Protection Issues and Solutions for Protecting Feeder with Distributed Generation

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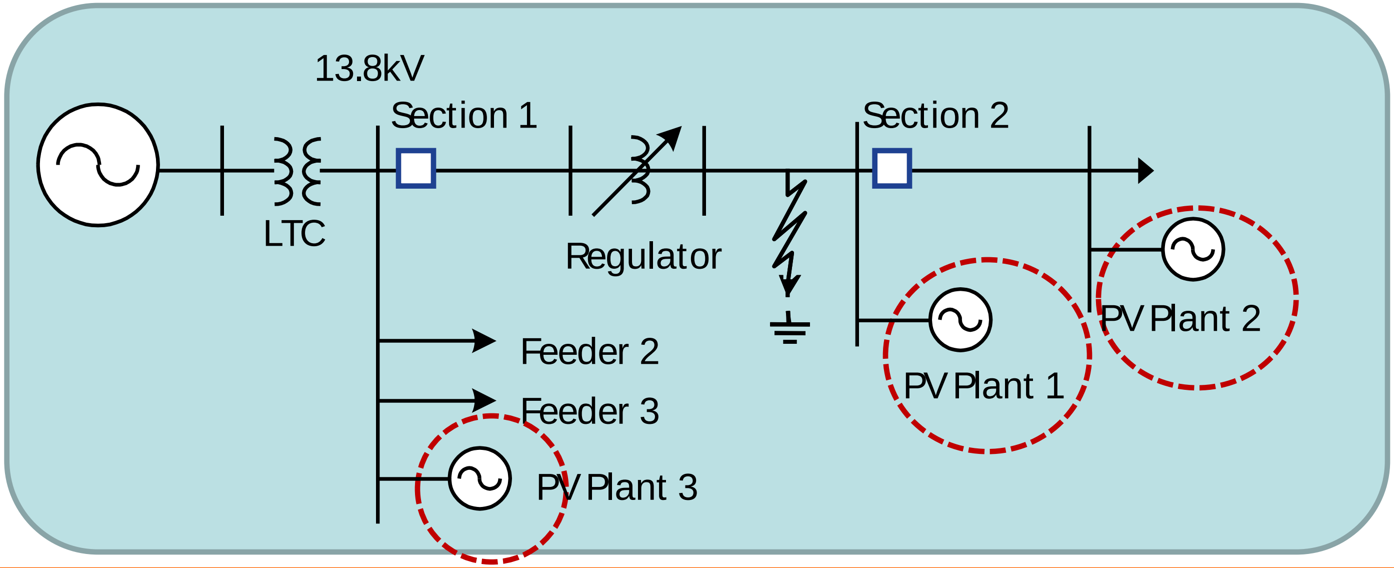
imagination at work

Outline

- Overview of Impact of Distributed Generation (DG) on Feeder Protection
- Inverter-Interfaced DG
  - Voltage vs. Current Control Scheme
  - Fault Current RMS Profile
  - DG Protection – Tripping time
- Case Study – Hardware in the Loop (HIL) Test
- Possible Solutions
  - Adaptive overcurrent protection
  - Distance and directional comparison
  - Partial differential protection

Overview of the Impact

Distribution Feeder with DGs Connected



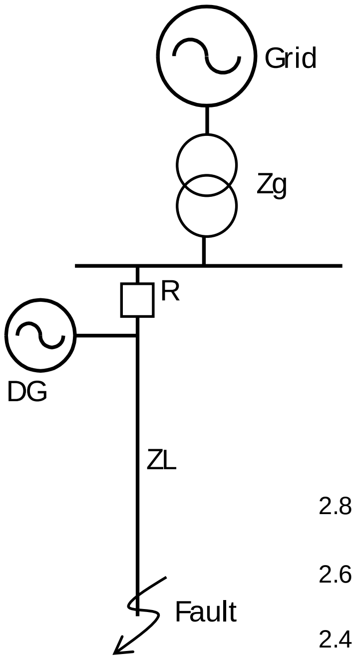
- **Bi-directional fault current**
  (multiple sources feed a fault)
- **Increased / decreased fault current**
- **Constantly changing fault levels**

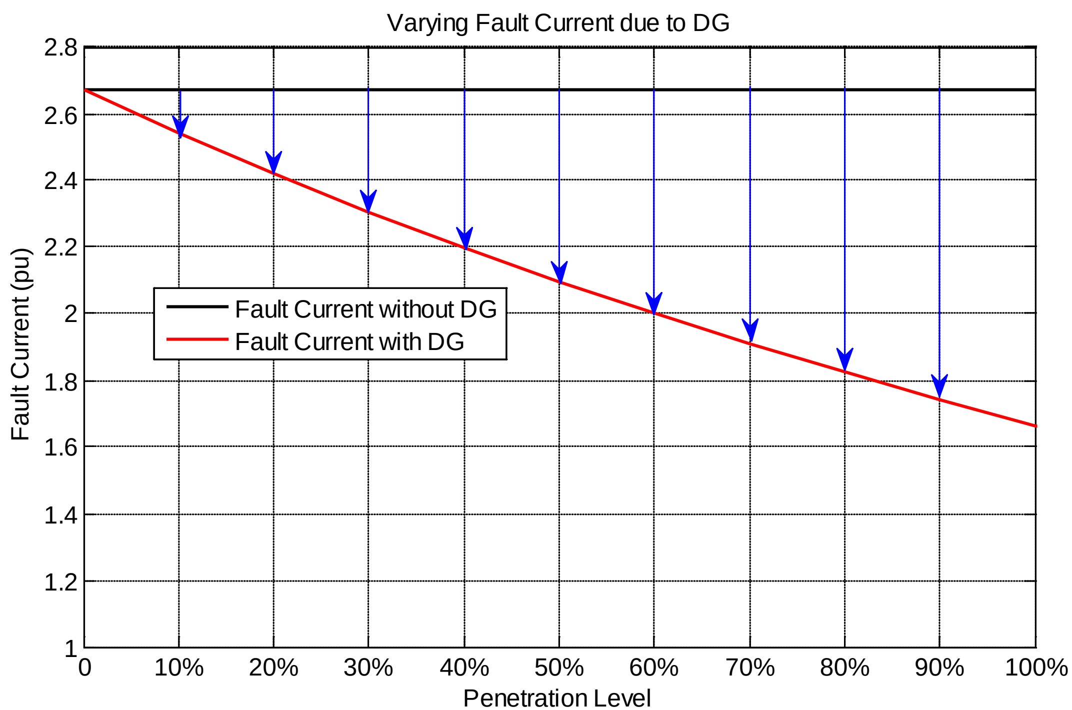
(connection status of DG is highly variable)

Conventional protection can be difficult to properly coordinate

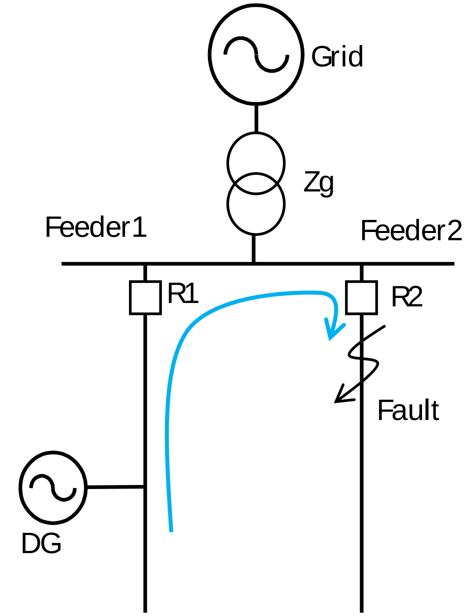
Overview of the Impact

Blinding of Protection



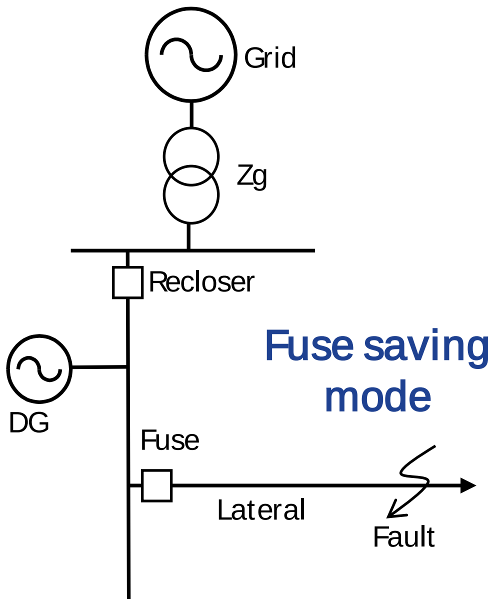


Loss of directionality



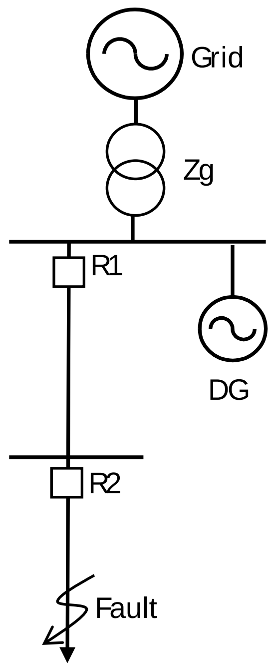
Overview of the Impact

Miscoordination (recloser - fuse)

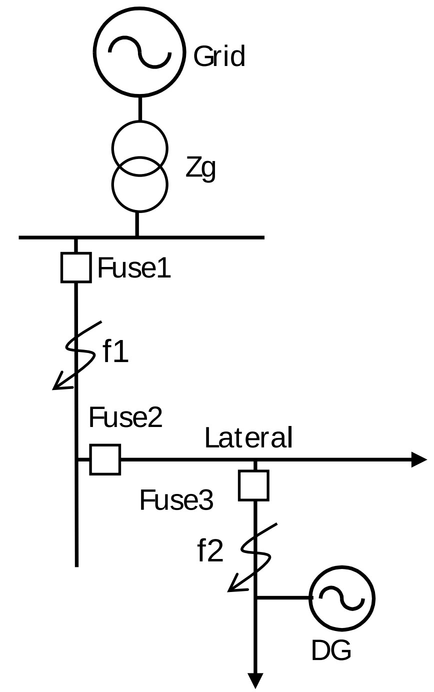


Fuse saving mode

Miscoordination (recloser - recloser)



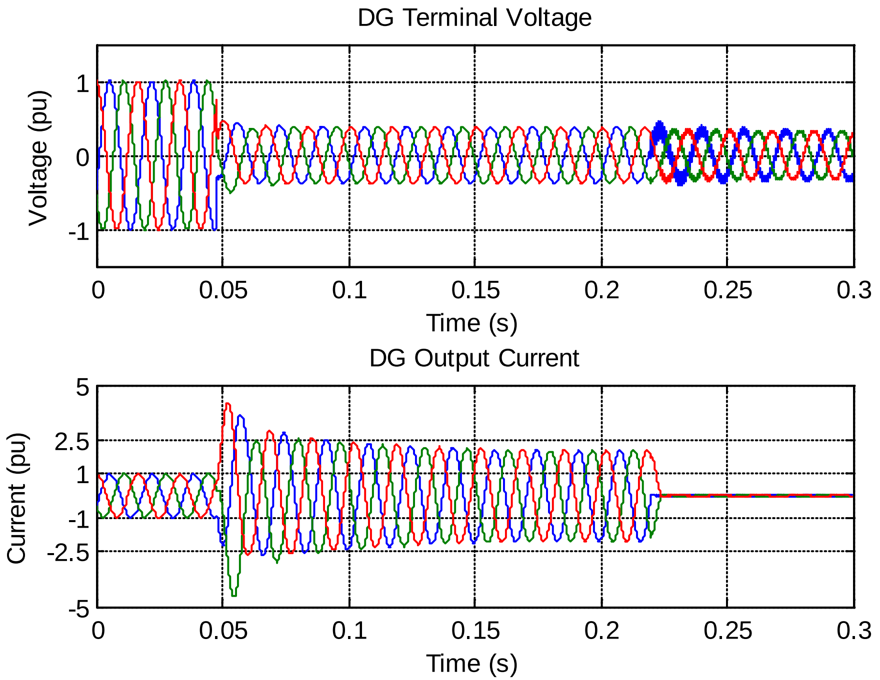
Miscoordination (fuse- fuse)



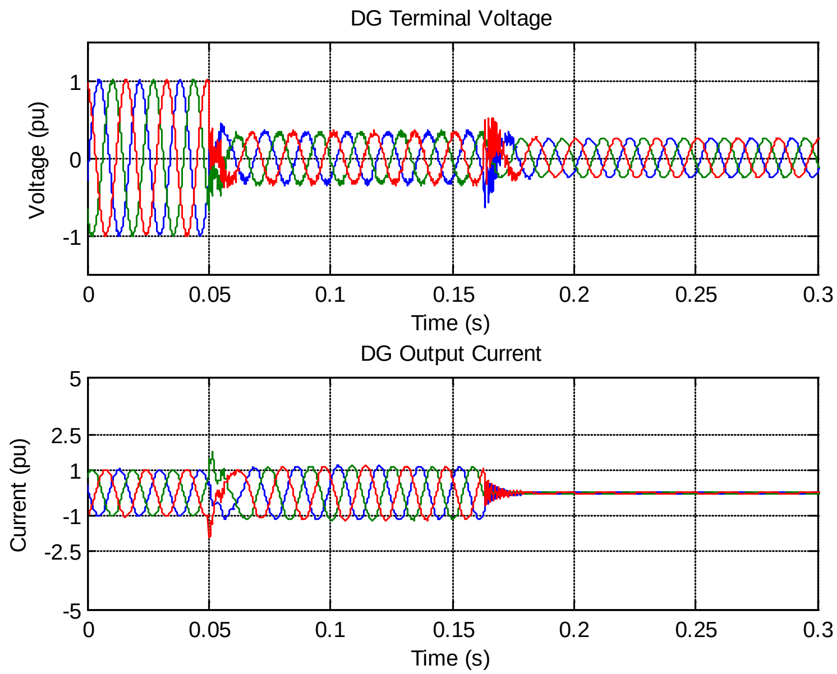
Factors Affecting the Impact

- **Features of DG**
  - Types of DG (conventional or IIDG)
  - Impedance / control and protection of DG
  - Grounding and interface transformer
- **Integration of DG**
  - Locations of DG on the feeder
  - Penetration level
- **System being integrated to**
  - Configuration and impedance of feeder
  - The existing protection of feeder

Conventional Generator vs. IIDG



(A) Synchronous generator



(B) IIDG

- Much less thermal fuse duty (I^2*t) with IIDG
- Rather high sub-transient and transient current with synchronous DG; IIDG settles down almost instantly

Fault Behavior of IIDG

- **Hard to predict using a generalized IIDG model**

  - Mainly determined by control

  - Individual designer has own preference

  - Non-linearities in both control and hardware protection

- **Hard boundaries constrain IIDG design**

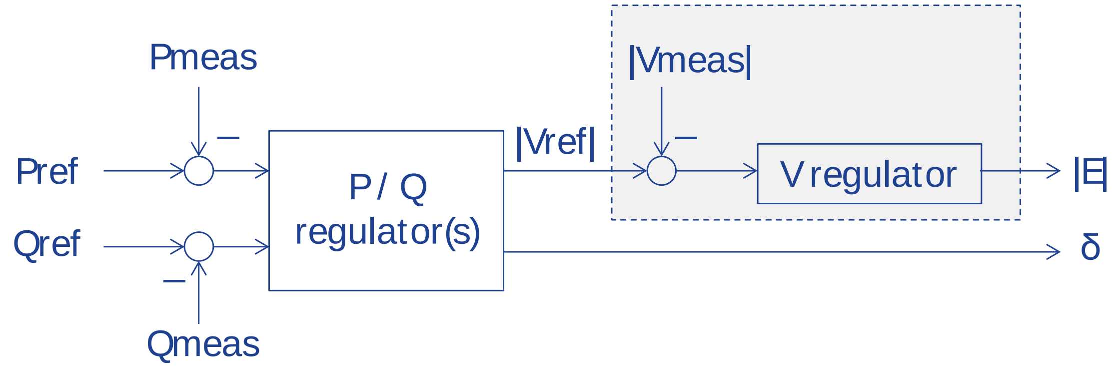
  - Overload limitations of IGBT devices

  - Certain standards pertaining to grid integration requirements

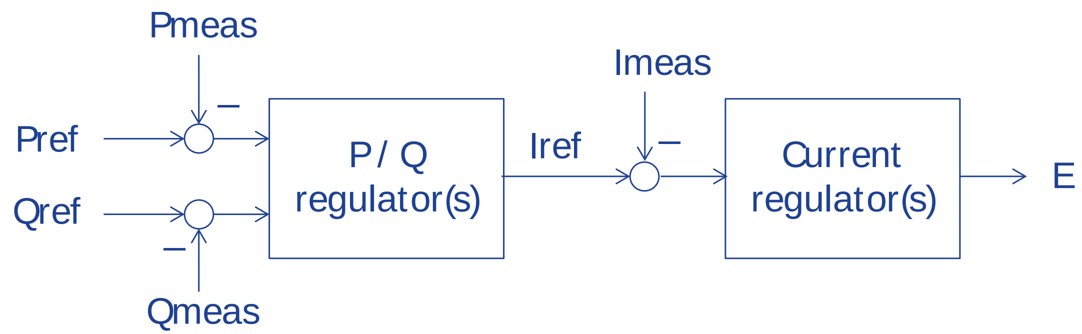
Hard to predict but still able to obtain a rough idea and estimate its impact on feeder protection.

Voltage vs. Current Control Scheme

- Both schemes regulate P & Q
- Voltage control directly regulates Vmag
- Current control directly regulate current

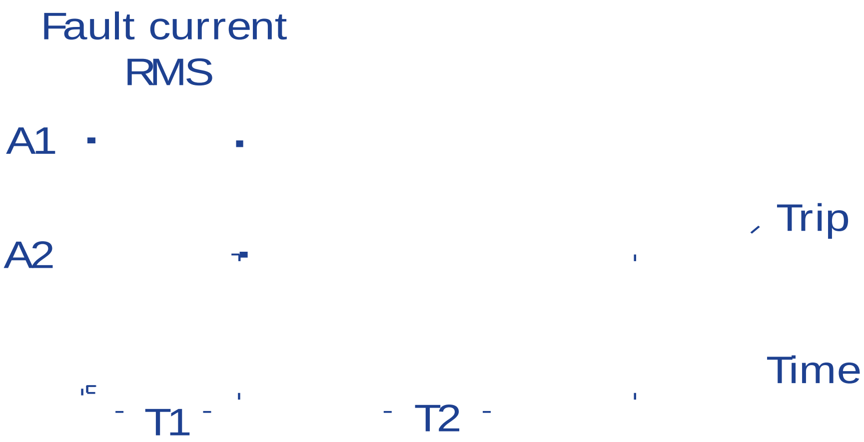


(a) Voltage control scheme



(b) Current control scheme

Fault Current RMS Profile



T1: transient fault duration
A1: transient fault current magnitude
T2: steady-state fault duration
A2: steady-state fault current magnitude

Voltage range (% of base voltage)[a]	Clearing time (s)[b]
$V < 50$	0.16
$50 \leq V < 88$	2.00
$110 < V < 120$	1.00
$V \geq 120$	0.16

[a] Base voltages are the nominal system voltages stated in ANSI C84.1-1995, Table 1
[b] DR ≤ 30 kW, maximum clearing times; DR > 30 kW, default clearing times

Other Aspects Affecting the Impact

- **Fault Current Composition**
  - No active voltage regulation (IEEE 1547)

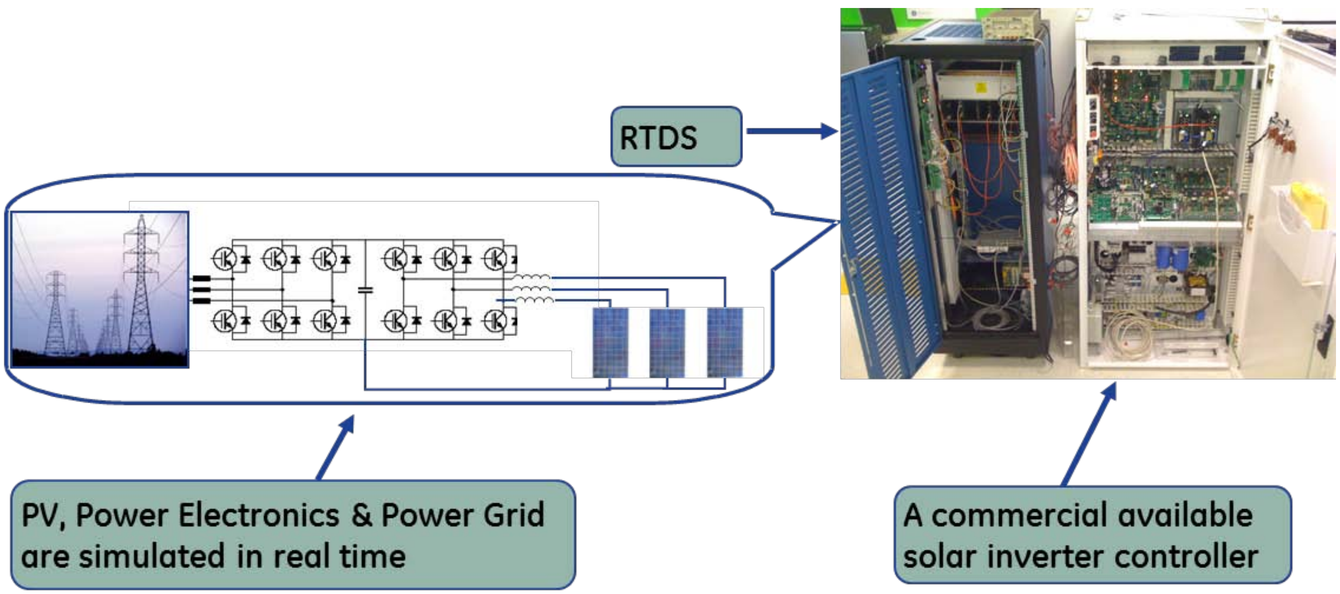
    (Very little reactive current during steady state; higher reactive current during transient)
  - Voltage regulation (E.ON grid code)

    (Significant level of reactive current based on voltage level)

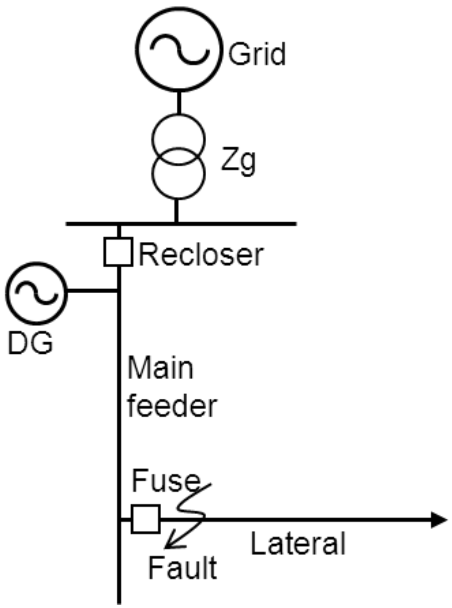
- **Sequence Current**
  - Negative sequence
  - Zero sequence (grounding and interfacing transformer)

Case Study - Setup

- Hardware-in-the-loop (HIL) Test Using RTDS and a Commercially Available Solar Inverter Control
- Existing protection: fuse-saving scheme

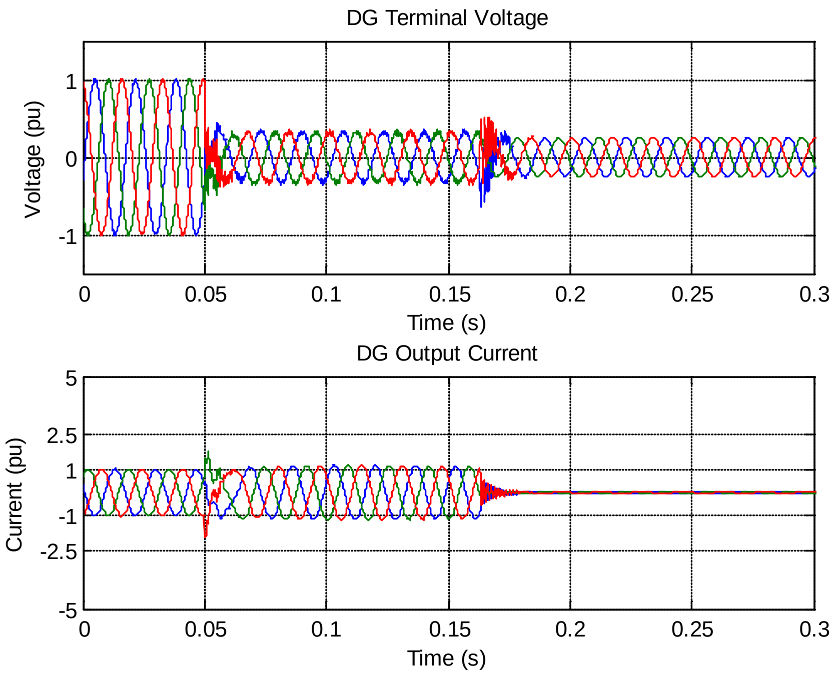


HIL setup



Test system

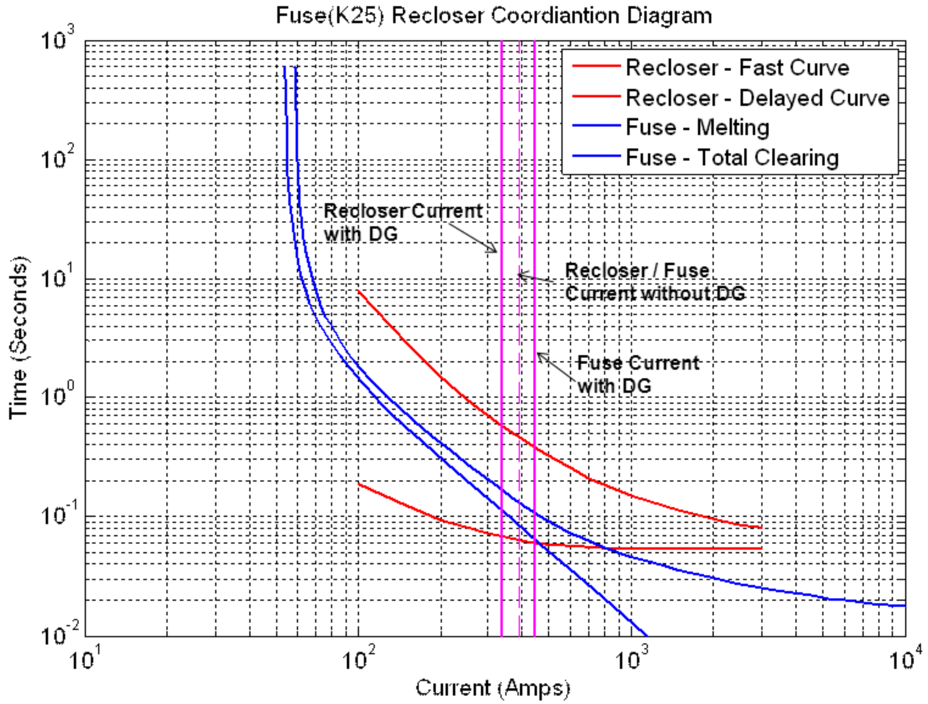
Case Study – IIDG Fault Behavior



- High peak current shown right after fault occurs
- Phase adjustment from PLL resynchronization
- Current settles down in half a cycle

Distance between Substation to Lateral	DG Terminal Voltage[1]	DG Output Current[2]	DG Output Current Contribution (degrees that I lags behind V)	Trip Time (second)
1 Miles	0.14 pu	1.2 pu	102.5	0.12
5 Miles	0.43 pu	1.2 pu	66.0	0.12
10 Miles	0.61 pu	1.2 pu	51.8	1.8
15 Miles	0.72 pu	1.2 pu	42.1	1.8

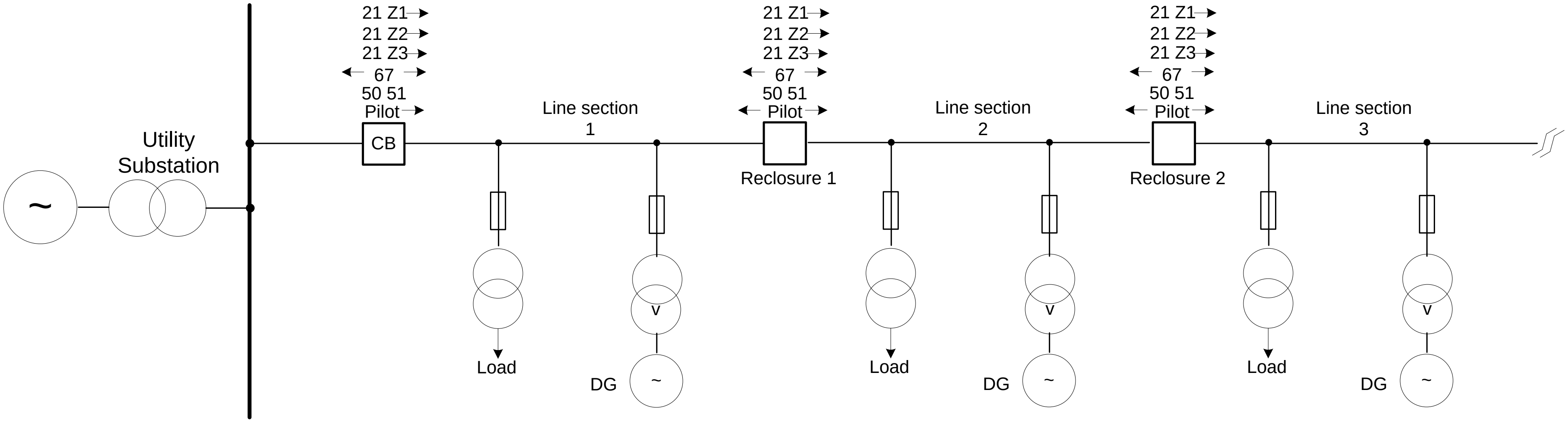
Impact on Fuse-Saving Scheme



Penetration Level	$I_{fuse} - I_{rc}$	
	With IIDG (pu / percentage change)(1)	With Synchronous Generator (pu / percentage change)(2)
50%	0.66 pu / 10.33%	0.85pu / 13.82%
100%	1.16 pu / 18.96%	1.42pu / 25.01%
150%	1.83 pu / 31.53%	2.29pu / 43.45%
200%	2.35 pu / 42.54%	2.97pu / 58.80%

Possible Protection Solutions

- **Adaptive Overcurrent Protection**
  - Directional overcurrent with dynamic settings
- **Distance and Directional Comparison Protection**

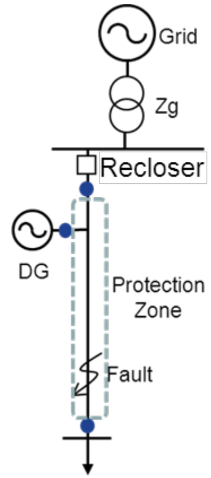


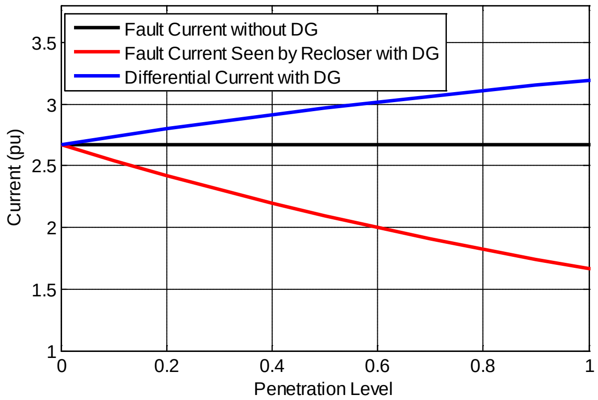
- **Means to Reduce Impact of DG**

Line Differential based Solution

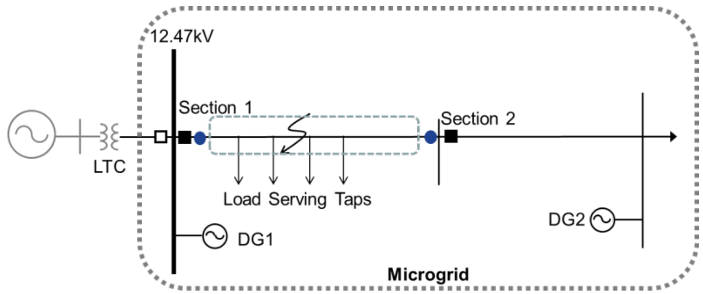
- Ignores load flow change
- Insensitive to fault current level change

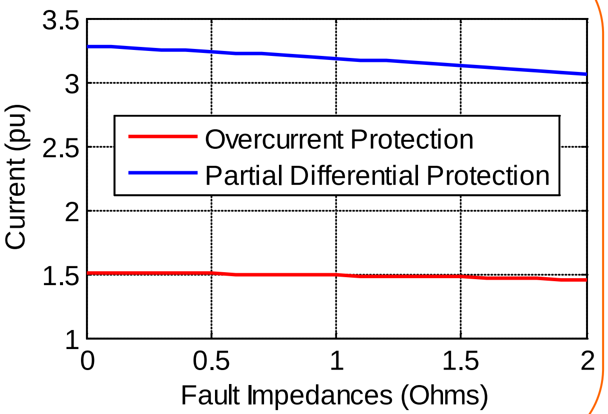
Application example 1



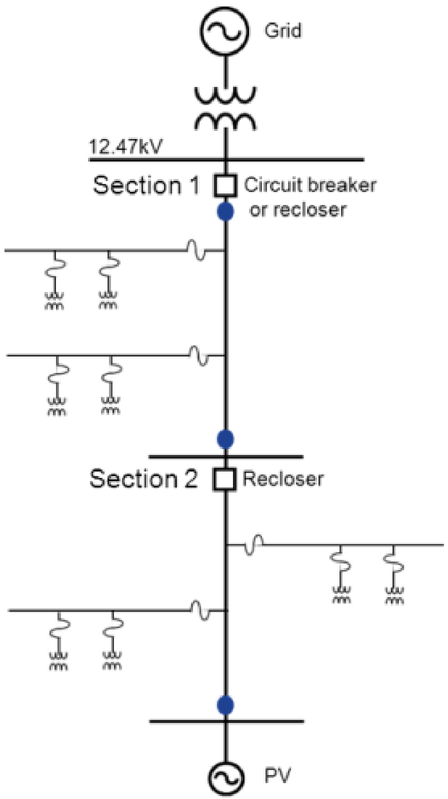


Application example 2

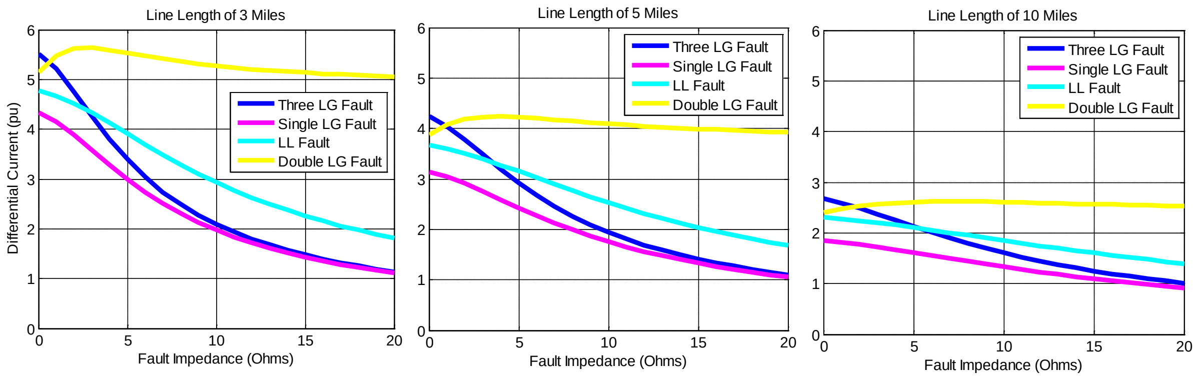




Partial Differential



- Leakage load tap current



- Motor back feeding
- Transformer inrush
- Zero-sequence current due to external ground fault

Conclusion

- DG poses a challenge on feeder protection
- IIDG should be treated separately from conventional generator
- Hardware boundaries and grid code help estimate IIDG's fault behavior
- Fault current limited by control, but the impact can be significant with high penetration level
- A developing area – many options being explored
- Simulation of fault scenarios of a feeder with a given type of DG will help

Thank You

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Questions?