Blocking Geomagnetically Induced Currents (GIC) with Surge Arresters

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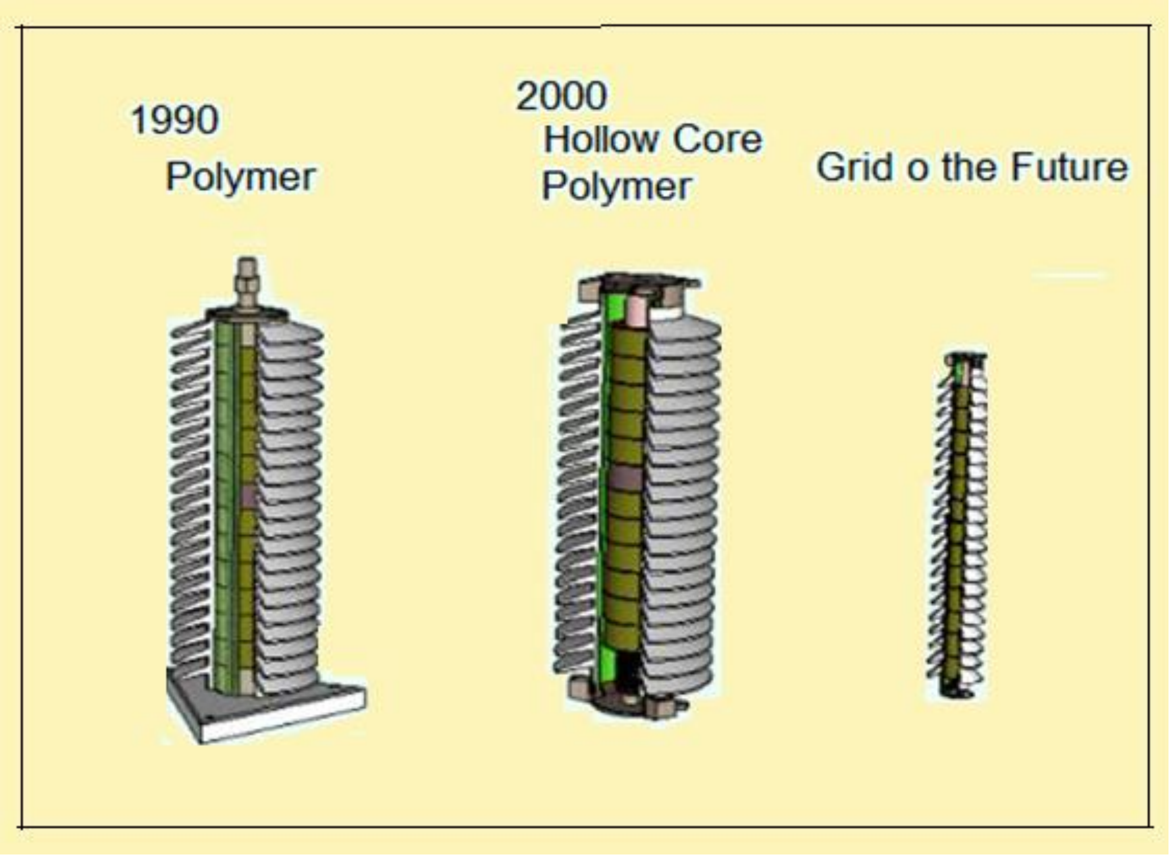
The Grid-of-the-Future Surge Arrester

"I can confidently predict that in the very near future, we will see much smarter arresters at very little added cost. Arresters will come from the factory with internal brains that will perform many useful tasks not even considered today. These smart arresters will not only watch over its own health, and the health of the system, it will transmit this data to those that need it the most."

Jonathan Woodworth, Arresterworks
INMR 2015 World Congress; Oct 21, 2015 Munich Germany

The Grid-of-the-Future Surge Arrester



Executive Order - Coordinating Efforts to Prepare the Nation for Space Weather Events

"The Secretary of Energy, in consultation with the Secretary of Homeland Security, shall develop in 120 days a plan to test and evaluate available devices that mitigate the effects of geomagnetic disturbances on the electrical power grid through the development of a pilot program that deploys such devices, in situ, in the electrical power grid."

President Obama, October 13, 2016

Grid-of-the-Future GMD Mitigation Technology; already here for testing in a Pilot Program

The assertion of the top surge-arrester world expert becomes very relevant to the technology we introduce fitting the notion of a ‘useful task not even considered today’

A simple, cost-effective, secure course to deal with the GMD major hazards by means of an novel surge-arrester GIC-blocking ability

The Surge Arrester Protective Functionality

In addition to transformer and line protection surge arresters/(MOV) have been extensively utilized for series capacitor protection

Transformer neutral-blocking devices use surge arresters for overvoltage protection

The Surge-arrester Protective Functionality: its Application to Neutral-Blocking Devices

Must recognize

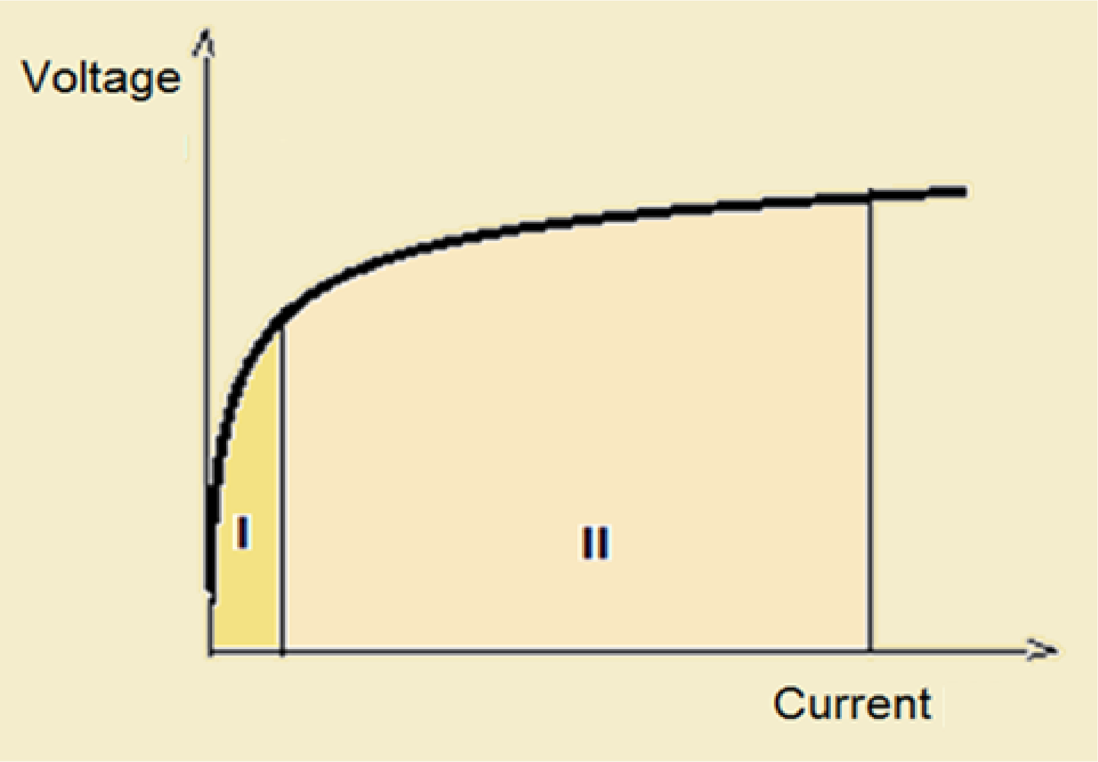
Exhaustive testing series performed at major High-power Labs

Full-scale live testing series performed at major Research Labs

Comprehensive simulations at both the academic and industrial levels

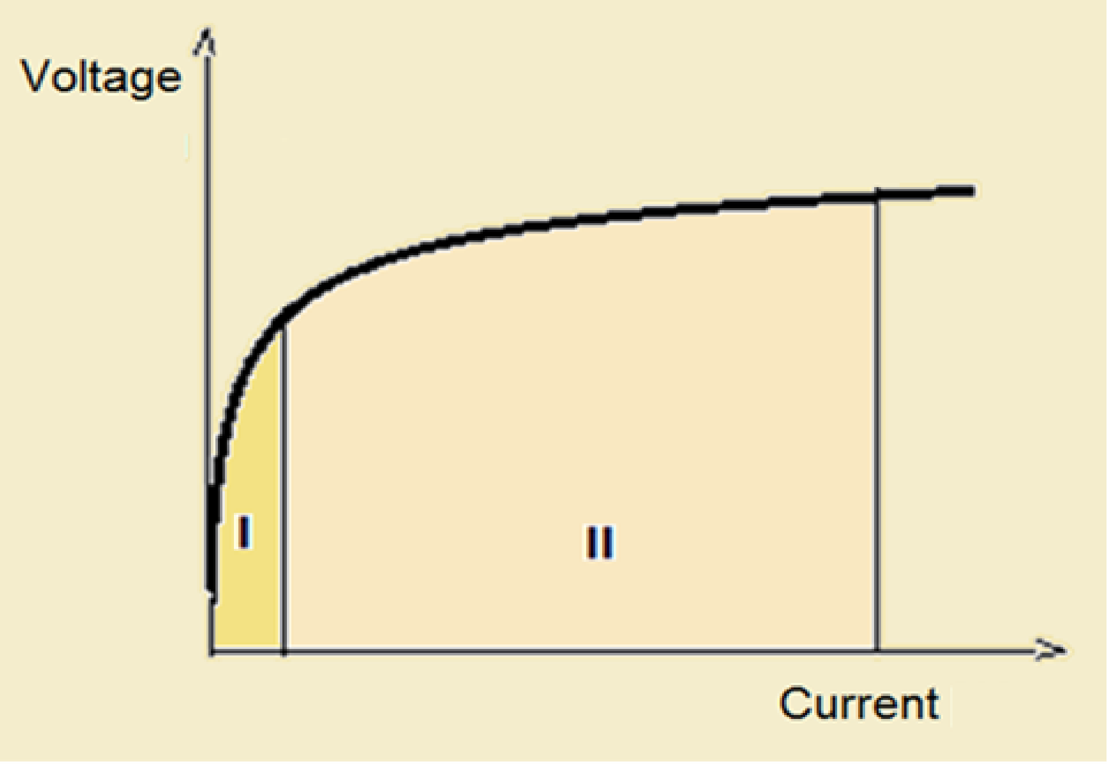
Arresters robustly passing all tests

The Surge Arrester Dual Functionality



Ohm’s Law applies to non-linear resistors; mind slopes at graph points of both Regions I and II

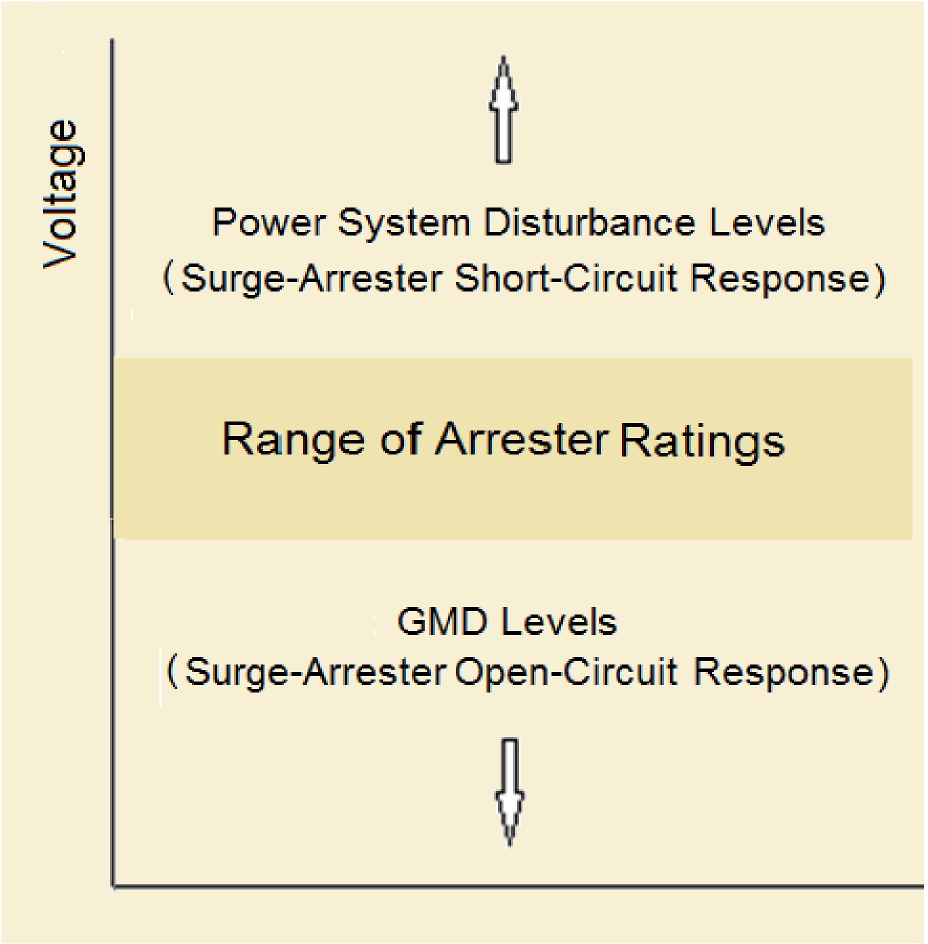
The Surge Arrester Dual Functionality



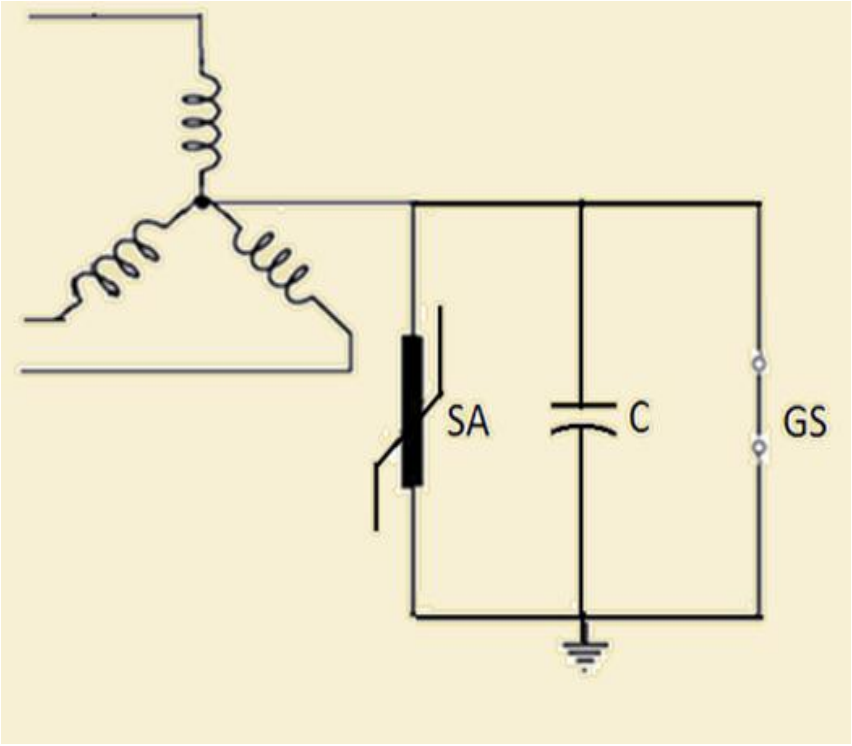
Region I: Resistance Very High; consistent with GMD voltages

Region II: Resistance Very Low; consistent with ground-fault disturbances

Comparative of Transformer Neutral Voltage Ranges



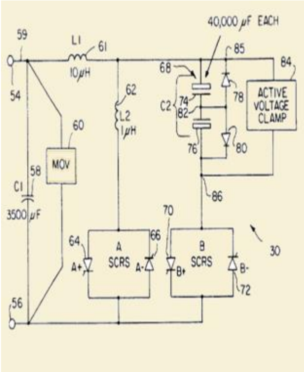
Why a GIC Neutral-Blocking Capacitor?



Why a Neutral-Blocking Capacitor?

Industry reluctance to this approach stemming from costs, size, complexity and perceived operational risks *

Understanding this problem, and its solution, starts with consideration of three power-system key states



* Failure modes for the most part unknown

Basic System Device Design States

Three basic power-system scenarios to consider, possibly in combination:

a) Ground-Fault Disturbances

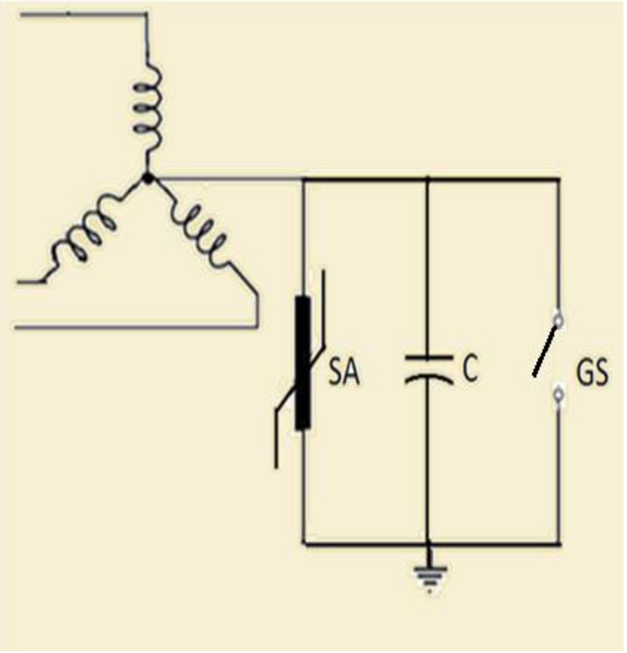
b) GMD/GIC

c) Steady State

Neutral-Blocking Capacitor Facts

Neutral surge arrester protects the shunt capacitor bank from ground faults

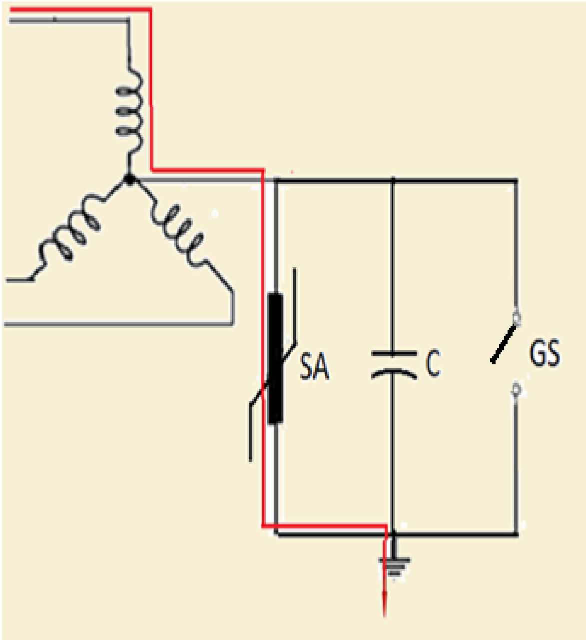
Still, surge arrester protects all components connected neutral-to-ground, including the winding neutral insulation to ground (typically 110 KV BIL)



Neutral-Blocking Capacitor Facts

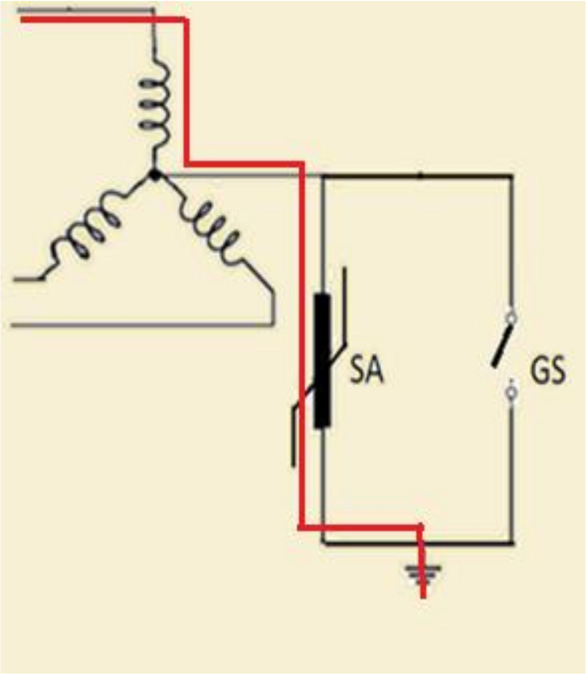
At ground faults surge arrester instantaneously shunts the capacitor bank protecting thus transformer's wye winding

Any perceived neutral-grounding capacitor functionality becomes unrecognizable



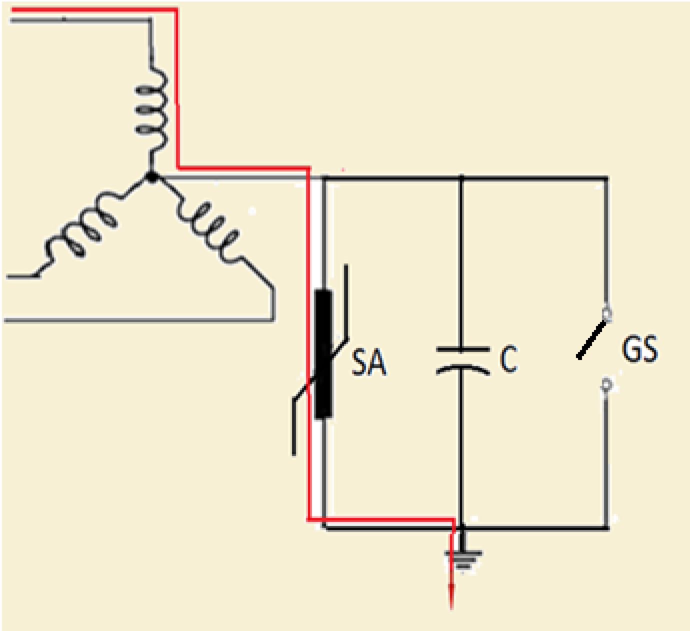
Neutral-Blocking Device Facts

Through a ground fault, surge arrester does fully protect the transformer winding neutral end, besides solidly grounding it after a few milliseconds from fault inception; <u>with or without a shunt capacitor</u>



Why a Neutral-Blocking Capacitor?

Ground Fault and GMD/GIC



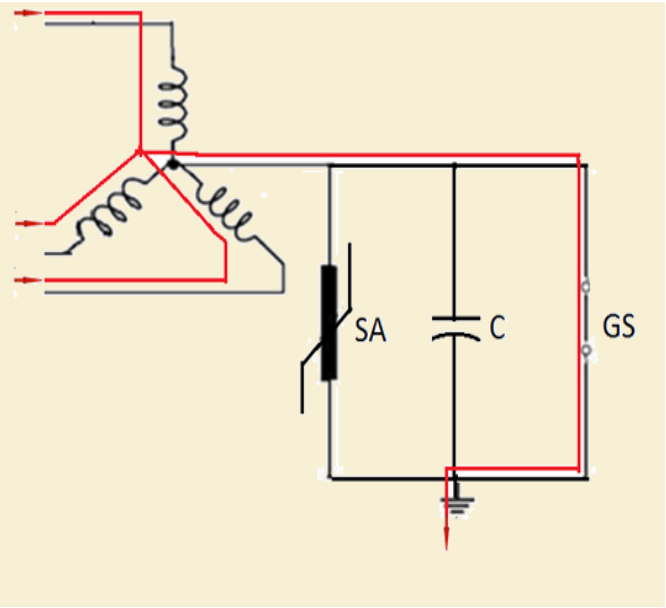
Mitigation Device Deployed

Inconsequential; **transformer protected** by Surge Arrester

Steady State and GMD/GIC

Mitigation Device Not Deployed

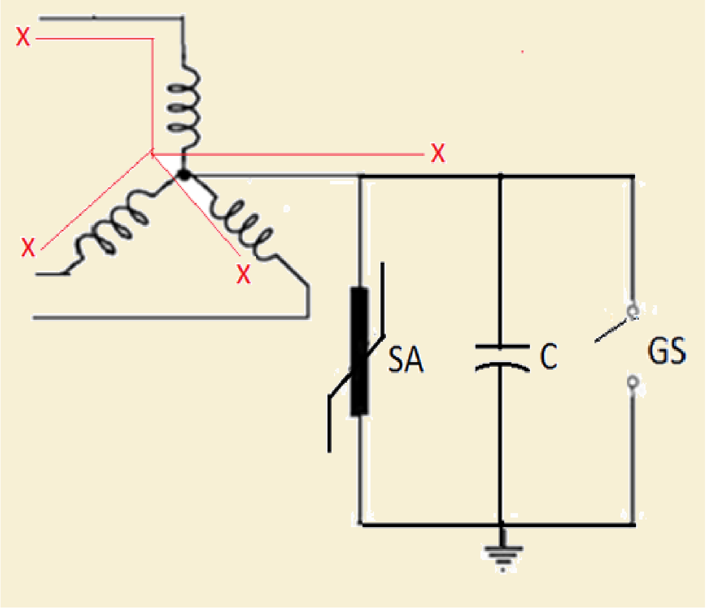
Problematic; transformer traversed by GIC currents



GMD/GIC Disturbance

Mitigation Device Deployed

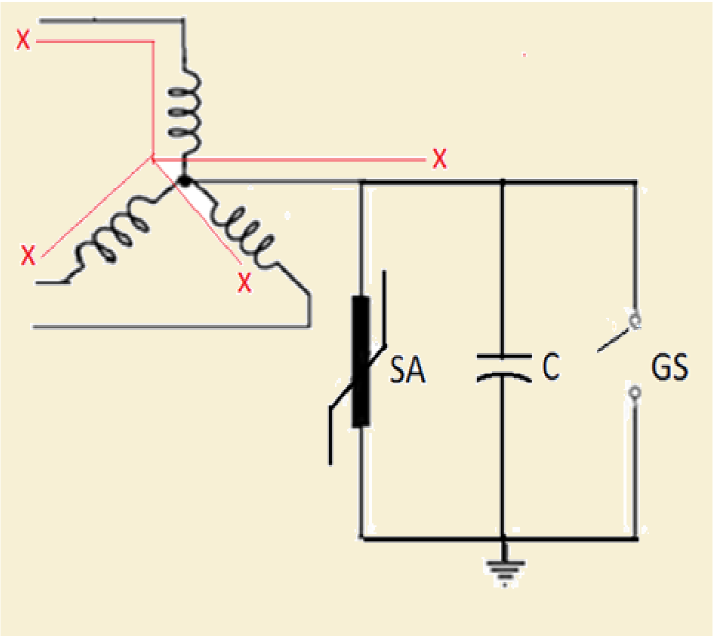
Inconsequential; transformer protected by a neutral-blocking scheme



Why a Neutral-Blocking Capacitor?

GMD/GIC Disturbance

Surge arrester, in parallel with capacitor, performs a not duly appreciated **blocking function** identical to the one carried out by the capacitor

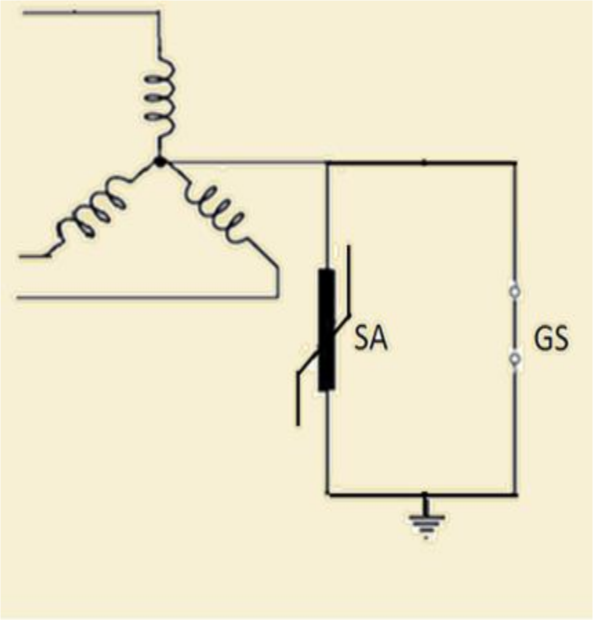


Otherwise GIC current could flow to ground through surge-arrester path *

* Actually, there is a record of that problem happening in a well-documented case

Why a Neutral-Blocking Surge Arrester

We
Propose



Why a Neutral-Blocking Surge Arrester

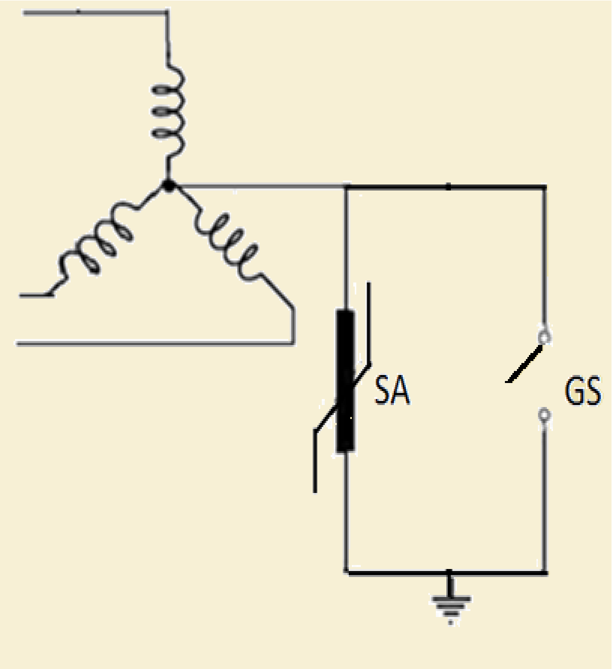
It can therefore be concluded, based on both the GIC blocking and ground-fault protection functionalities, the inclusion of a capacitor bank in a neutral-blocking scheme can not be justified from an engineering standpoint

Why a Neutral-Blocking Surge Arrester

Steady-state conditions with proposed arrester-device deployed

Unlikely state for Solar GMD

Very unlikely state for EMP/E3



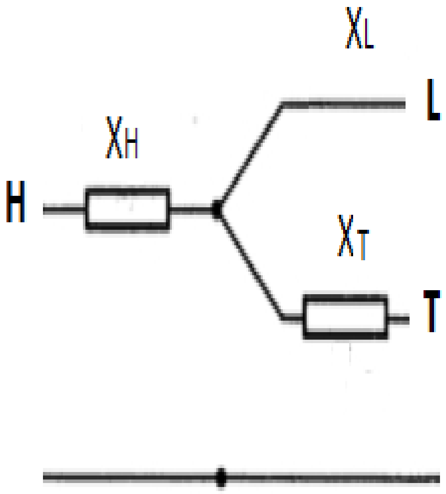
Steady-state Conditions: Arrester-Device Deployment Analysis

Typical Transformer apparatus:

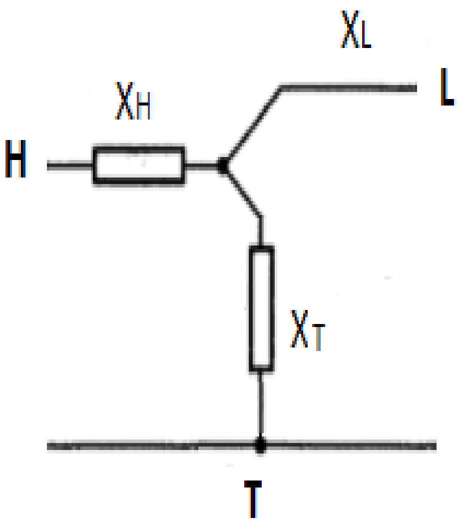
- Three-winding grounded Wye-Wye-Delta Autotransformer
- Two-winding Delta-Wye (grounded) GSU

Normal Steady-State Conditions

Typical three-winding Autotransformer



Positive/negative sequence per-unit equivalent circuit



Zero-sequence per-unit equivalent circuit

Steady-State Performance

Three-winding Autotransformer/Numerical Example

Grounding Coefficient before and after arrester deployment

Nameplate 500/435/100 MVA 500/345/66 KV

Grounded YYΔ Connection

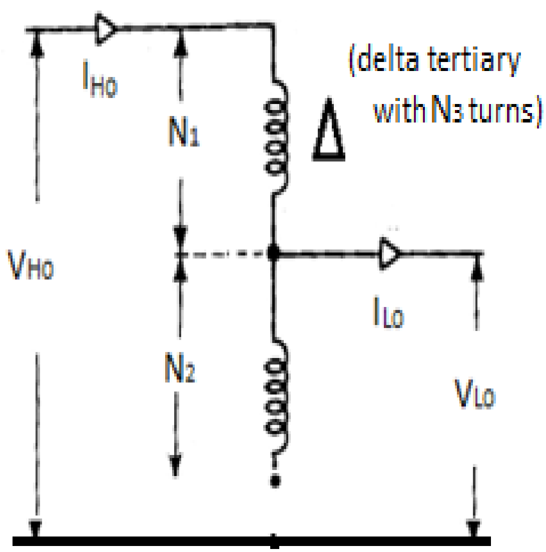
X_{HL} = 0.10 pu on a 500 KV/500 MVA base

X_{HT} = 0.17 pu on a 500 KV/100 MVA base

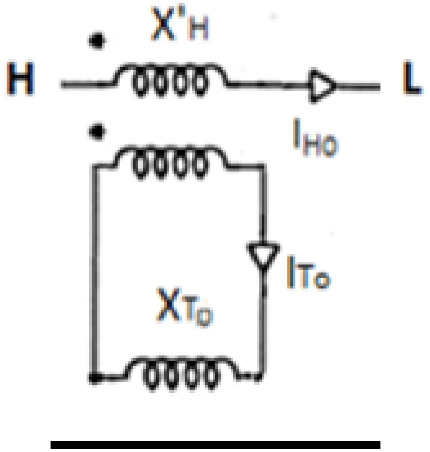
X_{LT} = 0.15 pu on a 66 KV/100 MVA base

Normal Steady-State conditions:
Neutral Arrester Device deployed

Three-winding Autotransformer



One-line diagram of device-caused neutral-to-ground isolation: zero-sequence flow.



Zero-sequence circuit with neutral isolated from ground

Steady-State Performance

Three-winding Autotransformer/Numerical Example

Grounding Coefficient before and after neutral arrester deployment

Conversion to 500 MVA base

$X_{HL} = 0.10$ pu

$X_{HT} = 0.17 \times 5 = 0.85$ pu

$X_{LT} = 0.15 \times 5 = 0.75$ pu

Steady-State Performance

Three-winding Autotransformer/Numerical Example

Grounding Coefficient for normal conditions

(no arrester blocking device deployment)

$$\frac{X_{HLzero\text{-}sequence}}{X_{HLpositive\text{-}sequence}} = 1$$

Steady-State Performance

Three-winding Autotransformer/Numerical Example

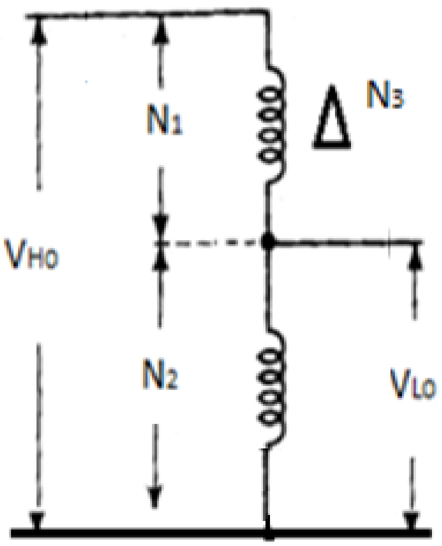
Grounding Coefficient before and after arrester deployment

Windings reactance computation

$$X_H = 0.5(X_{HL} + X_{HT} - X_{LT}) = 0.5(0.10 + 0.85 - 0.75) = 0.1 \text{ pu}$$
$$X_L = 0.5(X_{HL} + X_{LT} - X_{HT}) = 0.5(0.10 + 0.75 - 0.85) = 0.0 \text{ pu}$$
$$X_T = 0.5(X_{LT} + X_{HT} - X_{HL}) = 0.5(0.75 + 0.85 - 0.10) = 0.75 \text{ pu}$$

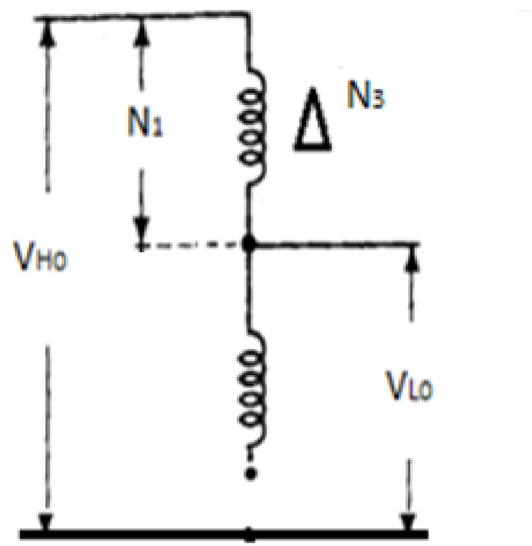
Steady-State Performance

High-to-Tertiary Turns-ratios / Correction factor before and after arrester deployment (causing zero-sequence neutral-to-ground isolation)



Normal Conditions

$$\text{Turns Ratio} = \frac{N_1 + N_2}{N_3}$$



Device Deployed (neutral isolation)

$$\text{Turns Ratio} = \frac{N_1}{N_3}$$

$$\text{Turns Ratio Impedance Correction Factor} = \left(\frac{N_1}{N_1 + N_2}\right)^2$$

Steady-State Performance

Grounding Coefficient after device deployment

Turns-ratio correction factor $\dfrac{N_1^2}{(N_1+N_2)^2} = \dfrac{(500-345)^2}{(500)^2} = 0.1$

Prevailing zero-sequence High-to-Low reactance becoming:

$$X'_{HT} = X_{HT}\,\frac{N_1^2}{(N_1+N_2)^2} = 0.85 \times 0.1 = 0.085 \text{ pu}$$

Steady-State Performance

Three-winding Autotransformer/Numerical Example

Grounding Coefficient after neutral arrester Deployment

$$\frac{X_{HLzero\text{-}sequence}}{X_{HLpositive\text{-}sequence}} = 0.085 / 0.1 = 0.85$$

Steady-State Performance

Three-winding Autotransformer:

Grounding Coefficient Summary

No neutral arrester deployment = 1.0

Neutral arrester deployment = 0.85

Note: grounding coefficient of 1.0 corresponds to a solidly-grounded equipment (IEEE Standard)

Steady-State Performance

It can be then securely asserted, from the steady-state consideration, a capacitor bank application could not be justified from an engineering standpoint to protect a grid autotransformer

Steady-state Performance

GSU Transformer

No zero-sequence flow may come from the generation side

Zero-sequence unbalance flow may develop from the transmission line side due to load or from line-parameter dissymmetry

Steady-state Performance

GSU Transformer

Zero-sequence components typically negligible

Neutral shift would be limited to a Ferranti-rise in the zero-sequence network

Zero-sequence flow through GSU immaterial as it refers to a line-end apparatus

Arrester device lends itself to a straight-forward specification from the unbalance examination

Conclusions

From:

Steady-state performance, parametrical invariance, GIC blocking, ground-faults, zero-sequence current residuals, etc, the standalone surge-arrester device compares favorably with the one based on a capacitor bank, yet without any of its undeniable inherent risks

The difference can only be found at the blocking-function means: one performed by a capacitor bank and another by a common surge arrester

Conclusions

Proposed Technology:

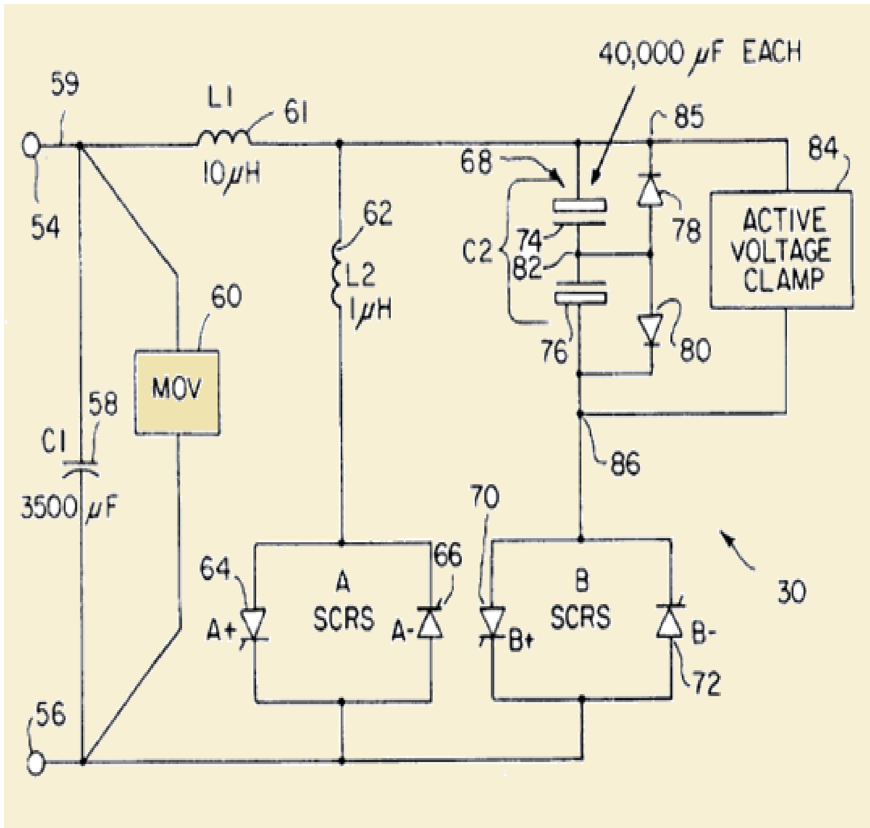
Enables a drastic cost and footprint reduction of mitigation devices as well as a foremost simplicity

It turns implementing capacitor banks for GIC neutral-blocking purposes into an unnecessary and costly redundancy with potential undesired consequences

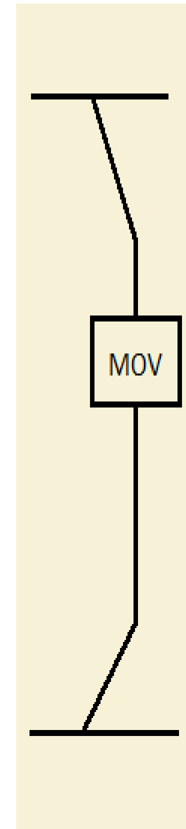
Conclusions

The surge arrester, typically used for protection of power equipment, in addition to being a component actually present within all known GMD mitigation devices, and performing a full GIC-blocking function already, should then be upgraded to be the very sole element designed to carry out such an essential function, all things considered

Conclusions



Capacitor Device



Arrester Device

Conclusions: Final Thoughts

Legitimate reservations regarding the incremental cost/benefit of adding massive capacitor bank assemblies, with complex ancillaries, merely to secure the flow of basically inconsequential ground currents associated to a few transformers at limited and short steady-state situations

Legitimate questions regarding such an incremental cost/benefit evaluation minding neutral-blocking units might operate infrequently and able to reduce basically around fifty percent of GIC upon some autotransformers *

*Drastic GIC suppression achievable by grid strategic device placing

Future/Ongoing Work

R&D on actionable early sensing of EMP shock waves

(presently in advanced testing state)

R&D to favorably address the challenging issue of GIC current interruption

Questions ?