Technical Report
PES-TR87

Protection of Wind Electric Plants

Prepared by the
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Protection of Wind Electric Plants: Report Contents

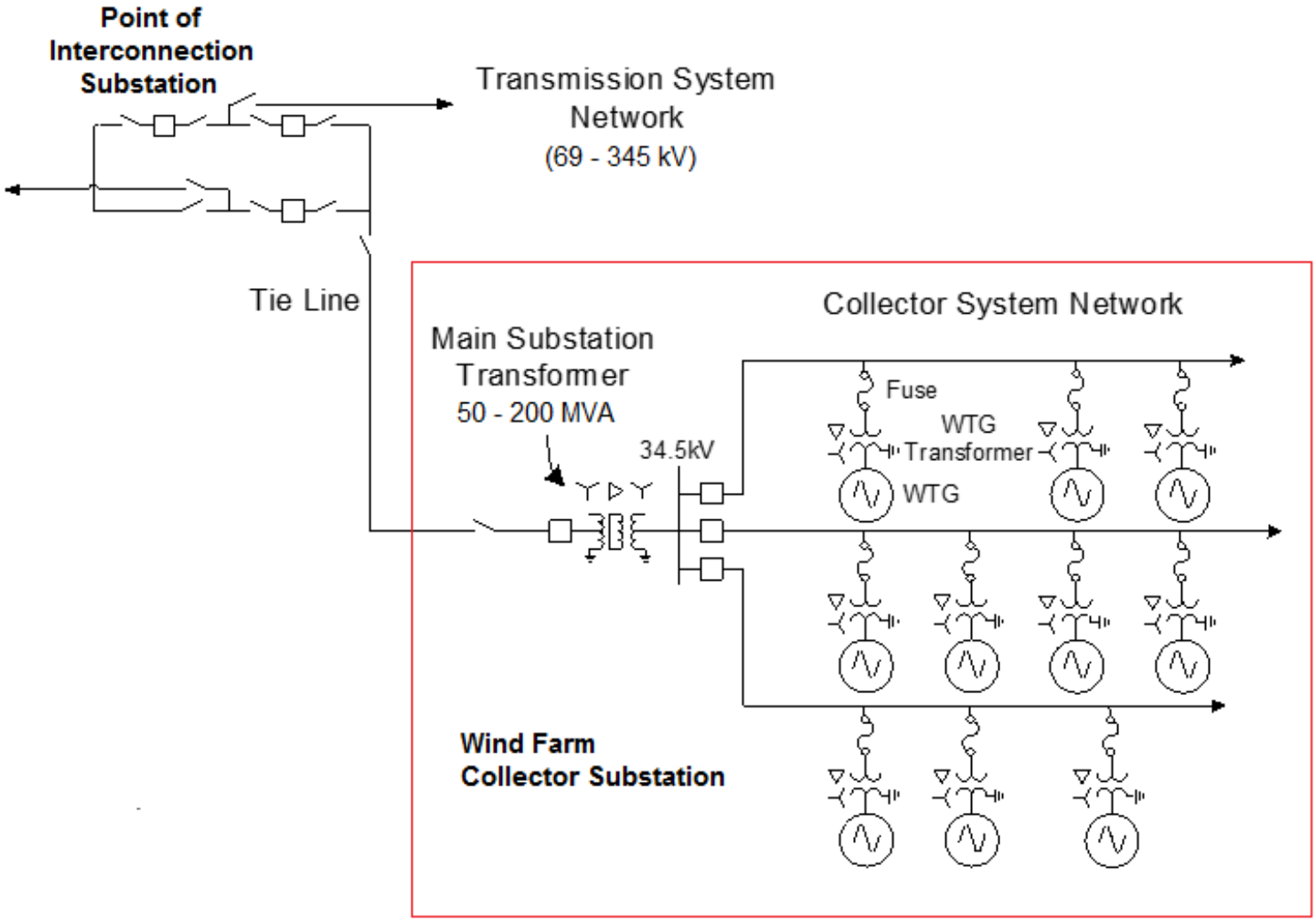
1. Introduction
2. Difference Between Wind Electric Plant Substations and Conventional Distribution Substations
3. Typical Protective Relay Schemes at Wind Electric Power Plant Substations
4. Conclusion
5. Bibliography

Appendix A: Directional Phase Overcurrent Setting Considerations for WTG Operation

Assignment:

Write a report to provide guidance on present relay protection and coordination practices at Wind-powered Electricity generating Plants (WEP). This report covers the engineering considerations for the design of the protection systems intended to protect all the elements that form WEPs.

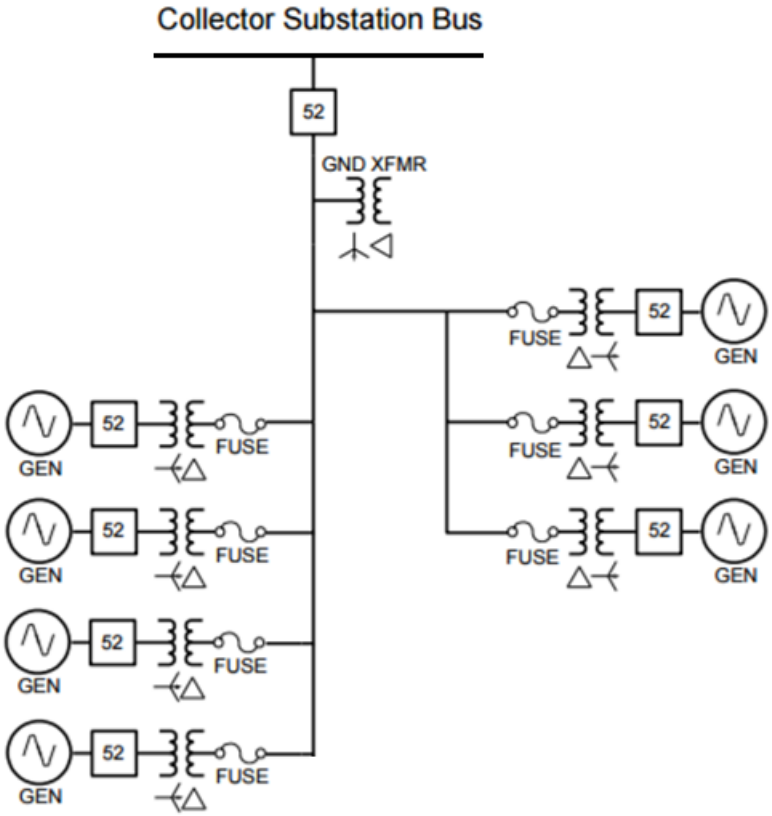
Single Line of a Typical Wind Farm Installation



The report specifically addresses:

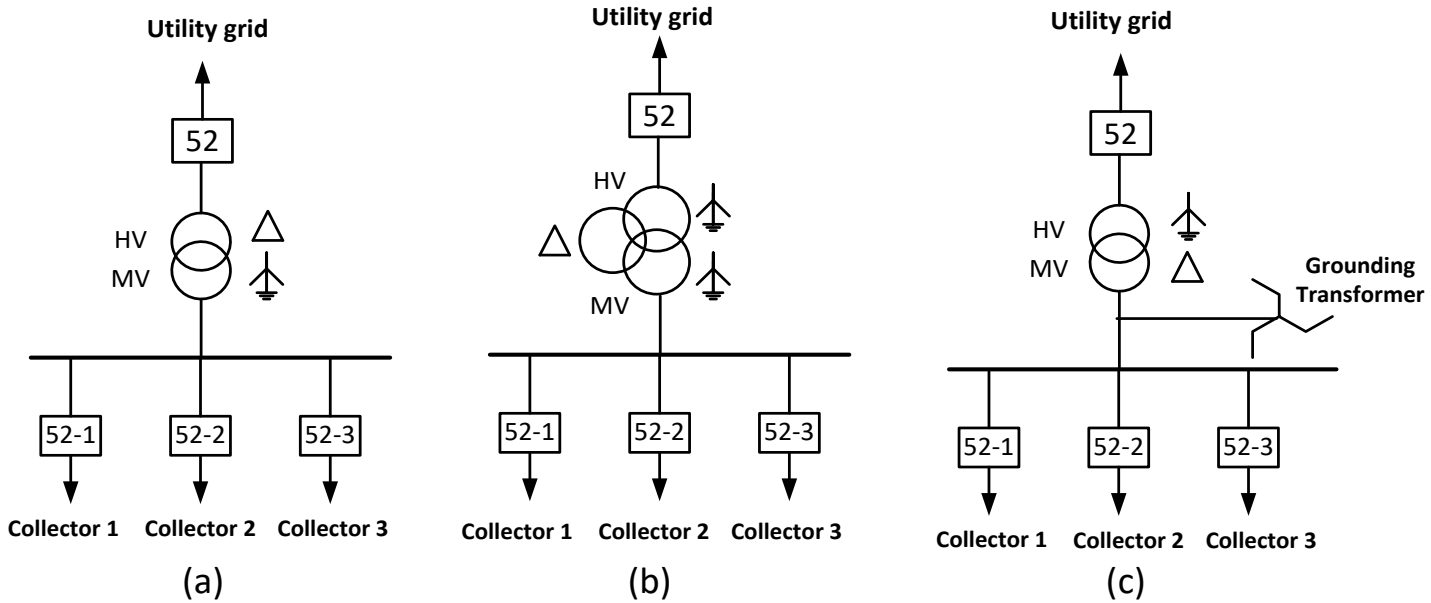
1. Collector Feeder Protection
2. Grounding Transformer Protection
3. Collector Substation Bus Protection
4. Main Power Transformer Protection
5. Capacitor / Harmonic Filter Protection
6. Transmission Line Protection

A Typical Wind Farm Collector Feeder Arrangement

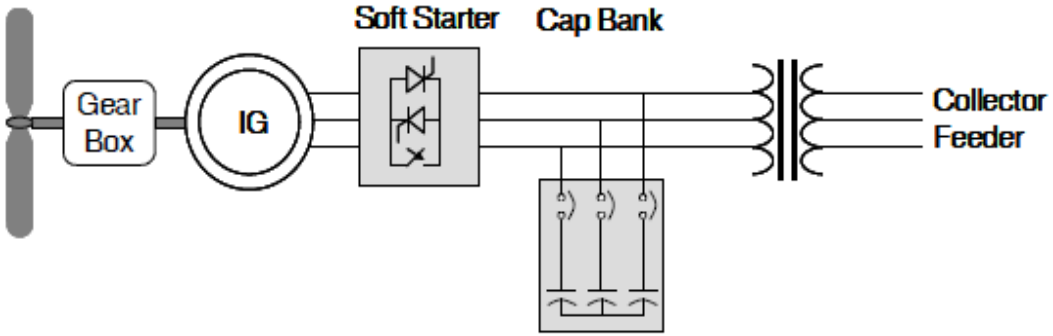


Typical Collector Feeder Cable Installation

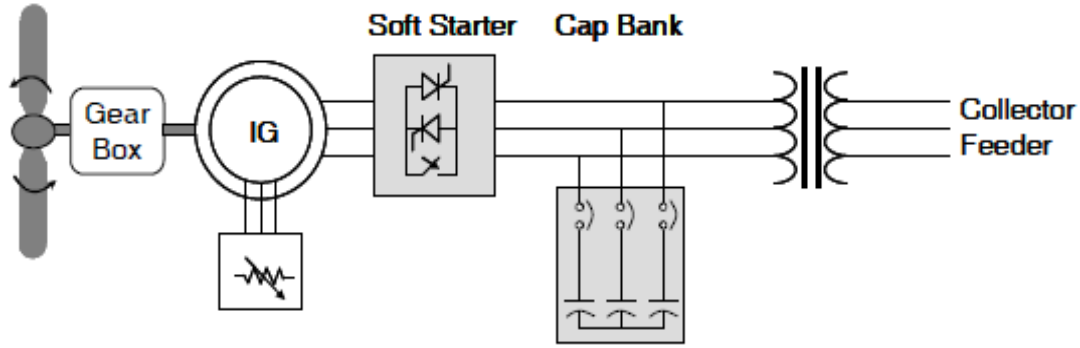
Typical Wind Farm Collector Substations



Typical Wind Turbine Generator Types

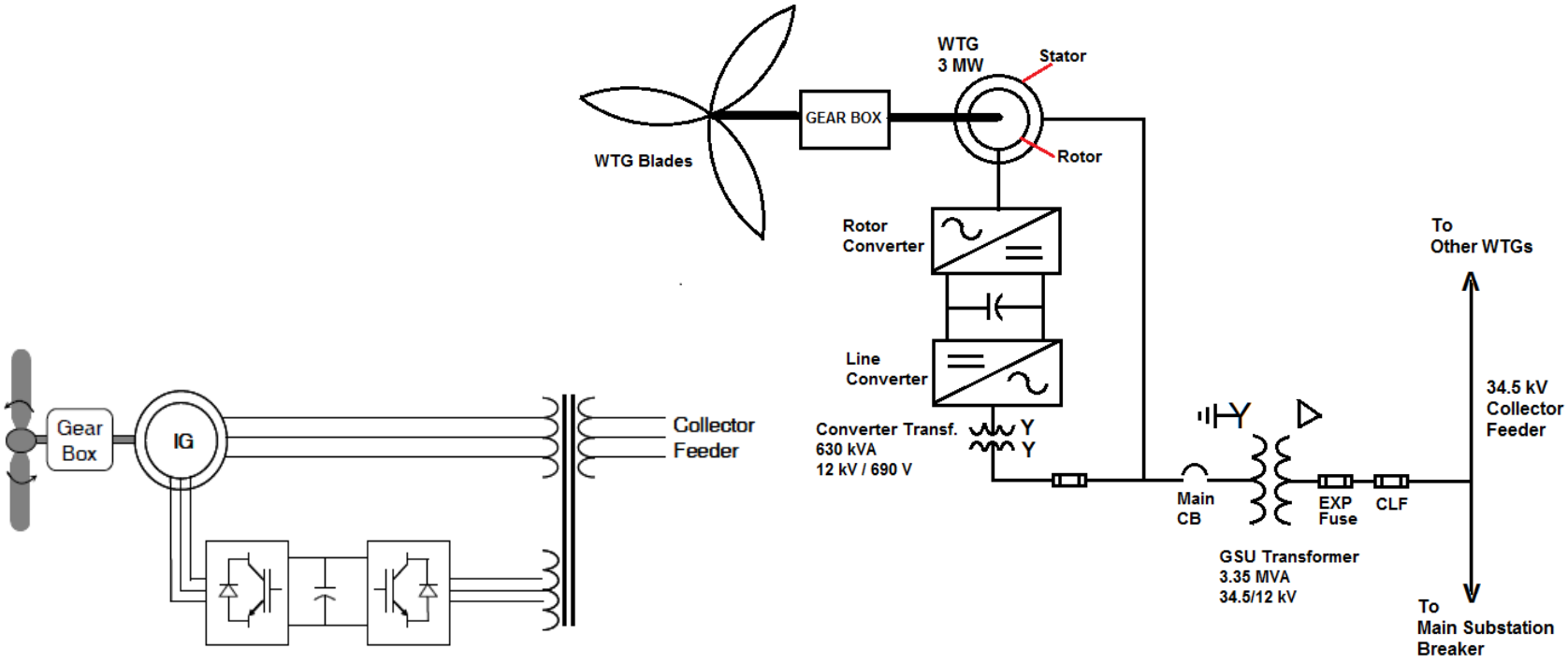


Type 1

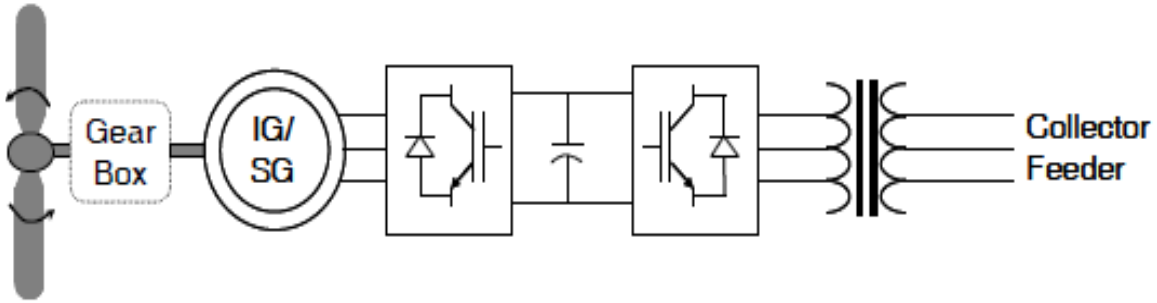


Type 2

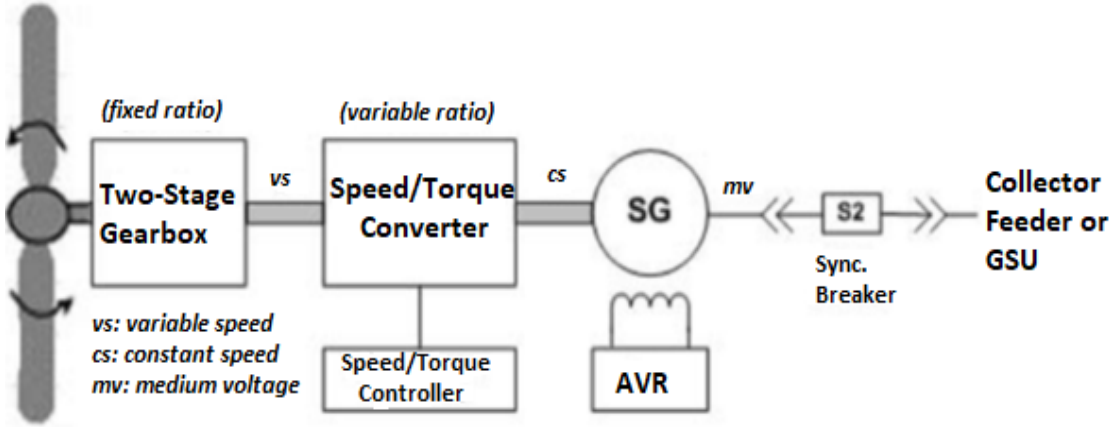
Type 3 Wind Turbine Generator Examples



Typical Wind Turbine Generator Types

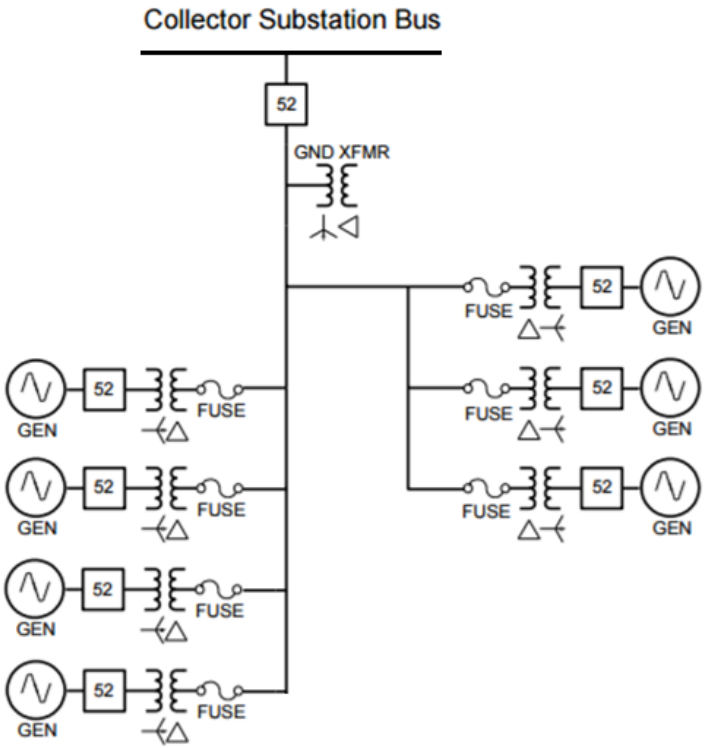


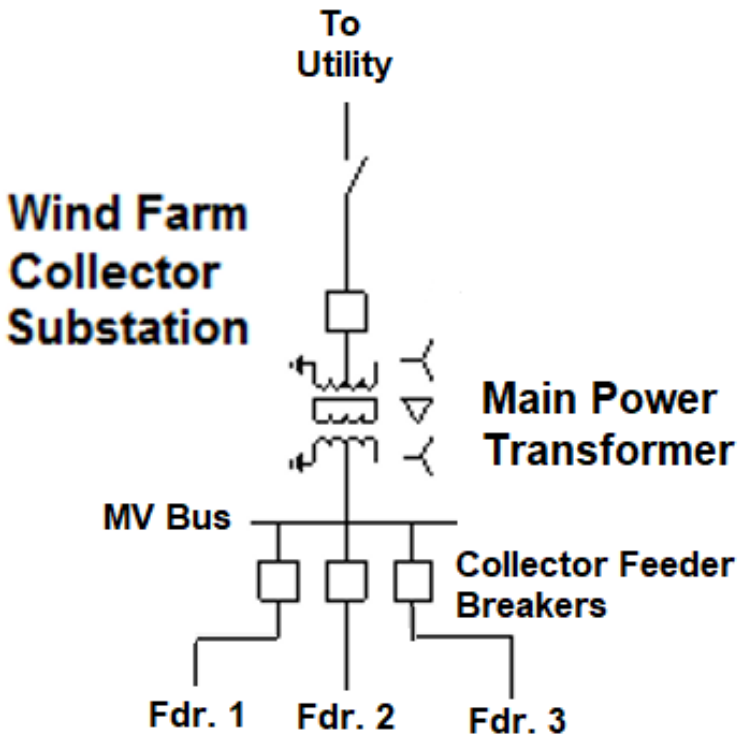
Type 4



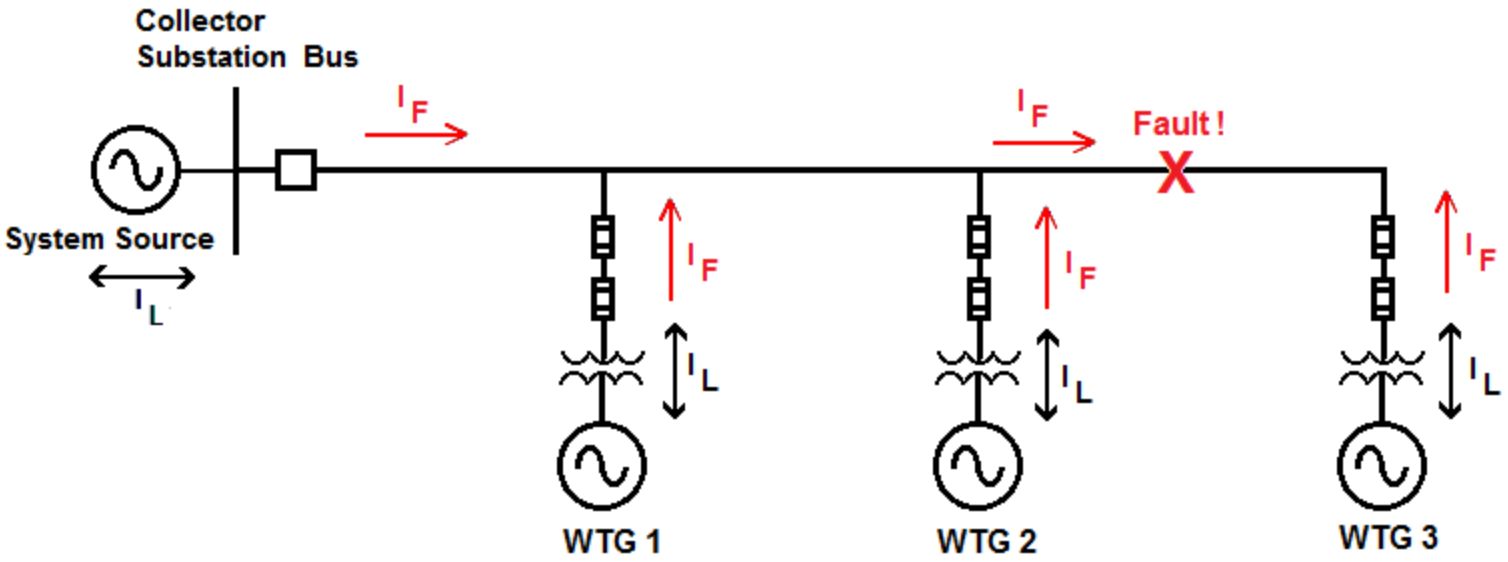
Type 5

Collector System Grounding





Collector feeders operate with both radial and network characteristics.



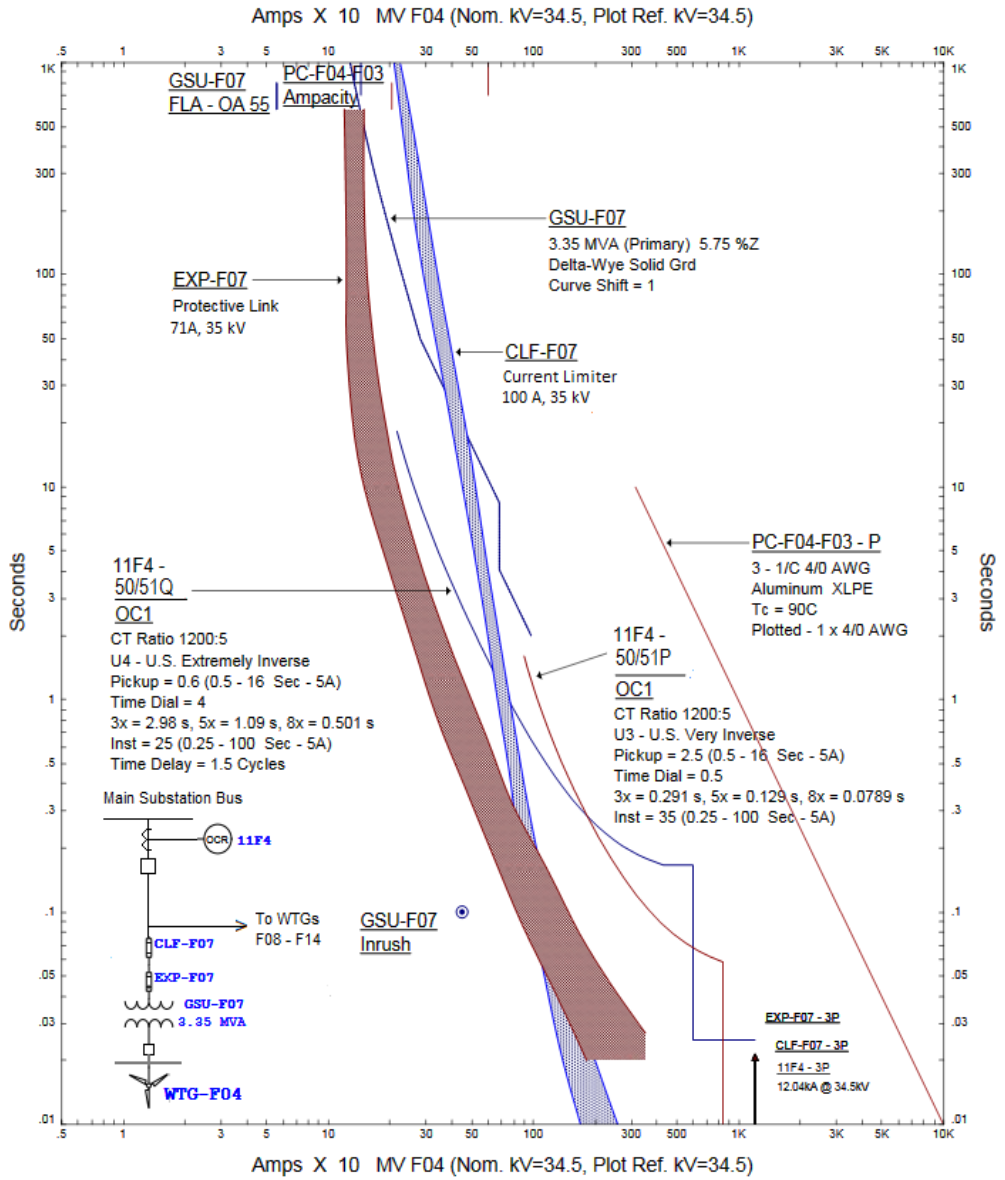
Commonly Used Collector Feeder Overcurrent Protection Schemes

1. Non-Directional Phase and Ground Overcurrent Protection
    1. Applicable when the system fault current is much greater than the combined output current of the WTGs.
    2. Trip current settings are well above normal load currents in both forward and reverse directions.
    3. Provides complete collector feeder protection but limited backup protection for individual WTG installations. Negative sequence elements can provide expanded backup protection.
2. Directional Phase and Ground Overcurrent Protection
    1. Forward direction is from the feeder breaker down the feeder to the WTGs.
    2. Relay trip current level can be set below combined WTG output current level.
    3. Provides complete collector feeder protection and expanded backup protection for individual WTG installations on the collector feeder.
    4. Can mis-operate under certain system load conditions.

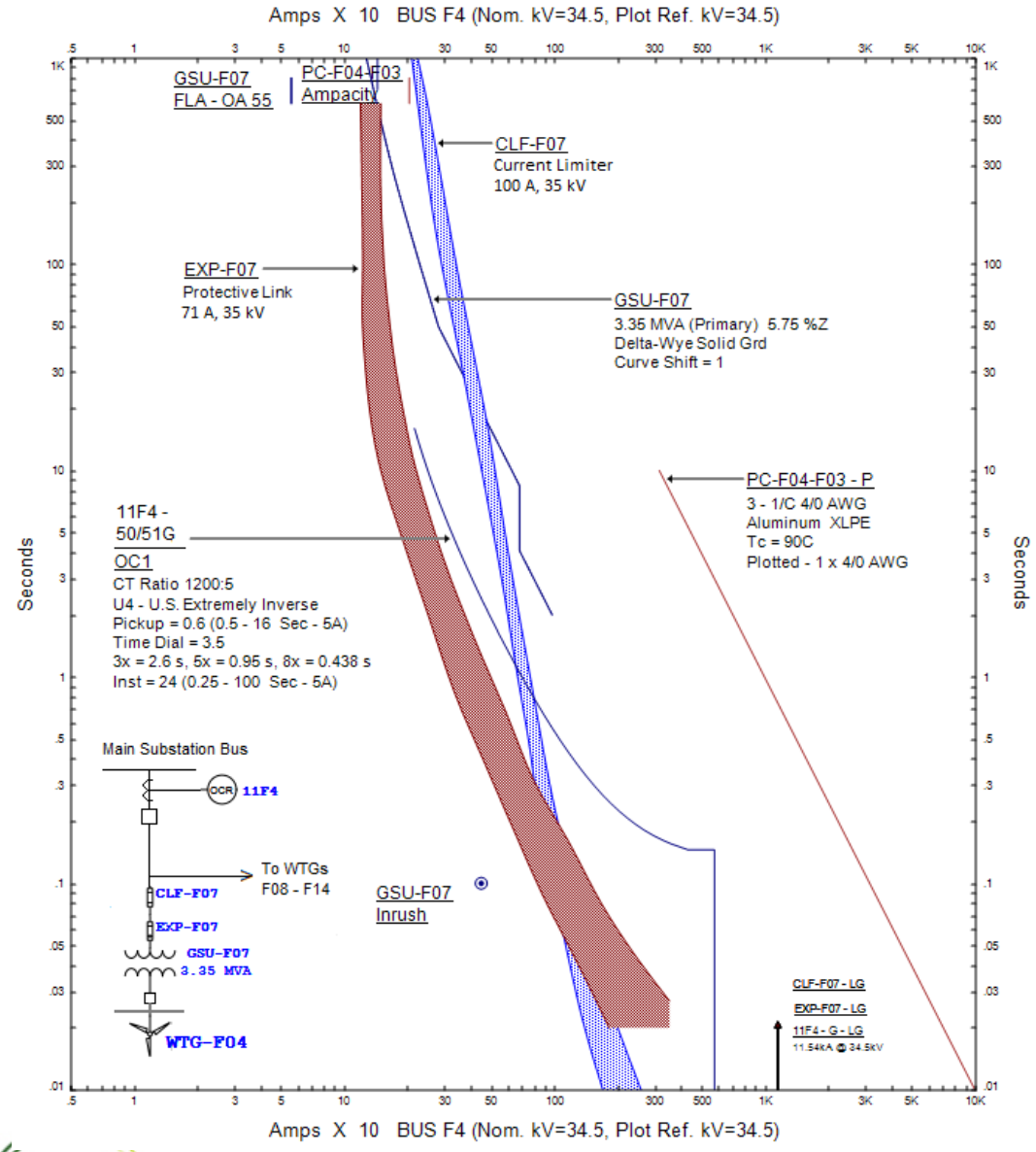
Overcurrent Protection Settings for Collector Feeders

Non-directional Overcurrent Relay Settings:

- **51P:** Pickup current setting may be established by regulating authorities such as NERC. Curve and time dial selected to coordinate with expulsion fuse at closest WTG GSU transformer.
- **50P:** Set pickup low enough to detect a 3-phase fault at the end of the feeder but high enough to avoid misoperation from combined GSU transformer inrush current.
- **51Q (If used):** Select desired 3-phase pickup current, curve, and time dial setting to coordinate with expulsion fuse at closest WTG GSU transformer. After coordination, use the desired 3-phase pickup current setting to calculate an equivalent I_2 or $3I_2$ pickup setting.
- **50Q (If used):** Select desired 3-phase pickup current to be low enough to detect a phase-phase fault at the end of the feeder but high enough to avoid misoperation from combined GSU transformer inrush current. Then use the desired 3-phase pickup current setting to calculate an equivalent I_2 or $3I_2$ pickup setting.
- **51G (51N):** Pickup current can be set to be 10-30% of 51P pickup but above the minimum current at which the GSU expulsion fuse begins to blow. Select curve and time to coordinate with the expulsion fuse.
- **50G (50N):** Set low enough to detect a single phase to ground fault at the end of the feeder but high enough to avoid misoperation from CT or system unbalance current when GSU transformers are energized.



Non-directional Phase and Negative Sequence TOC Coordination With WTG Fuses

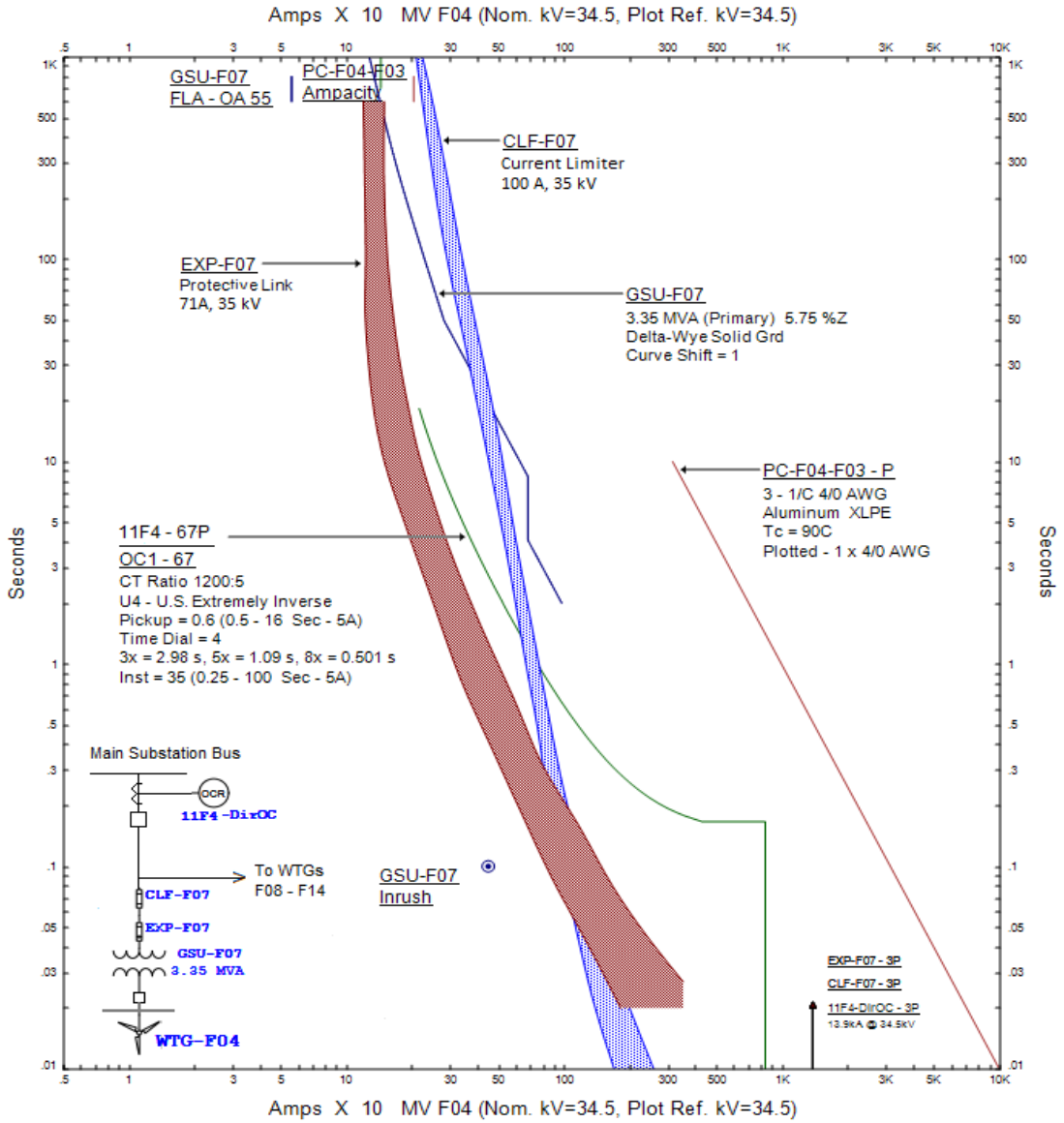


Non-directional Ground TOC Coordination With WTG Fuses

Overcurrent Protection Settings for Collector Feeders

Directional Overcurrent Relay Settings:

- **Phase Time Overcurrent 67PT:** Current pickup can be set below the collective WTG capacity of the collector feeder but above the minimum current at which the GSU expulsion fuse begins to blow. Select curve and time to coordinate with the expulsion fuse.
- **Phase Instantaneous Overcurrent 67PI:** Set pickup low enough to detect a 3-phase fault at the end of the feeder but high enough to avoid misoperation from combined GSU transformer inrush current.
- **Ground Time Overcurrent 67GT (67NT):** Can be set the same as 51G (51N).
- **Ground Instantaneous Overcurrent 67GI (67NI):** Can be set the same as 50G (50N).

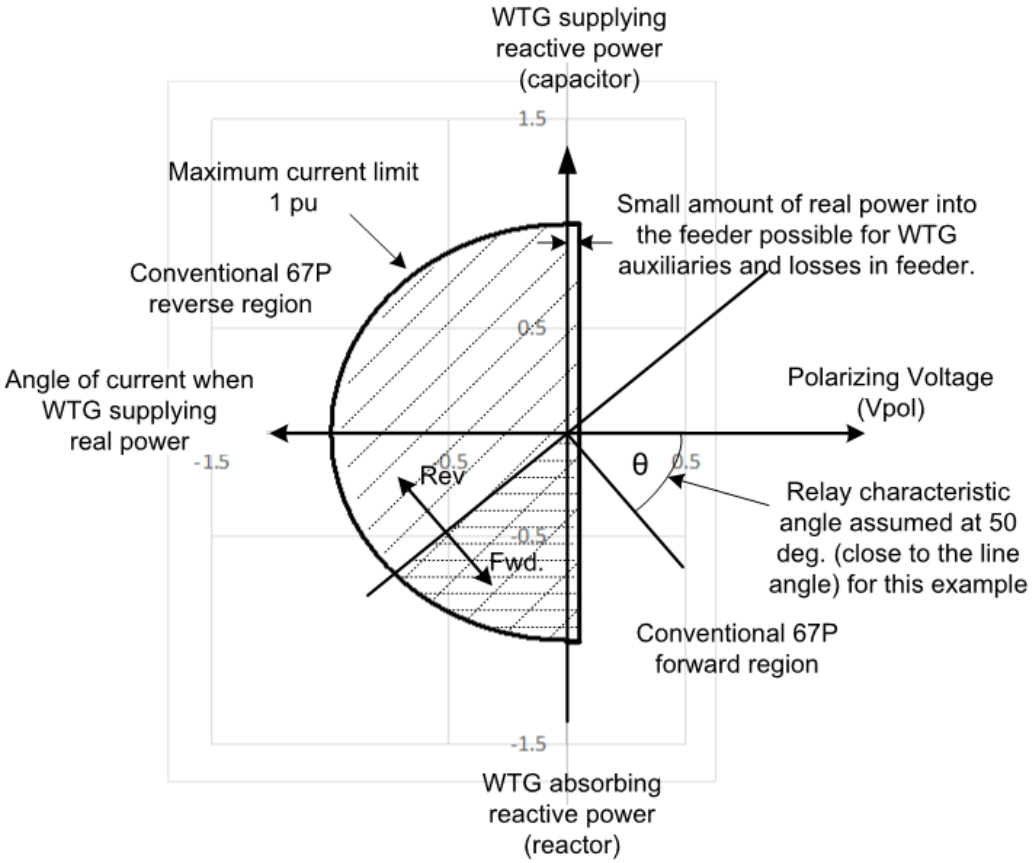


Directional Phase TOC Coordination With WTG Fuses

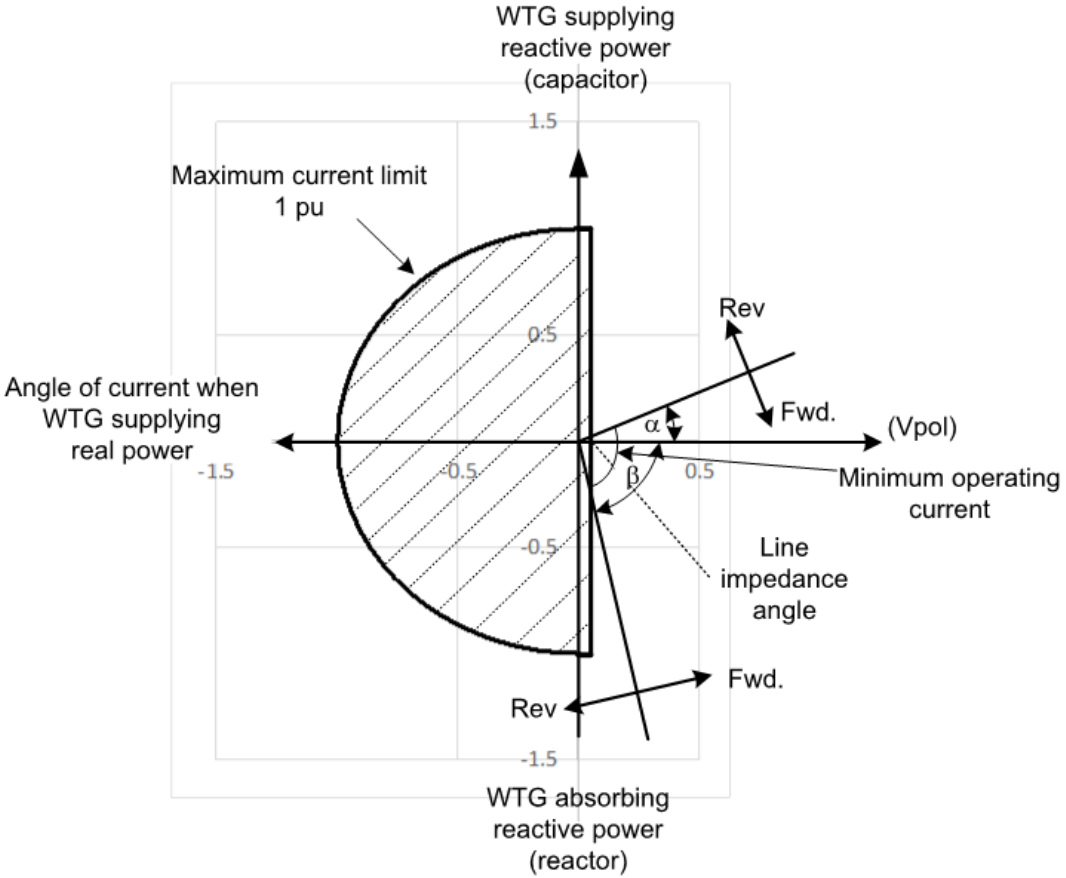
Directional Phase Overcurrent Protection

- Advantages:
  - Can be set below maximum collective WTG capacity to provide greater sensitivity than non-directional phase overcurrent protection.
  - Provides excellent coordination with WTG expulsion fuse and protects the smallest conductor at the end of the feeder.
- Disadvantages:
  - May require backup non-directional phase overcurrent elements to provide protection for the loss of polarizing voltage.
  - Directional supervision settings must be selected carefully to avoid potential mis-operation for changes in generator VAR outputs.

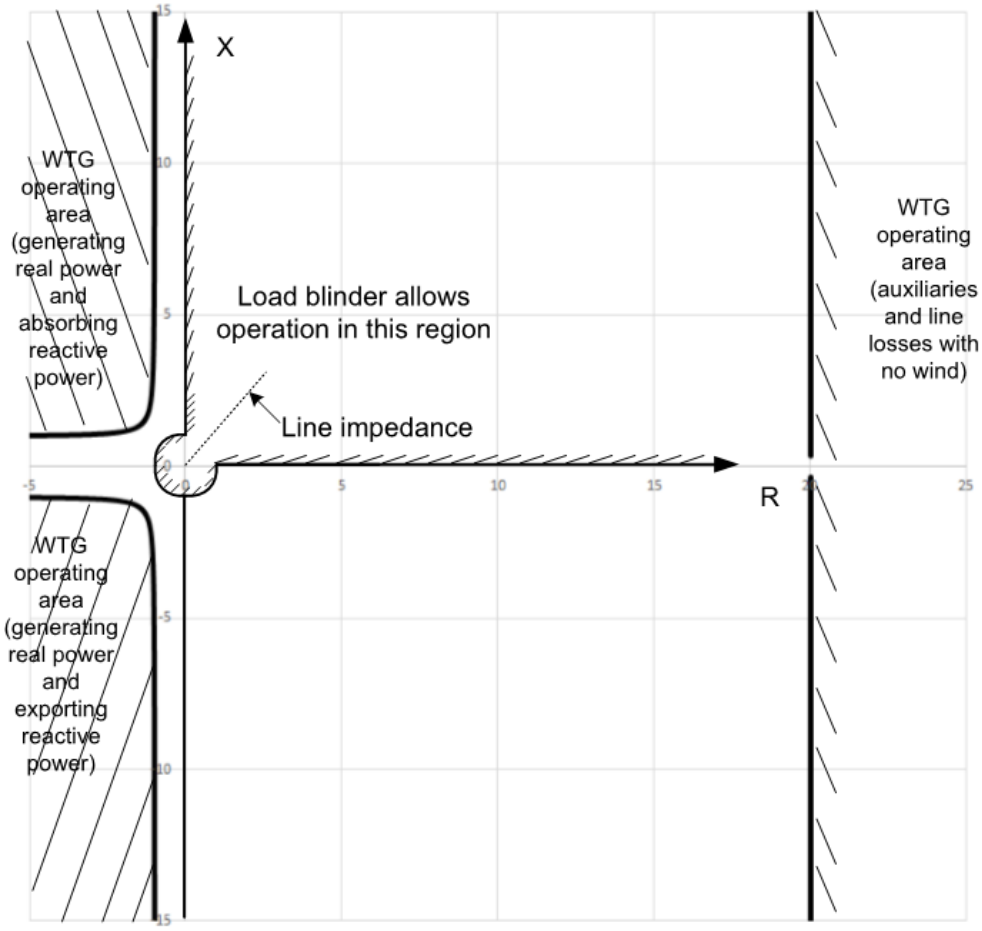
Conventional Phase Directional Element 67P Voltage and Current Phasor Diagram and Operating Region of Wind Generation



Phase Directional Element 67P With Adjustable Directional Blinders



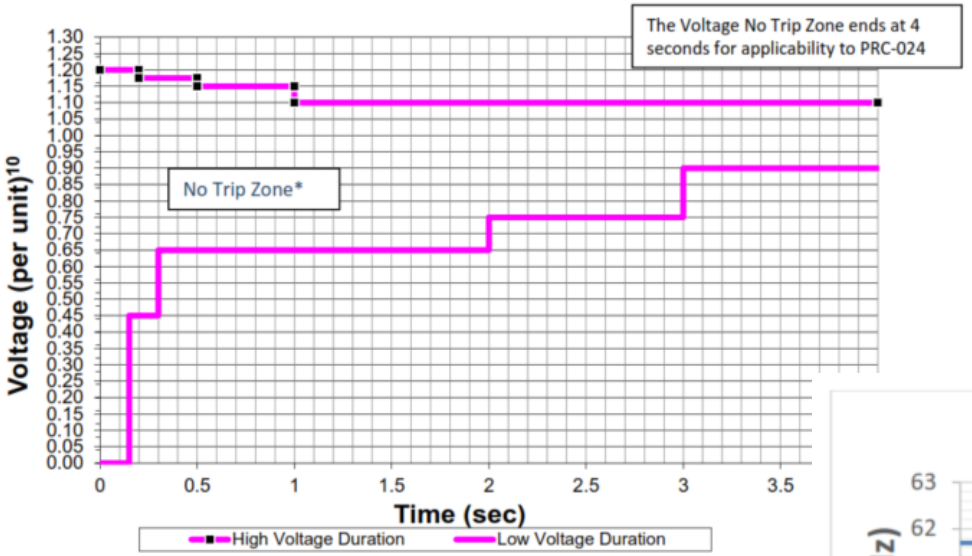
R-X Diagram Showing Normal Operating Regions of WTG and Example Positive Sequence Impedance Measuring Load Blinding Characteristic

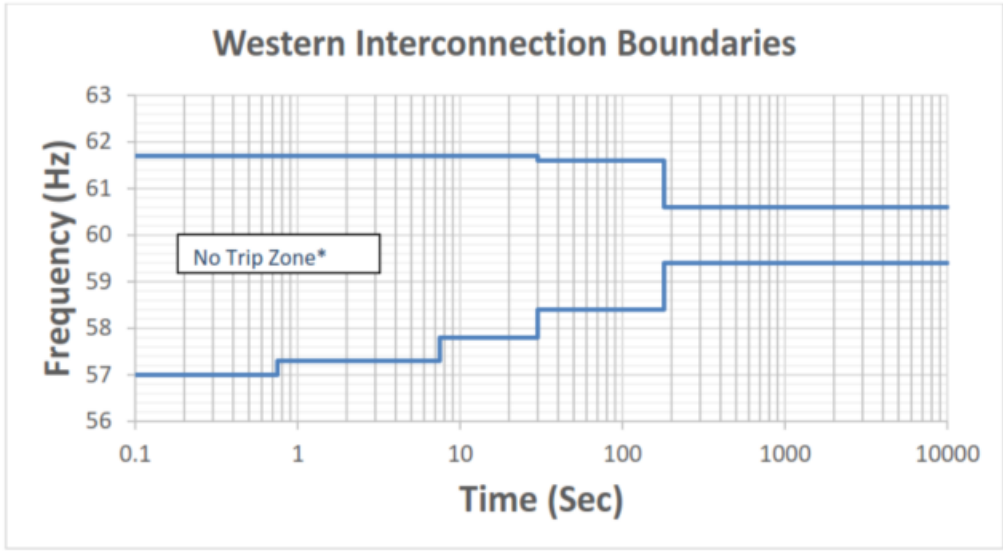


Voltage and Frequency Protection

PRC-024 — Attachment 2

(Voltage No-Trip Boundaries – Eastern, Western, and ERCOT Interconnections)

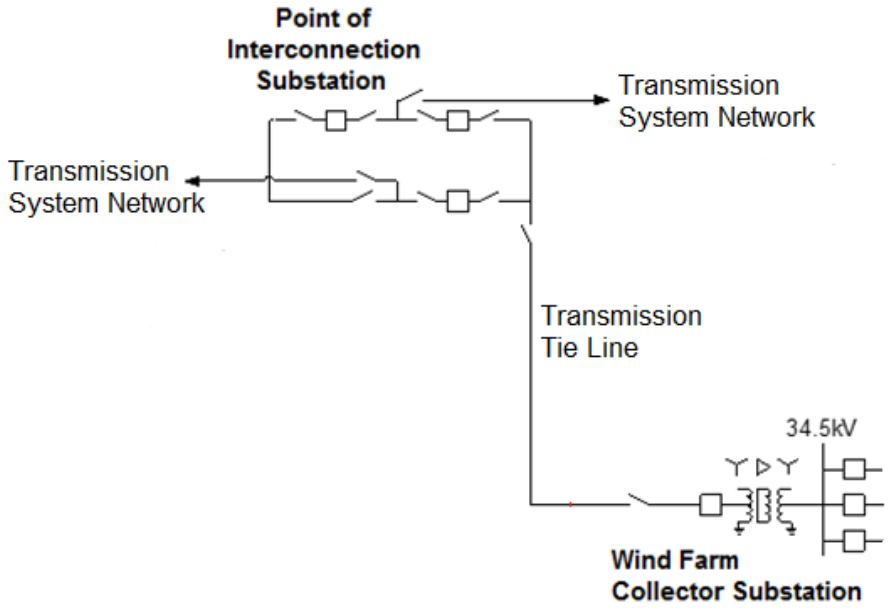




Transmission Tie Line Protection

Challenges for Transmission Line Protection

- Variability of source strength due to the variability of the wind.
- Low positive sequence fault current contribution from the wind farm.
- Little or no negative sequence fault current contribution from the wind farm.
- Zero sequence fault current contribution may or may not be present, depending on the wind farm transformer connection or operating status.



Possible Transmission Line Protection Solutions

- Line Differential
- Weak feed / echo trip logic for permissive overreaching transfer trip schemes
- Direct transfer trip
- Backup time delayed undervoltage (or overvoltage) protection
- Voltage supervision of breaker closure

Conclusions

- This report was intended to provide guidance to the protection engineer on present relay protection and coordination practices at wind power plants.
- The protection of wind electric plants can be unique and challenging due to the following:
  - Wind power plants are typically composed of numerous relatively small wind turbine generators (WTG) distributed geographically over a wide area.
  - The WTGs predominantly in service have some degree of inverter interface affecting the fault current levels and characteristics.
  - Substation electrical layouts and grounding options depend on the WTG connection to the collector feeder system and on the wind power plant connection to the utility's power grid.
  - Applicable regulatory requirements, such as low-voltage ride through (LVRT), may be required to enable the wind power plant to assist the grid during contingencies and maintain adequate power quality.
- The report provided an overview of the protection systems that have been successfully applied to wind power plants based on their unique electrical and operating characteristics.
- The report also presented some general engineering considerations for setting the protection elements assigned to wind power plant equipment.

Questions?