IEEE PES Transmission and Distribution Conference
2008

Panel Session –
”Large Wind Plant Collector Design”

Wind Farm Collector System Grounding

by

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Information contained in the following shall not be construed as detailed description of the properties or function of wind turbines manufactured by Vestas

Introduction

- Need for grounding
- Codes and Standards for grounding
- Wind Turbine Generator grounding design
- Foundation + Horizontal Electrode grounding design
  - Integrated with rest of wind power plant
- Collection System grounding design
- Grounding Transformers

Need For Adequate Grounding

A well designed grounding system serves to:

1. Establish an effective reference to earth potential for normal operation of
   - electrical & communication equipment
   - controls
   - protective devices (circuit breakers, fuses)
2. Limit voltage differences to values that will not cause undue hazards to personnel and equipment
3. Protect the wind turbine against lightning damage
4. Limit galvanic corrosion due to dissimilar metals

Codes and Standards

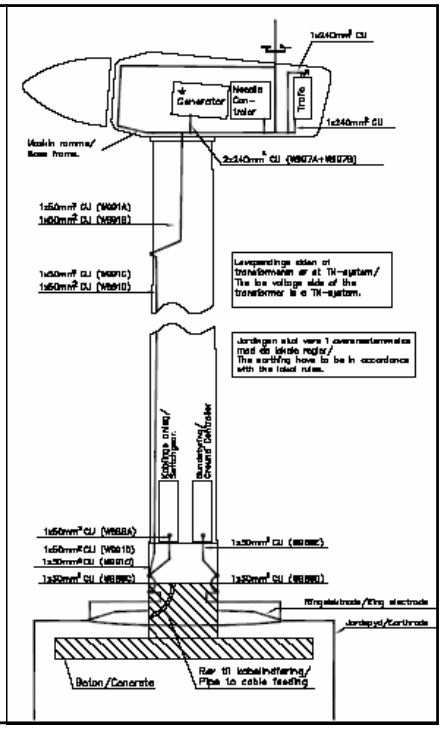
Grounding is necessary, and required by safety codes and standards, for personnel safety and protection of equipment in electrical systems

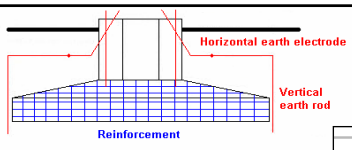
- North America
  - IEEE Standards
    - 80 Substations
    - 81 Measurements
    - 142 Industrial/Commercial (Green Book)
    - 1050 Instruments and Controls in Generating Stations
    - 1100 Sensitive Electronics (Emerald Book)
  - ANSI
    - NFPA 780 Lightning Protection
  - UL
    - 96A Lightning Protection
    - 467 Grounding/Bonding Equipment
  - NEC, CEC, NESC
- Europe
  - IEC
    - 61400-24
    - 61024-1 Lightning
    - 62305 Lightning Protect
      - -1 General
      - -3 Damage
      - -4 in Structures
    - 61364 Buildings
    - 61936-1 Pwr Syst > 1kV

Typical Wind Turbine Generator Internal Grounding Systems

TN-S

Considers Lightning and Power System Fault protections

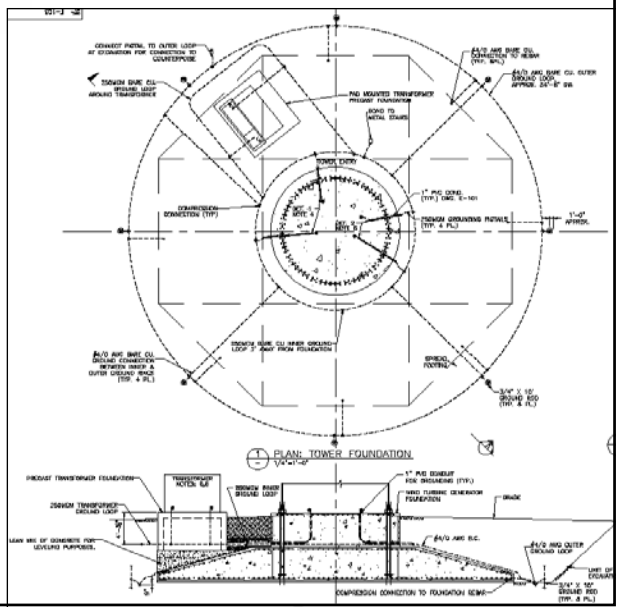




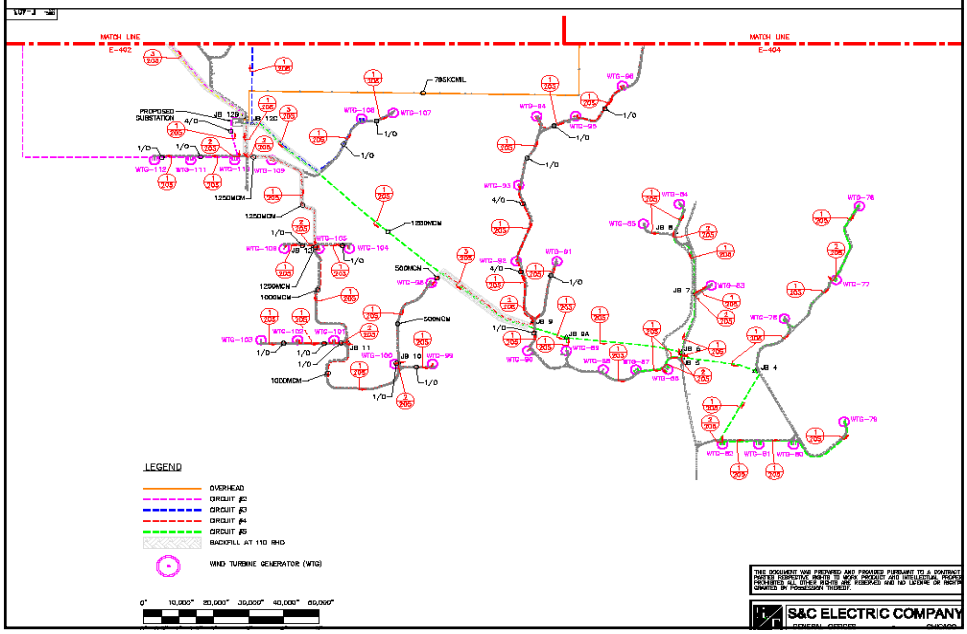
IEC Type B WTG Grounding Designs

- Ring Conductor
- Driven Rods

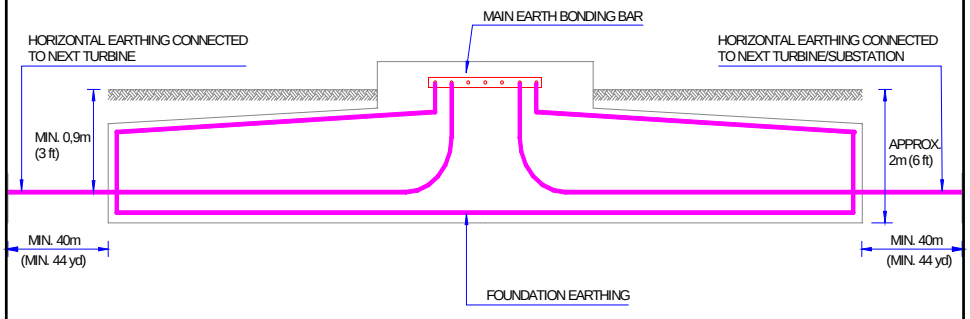
<= 10 Ohms

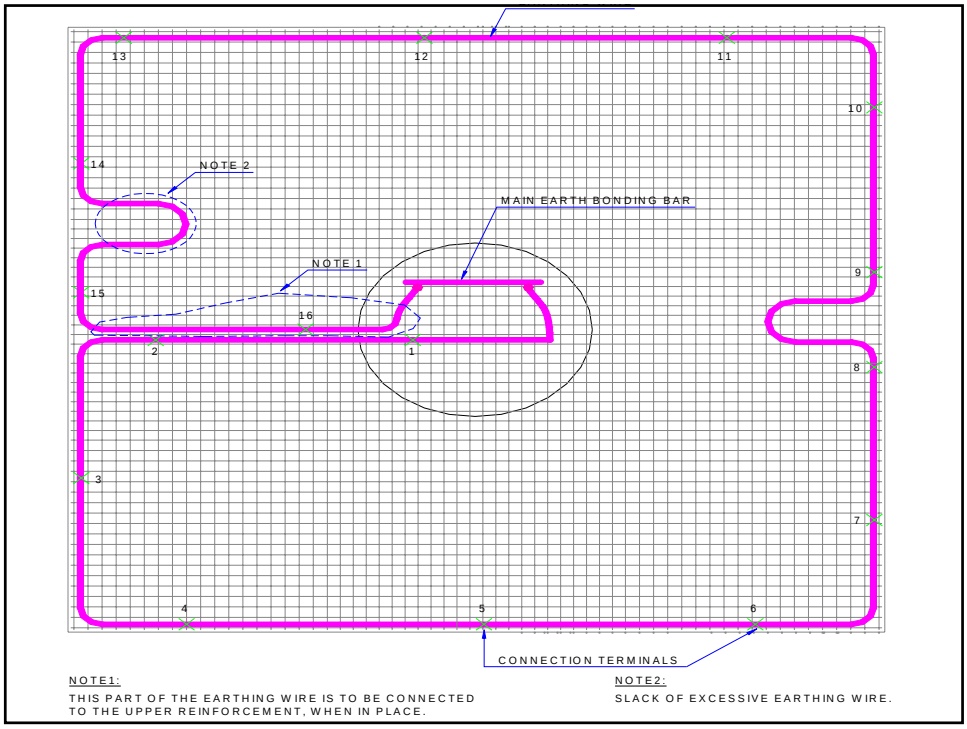


Ground System Interconnections



Foundation plus Horizontal Grounding Design Concept





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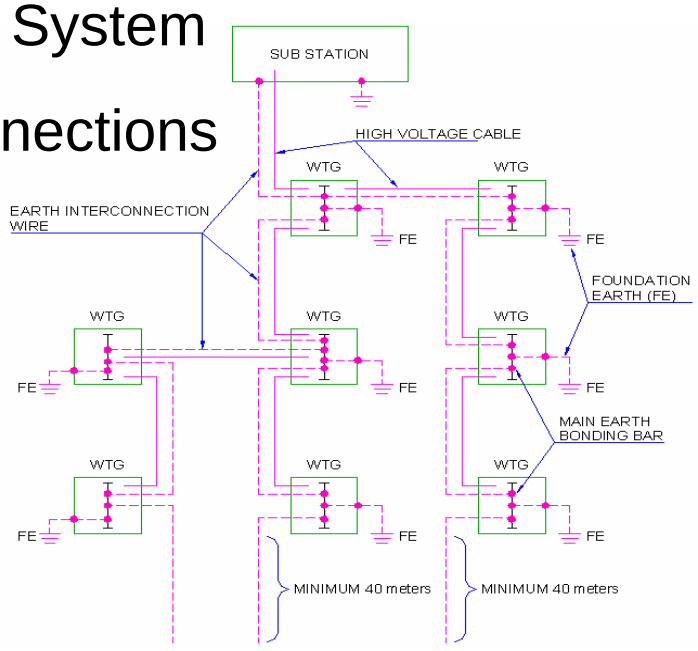
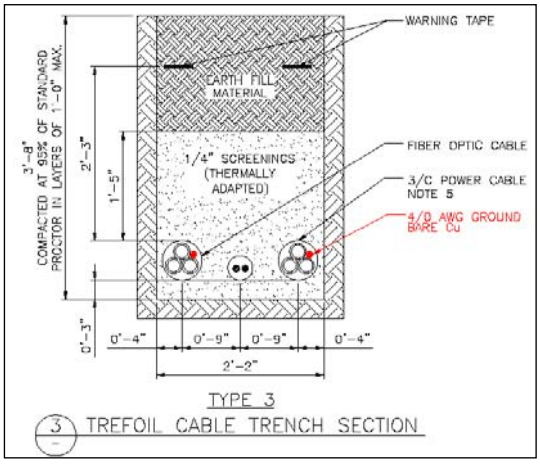


Collector System Engineering & Design

- Soil Resistivity
  - ranges from 10s to 1000s of ohm-meters
- Size of Cable Neutral/Shield
  - 1/3, 1/2, full size
- Cable Insulation Rating
  - 100%, 133%, 173%
- Expected Fault Duty
  - seeing higher levels due to
    - greater Duty from power offtaker at POI
    - larger park ratings – 100s of MW)
- Underground versus Overhead Constructions

Collector System Engineering & Design

- *Engineered System Drawings – Trench Grounding*
  - Feeder Circuits

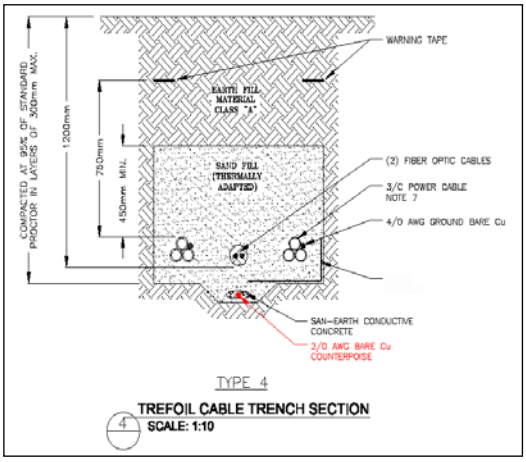


Collector System Engineering & Design

- *Engineered System Drawings – Trench Grounding*
  - Install ground in trench with Feeder Circuits

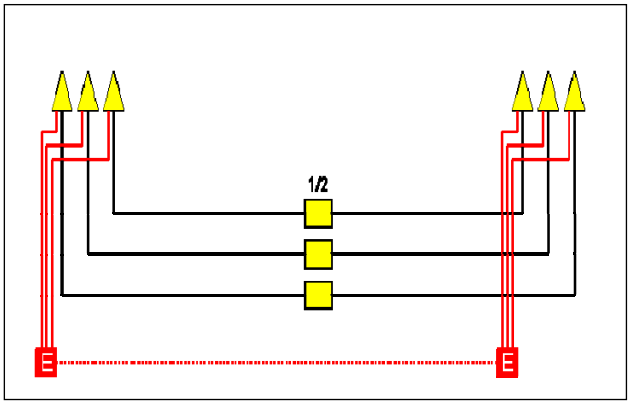
Collector System Engineering & Design

- *Engineered System Drawings – Trench Grounding*
  - Feeder Circuits
  - Counterpoise



Collector System Engineering & Design

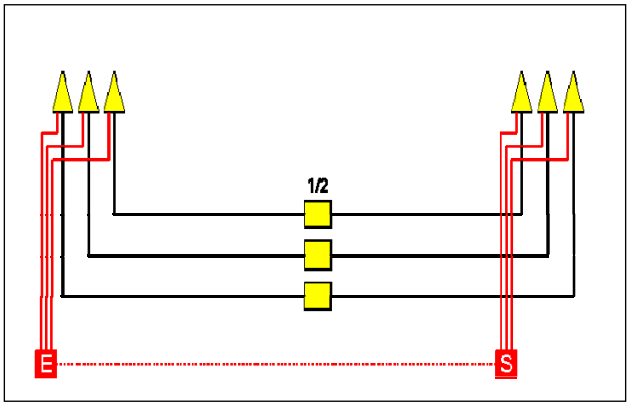
- *Engineered System Drawings – Sheath Grounding*
  - Solid Bonding



Collector System Engineering & Design

- *Engineered System Drawings – Sheath Grounding*
  - Solid Bonding

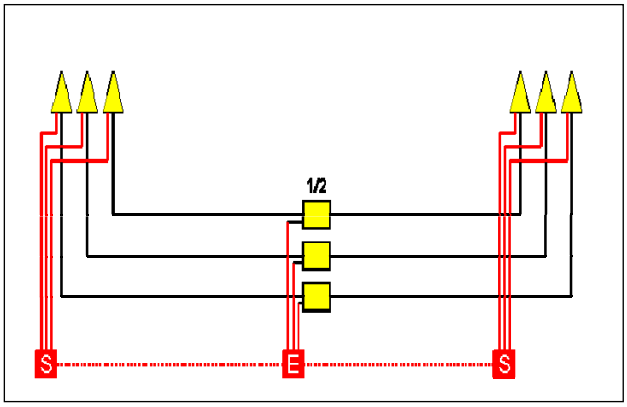
End-Point



Engineering & Design Requirements

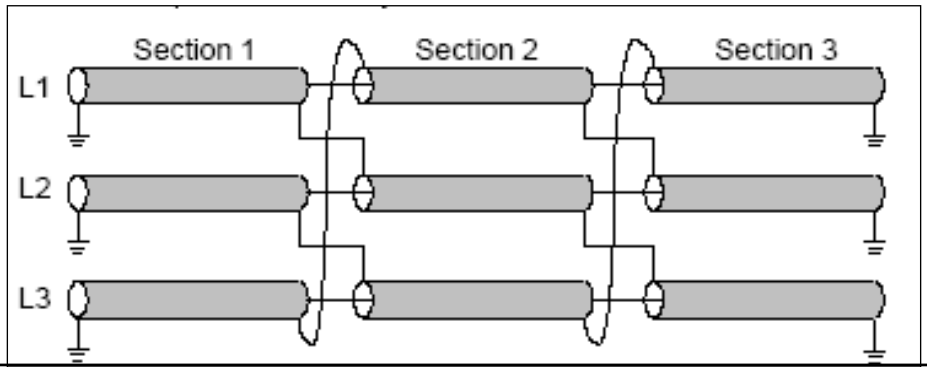
- *Engineered System Drawings – Sheath Grounding*
  - Solid Bonding

Mid-Point

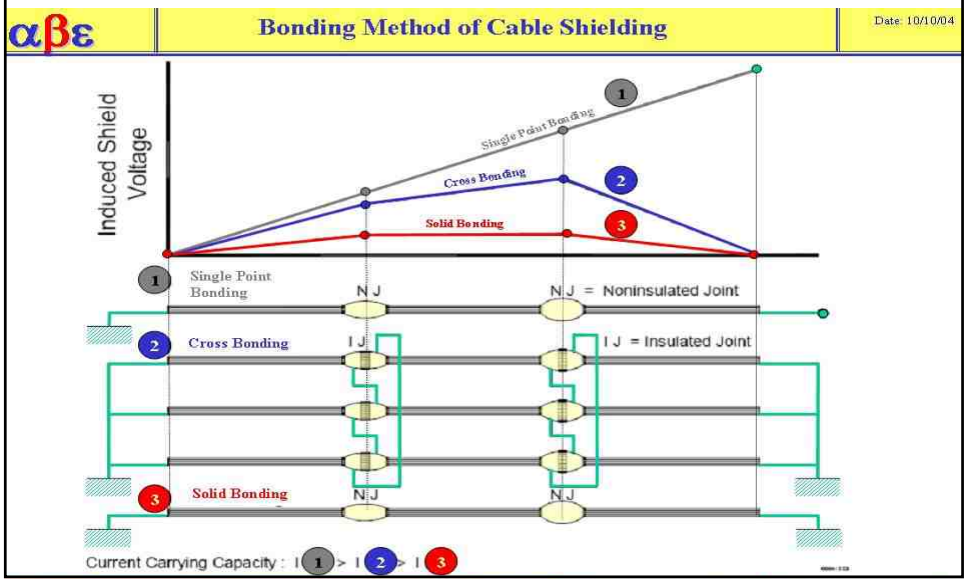


Collector System Engineering & Design

- *Engineered System Drawings – Sheath Grounding*
  - Solid Bonding
  - Cross Bonding



Collector System Engineering & Design (IEEE 575)



Connecting the Collector System to the Grid

- *Grounding Transformers*
  - Provide return path for ground fault current
  - Convert ± sequence current to zero sequence current
  - Prevent Voltage Elevation on un-faulted phases
  - Eliminate ferroresonance
  - Create an effectively grounded system
  - Winding Configuration Zig-Zag or Wye-Delta
  - Sizing
    - Feeder Circuits: ~5% of connected feeder load

      ∴ 30MVA collector circuit = 1.5MVA Grounding Transformer

Connecting the Collector System to the Grid

- *Collector Circuits – Feeder Grounding Transformers*

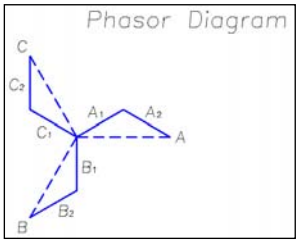
-Ground Current Source

-Connected on the WTG Side

-One Per Feeder

Connecting the Collector System to the Grid

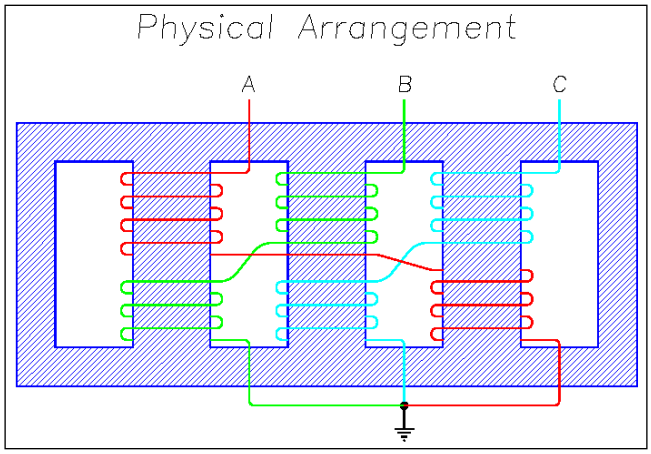
- *Grounding Transformers – Zig-Zag*



  - Series connection of windings forces equal currents
    - $IA_1 = IA_2$; $IB_1 = IB_2$; $IC_1 = IC_2$
  - Magnetic coupling of windings forces equal currents (1:1 Turns Ratio)
    - $IA_1 = IB_2$; $IB_1 = IC_2$; $IC_1 = IA_2$
  - As a result all currents are equal
    - $IA_1 = IA_2 = IB_1 = IB_2 = IC_1 = IC_2$

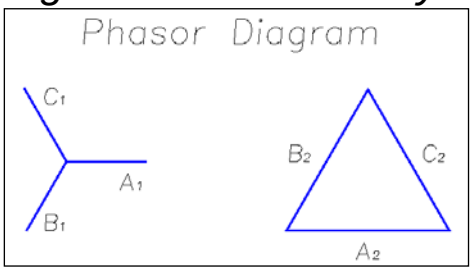
Connecting the Collector System to the Grid

- *Grounding Transformers – Zig-Zag*



Connecting the Collector System to the Grid

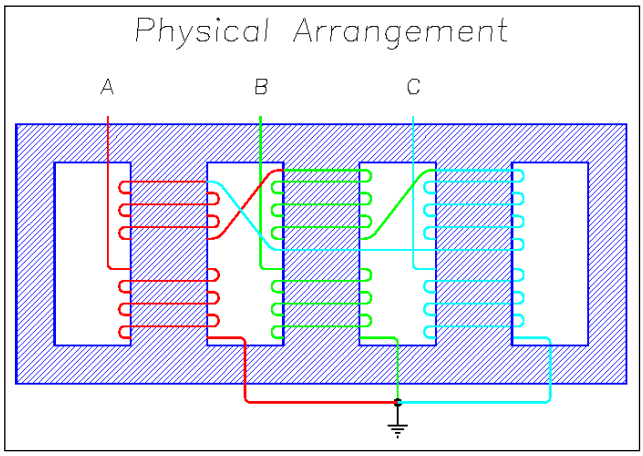
- *Grounding Transformers – Wye-Delta*



  - Series connection of windings forces equal currents
    - $IA_2 = IB_2 = IC_2$
  - Magnetic coupling of windings forces equal currents related by turns ratio
    - $IA_1 = nIA_2$; $IB_1 = nIB_2$; $IC_1 = nIC_2$
  - As a result all primary currents are equal
    - $IA_1 = IB_1 = IC_1$

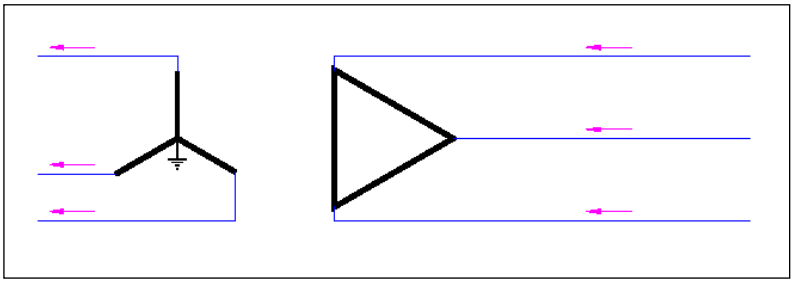
Connecting the Collector System to the Grid

- *Grounding Transformers – Wye-Delta*



Connecting the Collector System to the Grid

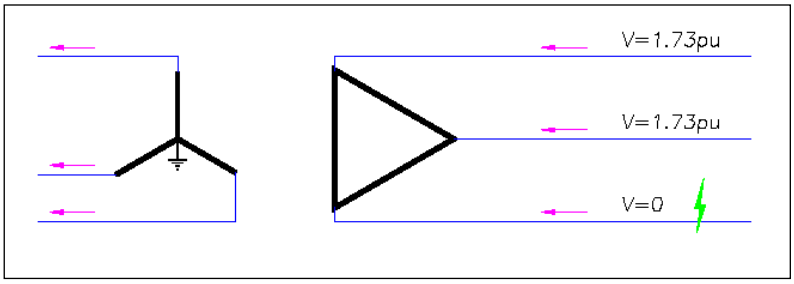
- *Current Flow – Pre-Fault*



– All voltages ~1.0pu

Connecting the Collector System to the Grid

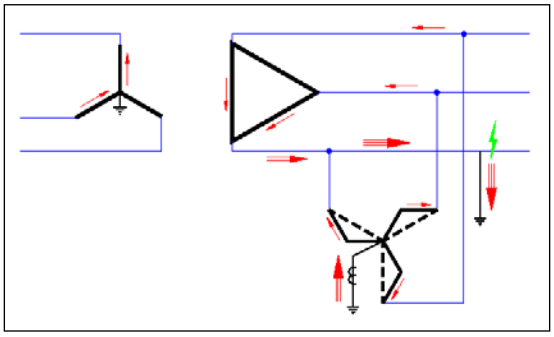
- *Current Flow - L-G Fault (Ungrounded)*



  - No path for ground fault current
  - Load current continues to flow
  - Elevated voltages on un-faulted phases

Connecting the Collector System to the Grid

- *Current Flow - L-G Fault (Grounding Transformer)*



Ground fault current returns through grounding transformer

  - Metering on ground leg senses fault current

Connecting the Collector System to the Grid

- *Delta Connected Systems*
  - Source of ground fault current – NO
  - Difficult to detect & locate ground faults
  - Elevated voltages (1.73pu or L-L) on un-faulted phases during fault conditions
    - Results in damaged equipment
      - Arrestors
      - Power Electronics
      - Cable Insulation
  - ***SOLUTION*** – GROUNDING TRANSFORMERS
  - ***SOLUTION*** – C-B WITH HIGH SPEED GROUND SWITCH
    - Within ~1 cycle of breaker trip all 3 phases are grounded

Connecting the Collector System to the Grid

- *Grounded-Wye Connected Systems*
  - Source of ground fault current – YES (Temporarily)
  - Source is removed as the faulted feeder circuit-breaker is tripped
  - WTGs will continue to generate for several cycles until removed from the circuit
    - Faulted feeder remains energized with elevated voltages on un-faulted phases
  - ***SOLUTION*** – GROUNDING TRANSFORMERS
    - Continue to supply zero sequence fault current until the fault is cleared thus eliminating over-voltages
  - ***SOLUTION*** – C-B WITH HIGH SPEED GROUND SWITCH
    - Within ~1 cycle of breaker trip all 3 phases are grounded


Questions?