Protection of Distribution Grid with DER and IEEE 1547.2 2023 Protection Guidance

Introduction

IEEE1547-2018 specifies requirements for DER to meet the challenges of high DER penetration.

Protection engineers need to recognize coordination of distribution schemes to support integration of DER.

Protection engineers must understand the need to consider ride-through.

This presentation is based on the guidance provided in IEEE1547.2-2023.

Protection Coordination

The protective devices' settings should be designed to properly differentiate local faults from system disturbances on the bulk power system so that the necessary resources do not get tripped offline prematurely adversely affecting the reliability of the bulk power system.

Increase in fault current due to high penetration of DERs on a feeder may cause fault current contribution decrease from the feeder breaker resulting in desensitization of upstream protective devices.

Desensitization can cause coordination problem and results in protective devices failure to trip or sequentially trip for faults within their zones of protection.

For DERs to operate in parallel with the area distribution system, proper coordination of all primary and backup protective devices must be ensured.

Short Circuit

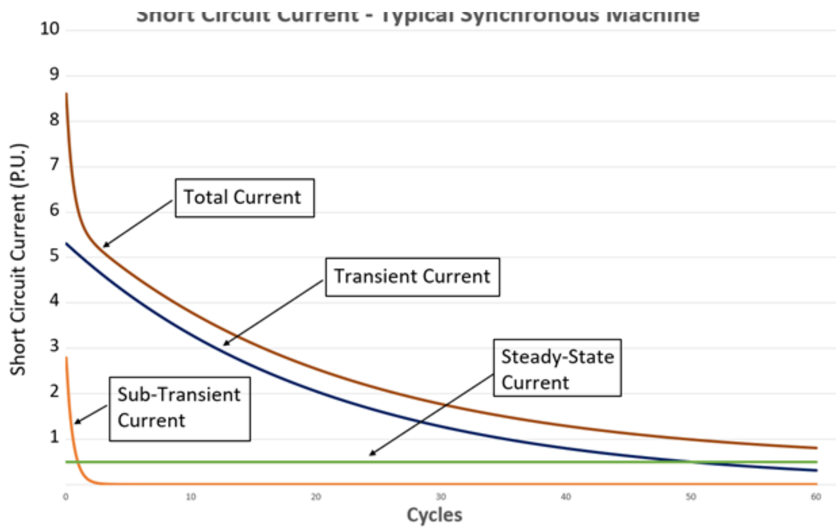
Short Circuit Considerations

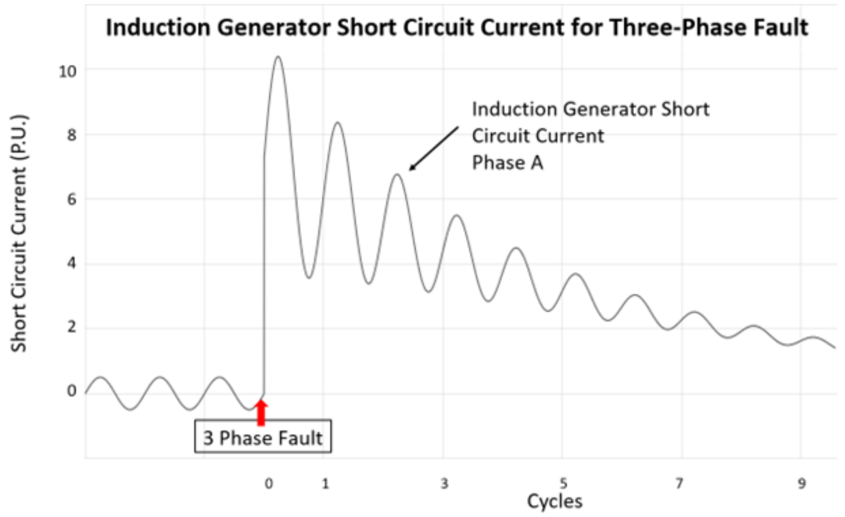
- The addition of DER to any feeder can have a substantial effect on short circuit values and their effect on protection systems

- Ground fault currents are of particular concern
  - They are common
  - Affect protection systems
  - DER may provide additional ground sources → Desensitization of protection systems.

Inverters and Short Circuits

- Modern inverters typically produce short current in the range of 100% to 120% of full load current.
- Short Circuit current can be maintained indefinitely.





Short Circuit

Rotating Machines and Short Circuits

Synchronous Machines

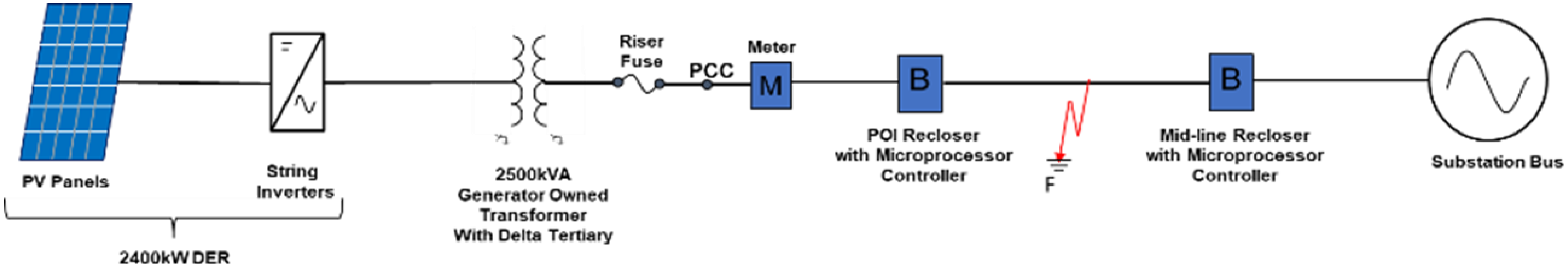
- 5 to 8 times full load current
- Decaying fault level over 60 cycles or more.

Induction Machines

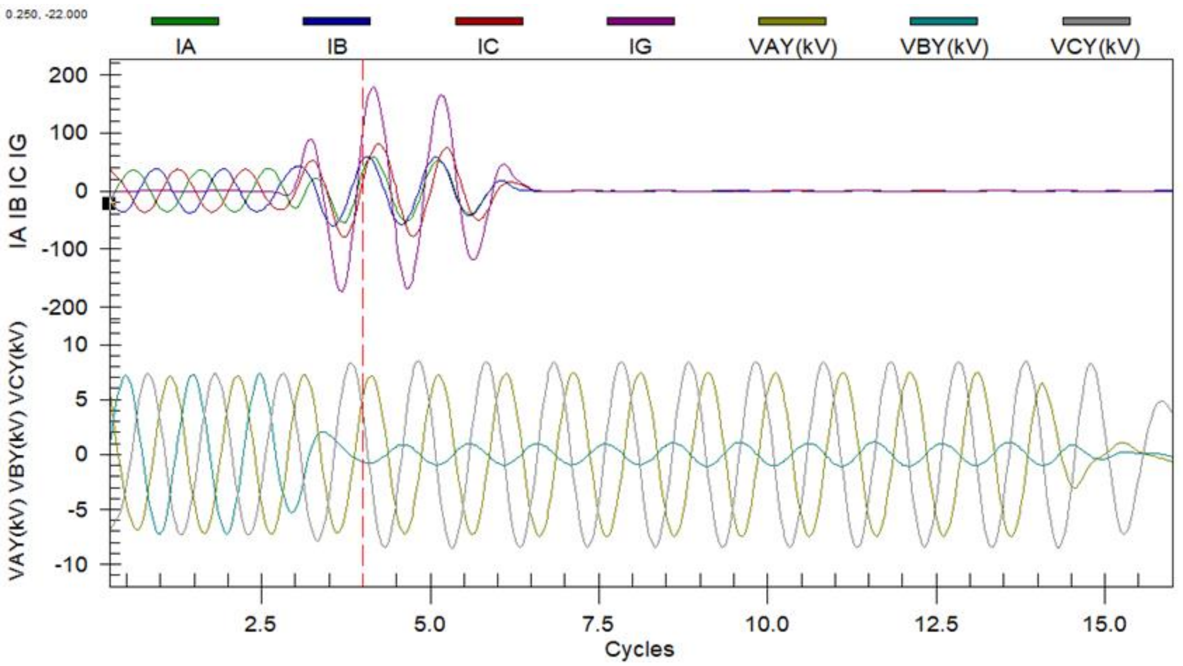
- 5 to the times full load current initially
- Decaying fault level over up to 12 cycles
- Little effect on grid and equipment

Configuration of Interconnection System-Transformer

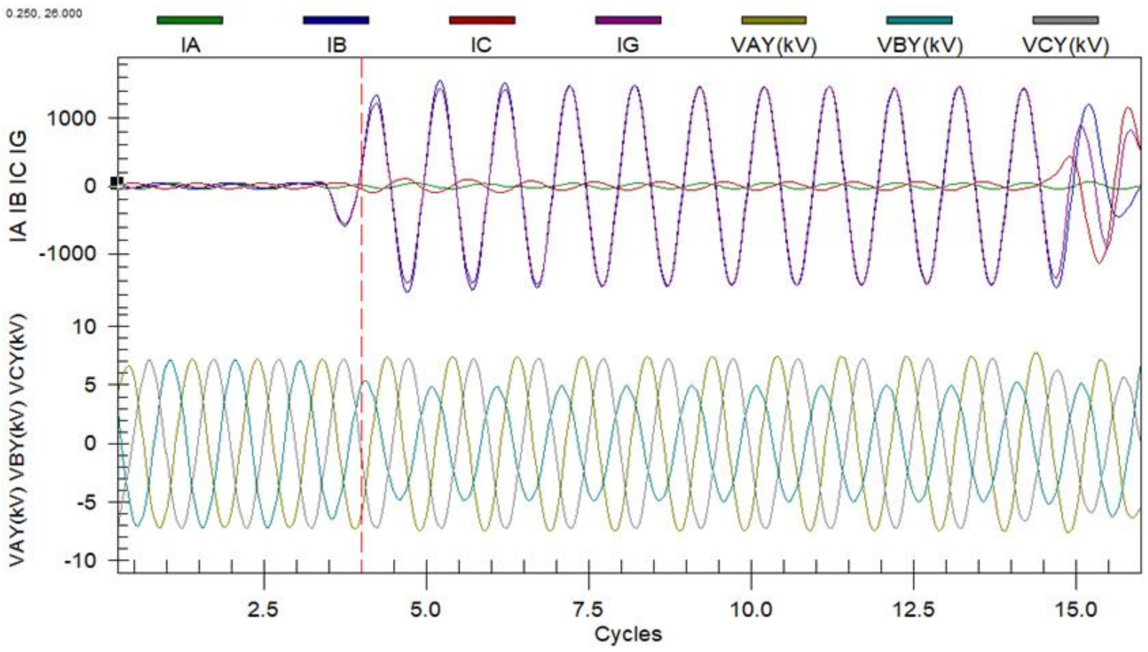
- Common Transformer Configurations used with DERs:
  - Yg – Delta, Yg – Yg, Yg – Y, etc.
  - Most central inverter based DERs, and BESS may require Yg – Delta or Yg - Y
- Transformer Impacts
  - Delta/Wye grounded transformers are ground current sources during ground fault. They are ground sources even when the DER is not generating.
  - Ground sources affect current distribution and adversely impact protection coordination upstream.



Configuration of Interconnection System-Transformer



Ground fault current contribution from a DER with delta - Yg intertie transformer



Ground fault current contribution from the Grid side to the same fault

Open-Phase Conditions

Causes of Open-Phase Condition

- Broken conductor, blown fuse, single phase recloser operation

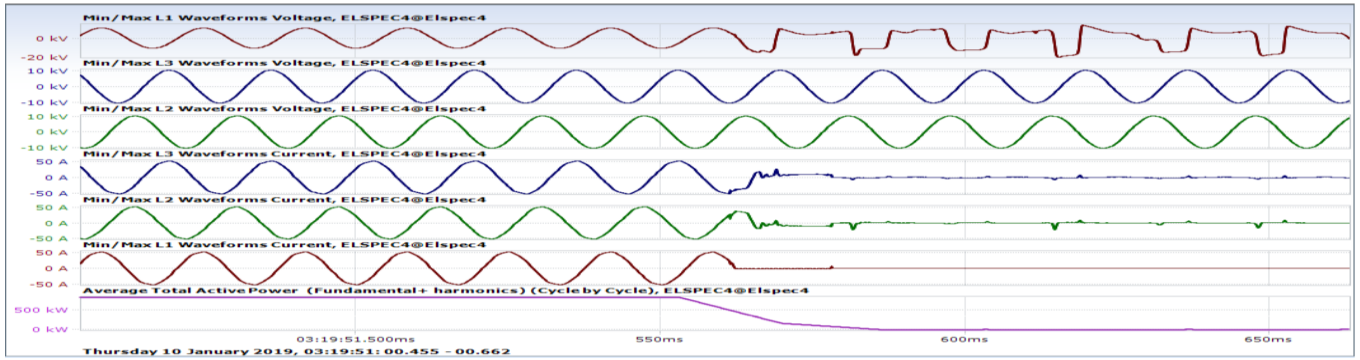
Challenges of detecting Open Phase Condition

- Transformer that involves Delta winding on the bus the DER is connected to (3-legged and some 5-legged transformers have the potential to regenerate the missing phase as well)
- Incorrect DER or relay settings

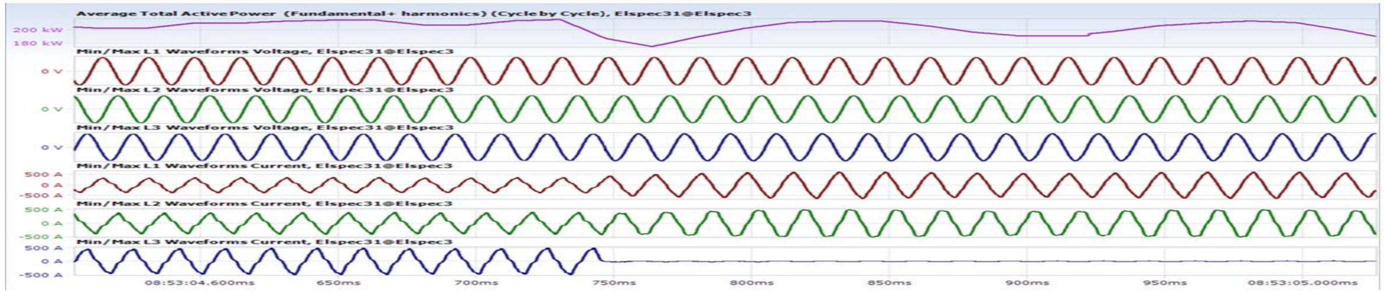
Impact of undetected Open-Phase Condition

- Single or double phasing of three-phase loads on the same feeder the DER is on and potentially damaging customers' equipment.

Open-Phase Conditions



DER response to open phase “A” at the PCC when connected via delta – Yg grounded intertie transformer (Current, Voltage and Power waveform capture)



DER response to open phase “C” at the PCC when connected via Yg – Yg grounded intertie transformer (Current, Voltage and Power waveform capture)

Coordination with Ride-Through

IEEE 1547-2018 requires both voltage ride-through and frequency ride-through in response to disturbances on the Area EPS that are not occurring on the feeder or section of the feeder the DER is connected to.

The setting of a PCC device (recloser) needs to coordinate with the ride through requirements. Failure to coordinate may result in widespread tripping of DER, possibly leading to system stability issues.

The feeder breaker settings typically do not interfere with ride-through.

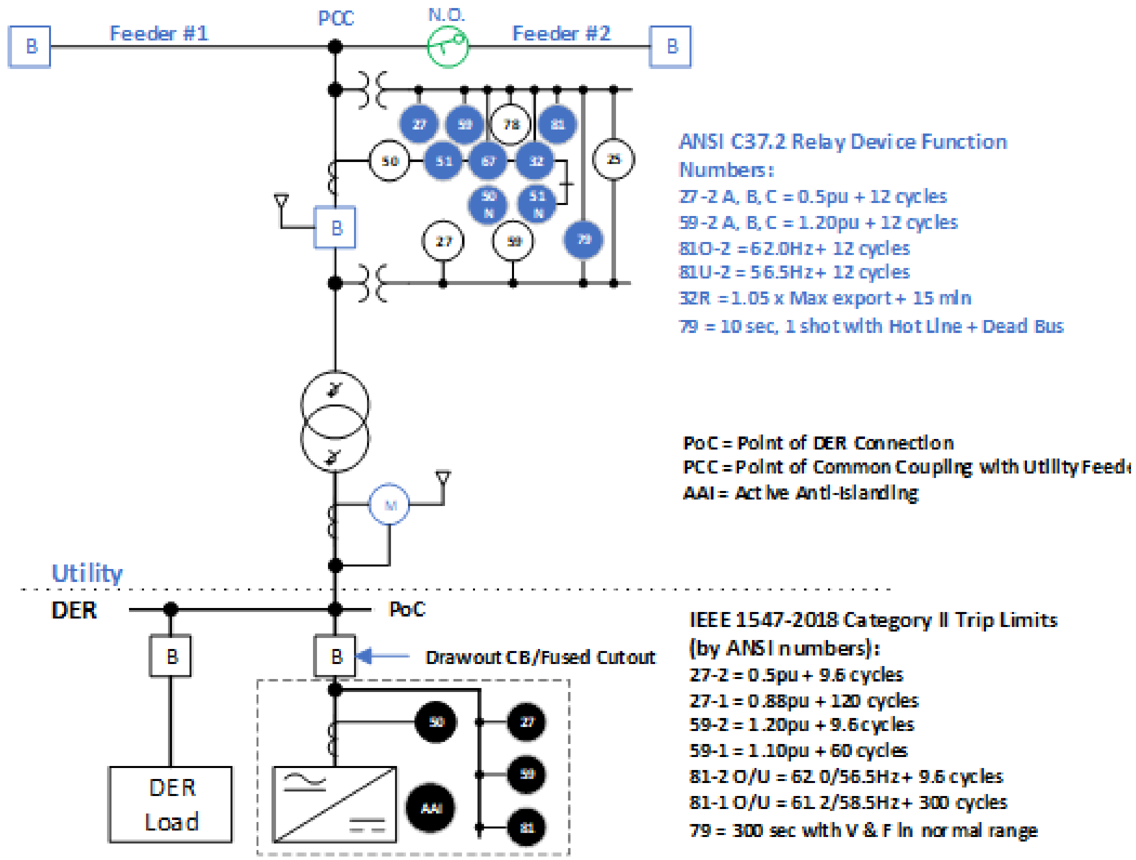
IEEE1547.2-2023 Ride Through Protection Guidance

Voltage and Frequency-IEEE1547-2018 has trip settings for the DER that coordinate with ride through. Setting PCC devices wider than the DER settings will not impede ride through.

Loadshedding-Determine if the level of DER on the feeder can help during loadshedding events and if is it appropriate to disable load shedding on the feeder.

Overcurrent-Phase and ground overcurrent (50/51) have little impact on ride-through. Negative sequence overcurrent (46) should be avoided, coordination with ride through is difficult. Voltage time overcurrent (51V) are not recommended for use with ride through.

PCC Recloser



Where do utilities use PCC Reclosers

- On DER ≥ 1MW or if interconnection transformer is a ground source

Why do utilities use PCC Reclosers

- Temporary settings to support hotline work
- Control over the DER during abnormal operating conditions
- Provide backup protection
- Implement DTT tripping

When the level of generation, at any load level, may cause the Area EPS to operate outside normal operating conditions under normal Area EPS configuration, it is considered high penetration. High penetration can be experienced by a line section, feeder or substation.

Overvoltages, reverse power flow and unintentional islands are common issues caused by high penetration that may result in the Area EPS operating outside normal operating parameters.

High Penetration

Islanding

Unintentional islanding events present significant risks to the safety, reliability, and adherence to frequency and voltage standards in electrical power systems.

Islanding Detection Techniques:

Passive Methods: Passive islanding detection techniques involve monitoring DER voltage, frequency, or vector parameters. These methods are relatively simple but may have non-detection zones, where islanding events go undetected.

Active Methods: Active islanding detection techniques use more complex mechanisms to detect islanding events. They are less affected by load-to-generation ratios but can interact in intricate ways with the power system, potentially leading to sustained unintentional islands if not properly implemented.

LROV

LROV is generally a balanced overvoltage phenomena with primarily positive sequence components and is dependent on the generation to load ratio.

- **Grid-following Inverter-Based Resources (IBRs)**: Operate as regulated constant current sources, maintaining a steady current injection regardless of changes in terminal voltage.
- **Response to Load Disconnection**: Following a sudden load disconnection, IBR maintain a constant current output until protective elements act to force a momentary cessation or trip.

Short-Circuit Ratio Change: During this transient period the short-circuit ratio (SCR) changes even as the IBR continues to regulate its current output.

Voltage Rise (Load Rejection Overvoltage - LROV): The sudden increase in source impedance following a load disconnection can lead to the phenomenon, known as Load Rejection Overvoltage (LROV) which cause rapid voltage rise at the IBR terminals.

GFOV

GFOV is a primarily an unbalanced overvoltage phenomena with positive, negative and zero sequence components.

Concern during Ground Faults Occur During Islanding: During islanding, the presence of DERs can compromise system grounding and potentially lead to overvoltage on unfaulted phases during ground faults.

Impact of DER Characteristics: IBR have unique characteristics such as high impedance and a lack of a traditional ground source which make traditional approaches to overvoltage protection less applicable.

Limiting GFOV Duration: Overvoltage protection mechanisms in IBR are typically designed to limit the duration of GFOV during islanded conditions.

Nature of GFOV: GFOV is described as an unbalanced overvoltage condition. Unlike Load Rejection Overvoltage (LROV), which can occur regardless of grounding, GFOV is influenced by the type of system grounding during a ground fault.

Effectiveness of Grounding: Proper grounding is effective in mitigating GFOV, but may not affect the positive- and negative-sequence components of LROV.

GFOV Mitigation Strategies

Grounding Considerations: Proper grounding for mitigating GFOV includes considering the role of grounded loads and ensuring effective grounding through connected loads.

DER Control Tuning: Adjusting the control settings of the DER can help mitigate GFOV by optimizing their response to fault conditions.

Protection Relays: Protective relays such as 59N (Ground Overvoltage Element) or "3V0" protection detect zero-sequence voltage and are specifically designed to protect against GFOV.

Line-Neutral Connected Load: Ensuring the availability of sufficient line-neutral connected load can also help mitigate GFOV by providing a path for fault currents.

Transformer Winding Configurations: Transformer winding configurations may impact the ability to mitigate GFOV if they do not accurately indicate primary line-neutral voltages.

LROV Mitigation Strategies

Faster Tripping Times: Implementing faster tripping times can help mitigate LROV by quickly disconnecting or isolating the affected equipment.

Transfer Trip Mechanisms: Transfer trip mechanisms can be employed to initiate trips or disconnections in response to LROV, helping to prevent or minimize overvoltage conditions.

Consideration of Side Effects: When implementing overvoltage mitigation strategies, it's crucial to consider potential side effects and ensure that the chosen approach does not inadvertently cause other issues in the system.

Reverse Power Flow

When generation exceeds the available load in a section of the feeder, feeder head or at the substation transformer level, feeders experience reverse power flow.

Reverse power flow impacts how protection schemes are implemented and work on affected feeders and substations.

DERs on impacted feeders may not be able to see phase-ground faults on the transmission line passed the substation’s delta - Yg transformer.

Such a situation may need a combination of 3V0 to detect the fault and DTT to isolate the DER.

Guidance for High Penetration

To manage the challenges associated with high penetration of Distributed Energy Resources (DERs), several protection mitigation methods are being explored:

- **Direct Transfer Trip (DTT)**
- **Distribution Power Line Conducted Permissive Signal (DPLCPS)**
- **Wide Area Protection Using Synchrophasor Data**
- **Other Protection Schemes: (Utility grounding switches and capacitor switching)**
- **Reclose Blocking**
- **3V0 (59N) Protection**

Conclusion

In this presentation and paper is discussed:

•Improved practices to protect the distribution grid in coordination with bulk power system reliability needs.

•Minimal requirements for high DER penetration.

•The specific behavior of inverter based to faults.

•Protection methodologies for several protection issues.

By embracing the coordination needs of DER:

> *Protection engineers can reduce technical barriers to the ongoing transformation of modern power systems.*

IEEE 1547.2-2023 provides further guidance