

Fault Current Contributions from Wind Plants

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Presentation Overview

Joint Working Group

The Issue

Structure of the Report

Wind Plant Configuration

Wind Turbine Generators Performance by Types

Wind Plants Relaying

Fault Interrupting Equipment

Analysis of Data from Fault Events

Conclusion

Questions

Joint Working Group

Members from 3 Technical Committees of PES:

Transmission & Distribution

Electric Machinery

Power System Relaying

WG Chairmen: Reigh Walling, Ron Harley, Dean Miller

WG Vice Chair: Gene Henneberg

Diverse Background of Members

Academia

Manufacturing

Utilities

Engineering Consulting

Research Labs

Working Group Assignment



Prepare a Report: To characterize and quantify short circuit current contributions to faults from wind plants for the purposes of protective relaying and equipment rating, and to develop modeling and calculation guidelines for the same.

Started 2008

Draft 7.1 of the Report Was Distributed

Estimated Completion Date: 2013

The Issue

- Wind Plants use different types of generators than other power generation facilities
- Wind turbine generators tolerate rapid fluctuations in prime mover, due to wind speed fluctuations
- Traditional rigid mechanical and electrical coupling of a turbine and synchronous generators will not tolerate the rapid fluctuation in the prime mover
- Response to faults is different
- Safe, reliable operation of the electrical power system requires the ability to predict and model the sources of fault current

Structure of the Report

1. Introduction
2. Wind Power Plant Design
3. Wind Turbine Generator's Response to Faults
4. Fault Interrupting Equipment Issues
5. Wind Plant Protective Relaying
6. Data Requirements
7. Actual Performance / Experience
8. Conclusion

Wind Plant Configuration

- Multiple wind turbine generators ranging in size (500 – 7,000 kVA)
- Each wind turbine generator with its own step-up transformer stepping the voltage from 600 – 1000 V up to typically 34.5 kV
- Collector lines, mostly under ground, bring the output of several generators back to a collector substation
- At the collector substation there are breakers for the individual collector lines and the power is transformed from the 34.5 kV to the Transmission Provider's system voltage

Wind Plant Configuration (cont.)

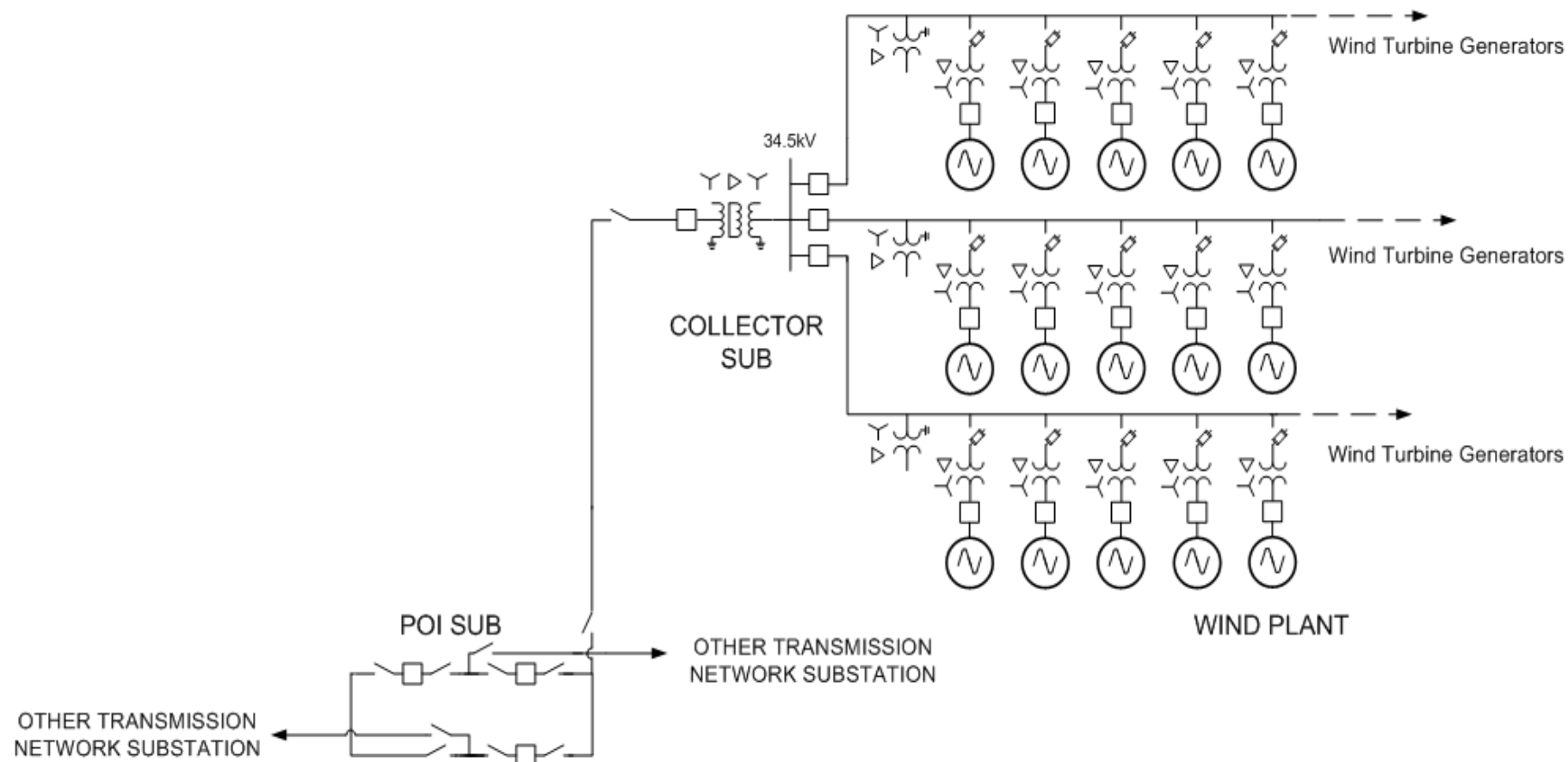


- Reactive power devices may also exist in the collector substation
- Tie transmission line to the Point of Interconnection (POI) substation
- POI substation ties the Wind Plant into the power network

Wind Plant

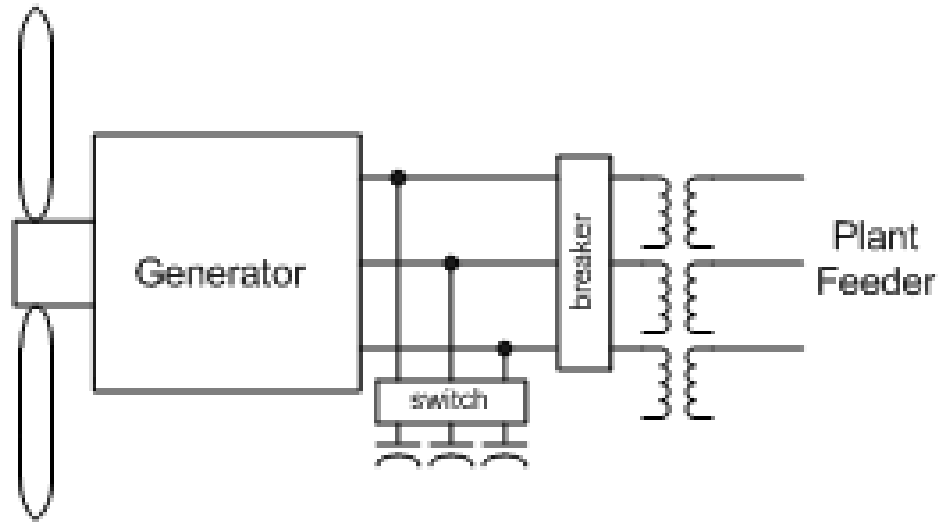


Wind Plant



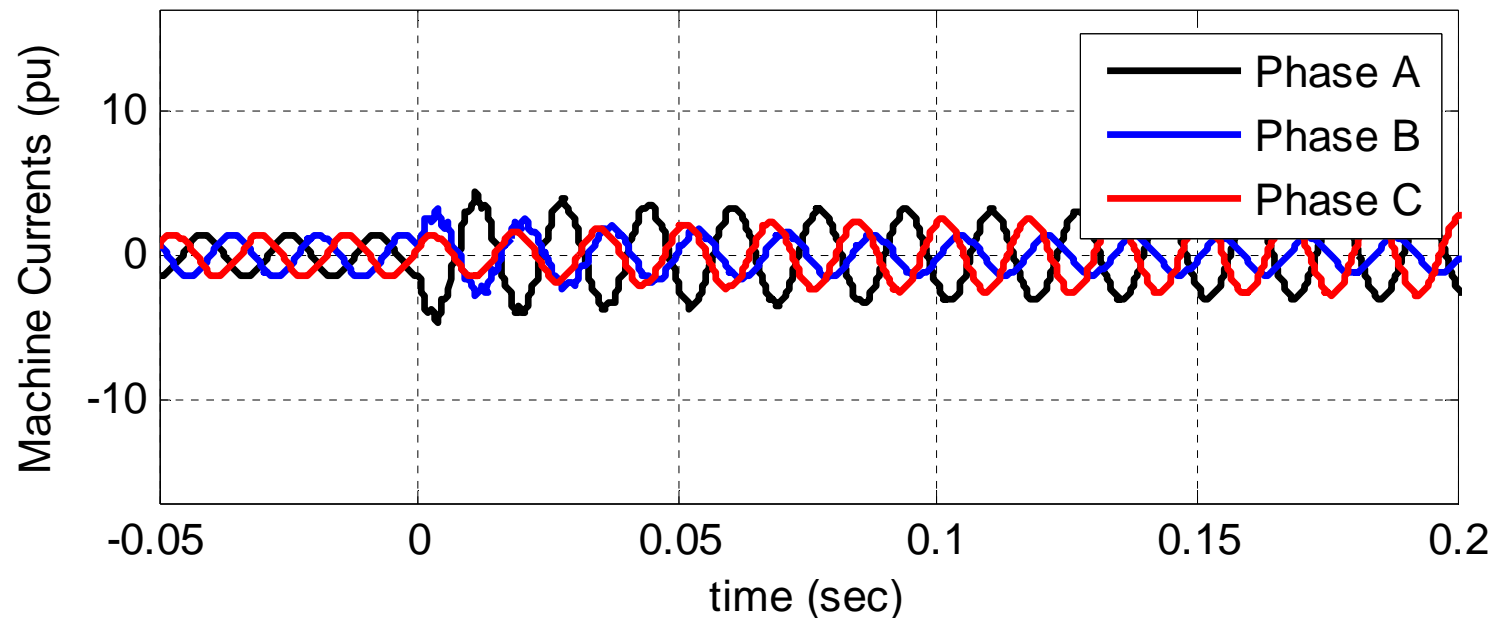
SYSTEM ONE LINE
DIAGRAM

Type 1 Wind Turbine Generator



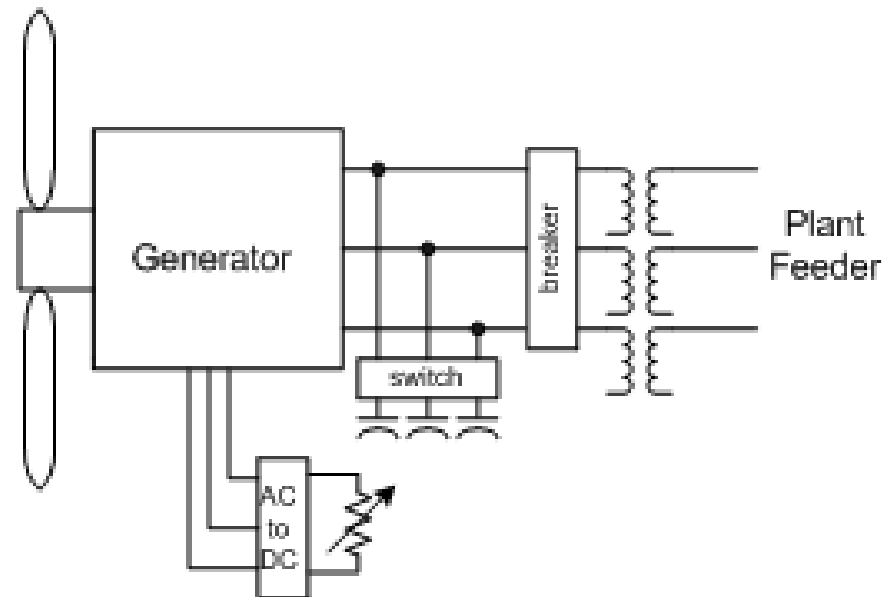
- Squirrel cage induction generator
- Initial fault current is 4 – 6 X full load current
- Without reactive support, fault current deteriorates rapidly
- Switched shunt capacitors for power factor control

Type 1 WTG Response to Fault



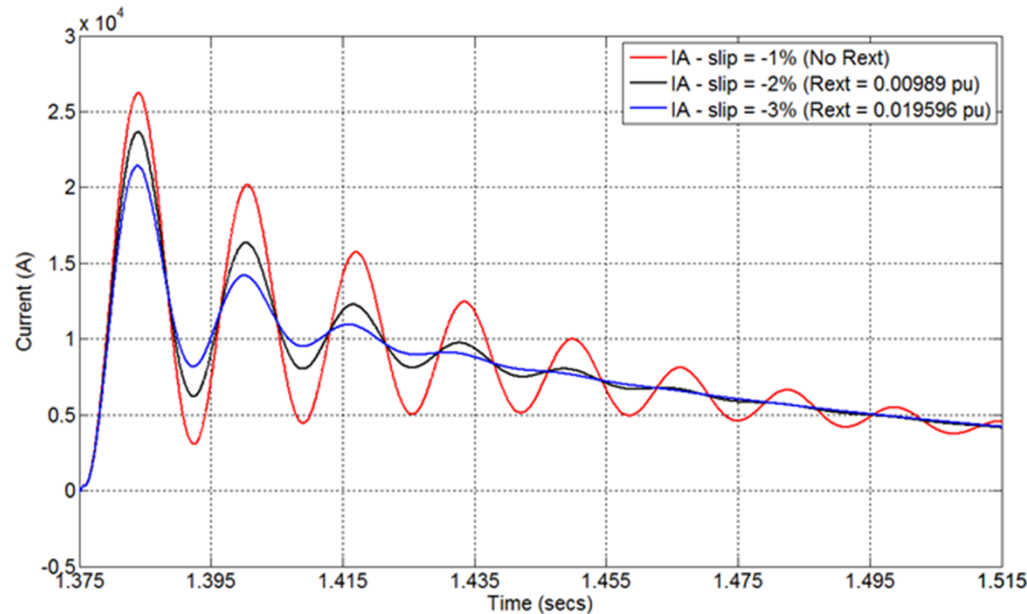
- Single Phase to Ground fault on the Terminal of the Generator Step-up Transformer
- Study results have refined some of the earlier assumed theories.

Type 2 Wind Turbine Generator



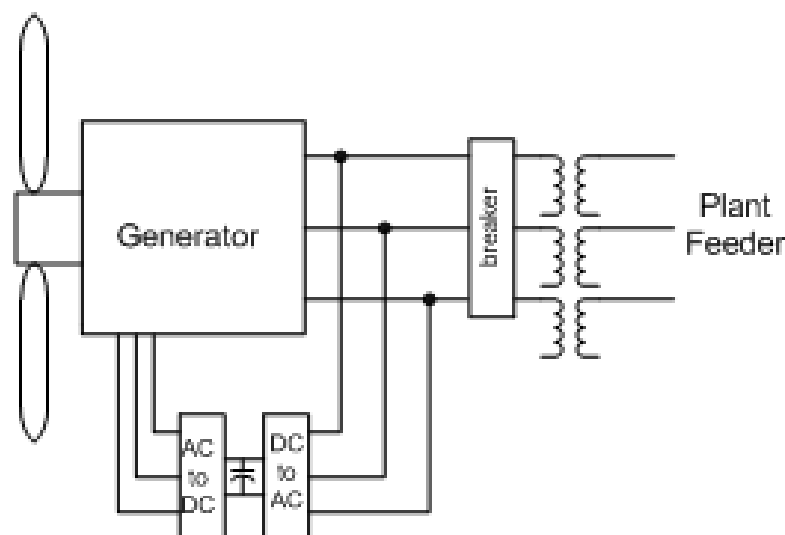
- Wound rotor induction generator
- Initial fault current is 4 – 6 X full load current
- Power electronic switched capacitors maintains the sync. energy & the fault current contribution
- Uses rotor winding damping resistor to produce power over a wider shaft speed range

Type 2 WTG Response to Fault



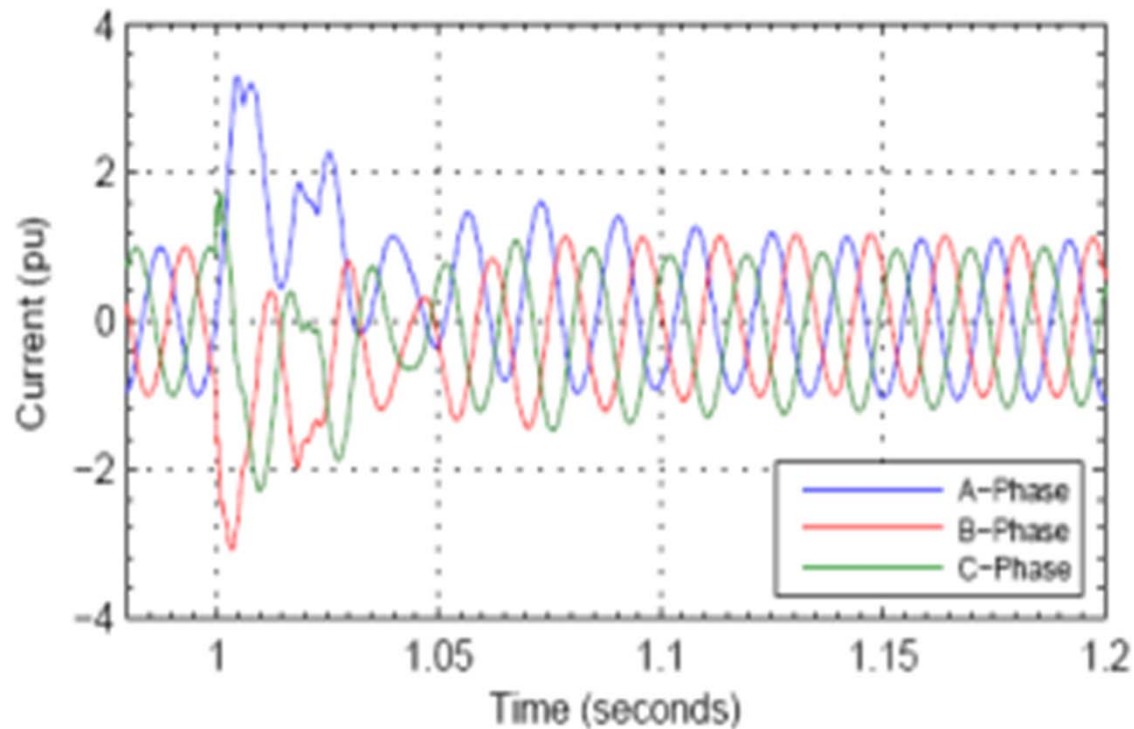
- Three Phase Fault on the Terminal of the Generator with Different Levels of External Rotor Resistance
- Model was validated with data from a wind plant fault event.

Type 3 Wind Turbine Generator



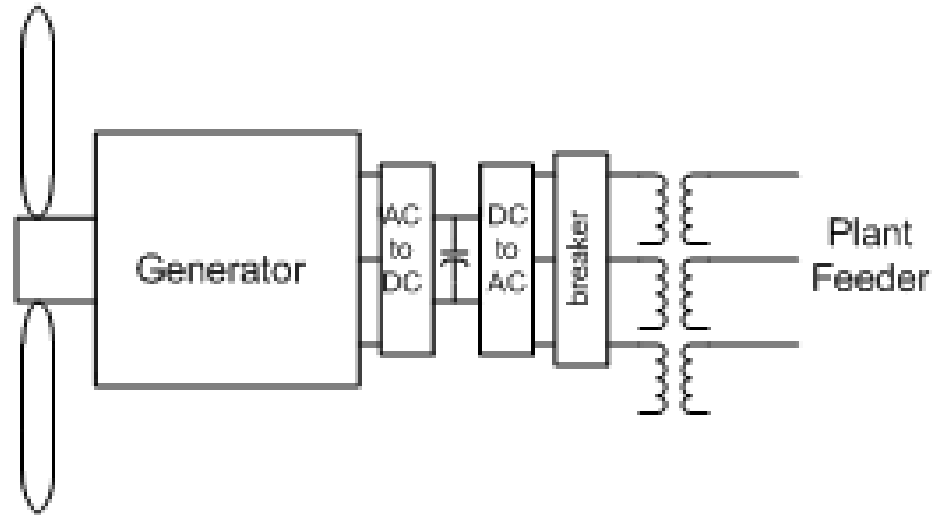
- Asynchronous generator (variable speed double fed generator)
- Variations in rotor current magnitude and angle controls real & reactive power
- Controls of power electronics limits fault current until the “crowbar” action, then the current increases
- Fault current is maintained for longer time period

Type 3 WTG Response to Fault



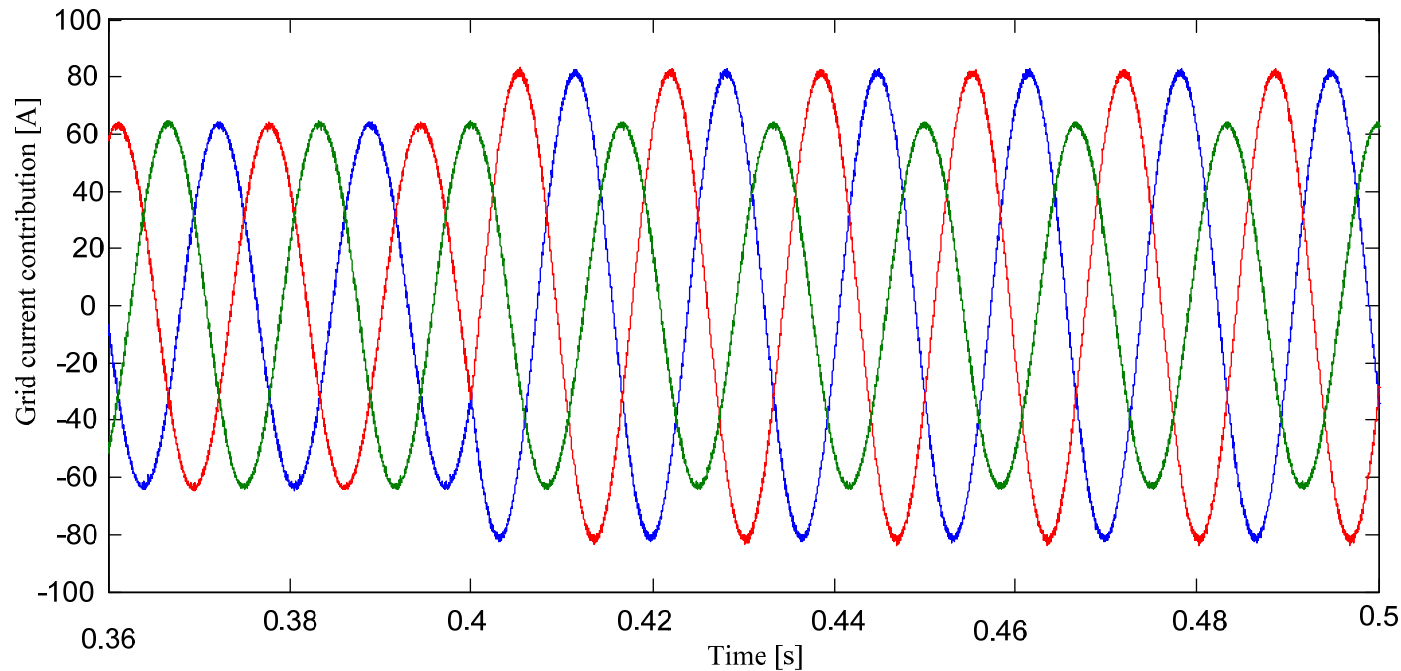
- Fault current for a fault reducing the voltage at the unit step-up transformer MV terminals to 20%.
- Initially with crowbar action

Type 4 Wind Turbine Generator



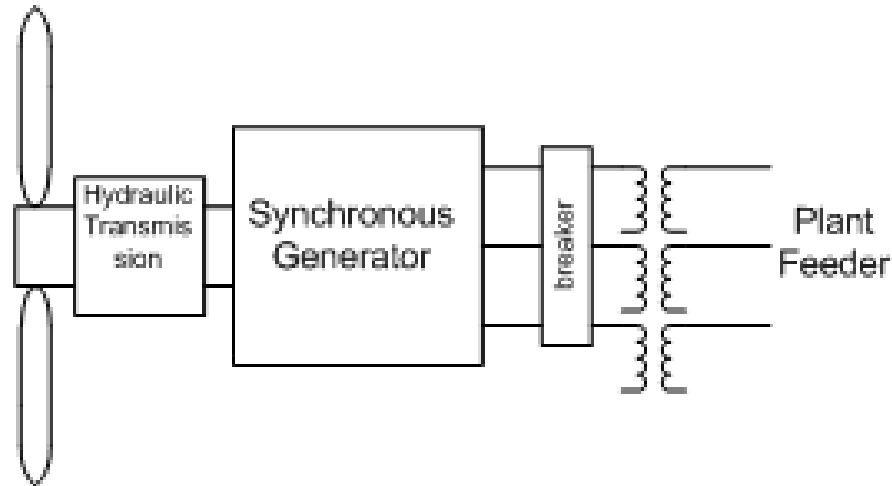
- Synchronous or induction generator
- Varies firing angle of inverters for real & reactive power control
- Fault current is limited and maintained by the by power electronics

Type 4 WTG Response to Fault



Single Phase to Ground Fault on the Terminals of the Generator

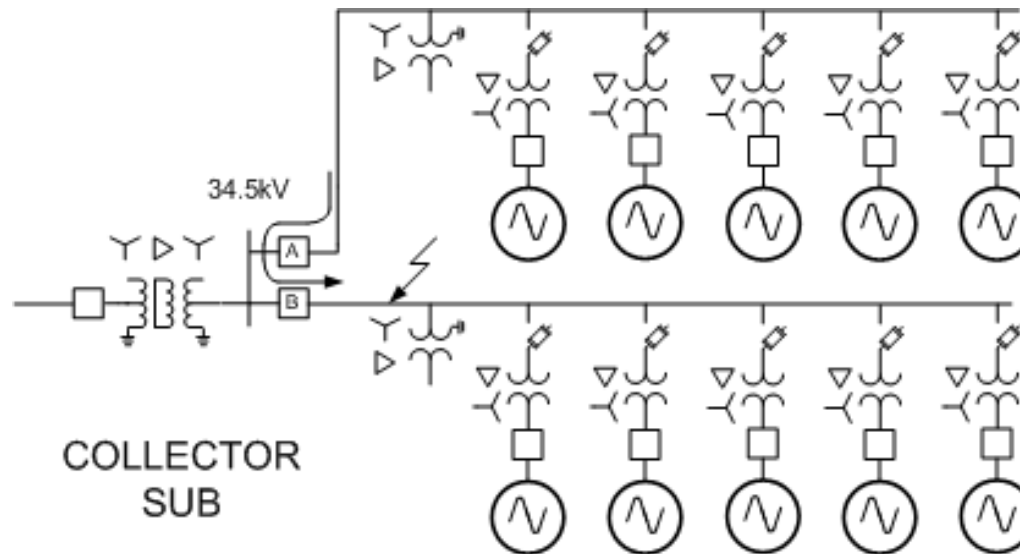
Type 5 Wind Turbine Generator



- Synchronous generator
- Variations in wind turbine speed are compensated in the hydraulic transmission
- Reactive power controlled by field current
- Fault current similar to any other synchronous generator

Protective Relaying for the Collector Substation

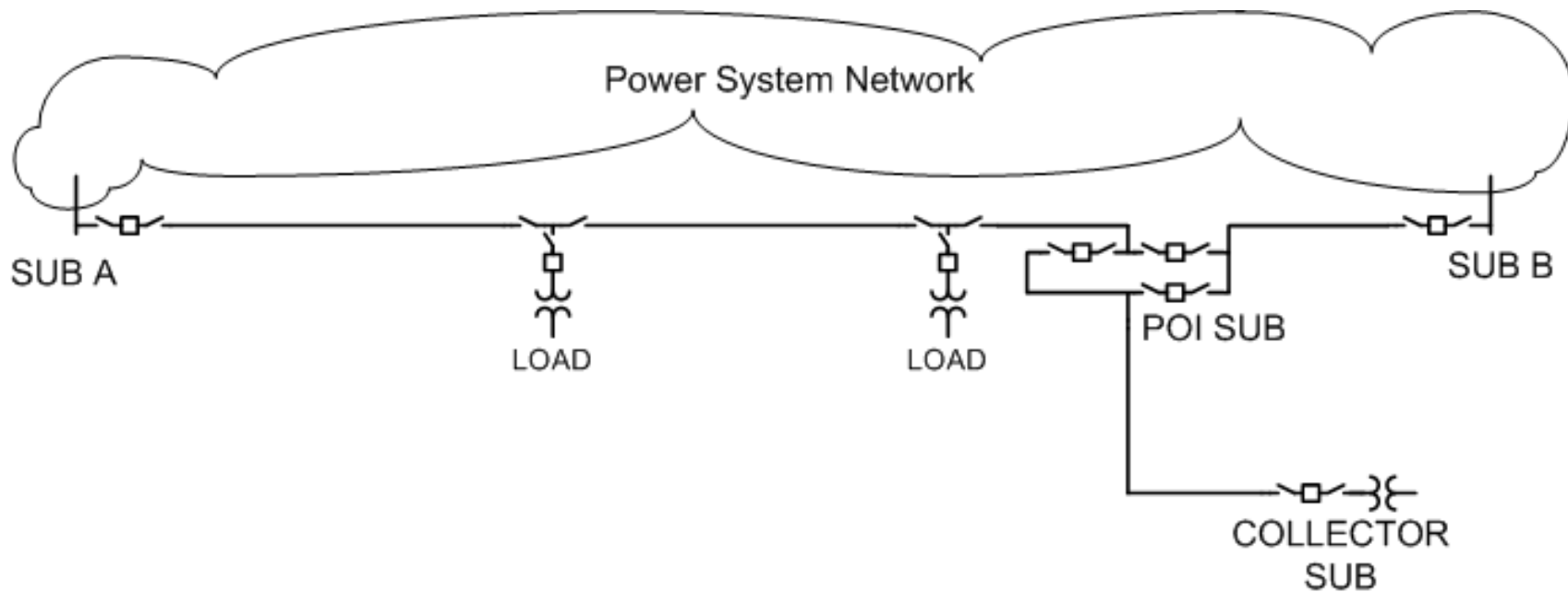
- Collector lines
 - Combination of directional and non-directional overcurrent relays
 - Coordinated with generator step-up transformer fuses and relays on the other lines



Protective Relaying for the Collector Substation (continued)

- Power Transformer
 - Current differential & sudden pressure relays to detect internal faults
 - Overcurrent relays to protect the transformer from damage due to slow clearing of line or bus faults
- 34.5 kV bus
 - High speed protection is desirable to limit damage
 - Including the bus in the transformer protection zone may delay the restoration of the bus

Transmission Voltage System Interconnections, Looped System



Tie Line Protective Relaying

- POI adjacent to the Collector Sub
 - Common ground mat
 - Bus differential relaying
- POI remote from the Collector Sub
 - Line current differential relaying system
 - Works well for variable sources of fault current
 - Optical fiber cable installed on the transmission line provides the communication medium

Over/under Voltage Magnitude & Frequency

- Installed at the POI Sub
- For the protection of the Transmission Provider's equipment and customer's equipment
- Multiple pickup levels with different time delays
- Pickup levels closest to the normal operation range have the longest time delays
- Disconnect the 34.5 kV collector lines

Fault Interrupting Equipment Issues

- Additional fault current from the wind plant
- Additional fault current due to the enhancements of the transmission network to handle the additional load current
- Higher X/R ratios increases the DC component
- Characteristic of fault current from some types of WTG delay the first zero crossing

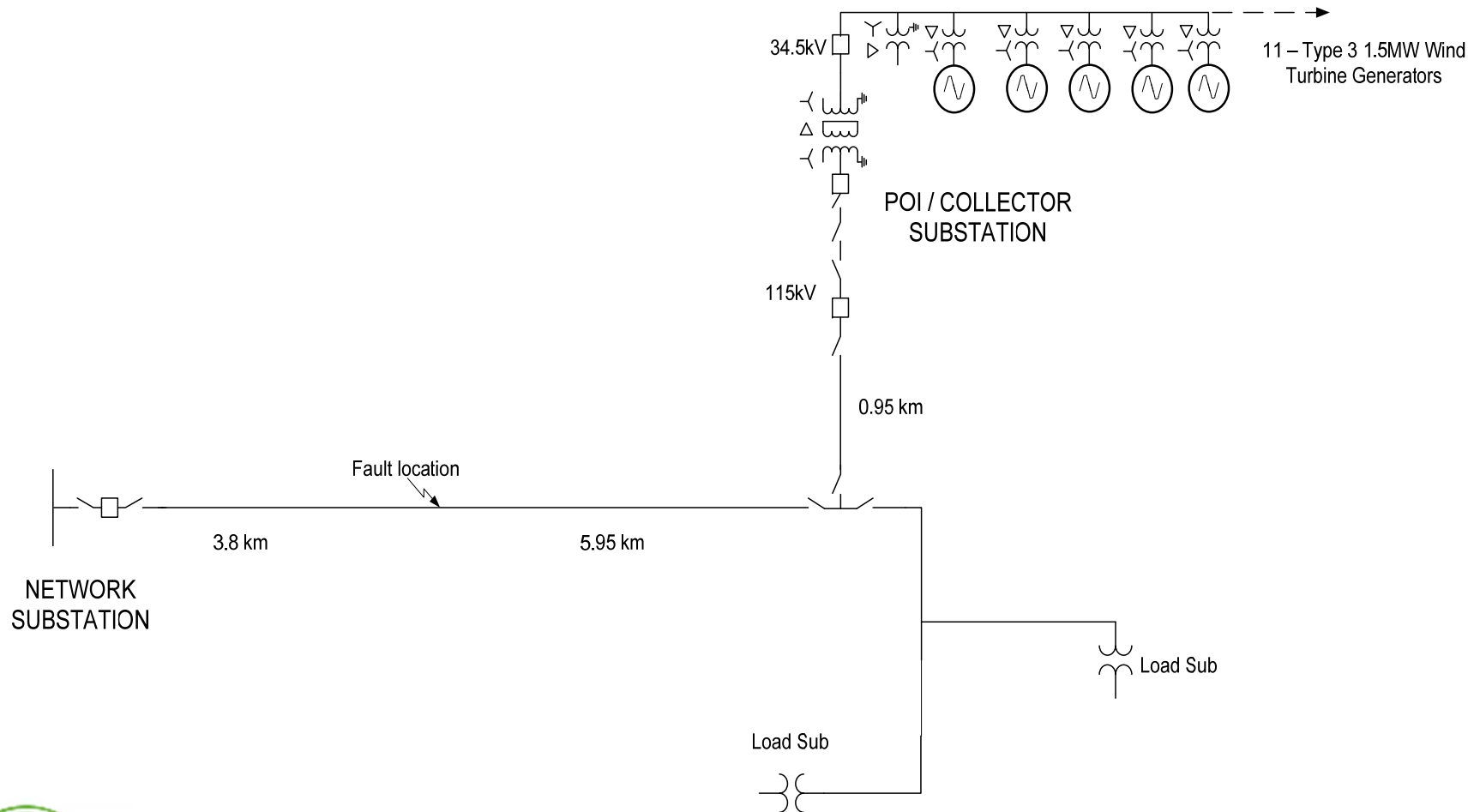
Analysis of Data from Fault Events

- Analysis of data from relays for tie line faults
- 4 fault events, 2 with type 2 WTG, 2 with type 3
- 3 with Single phase to ground faults, 1 with phase to phase
- Direct calculation of wind plant collective negative and zero sequence impedance
- Use of fault study program to determine generator positive and negative sequence impedance

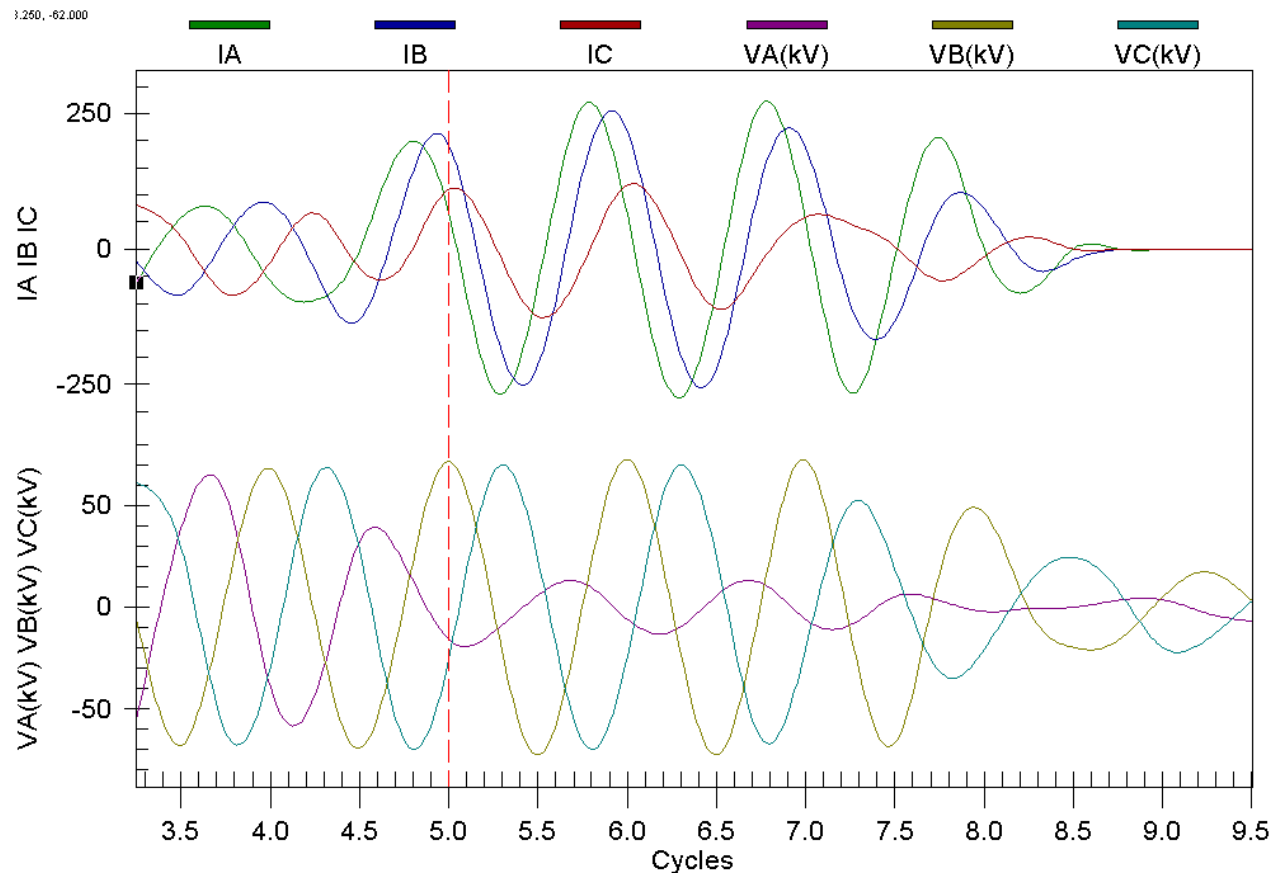
Example of Data from Fault Event

- 11 – 1.5 MW type III wind turbine generators
- Collector substation with a 34.5 to 115 kV wye-delta-wye step up transformer
- 17.7 MW and 3.2 MVAR into the transmission system prior to the fault
- A phase to ground fault occurred on the line to the network substation, 3.8 km from the network substation.

One Line Diagram

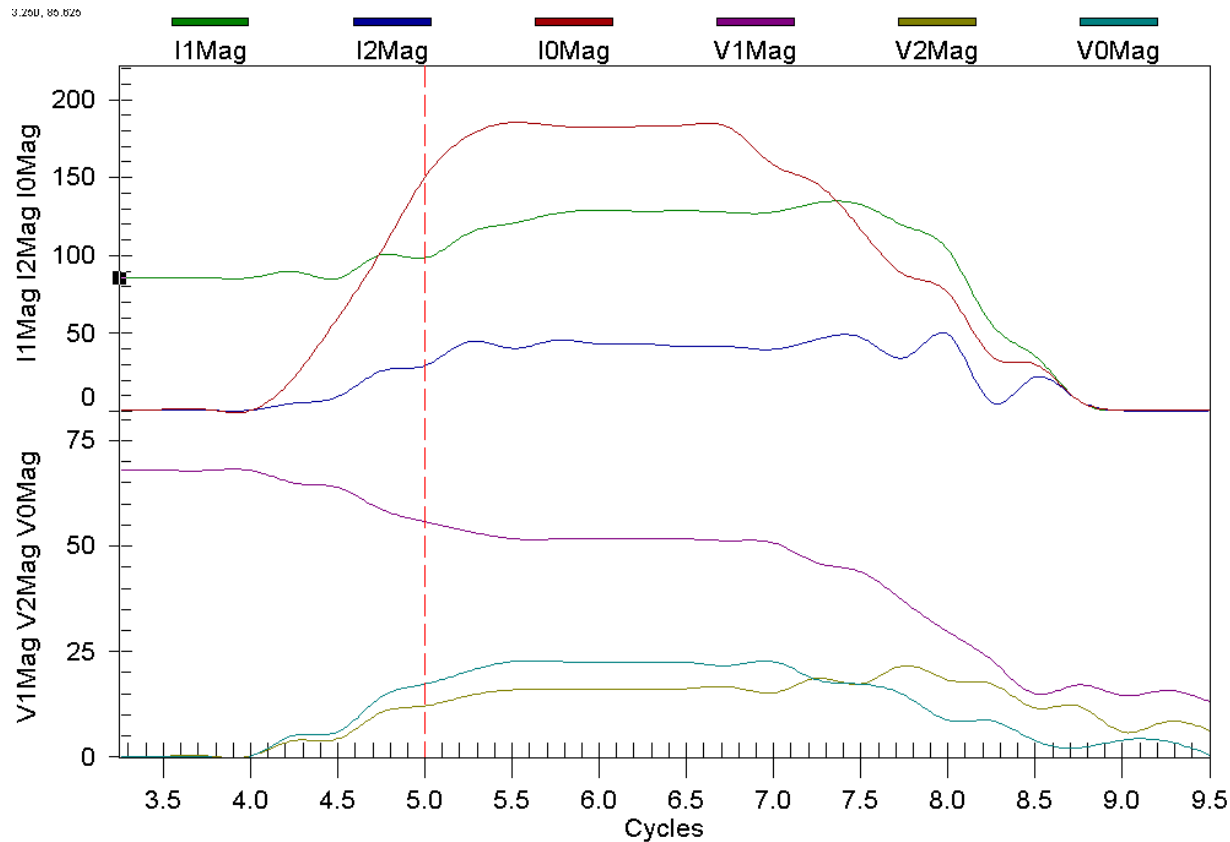


Type 3 WTG Fault Event



Relay Fault Record of Filtered Currents & Voltages for POI/Collector Sub

Sequence Quantities Magnitudes



1.9 cycles from the start of the fault at time 6.3

$V1 = 51,681 \text{ V}$, $I1 = 129 \text{ A}$, $V2 = 16,090 \text{ V}$,

$I2 = 43 \text{ A}$, $V0 = 22,557 \text{ V}$, $I0 = 182 \text{ A}$

Results from the Analysis

- Generator Z1 0.2 pu @ 1.626 MVA
- Generator Z2 0.33 pu @ 1.626 MVA
- Wind plant Z0 123.9 ohms, 115 – 34.5 kV transformer with the affect of the grounding transformer on the 34.5 kV bus
- Phase to neutral voltage on the terminals of the generators during the fault was 0.51 - 0.52 pu

Conclusion

- Draft 7.1 of the report has been distributed to the working group members
- All of the writing assignment have been completed
- 90 page report
- 16 authors
- Editorial and technical committee approval process will most likely to take most of 2013.

Questions

