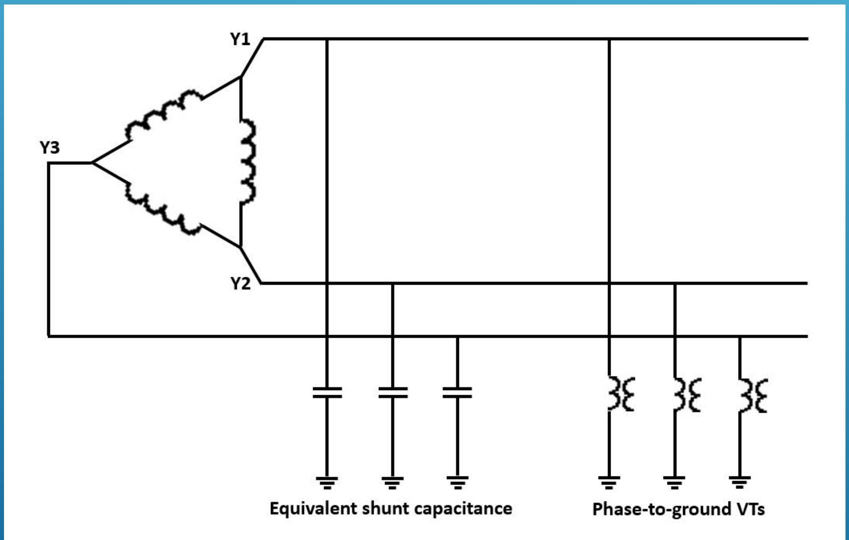


A ground fault on an ungrounded network will produce very little ground fault current

Also, if the network is loaded, the small ground fault currents are difficult to distinguish from noisy loads or switching events

Voltage measurement is usually used to detect ground faults on ungrounded systems

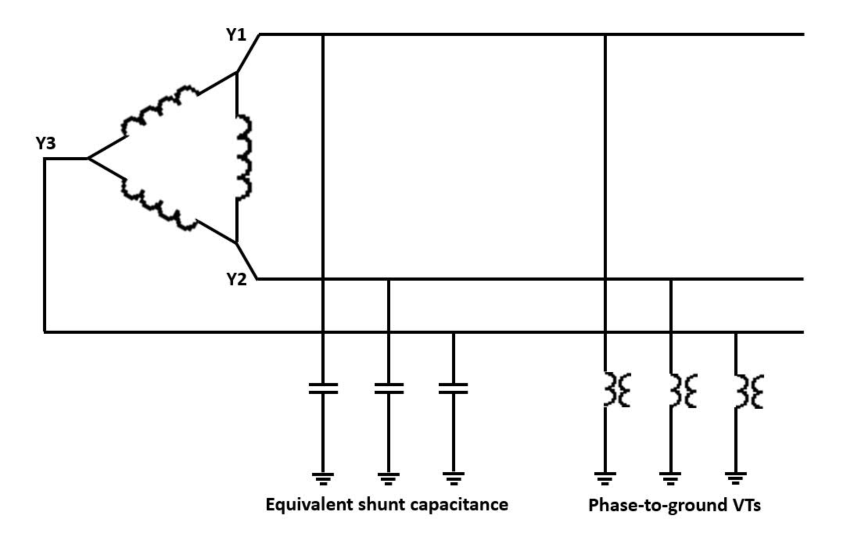
FERRORESONANCE



Ferroresonance can occur when traditional VTs are connected line-to-ground on an ungrounded system and the system is subject to a disturbance

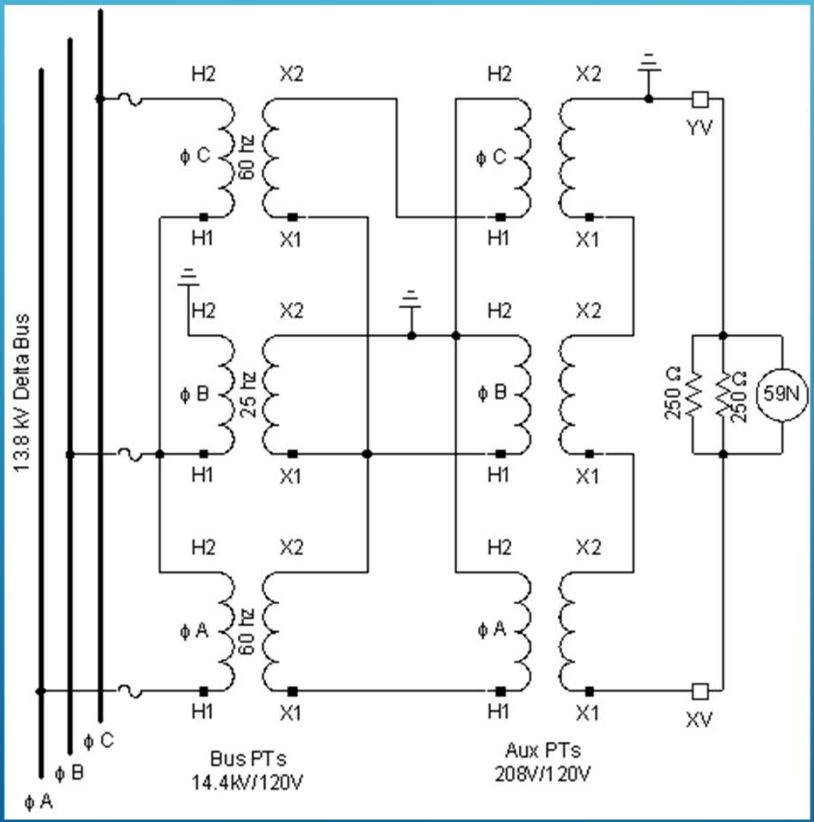
The disturbance can trigger oscillations to develop (ferroresonance) between the VT primary inductance connected to ground and the shunt capacitance connected to ground

FERRORESONANCE



Ferroresonance oscillations → may lead to higher phase-to-ground voltages → repetitive saturation → high currents → heating → eventual failure of the VT

BPA TERTIARY GROUND DETECTOR SCHEME

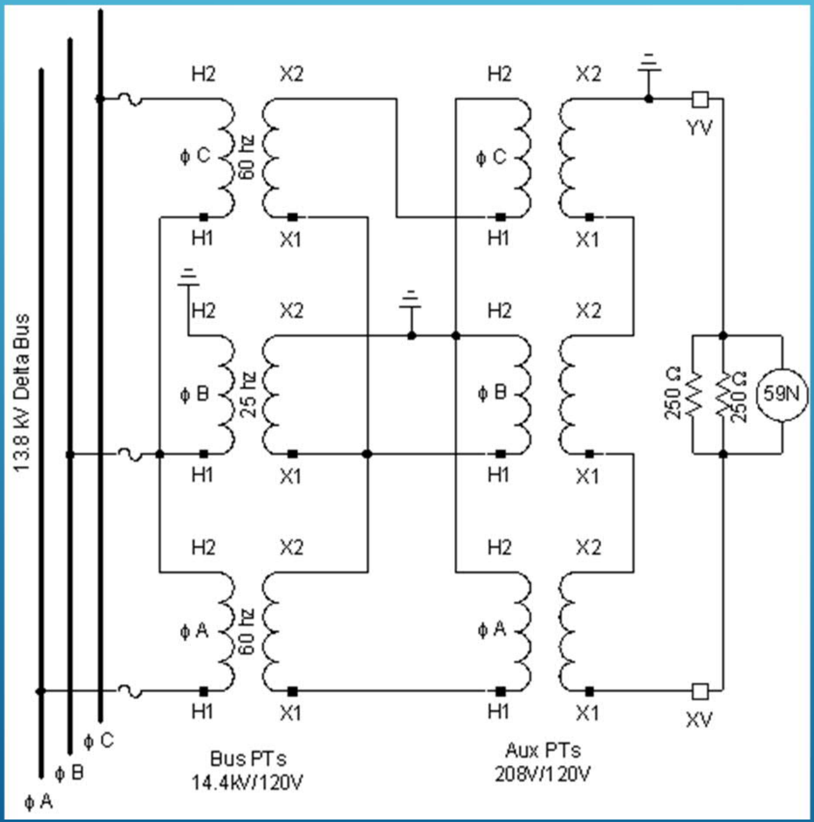


BPA developed and applied a unique voltage sensing scheme

Purpose: detect a ground fault on any phase of the system fed from the delta connected tertiary winding

Ground fault detection method: voltage imbalance in the delta tertiary fed system

BPA TERTIARY GROUND DETECTOR SCHEME



Complex arrangement

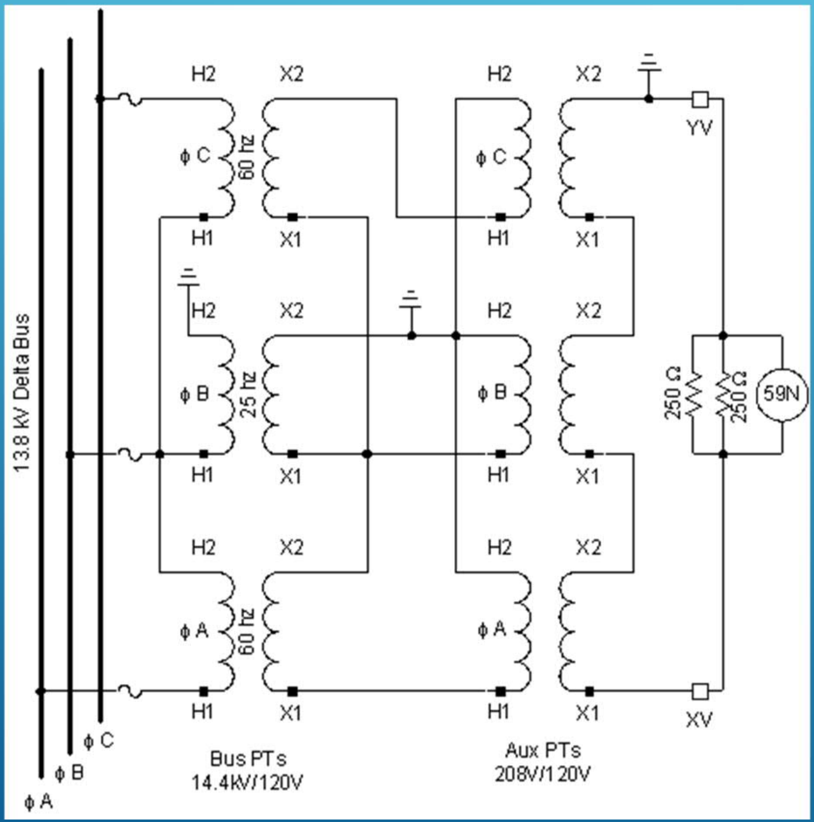
- all carefully designed to avoid ferroresonance

Auxiliary VTs connected in broken delta – connected to a voltage relay

Normal: voltage across the relay is 0 volts (voltages balance, sum to 0)

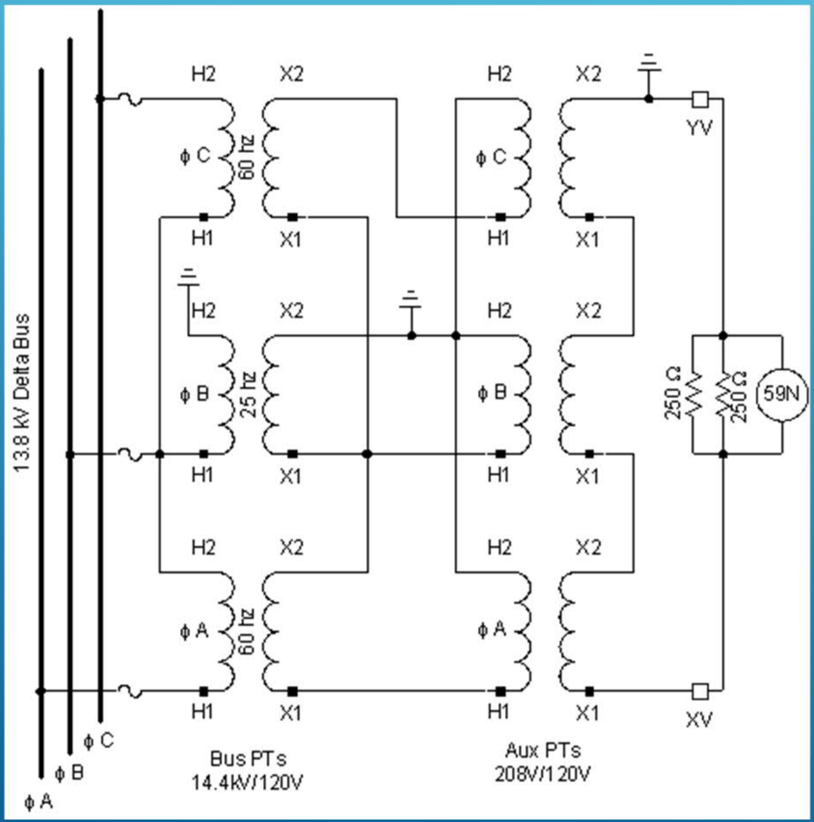
Single phase-to-ground fault: imbalance within the broken delta → voltage across the relay → pickup

BPA TERTIARY GROUND DETECTOR SCHEME



	No Ground	AØ Grounded	BØ Grounded	CØ Grounded
Voltage $V_{XVA-YVC}$	0 Volts	115 ∠150° Volts	115 ∠30° Volts	115 ∠-90° Volts

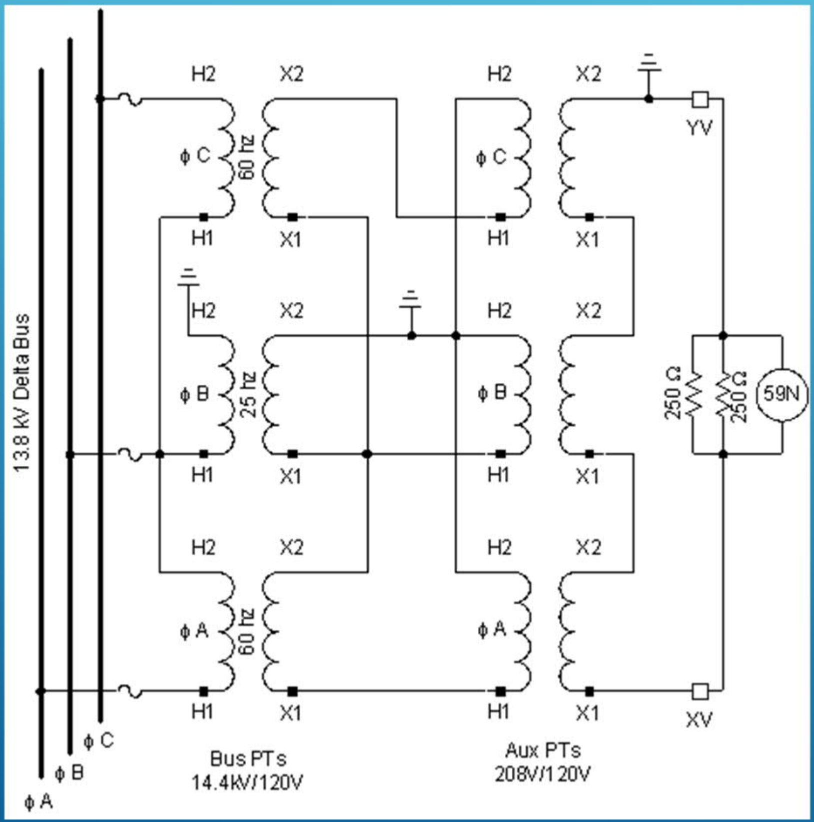
BPA TERTIARY GROUND DETECTOR SCHEME



On detection of a ground fault:

- trip the transformer
- trigger the station event recorder
- send an alarm to SCADA

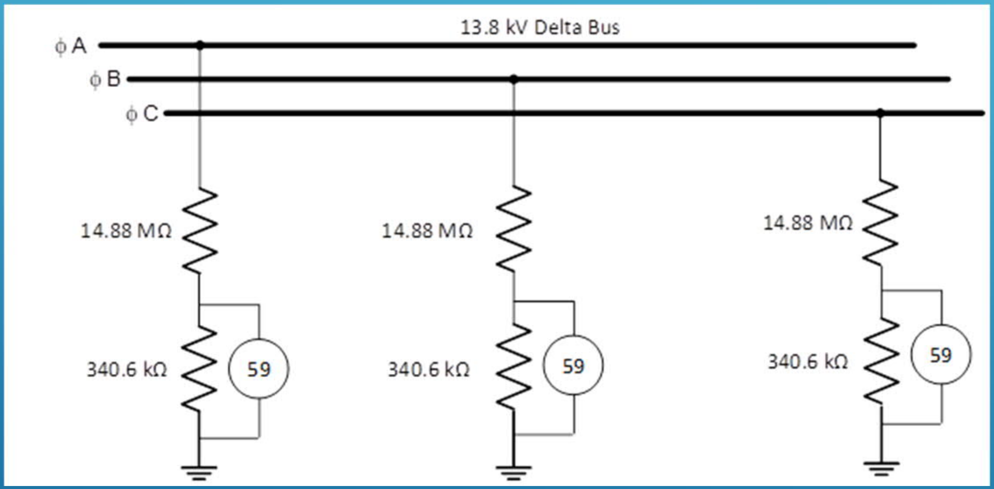
BPA TERTIARY GROUND DETECTOR SCHEME



Largely successful (protecting the VTs from ferroresonance oscillations)

.... but still had the drawback that HV VT fuses occasionally blew, causing an unwanted outage

NEW PROPOSED GROUND DETECTOR SCHEME



Uses resistive voltage divider, per phase

Benefits:

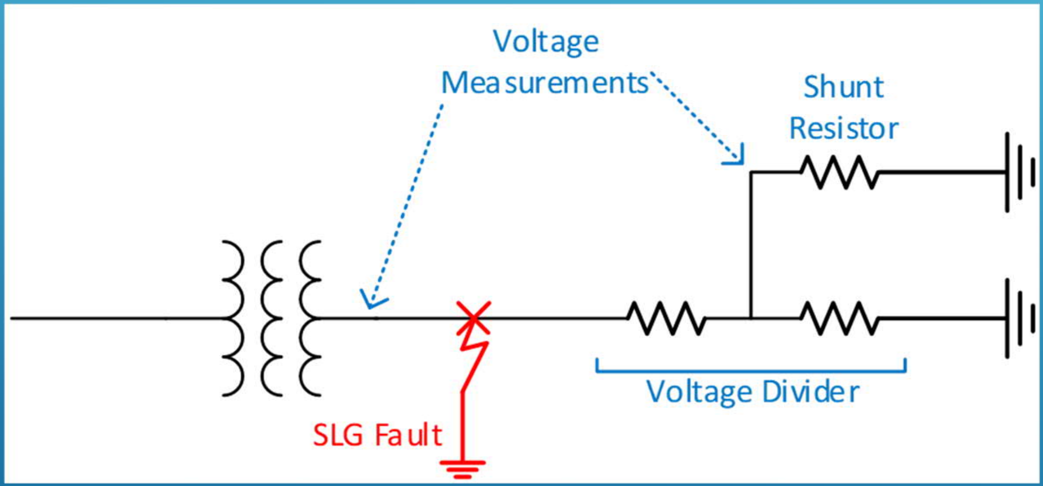
Off-the-shelf, robust, inexpensive, immune to ferroresonance

Output that is measurable by a modern-day digital relay

High accuracy (better than 1%), zero phase-shift

Housed in a body with full electrical and mechanical ratings for post insulator installation

SIMPLIFIED DIAGRAM OF MODELED SYSTEM

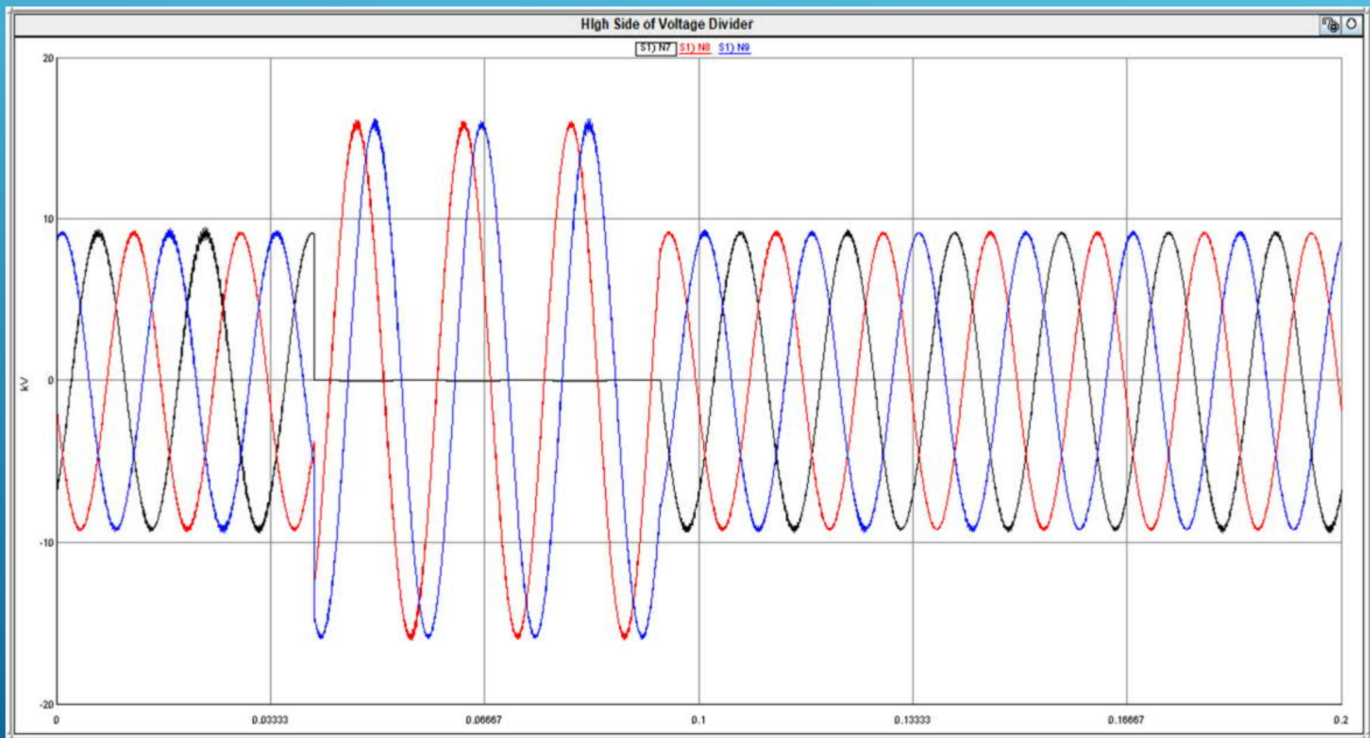


Upfront verification before proceeding further:

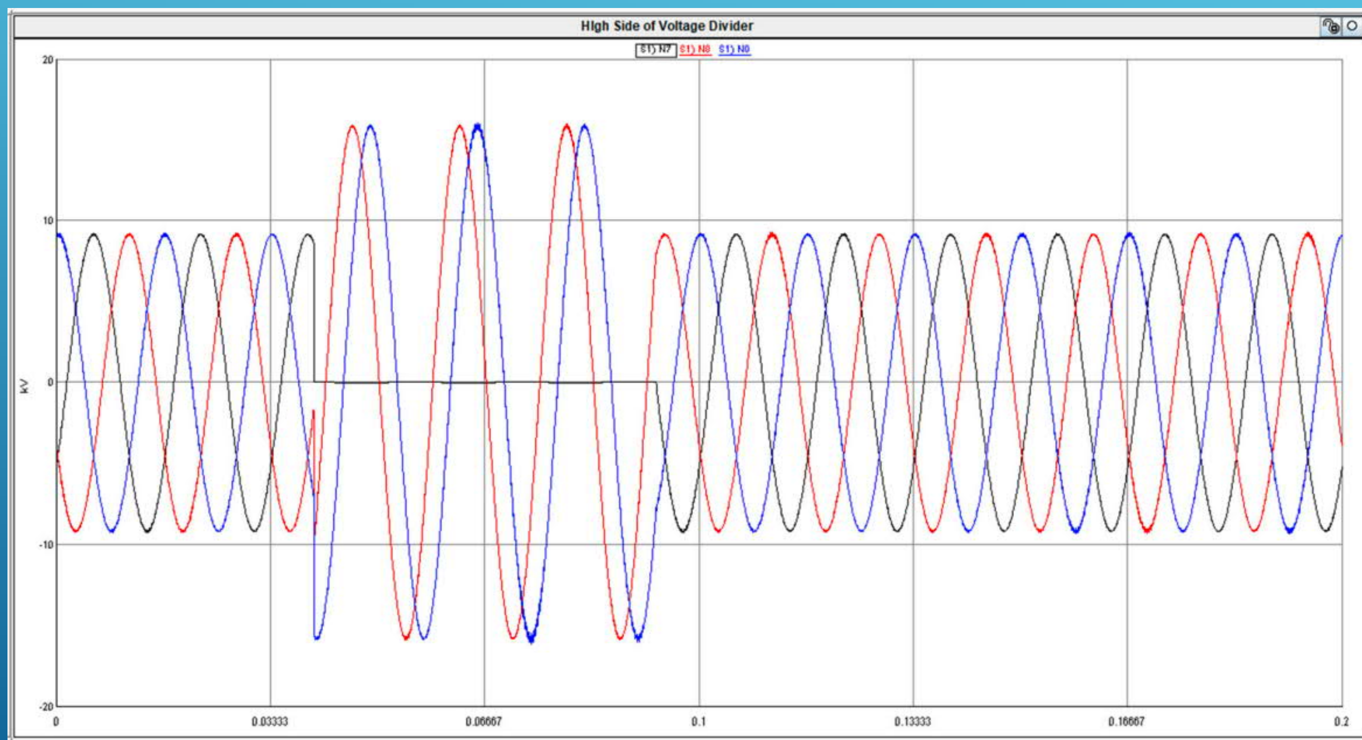
… assess the impact of the parallel resistance to the resistance of the voltage divider

… ensure that adding the voltage divider + shunt resistor does not adversely impact the primary voltage

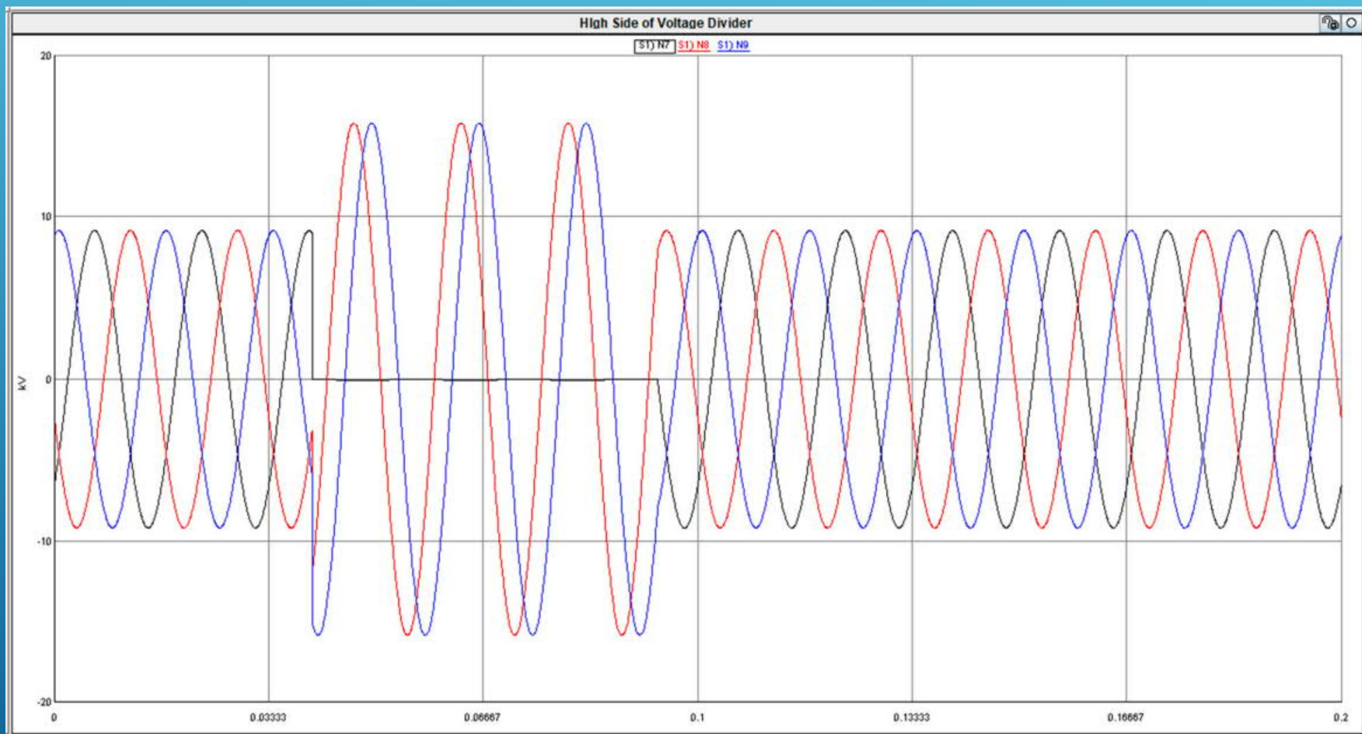
SYSTEM VOLTAGE WITHOUT VOLTAGE DIVIDER



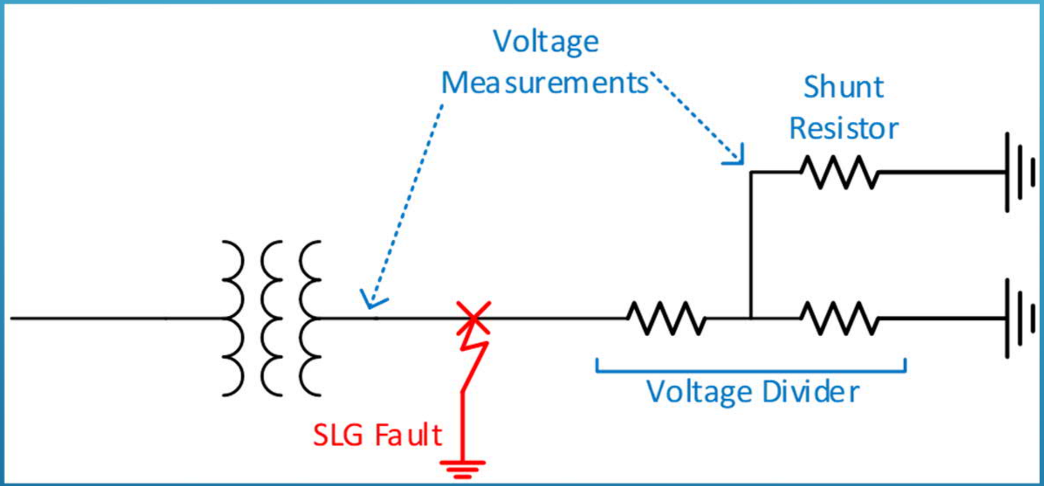
SYSTEM VOLTAGE WITH VOLTAGE DIVIDER



SYSTEM VOLTAGE WITH VOLTAGE DIVIDER AND SHUNT RESISTOR



CONCLUSION FOLLOWING MODELING ANALYSIS



No change in the voltage magnitudes or phase angles between the different scenarios

→ there is no meaningful impact on the delta connected system voltage by adding the voltage divider + shunt resistor

SHUNT VOLTAGE DIVIDER LOCATION

Main hurdle: the cable length from the voltage divider output can have a maximum length of 35’

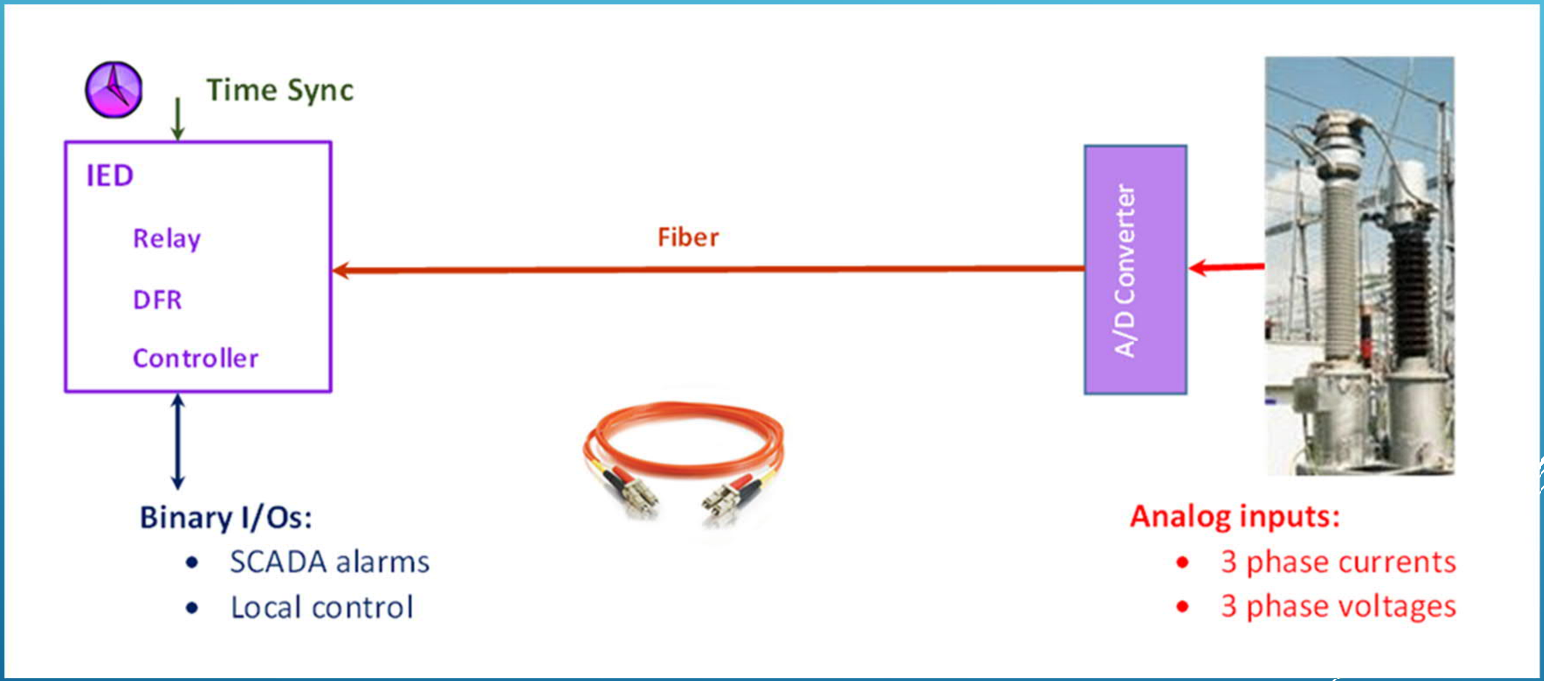
SHUNT VOLTAGE DIVIDER SOLUTION REQUIREMENTS

The voltage measurement solution must be able to:

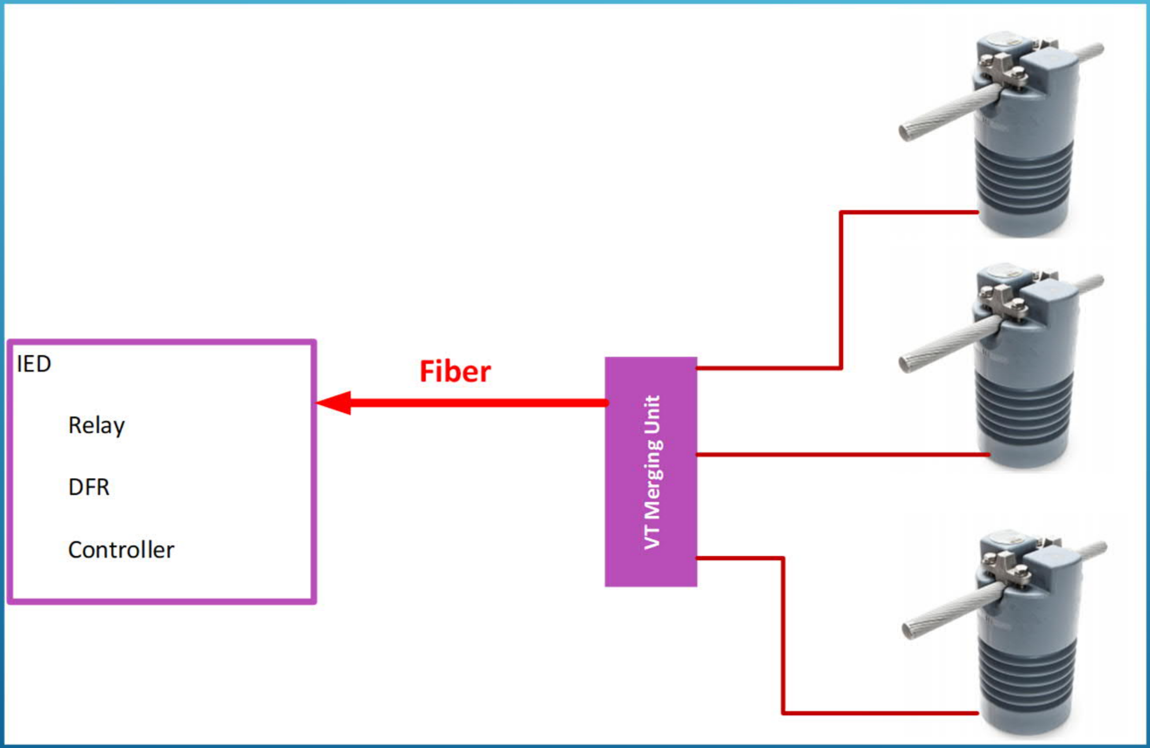
1. make sufficiently accurate voltage measurements at the voltage measurement location in the substation yard

2. make these measurements available to the protection relay located in the substation control building

61850 AND MERGING UNITS



APPLICATION DIAGRAM WITH USE OF VT-MU

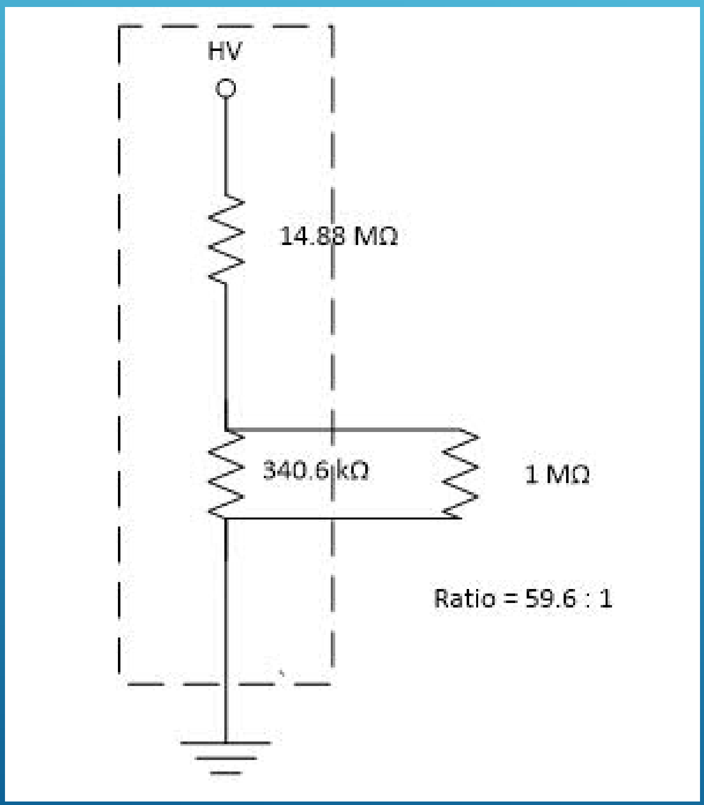


VT-MU located close to the voltage divider

Sends voltage data samples to the protection relay over a fiber optic Ethernet cable – IEC61850 standard

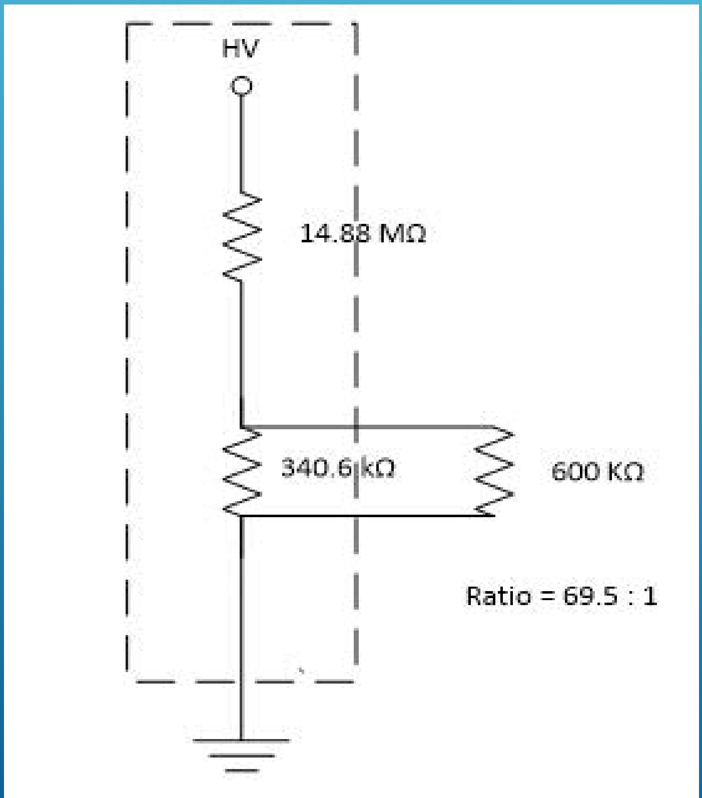
FO cable supports the distance

SHUNT VOLTAGE DIVIDER SECONDARY IMPEDANCE



Tuned to a ratio of 60:1 when the device connected to the voltage divider output has an input resistance of 1MΩ

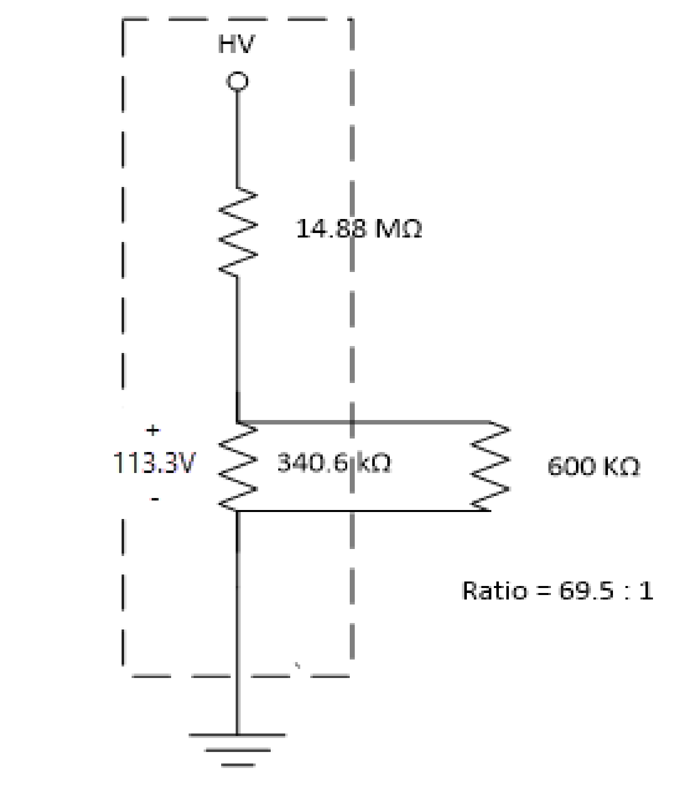
SHUNT VOLTAGE DIVIDER SECONDARY IMPEDANCE



The ratio will change when the device connected to the voltage divider output has an input resistance different from 1MΩ

Example: for a device with an input resistance of 600kΩ, the ratio changes to 69.5:1

MEASURED VOLTAGE ACROSS VOLTAGE DIVIDER



Merging unit sampled data is streamed in primary values

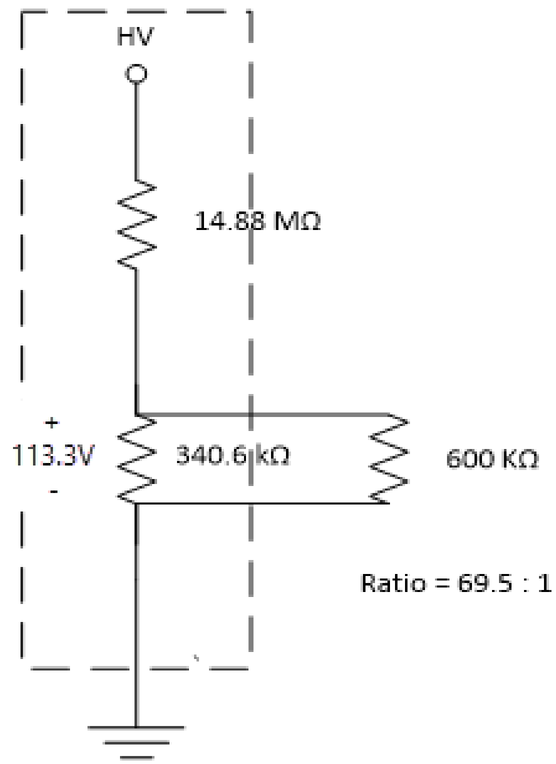
Voltage divider output = 113.3V (measured) for 1 per unit primary voltage

For a merging unit with 1 per unit secondary voltage input = 120V, scaling is required to get correct reporting of the voltage

System voltage of 13.8kV phase-to-phase = 7.97kV phase-to-ground

Need to set MU Pri/Sec voltage ratio to 8.46kV:120V

ENVISAGED APPLICATION SETTINGS



Undervoltage pickup level:

70% of the nominal phase-to-ground voltage

Time delay:

5s definite time

FULL SCALE TESTING

To date:

- Relays have been configured
- Compatibility with the resistive voltage divider has been demonstrated – high voltage applied and checked that it was correctly read by each relay

a. Hard single line-to-ground (SLG) fault, A phase
b. Hard single line-to-ground (SLG) fault, B phase
c. Hard single line-to-ground (SLG) fault, C phase
d. Partial (impedance TBD) single line-to-ground (SLG) fault, A phase
e. Partial (impedance TBD) single line-to-ground (SLG) fault, B phase
f. Partial (impedance TBD) single line-to-ground (SLG) fault, C phase

CONCLUSIONS

Detection of ground faults on ungrounded delta-tertiary systems has traditionally been a difficult challenge

Traditional VTs are vulnerable to damage due to ferroresonance

A new proposed approach uses resistance voltage dividers that are immune from ferroresonance

The resistive voltage divider requires the device connected to its output to be close by – overcome by using a MU located close by that publishes a 61850 compliant sample value stream for receipt by the protection relay located in the substation control building

Modeling concluded that the addition of the voltage divider + VT-MU did not adversely impact delta-system primary voltage

Site testing scheduled to take place the week of March 28