

# Fault Current Contributions from Wind Plants

*Joint Technical Committee Meeting  
January 16, 2014*



# Presentation Overview

Joint Working Group

The Issue

Structure of the Report

Major Components of Wind Plants

Wind Turbine Generator's Response to Faults

Wind Plant Protective Relaying

Actual Performance / Experience

Conclusion

Future Plans

Questions

# Joint Working Group

Members from 3 Technical Committees of PES:

Transmission & Distribution

Electric Machinery

Power System Relaying

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# 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

# The Issue

- WTGs' tolerate rapid fluctuations in prime mover
- Traditional rigid mechanical and electrical coupling of a turbine and synchronous generators
- Different types of flexible coupling are used
- WTGs' response to faults differently
- Ability to predict and model the sources of fault current is needed

# 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
9. References
10. Standards
11. Abbreviations

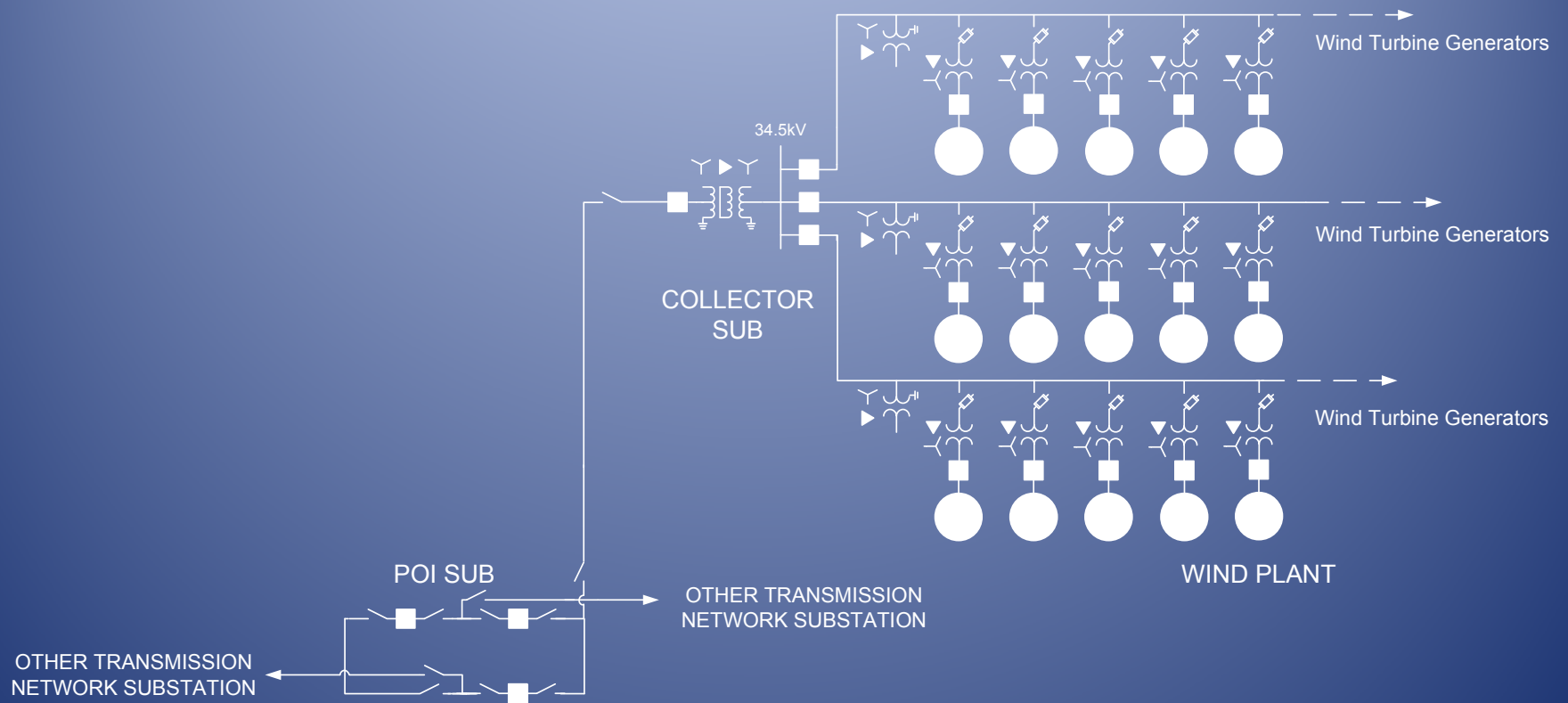
# Major Components of Wind Plants

- WTGs
- Collector lines
- Collector Substation
- Tie line
- POI Substation

# Wind Plant

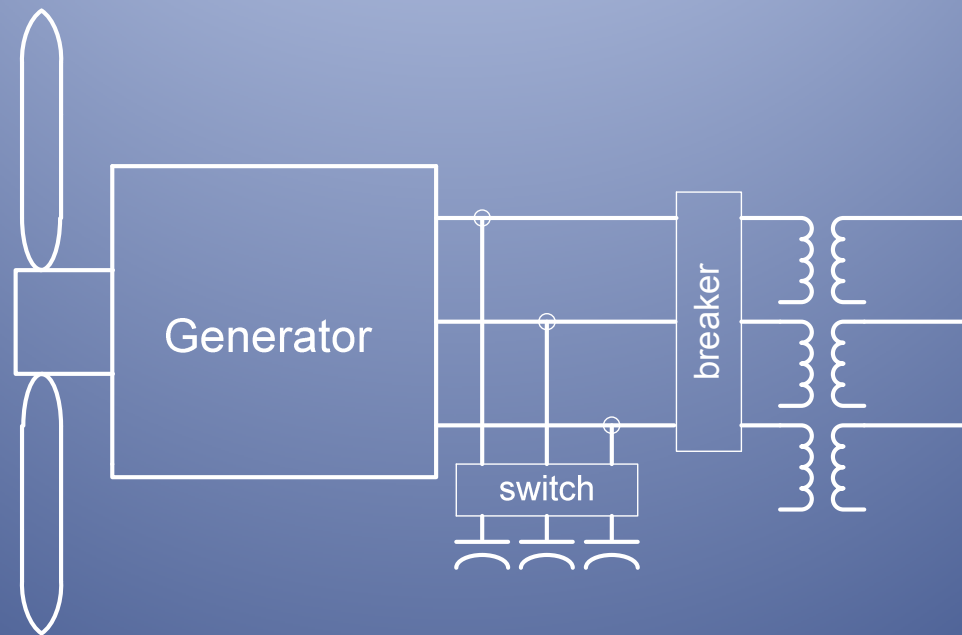


# Wind Plant



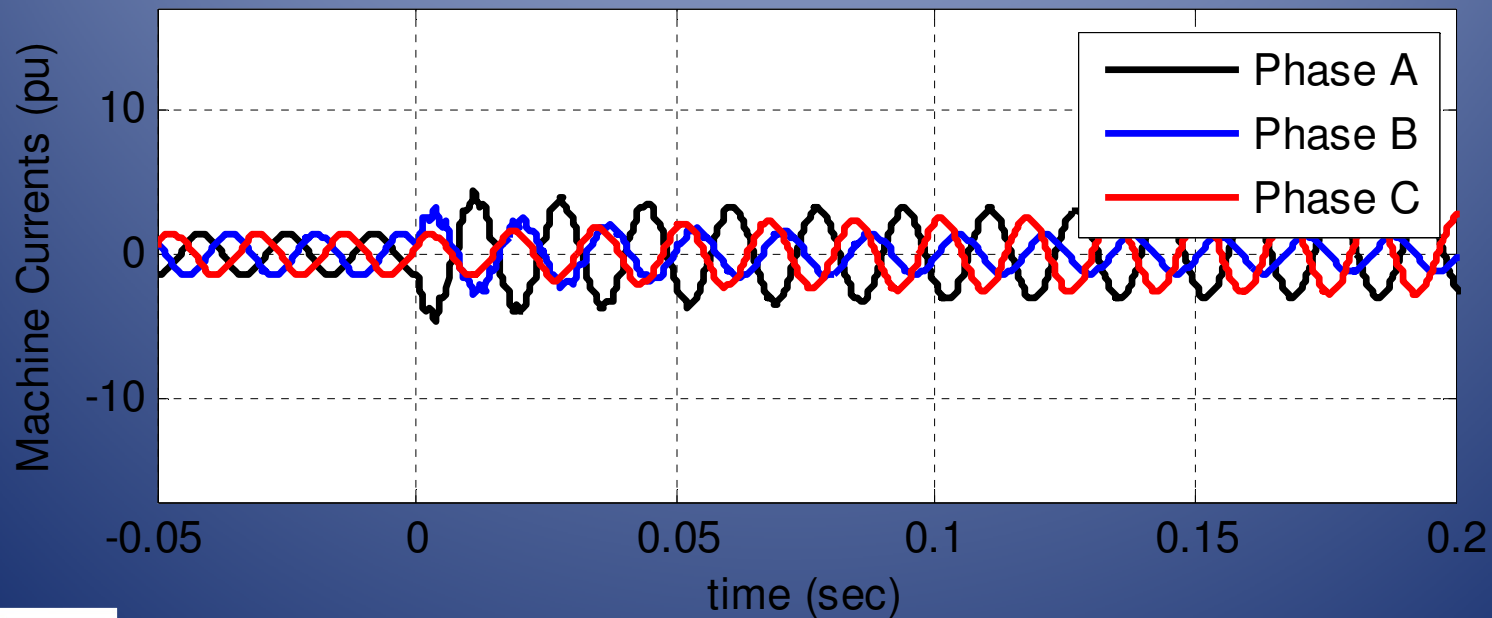
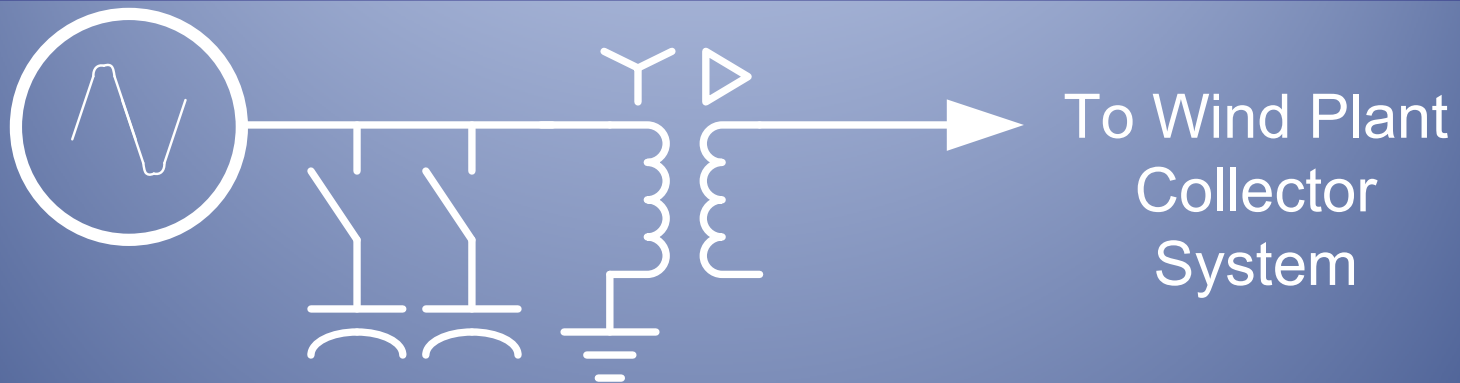
SYSTEM ONE LINE  
DIAGRAM

# Type I Wind Turbine Generator



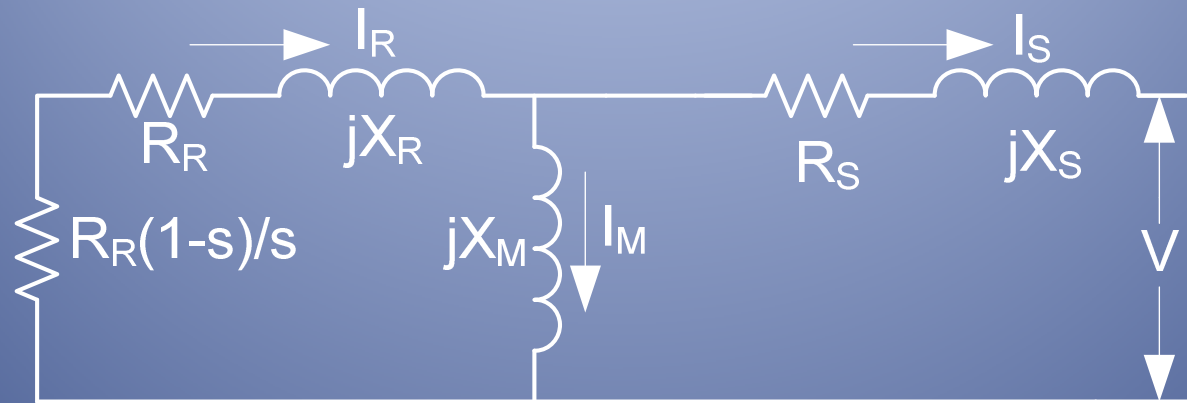
- Squirrel cage induction generator
- Switched shunt capacitors for power factor control
- Rotor must be turning slightly faster than the stator field

# Type I Wind Turbine Generator



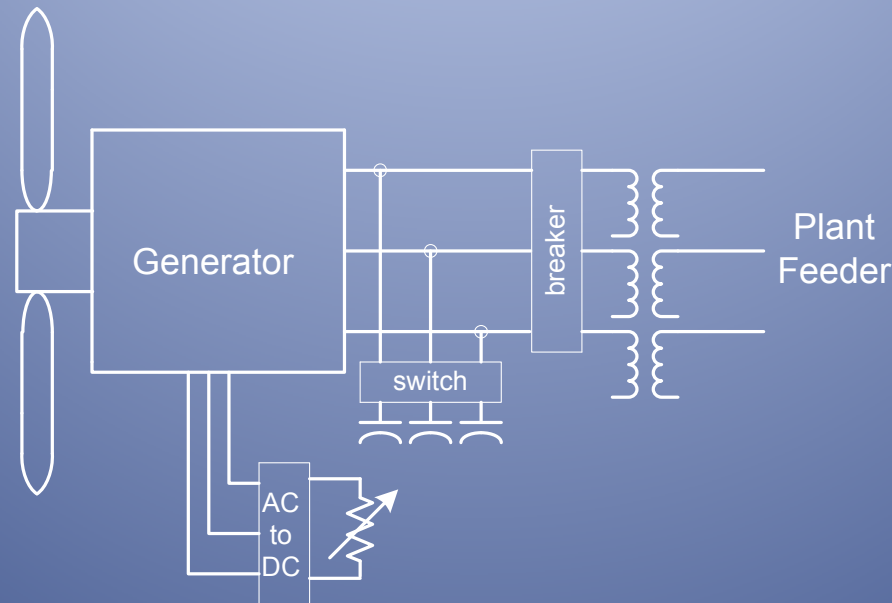
Single Phase to Ground fault on the Terminal of the Generator Step-up Transformer

# Type I Wind Turbine Generator



$$X' = X_S + \frac{X_m X_R}{X_m + X_R}$$

# Type II Wind Turbine Generator



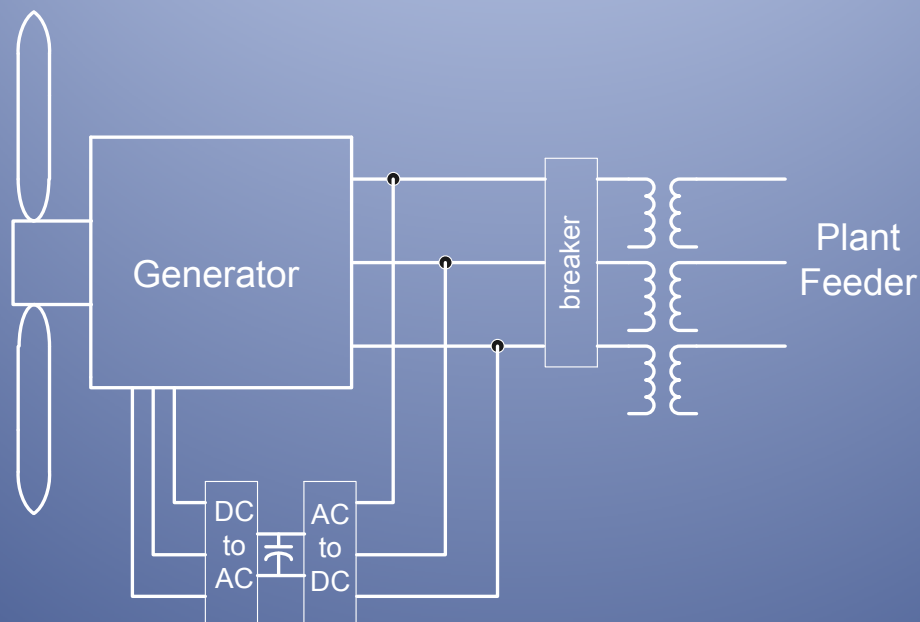
- Wound rotor induction generator
- Rotor must be turning faster than the stator field
- Rotor winding resistor increases speed range for power production

# Type II WTG Response to Fault

- Similar equivalent circuit to Type I except with the external rotor resistor
- Value of the external rotor resistor decreases the magnitude of fault current and reduce the damping time
- For faults on the collector system the affect of the resistor is not significant

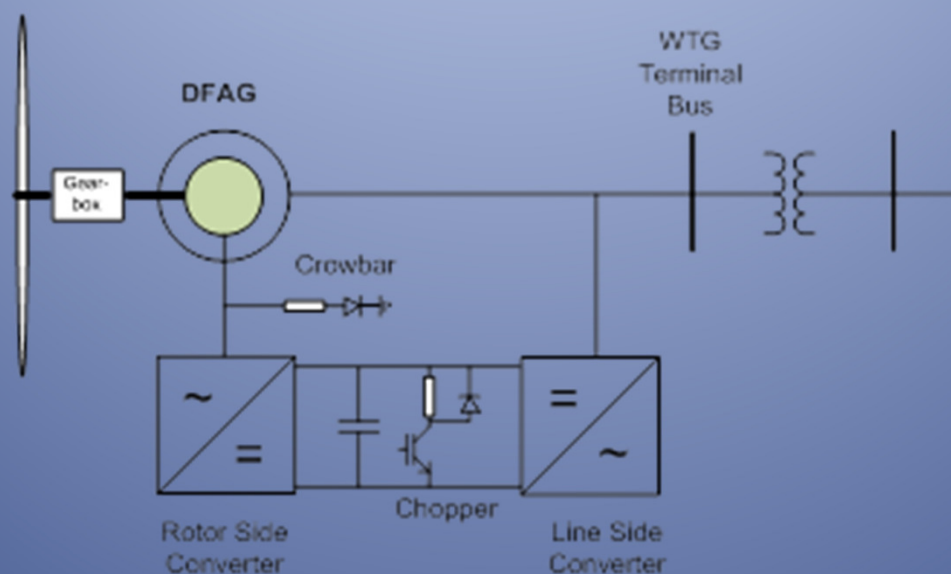
Slip	Calculated fault current with rotor resistance	Calculated fault current without rotor resistance	Difference in the two values
	Fault current (A)	Fault current (A)	%
-1%	10880	10882	0
-2%	10660	10548	1.05
-10%	9726	10520	8.16

# Type III Wind Turbine Generator



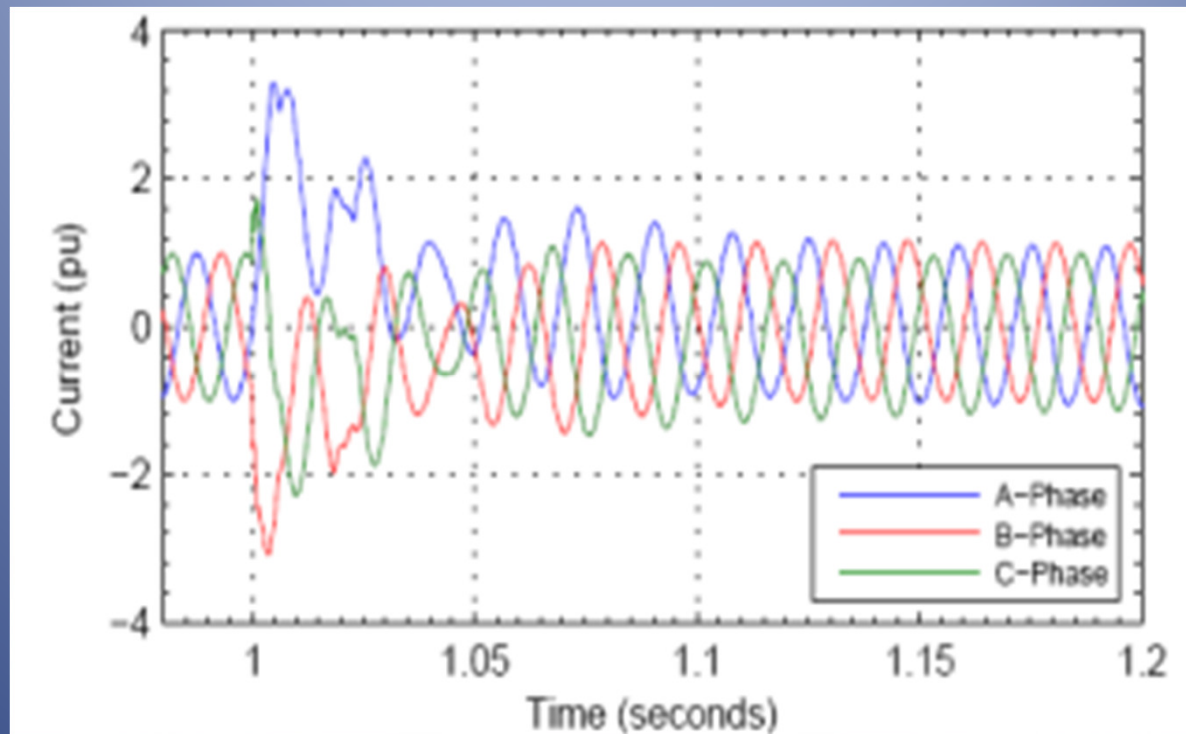
- Asynchronous generator (variable speed double fed generator)
- Variations in rotor current magnitude and timing controls real & reactive power
- Produces power at rotor speeds less than and greater than stator field

# Type III Variable Response to Faults



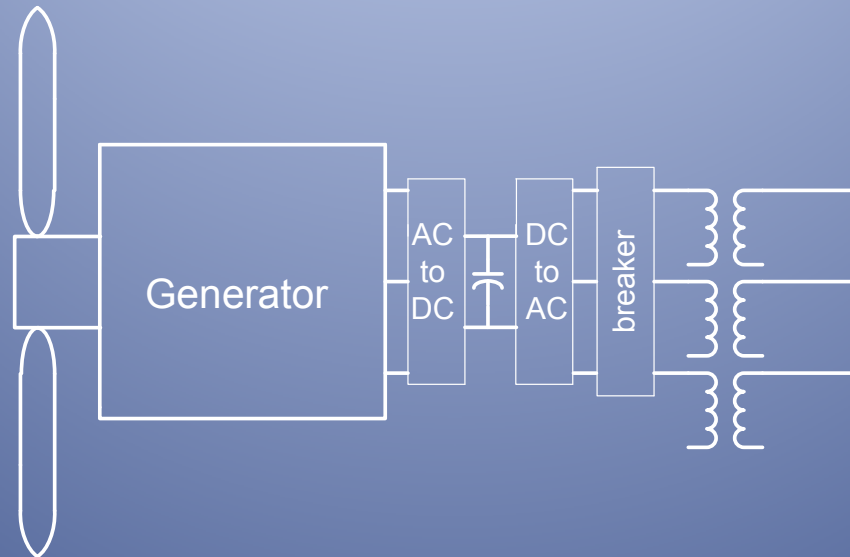
- Non-severe faults (higher voltage) operates like STATCOM, increases reactor power to boost voltage
- Severe faults, shunts rotor field, responses similar to an induction generator for a period

# Response to Severe Fault



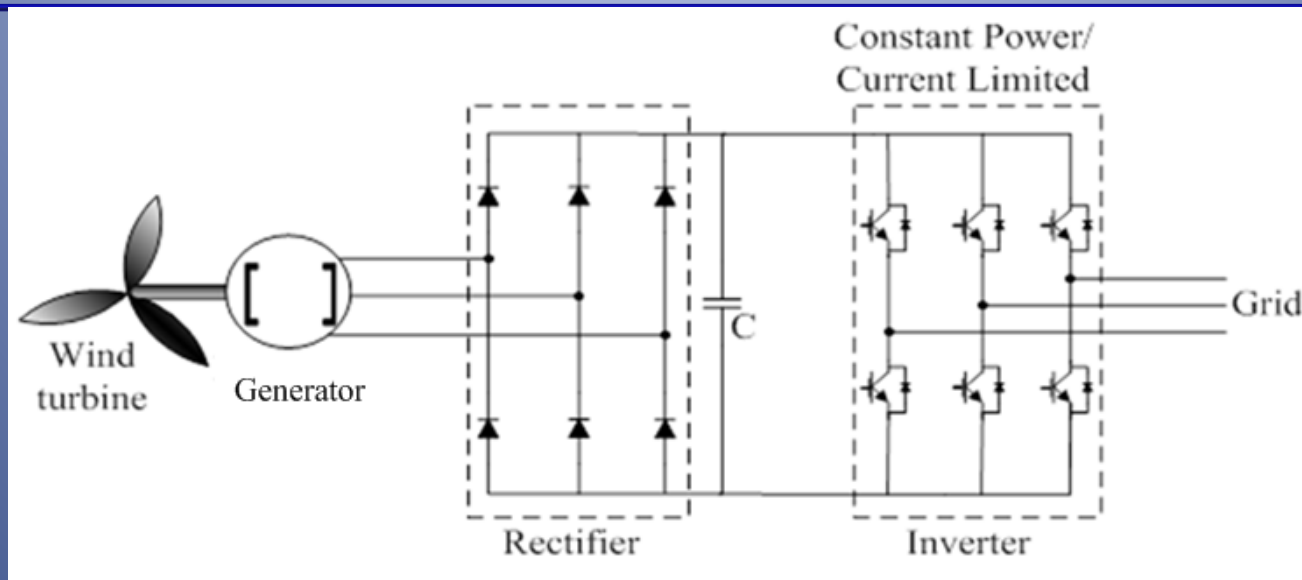
- Fault current for a fault reducing the voltage at the unit step-up transformer MV terminals to 20%.
- Initially with shorted rotor

# Type IV Wind Turbine Generator



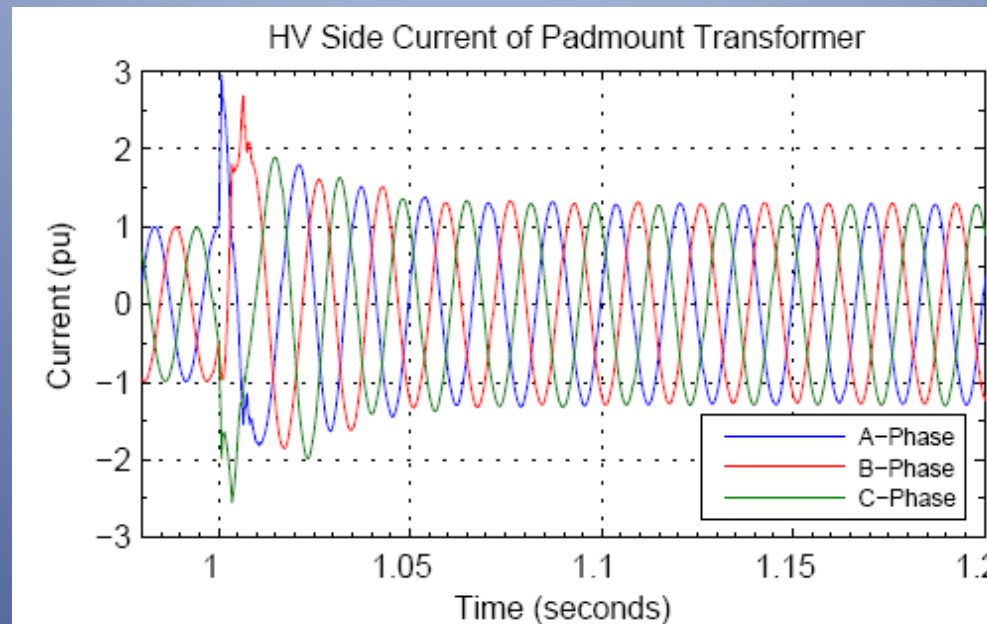
- Synchronous or induction generator
- Varies firing angle of inverters for real & reactive power control
- Produces power over a wide range of wind speeds

# Type IV WTG Response to Fault



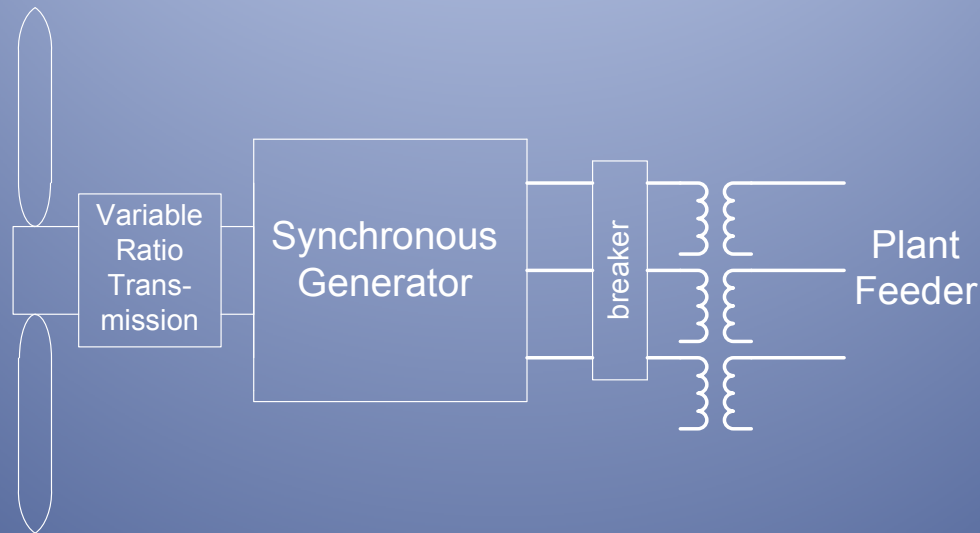
- Fundamentally determined by the inverter controls
- 2 cycles of maximum current to maintain power flow in spite of low voltage
- Controls detect a fault condition and switch into a predetermined mode of operation

# Type IV WTG Response to Fault



- 3 phase fault on the terminals of the step-up transformer
- Controlled fault mode of 1.1 pu current
- Typically supplies balanced current for unbalanced faults

# Type V Wind Turbine Generator



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

# Wind Plant Protective Relaying

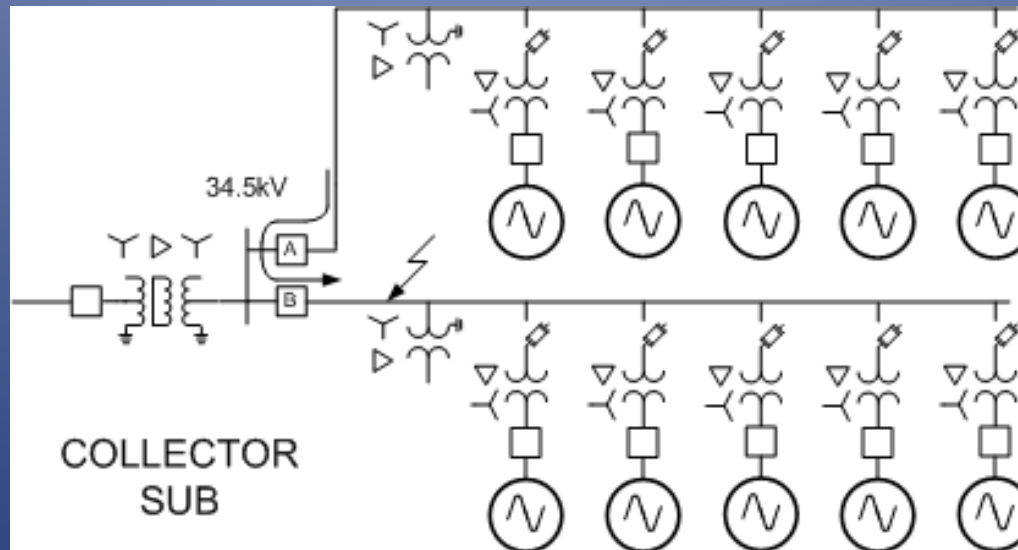
- Collector System
- Transmission Interconnection
- Distribution Interconnection

# Wind Plant Protective Relaying

- WTGs in the early wind plants disconnected in the first cycle for faults on any line well beyond the POI substation
- Contributed very little fault current
- Not a issue for relaying but a problem for the power system
- Low voltage ride-through rules
- To remain connected, supply reactive power to the fault
- Contribute fault current to system fault for a extended period
- Reactive, synchronizing power, supplied from SVC, STATCOM or WTGs

# Collector Feeder Relaying

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



# Power Quality and Islanding Relaying

- Under/over voltage and frequency relaying installed at POI
- For the protection of the Transmission Provider's equipment and customers' 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

# Connection to Distribution Systems

- Unique issues from a transmission interconnection
- Maximum generation and minimum load
- Fault current back feed through the feeder breakers
- Reverse power flow through voltage regulation devices

# Hot Line Reclose Blocking

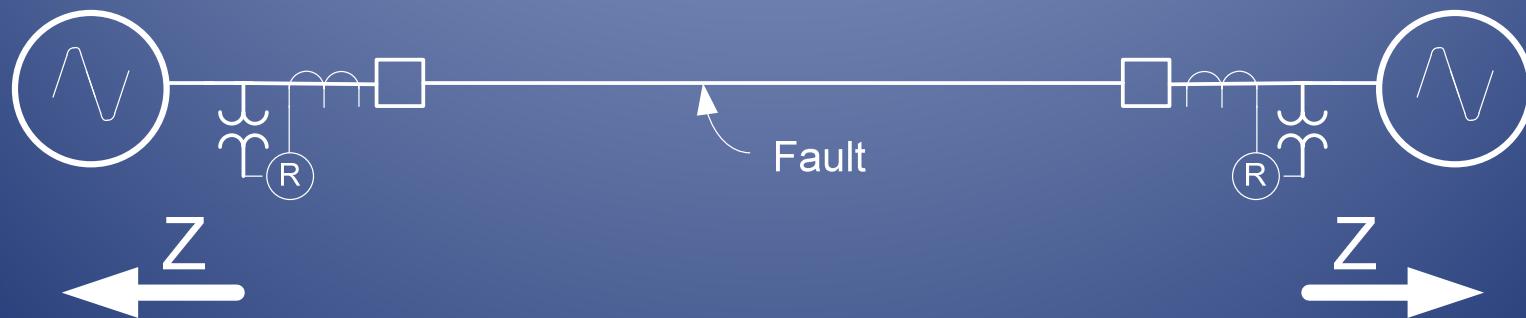
- Wind Plant cannot follow load levels
  - Wind Plant will go dead
  - Timing is the issue
- Line relays at POI may not operate or may be delayed
  - Reclosing into a non synchronous generator not a issue
  - No chance of a successful reclose
  - Damage to customer motors, wind plant will keep the motors rotating but decelerating because the wind plant cannot maintain the frequency

# Actual Performance / Experience

- Analysis of data from relays for tie line faults
- 4 fault events, 2 with type II WTG, 2 with type III
- 3 SLG faults, 1 phase to phase fault
- Goal is to measure the apparent sequence impedance of the WTG during the fault
- Direct calculation of wind plant  $Z_2$  &  $Z_0$
- Used fault study program to determine WTG  $Z_1$  &  $Z_2$

# Process for the Measurement

- Use the fault records from the line relays
- Location of fault or amount of fault impedance is not an issue
- Status of all of the WTGs and the impedance of the all other components of the wind plant are needed



# Symmetrical Component Networks

Negative and Zero sequence

$$Z = V / I$$

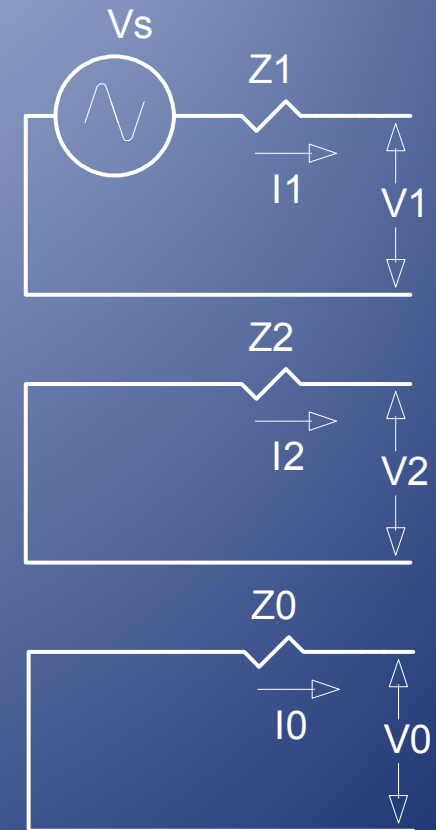
V & I are known

Positive sequence

$$V_1 = V_s - I_1 (Z_1)$$

$$Z_1 = (V_s - V_1) / I_1$$

Both  $Z_1$  &  $V_s$  are not known



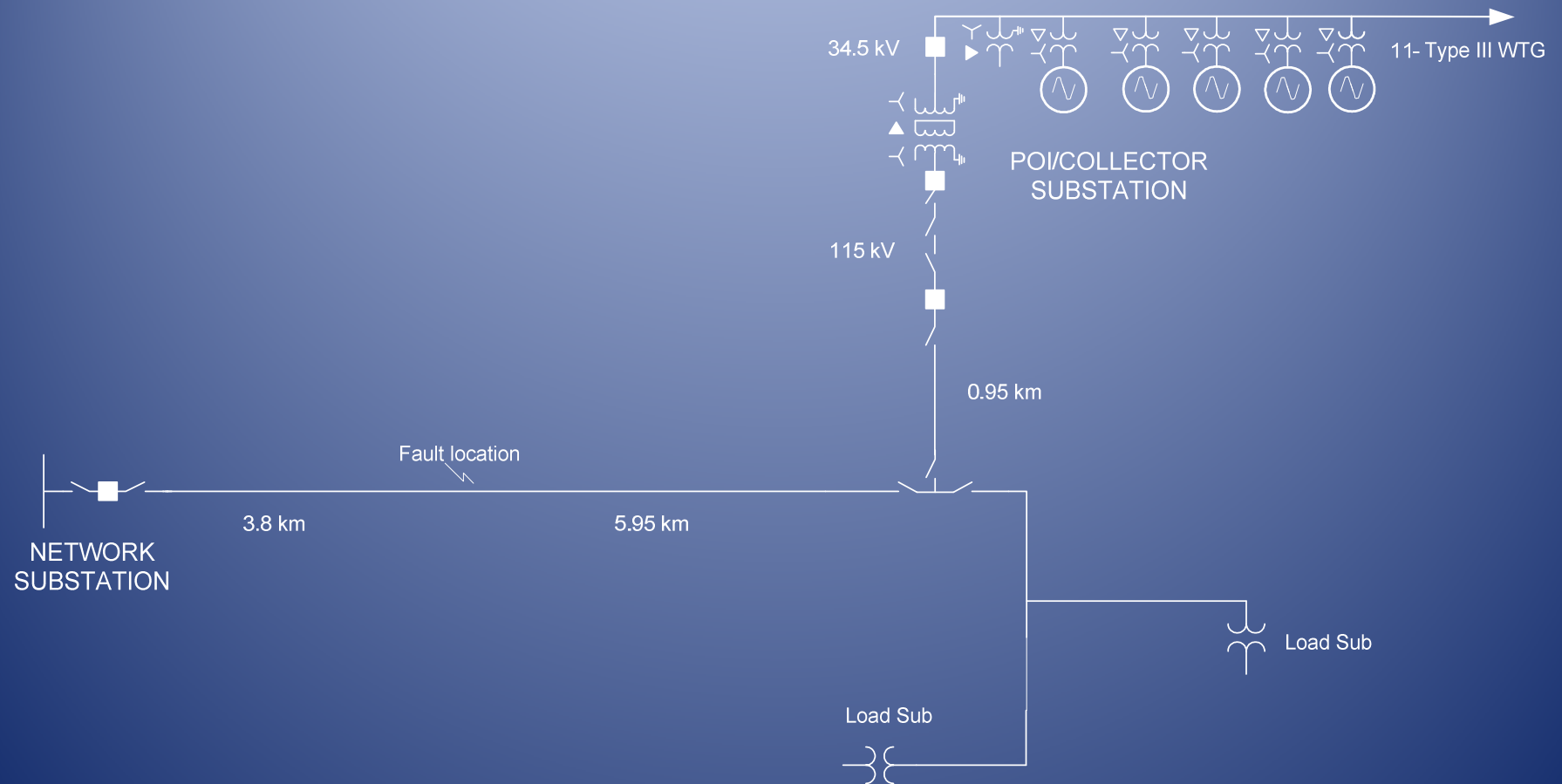
# Positive Sequence

- Using negative sequence value for WTG
- Detailed fault system model of Wind Plant
- Prefault load flow
- Fault study program
  - Preload the fault study model with the prefault load current and voltage
  - Determined the fault impedance by matching the negative sequence currents
  - Determined the WTG  $Z_1$

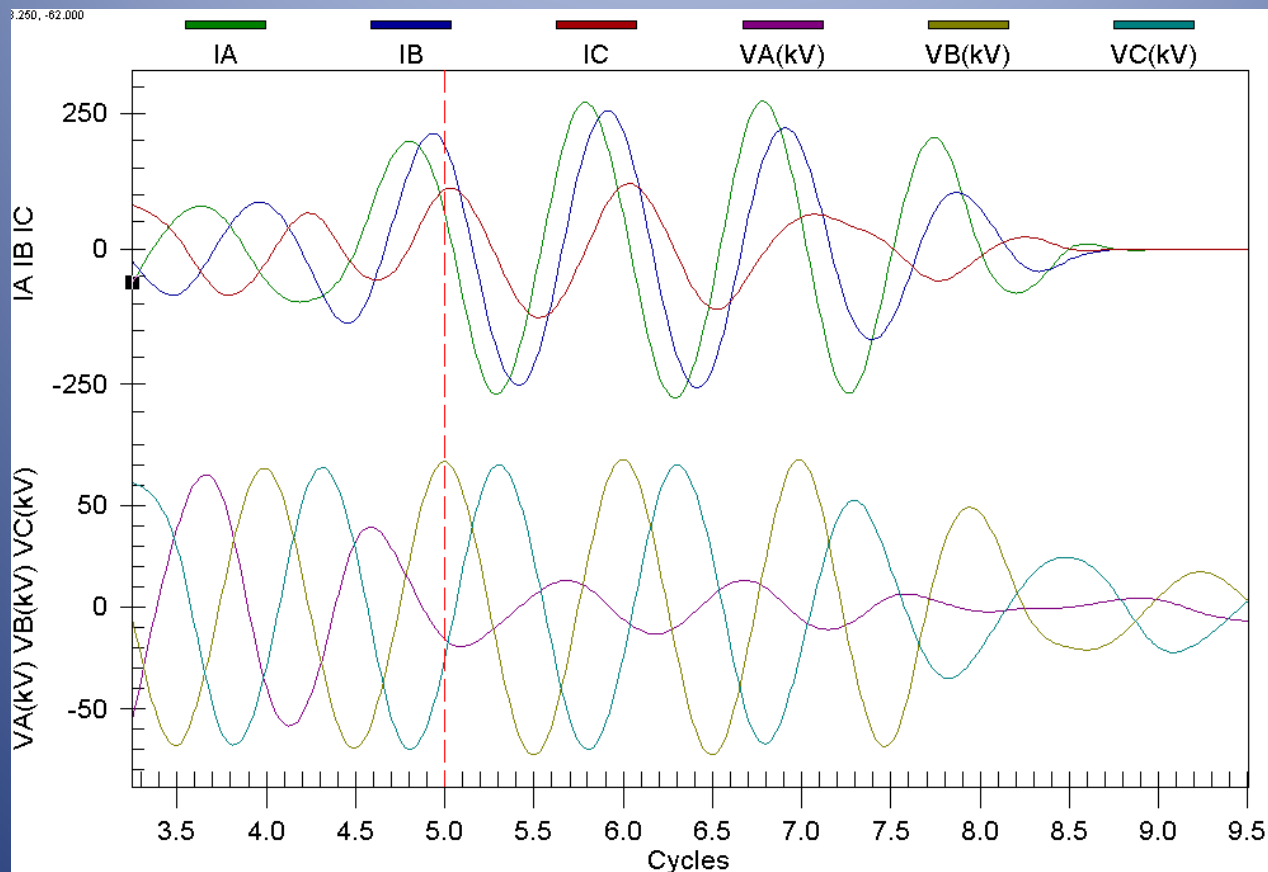
# Wind Plant 4

- 11 – 1.5 MW type III WTGs
- 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 , 3.8 km from the network substation.

# Wind Plant 4 One Line Diagram

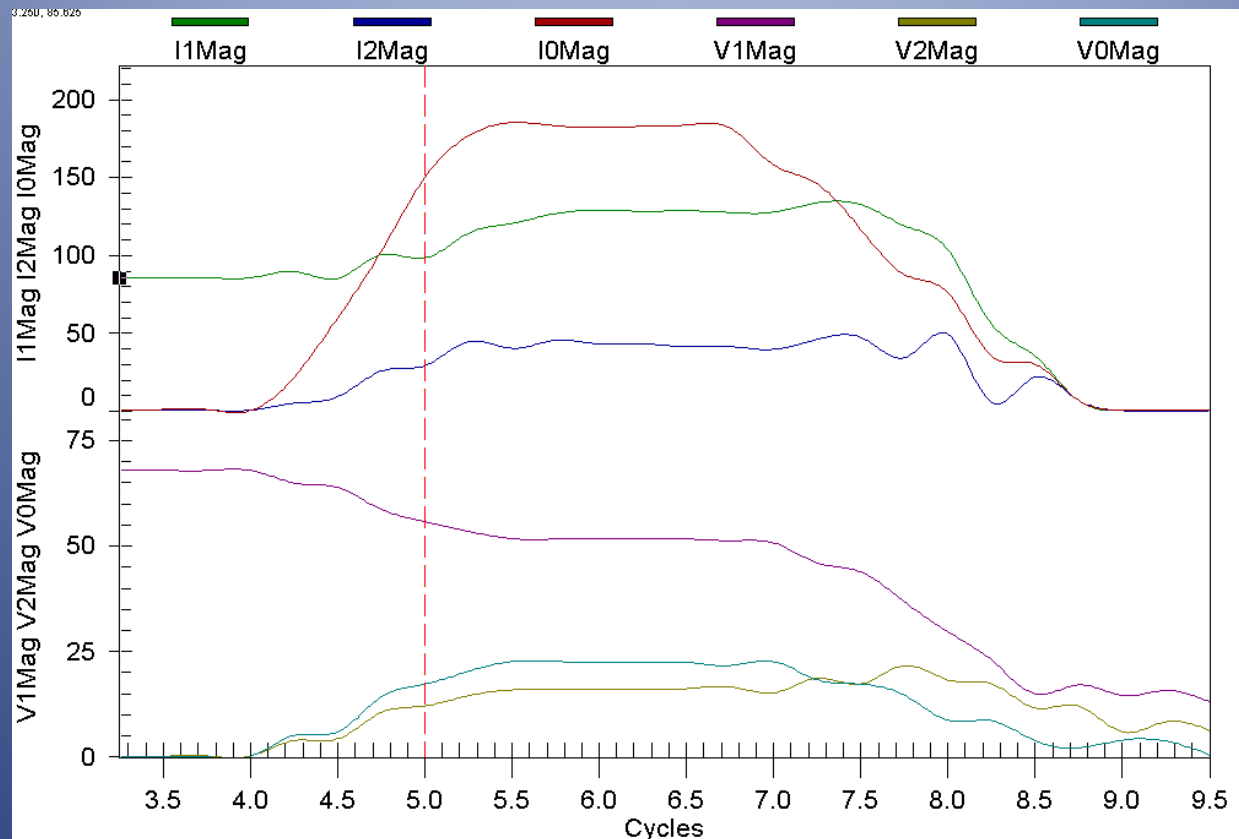


# Type 3 WTG Fault Event



Filtered Currents & Voltages from  
POI/Collector Sub

# Sequence Quantities Magnitudes



Sampled at 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 at the terminals of the generators during the fault was 0.51 - 0.52 pu

# Conclusion

- Type I & II WTG, use the induction generator rotor and stator reactance
- Type III WTG, variable nonlinear response but for close-in faults (which included the tie line faults) responds similar to Type I for approx. 2 cycles during a critical relay fault detection period
- Type IV WTG, like STATCOM contributing reactive current to try to support the voltage until controls detect the fault condition, approx. 2 cycles, shifts to pre-set mode
- Type V WTG, like a typical synchronous generator

# Future Plans

- Report is finished and will be posted on the PSRC web site
- Joint Working Group will continue with the plan to present a tutorial session based on the report at the PES GM
- A new Task Force has been formed to produce a report for the modification of fault study programs to include WTG models

# Questions?

