PHASOR BASED TRANSIENT EARTH-FAULT PROTECTION

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HITACHI ABB POWER GRIDS

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2. Isolated and Resonant grounding
3. Energy/Power flow in High-Impedance Grounded Network during a GF
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6. Sampling Rate Issues / Understanding
7. Conclusion

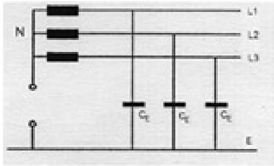
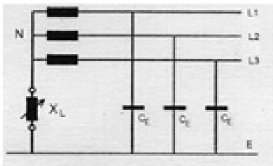
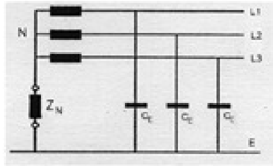
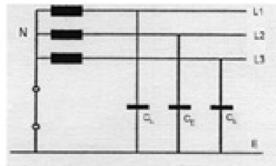
Why power system grounding is important?

Type of neutral point grounding of an electrical network determines:

1) Magnitude level of the ground-fault current at the fault point
2) Safety: Step and Touch voltages in vicinity of the fault point
3) Operation of the network during a ground fault which is the most common type of faults (e.g. influence continuity of supply)
4) Type of protective relays which shall be used
5) Overvoltage condition on healthy phases during the GF (transient and steady-state)
6) Design and price level of the installed equipment (e.g. insulation level).
7) Interference with other equipment (e.g. communication equipment)

Type of grounding used throughout the World

Different grounding principle

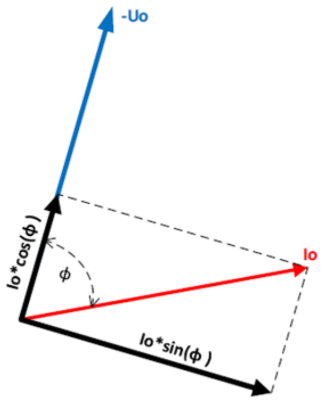
	isolated	compensated	low impedance	solid
				
GF Current	I_C	**Theoretically 0A**	I_{lim}	I_{SC}
Voltage factor	$k = \sqrt{3}$	$k = \sqrt{3}$	$k \sim 1\text{-}1{,}4 \,/\, \sqrt{3}$	$k \sim 1\text{-}1{,}4$
GF Property	self extinction possible $I_{fault} < 35A$	self extinction possible $I_{fault} < 65A$	steady arc	steady arc
Customers	Uninterrupted power supply	Uninterrupted power supply	immediate interruption	immediate interruption
Application	limited to small networks with $I_C < 35A$	up to an I_C of a few 100 A $I_{fault} < 65A$ / up to **132** kV	Grounding via earthing resistance or earthing reactor	transmission systems solidly grounded

Compensated/Resonant grounding suppress the GF current at the fault point!

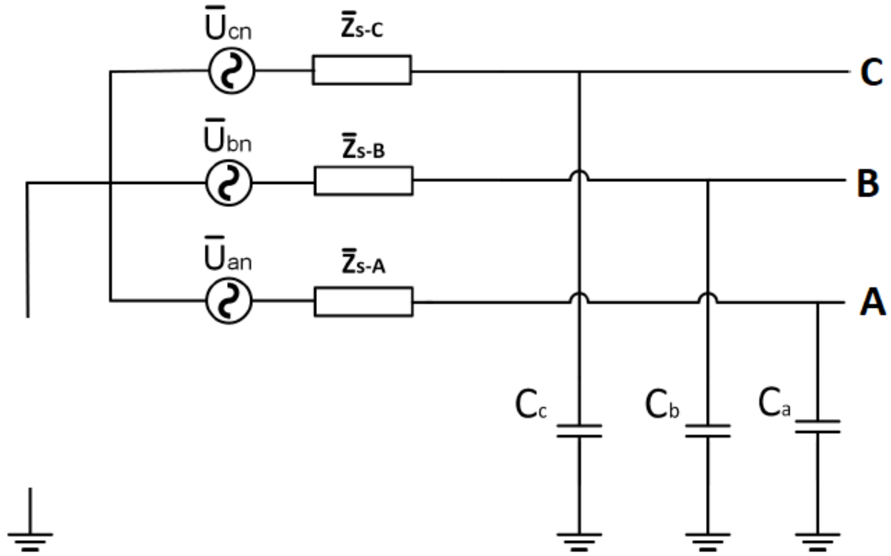
Isolated Power Systems

Used terminology throughout the World:

1. Isolated system
2. Not grounded system
3. Io∗sin(ϕ) current component

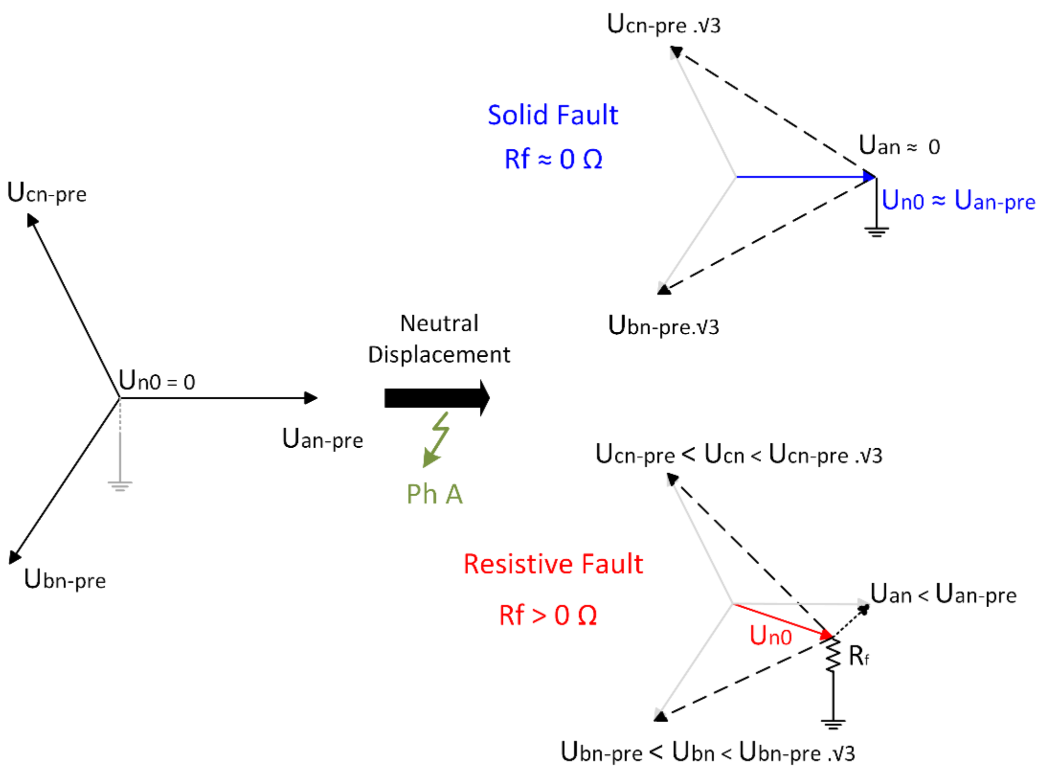


Power system circuit

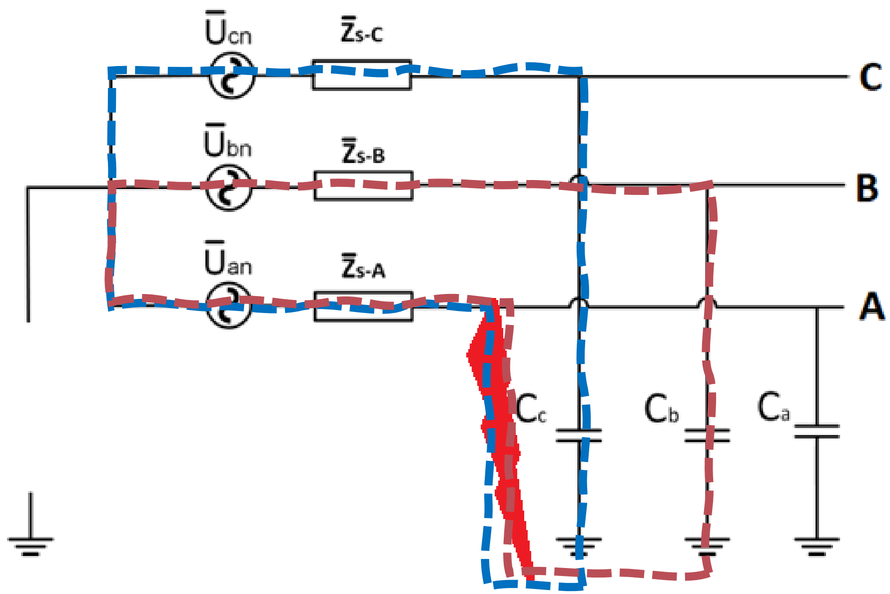


Isolated Power Systems

What happens for voltages in the two healthy phases:



What happens with currents during a Ground Fault



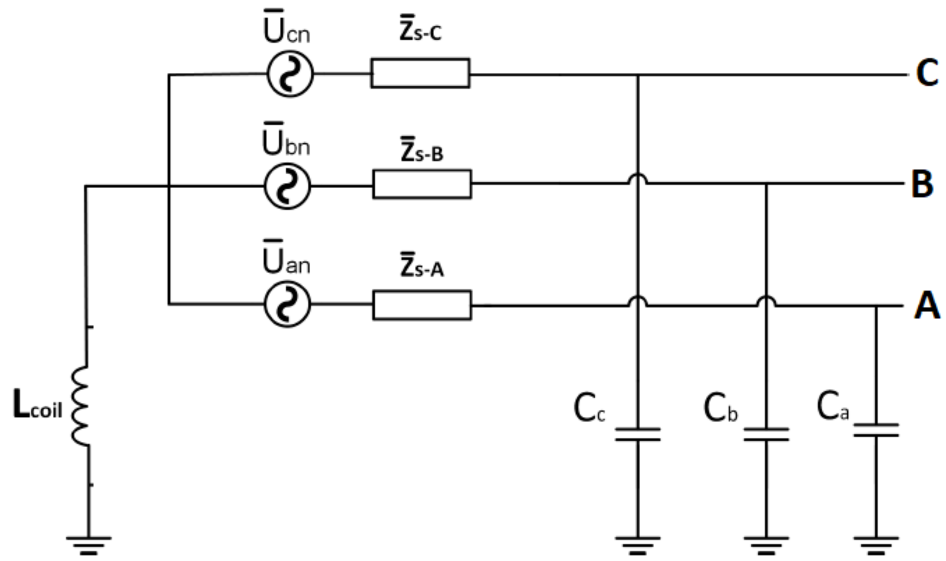
GF current becomes capacitive at the fault point.

Compensated Power Systems

Used terminology throughout the World:

1. Compensated system
2. Resonant grounding
3. Petersen coil
4. P-coil
5. Arc suppression coil
6. Resonance coil
7. Parallel resistor
8. Io∗cos(ϕ) current component

Power system circuit

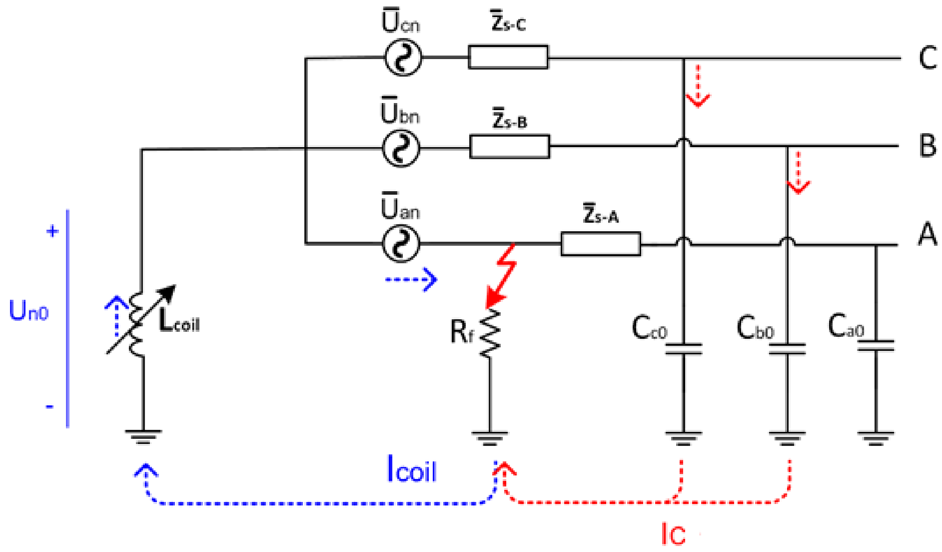


Compensated Power Systems

Different variants exist throughout the World:

1. **ASC = Arc suppression coil** / Petersen coil / Resonance coils / P-coil
2. **Single Petersen coil** (i.e. centralised compensation). Here only one large, single Petersen coil is used to compensate capacitance of the entire network.
3. **Distributed compensation**. Here typically only one large Petersen coil is used for regulation. However, at the same time many small fixed neutral coils are distributed along the (long) feeders to partly compensate the feeder capacitance.
4. **Multiple Petersen coils**. Here several large Petersen coils are used.

What happens during a ground fault in such system?



Icoil=-Ic
Then GF current is Zero!

Simplified Zero-Sequence Equivalent Circuit for Compensated System

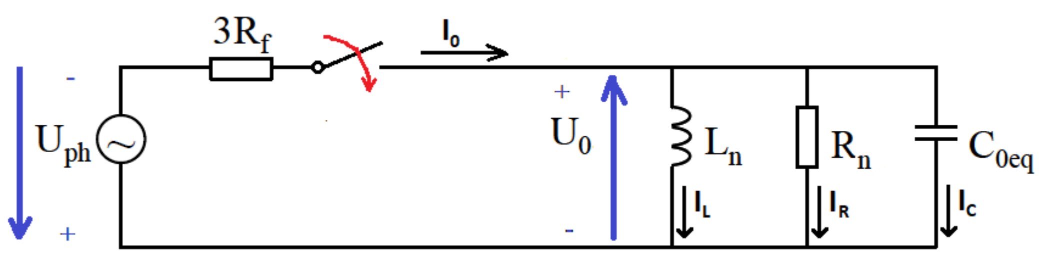
Used in Protection Books/Papers,
Drawn for the quantities at the fault point

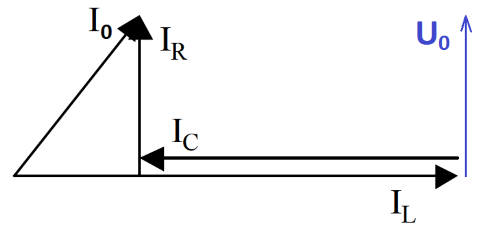
Note the following:

1. Lumped circuit as seen from the fault point
2. Do not show individual feeder CTs/VTs
3. It is a simple parallel R-L-C circuit ☺
4. This circuit is energized (i.e. switch is closed) when GF happens
5. Adding a feeder increases the capacitance value which shall be compensated by automatic coil adjustment
6. For ideally compensated system this is valid:

$$\omega * L = 1/(\omega * C) \text{ at rated frequency (e.g. } f_r = 60\text{Hz)}$$
$$\omega_r = 2 * \pi * f_r$$
$$I_L = -I_C \ @\ f_r$$

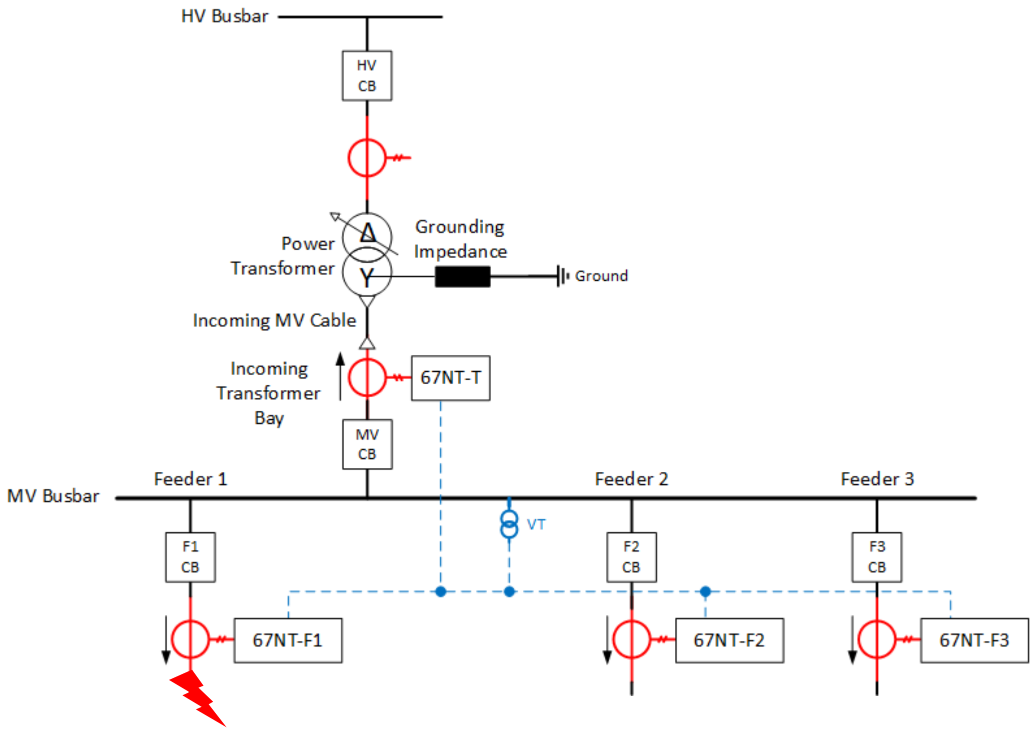
Simplified equivalent circuit for a GF



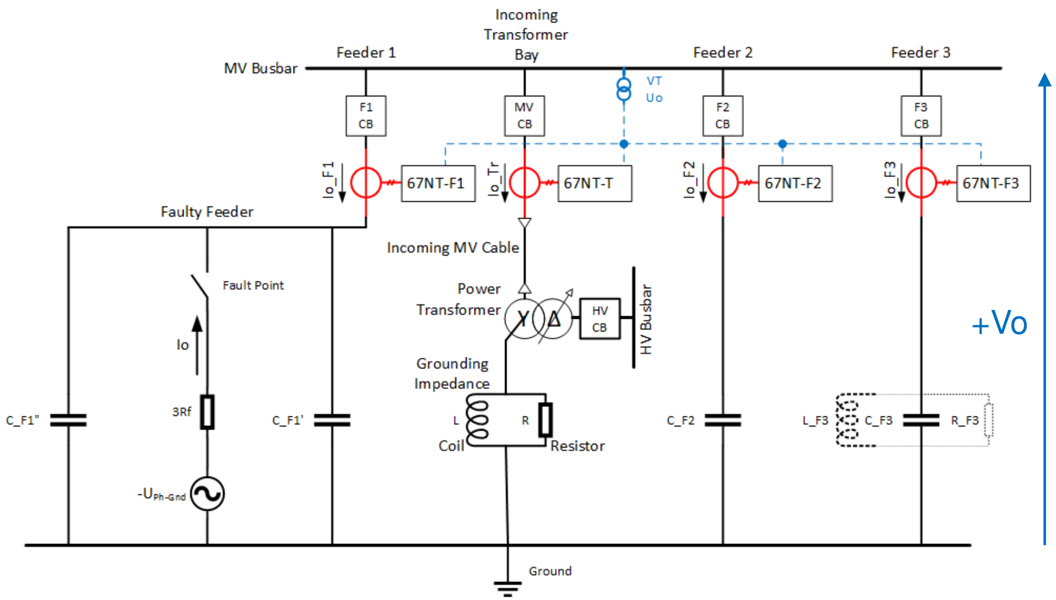


Complete Equivalent Circuits for the Zero-Sequence System

Example Substation



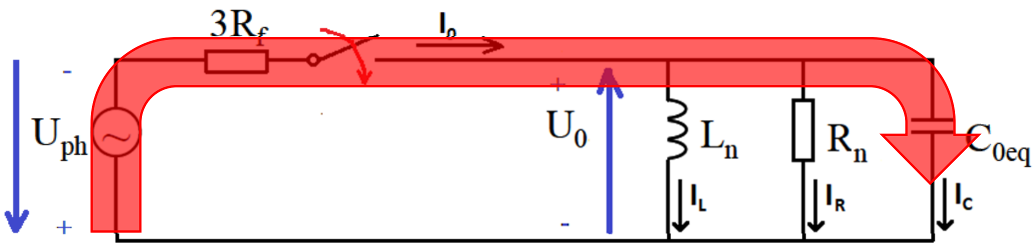
Equivalent Circuit for an GF in Feeder 1



Understanding GF in a High-Impedance Grounded System

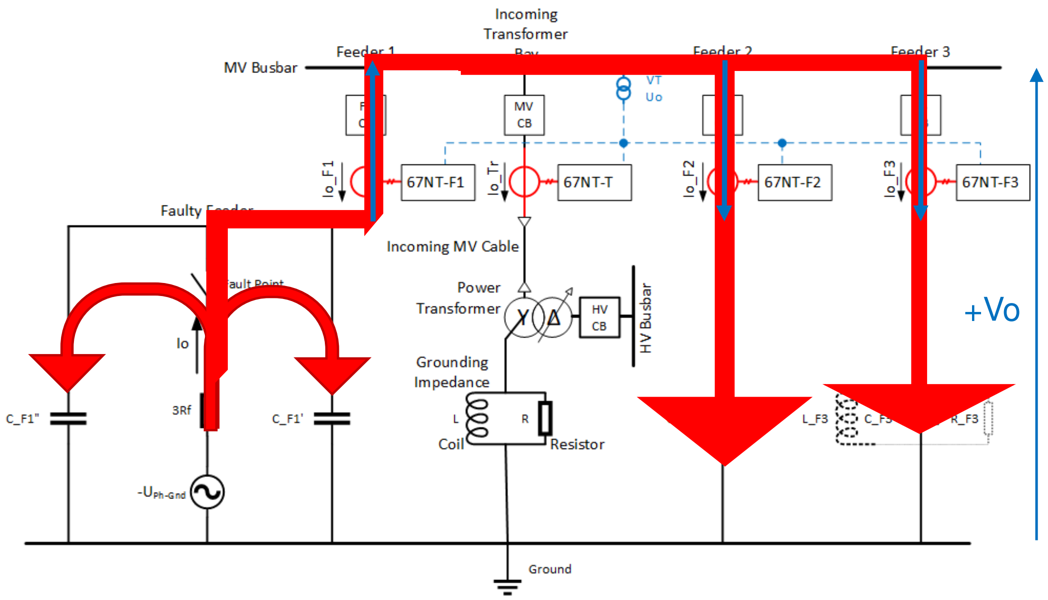
What happens with Power/Energy when GF happens?

Simplified Equivalent Circuit



Stored_Energy = ½∗V²∗C

Complete Equivalent Circuit



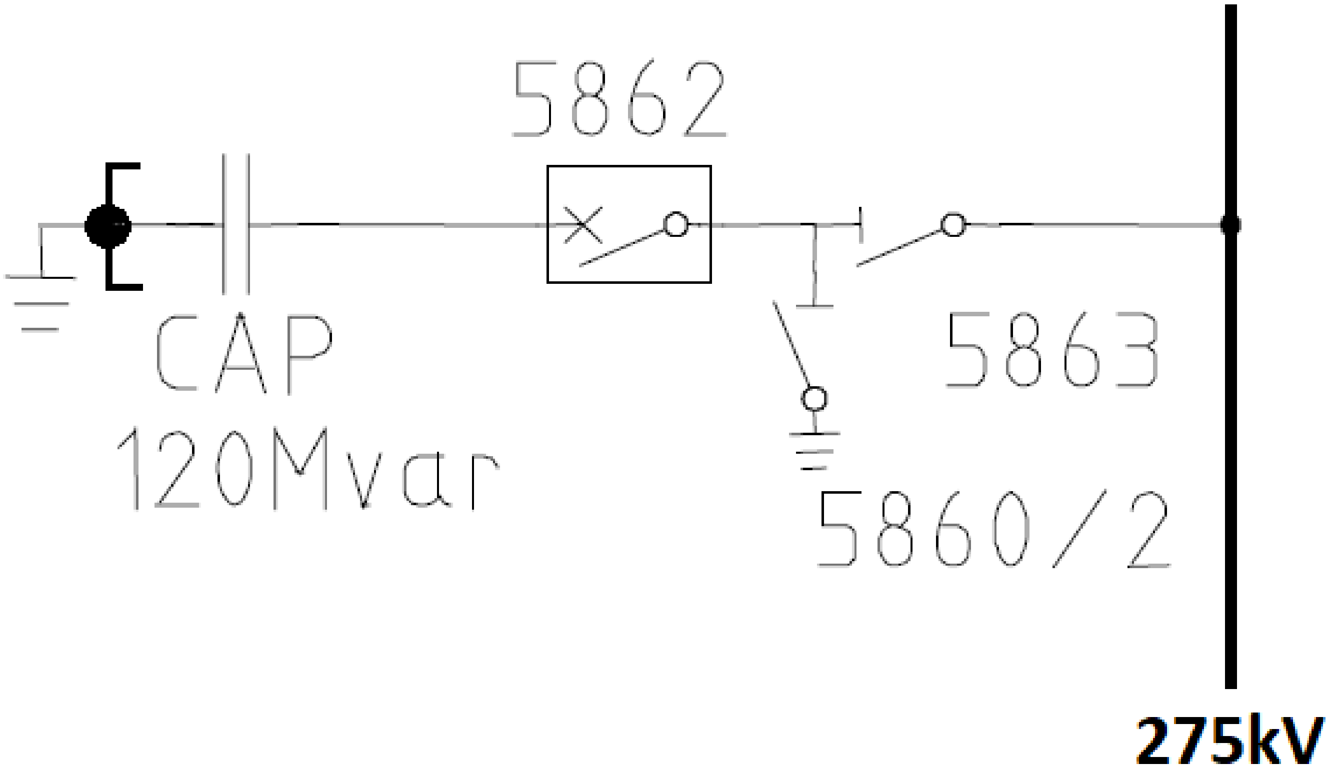
Distributed Capacitances must be charged first !!!

Energizing of a Shunt Capacitor Bank in a 3-Ph, 275kV, 50Hz System

Can shunt capacitors absorb Active Power when Energized?

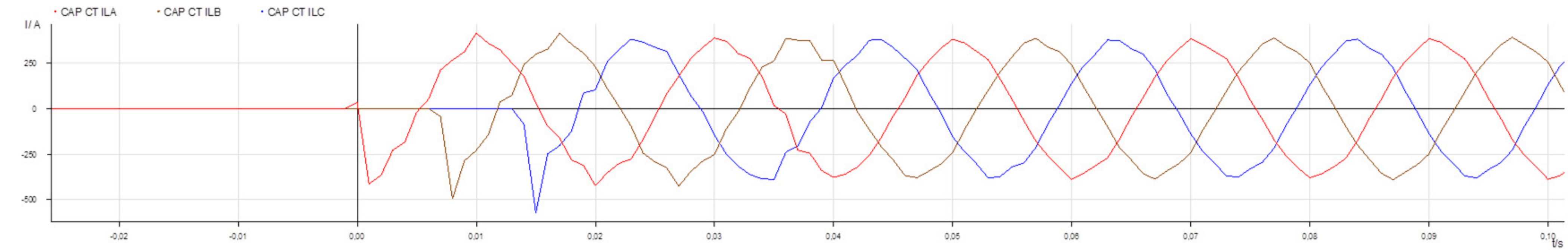
Installation info:

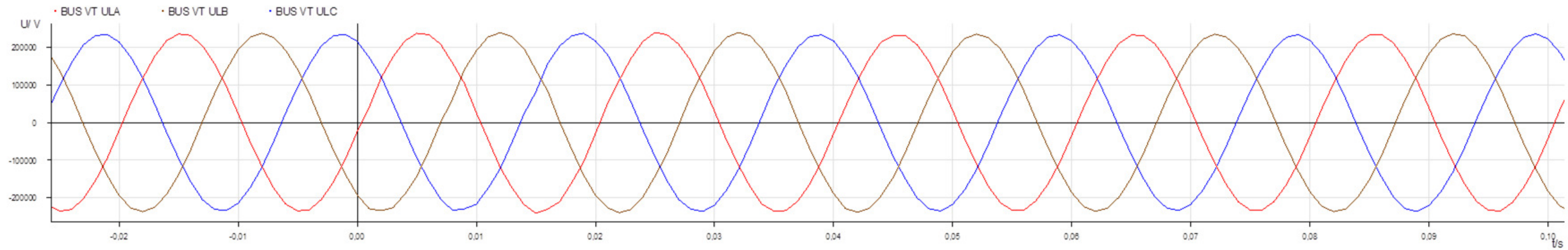
1) 120MVAr, 275kV Cap Bank
2) Star connected
3) Directly grounded
4) Each phase is “independent” ☺
   and can be treated as a single-phase circuit
5) Point on Wave switching was used (minimal transients)



Energizing of a Shunt Capacitor Bank in a 3-Ph, 275kV, 50Hz System

Recorded 3-Ph Currents and Bus Voltages during capacitor bank energizing

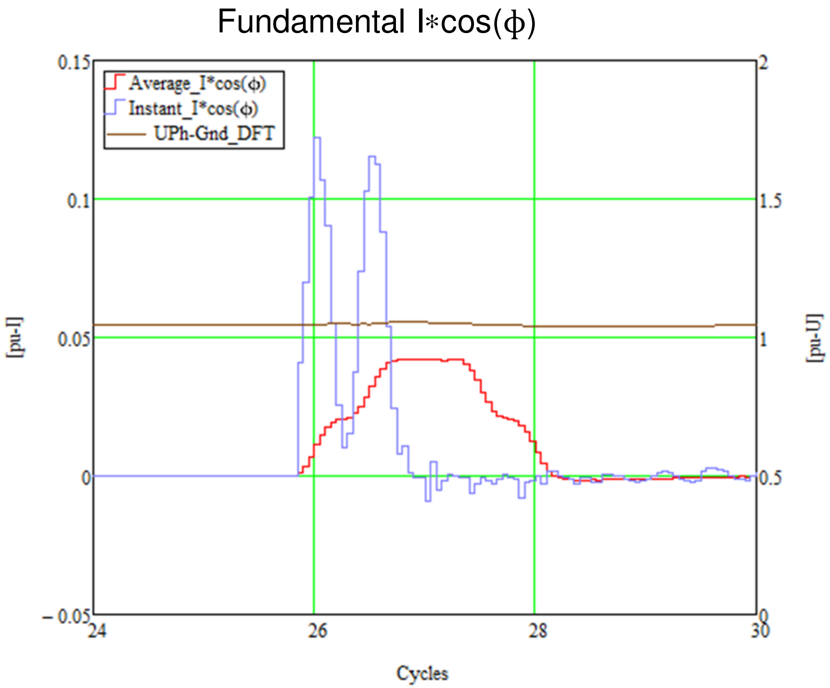


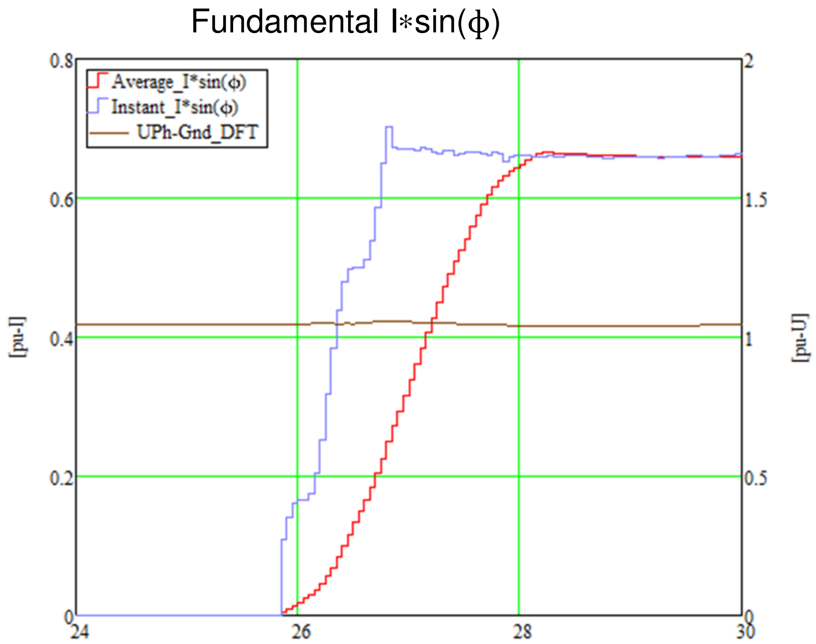


Point on Wave relay is used to close the CB (i.e. to minimize the transients)

Energizing of a Shunt Capacitor Bank in a 3-Ph, 275kV, 50Hz System

Behavior of I*cos(ϕ) and I*sin(ϕ) components during CB closing for one of the three phases





Capacitor must be charged first. That is the reason for Transient appearance of I*cos(ϕ) quantity.

Use Energy Flow Rules in the Zero-Sequence Circuit for HiZ grounded systems

The new transient GF protection function is based on the following two fundamental principles:

1. Distribution of the energy and associated active transient power for the fundamental frequency phasors of the residual quantities at the moment of an GF inception in a high-impedance grounded network (charging of distributed capacitances).
   - **$I_{o1} * \cos(\phi_1)$ component shall be used for the fundamental frequency residual phasors**
   - $I_{o1} * \sin(\phi_1)$ component shall NOT be used for the fundamental frequency residual phasors

2. Oscillation of the energy and associated reactive transient power for the higher harmonic frequency phasors of the residual quantities at the moment of an GF inception in a high-impedance grounded network.
   - **$I_{oh} * \sin(\phi_h)$ component shall be used for higher frequency residual phasors**
   - $I_{oh} * \cos(\phi_h)$ component shall NOT be used for higher frequency residual phasors

3. Uo magnitude measurement de-coupled from Transient GF protection operation
   - **-Uo phasor is only used as a polarizing quantity within Transient GF Protection**

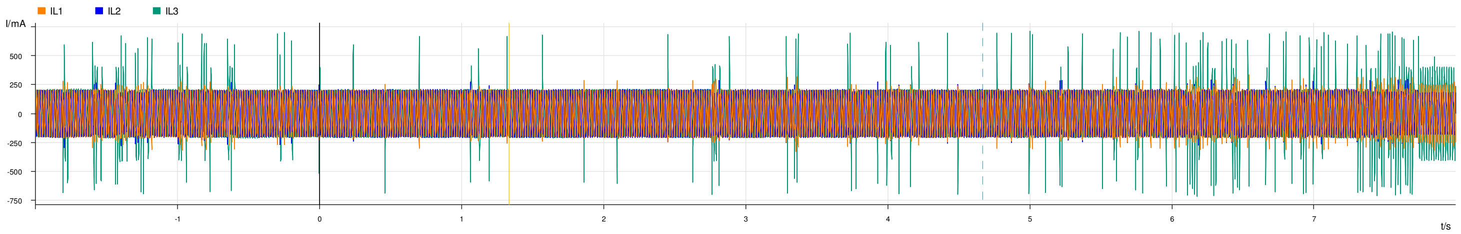
Testing of this Methodology

Single phase to ground fault in 13.8kV, 60Hz, resistive grounded system

10s long record

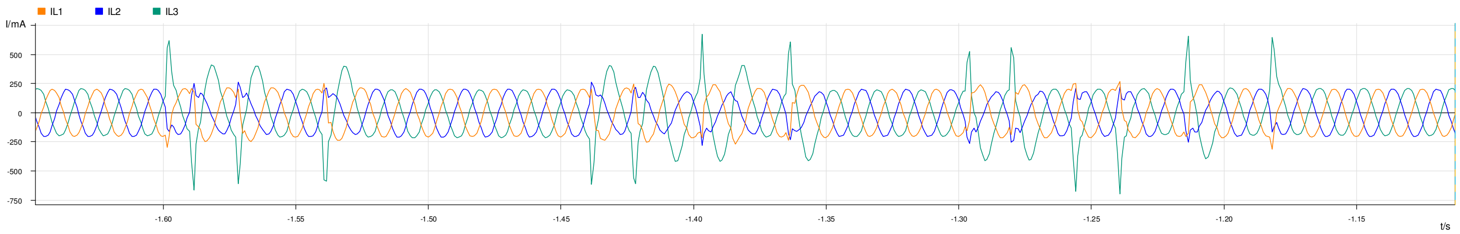
Three-phase currents shown
GF in phase C (i.e. L3)

VT ratio VTR=13.8/0.12
CT ratio CTR=1000/1



1s long part of this record

Three-phase currents shown

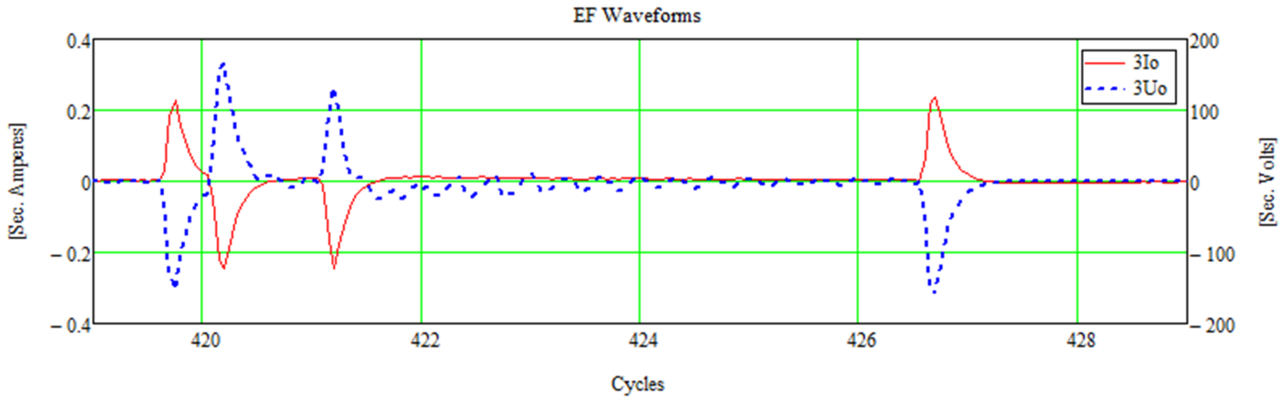


Single phase to ground fault in 13.8kV, 60Hz, resistive grounded system

10 cycles long part of the record

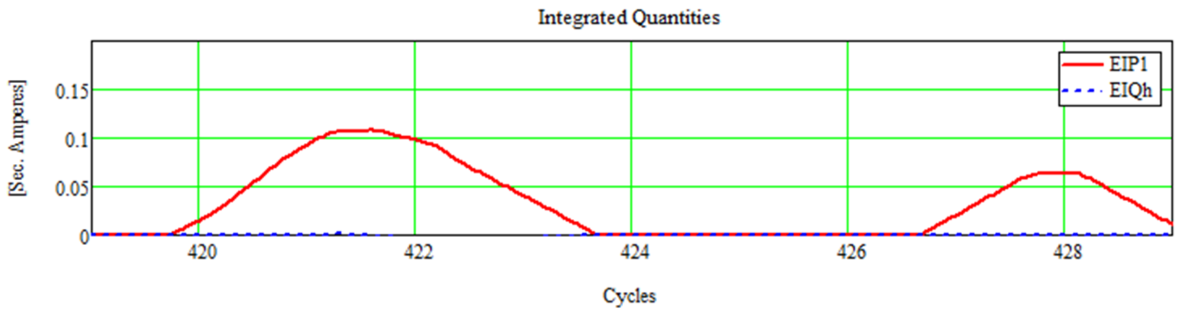
3Io and 3Uo shown

VT ratio VTR=13.8/0.12
CT ratio CTR=1000/1



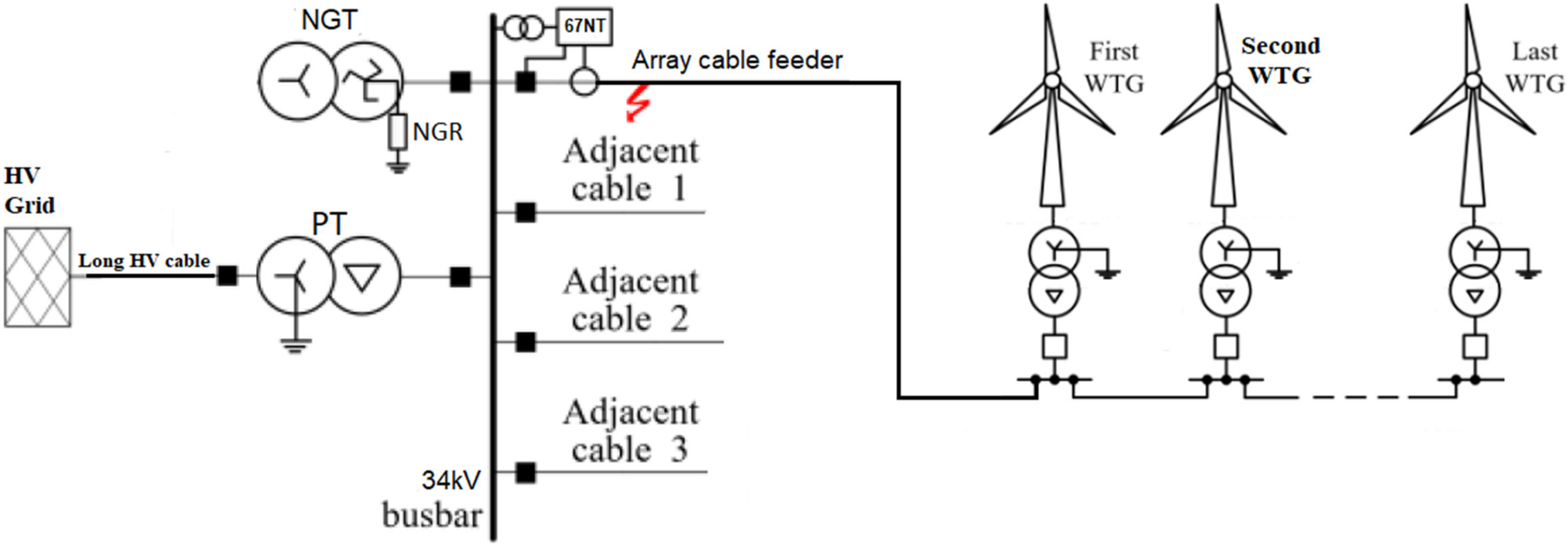
Same time period as above

Integrated quantities shown:
EIP1
EIQh



Single phase to ground fault in an Offshore Wind Farm: 34kV, 50Hz

Simplified SLD of the offshore wind farm and GF location in Array Cable Feeder



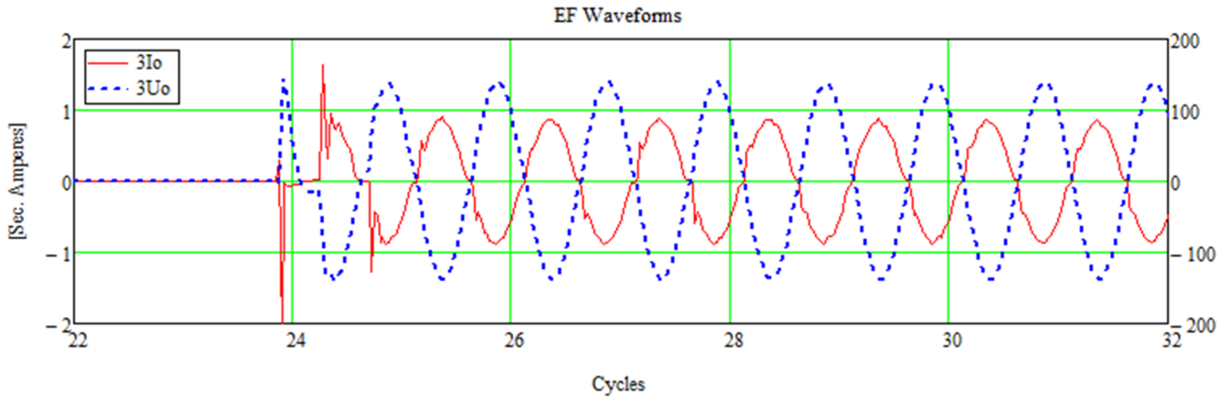
NGR is dominant impedance in the zero-sequence circuit (i.e. resistive grounding)

Record from the faulty feeder in the Offshore Wind Farm: 34kV, 50Hz

10 cycles long record

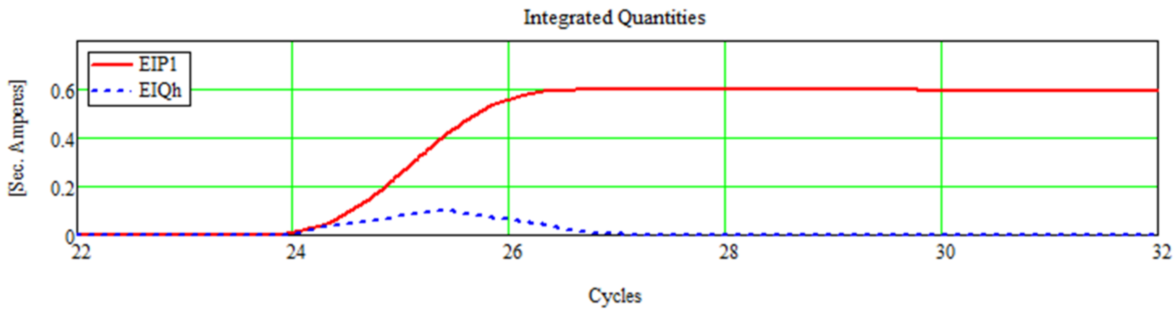
3Io and 3Uo shown
VTR=34/0.1

CTR= 1000/1



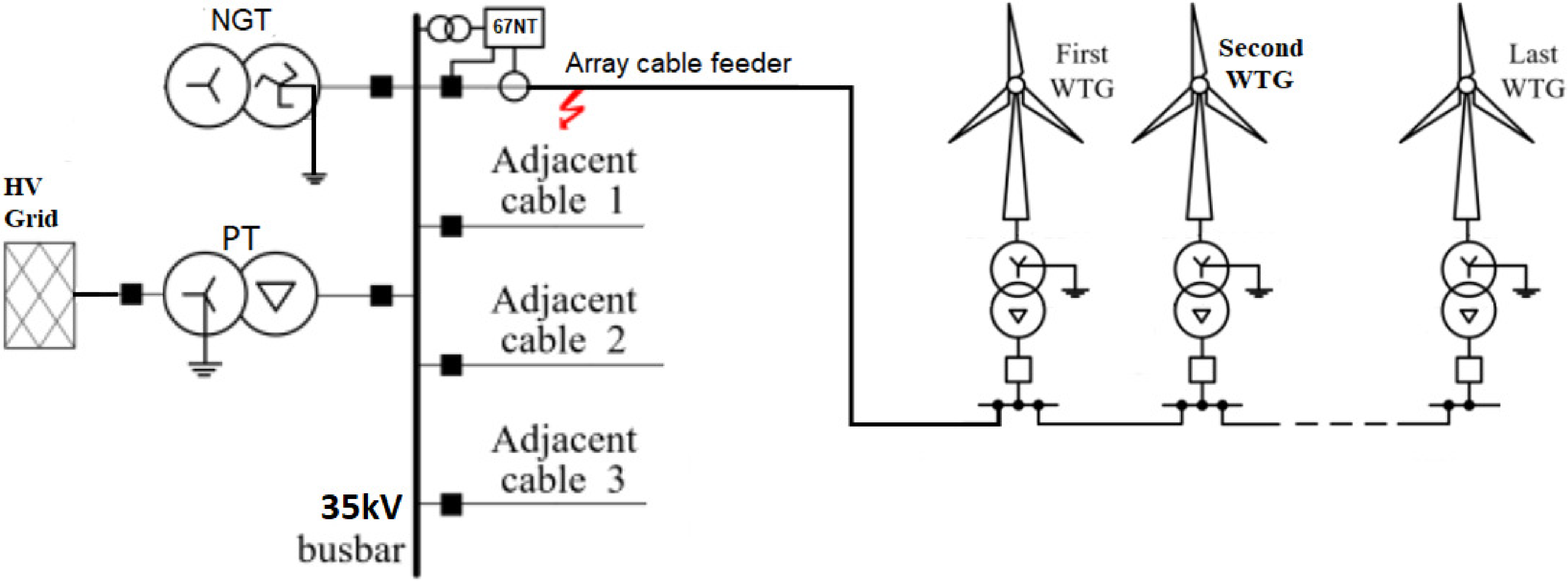
Same time period as above

Integrated quantities shown:
EIP1
EIQh



Single phase to ground fault in an Onshore Wind Farm: 35kV, 50Hz

Simplified SLD of the onshore wind farm and GF location in Array Cable Feeder



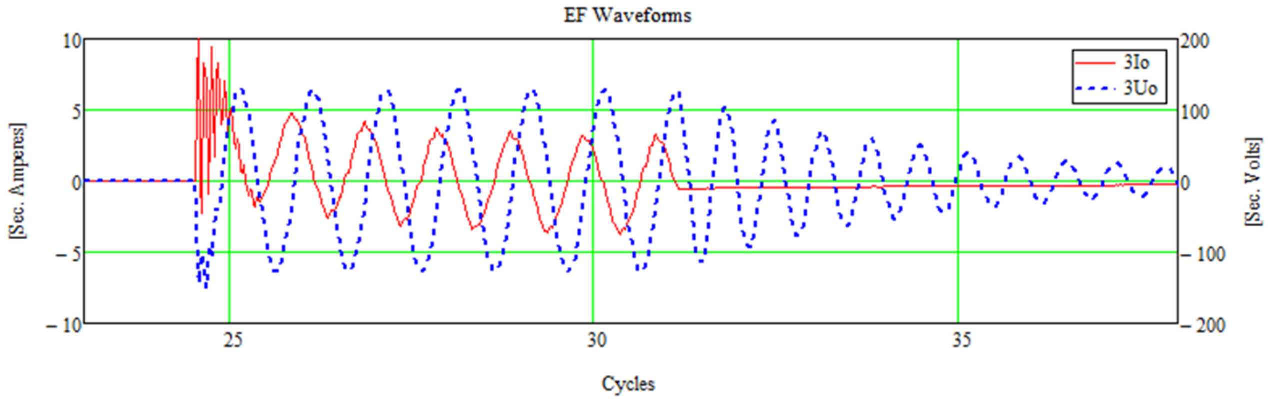
NGT is dominant impedance in the zero-sequence circuit (i.e. reactor grounding).

Record from the faulty feeder in the Onshore Wind Farm: 35kV, 50Hz

15 cycles long record

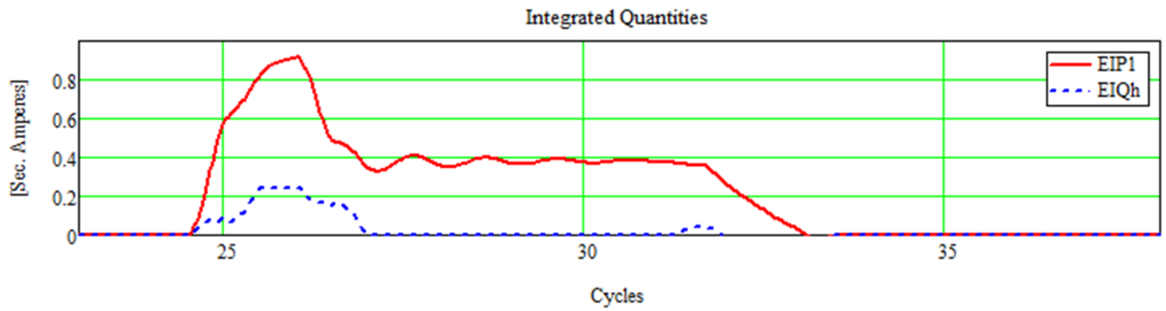
3Io and 3Uo shown
VTR=38/0.1

CTR= 400/5



Same time period as above

Integrated quantities shown:
EIP1
EIQh

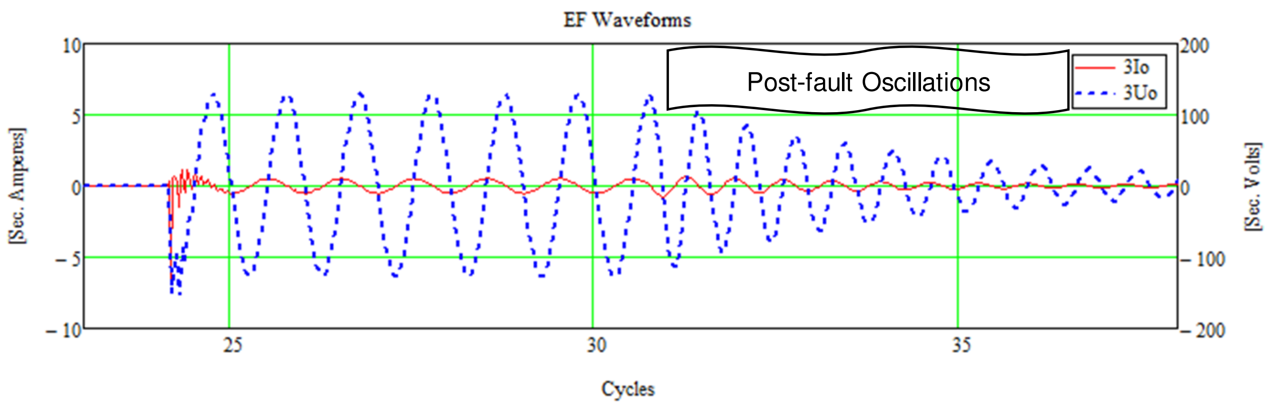


Record from the healthy feeder in the Onshore Wind Farm: 35kV, 50Hz

15 cycles long record

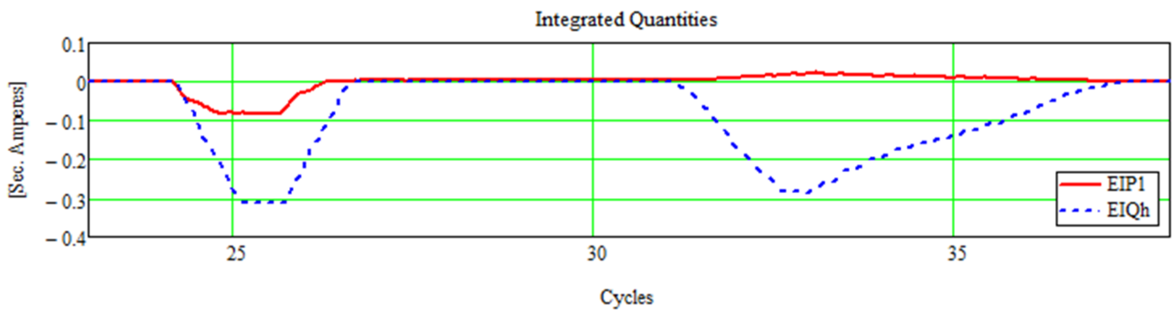
3Io and 3Uo shown
VTR=38/0.1

CTR= 400/5



Same time period as above

Integrated quantities shown:
EIP1
EIQh

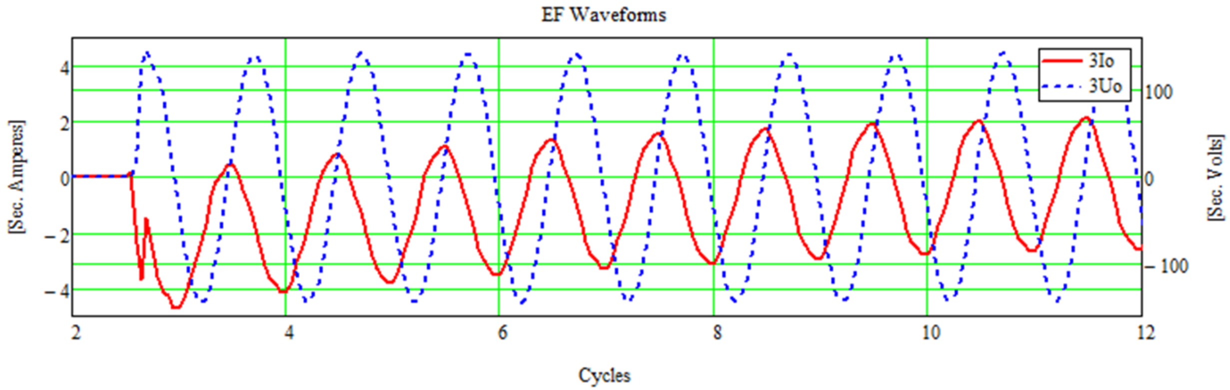


Record from the faulty OHL in 66kV; 50Hz, resonant grounded system

10 cycles long record

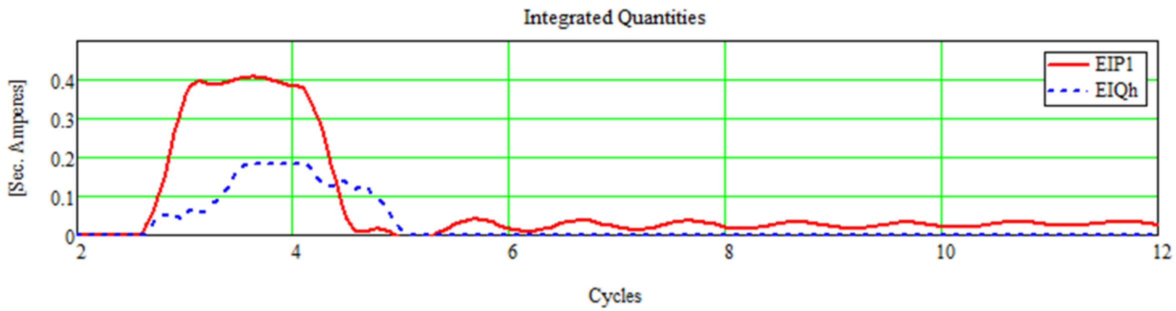
3Io and 3Uo shown
VTR=66/0.11

CTR=600/5



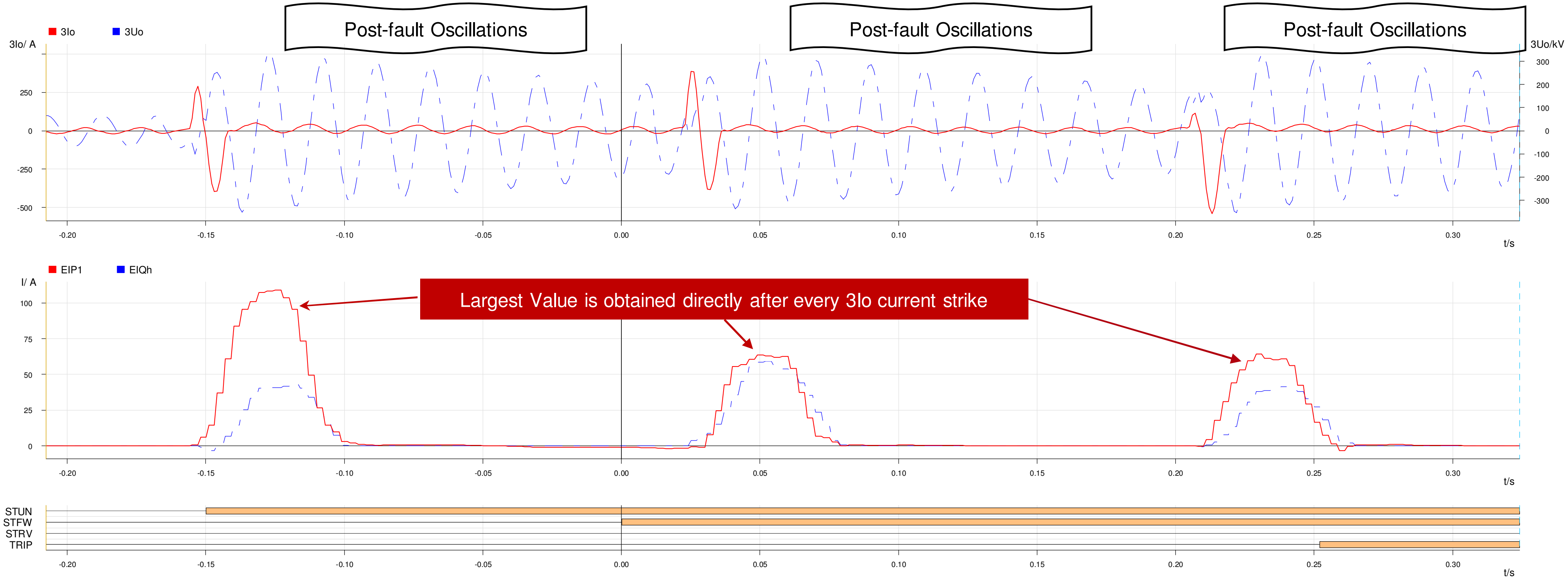
Same time period as above

Integrated quantities shown:
EIP1
EIQh



Record from the faulty OHL in 132kV; 50Hz, resonant grounded system

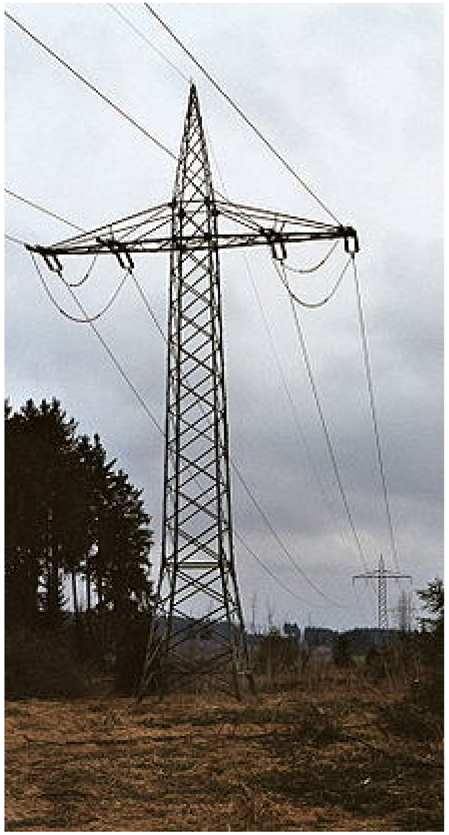
Record when tree was touching a phase conductor



Two-phase 132kV and 110kV System for Railway Supply at 16.7Hz

110kV and 66kV systems are resonant grounded

2-Ph OHLs



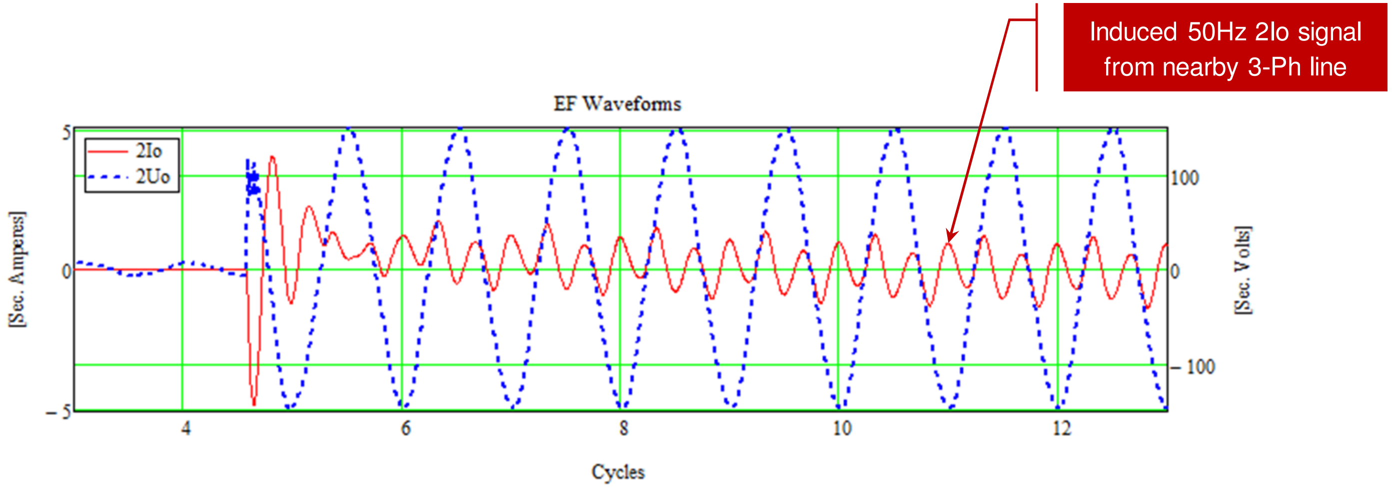
Record from the faulty OHL in 110kV; 16.7Hz; 2-Ph Network

10 cycles long record

2Io and 2Uo shown

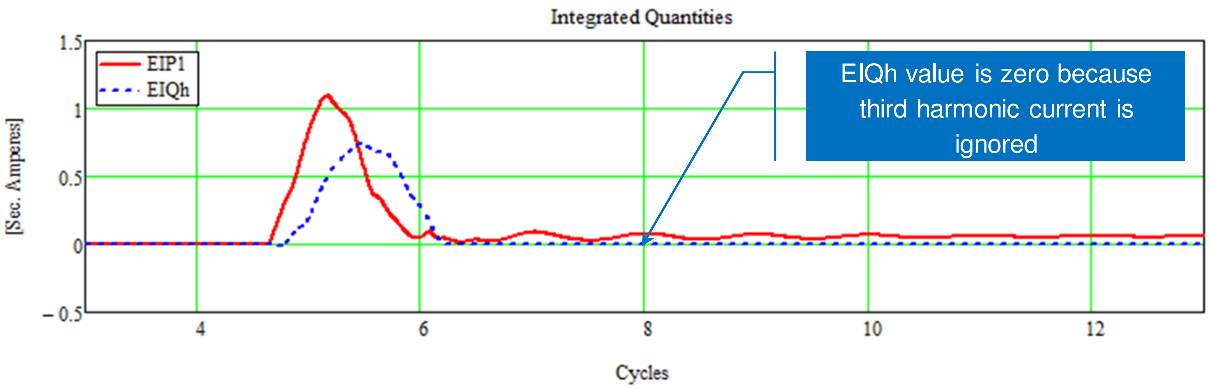
VTR=110/0.1

CTR= 600/1



Same time period as above

Integrated quantities shown:
EIP1
EIQh (excluding 3rd harmonic)



Any Sampling Rate Issues ?

Record from the faulty Cable in 10kV, 50Hz Network / Sampling Rate Issues

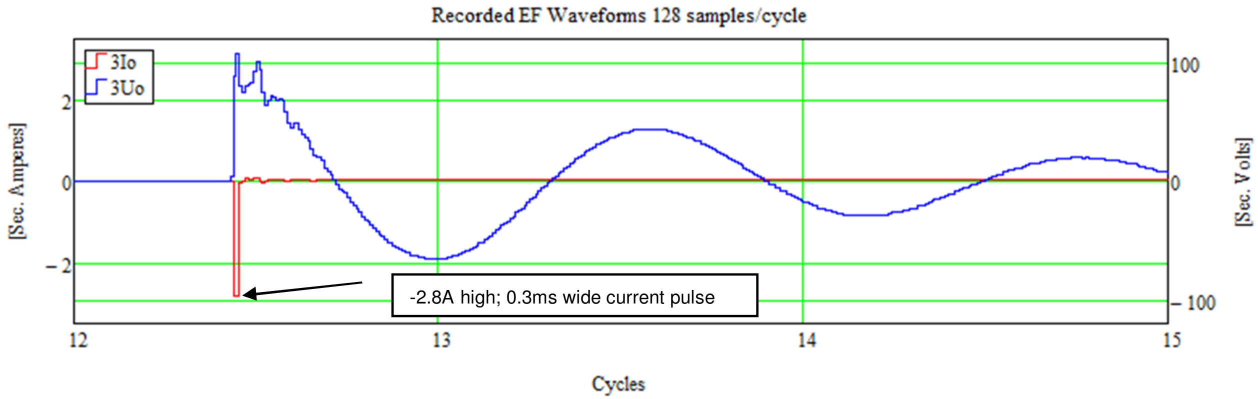
3 cycles long record

3Io and 3Uo shown

VTR=10/0.11

CTR= 90/1

128 samples per cycle



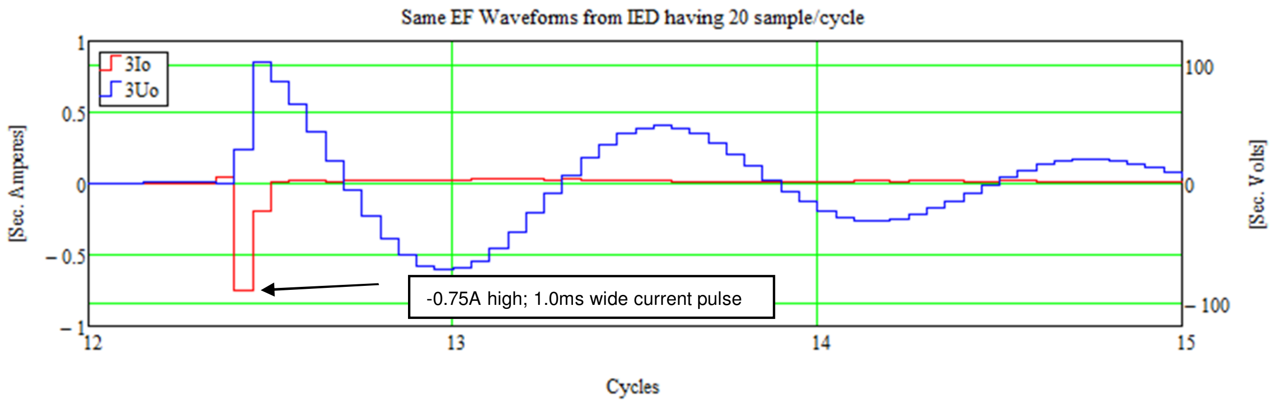
Same record as above shown

3Io and 3Uo shown

VTR=10/0.11

CTR= 90/1

20 samples per cycle from IED



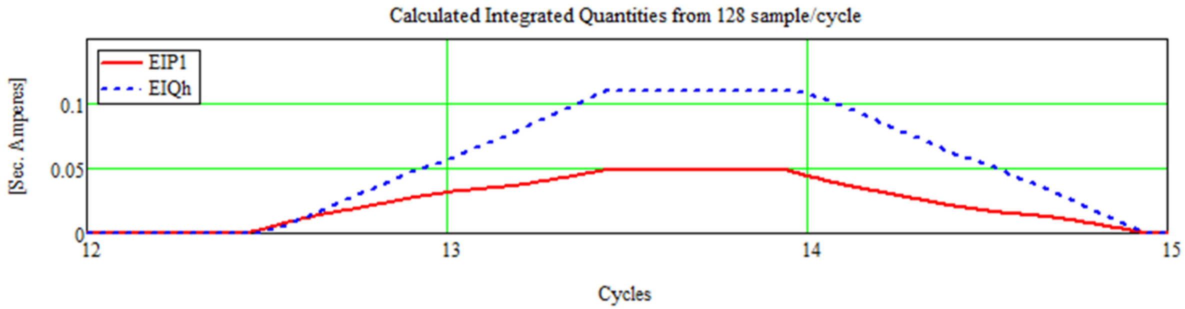
Actual signal energy content (i.e. area below the two current pulses) is approximately the same!

Record from the faulty Cable in 10kV, 50Hz Network / Sampling Rate Issues

3 cycles long record

EIP1
EIQh

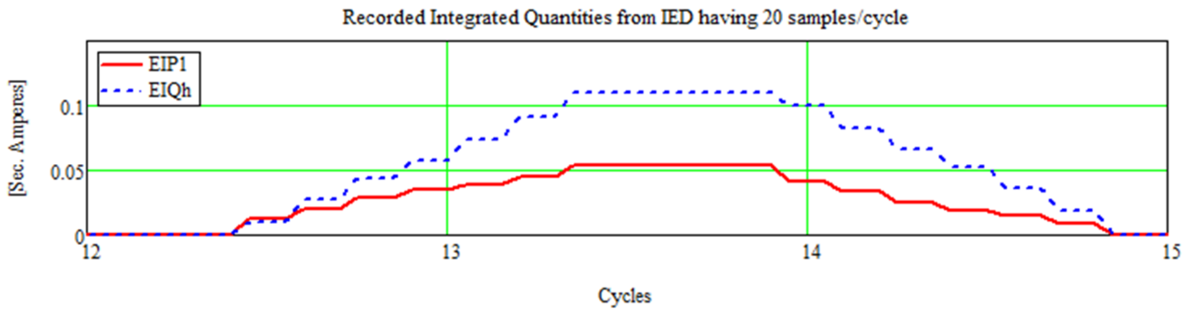
128 samples per cycle used



Same record as above shown

EIP1
EIQh

20 samples per cycle from IED



Conclusion

Transient Ground Fault protection 67NT is available having methodology which is:

1. Universal (applicable to all high impedance grounded power systems)
   a) 60Hz, 50Hz, 16.7Hz
   b) Three-phase and Two-phase power system
   c) Over or under compensated resonant grounded systems
   d) Systems grounded via Resistance and/or Reactance
   e) Isolated systems
   f) Power networks which change type of grounding during their operation
   g) OHL based or power cable based or even mixed network
2. Based on Energy/Power flow rules at Ground Fault inception (clear physical background)
   a) Having two independent measuring principles
3. Using only “healthy phasor components”
4. De-coupling residual current from residual voltage measurement (-3Uo used as polarizing voltage only)
5. Transient but it does not use directly raw analogue samples for its operation
6. Using relatively low sampling rate for its calculations (20 samples per cycle) due to advances analogue acquisition chain in the IED
7. Extremely simple but very effective

Comments, Other Opinions or Questions are Welcomed