Microgrid Protection

Challenges and Recent Developments

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Outline

- Fault characterization- microgrid
- Different protection issues
- Available/possible solutions

Microgrid

- The electric grid of the future must be resilient, reliable, and local. This means MICROGRIDS. *NEMA—National electrical manufacturers association—*

- College campuses, commercial districts, healthcare facilities, and military bases have already realized the benefits of building a microgrid.

100% Renewable Microgrid for Simris, Sweden's Rural Community --Link

- In the rural town of Simris, E.ON, European utility company, has been testing the islanding of a 100% renewable microgrid. During harsh winter storms, remote areas, with falling trees causing damage to overhead power lines, resulting in power outages. Reliable microgrids that can quickly switch to island mode in these situations will increase resilience.

- Once every five weeks, the 150 customers of Simris take part in an experiment. The community turns into a power island, relying on 500 kW of wind and 442 kW of solar generation capacity, as well as the 800-kWh battery installed and a backup renewable fuel generator.

Microgrid

- Microgrid- a disruptive technology—in energy sector

  power market, power technology, existing infrastructure

- What is new?

-Renewable Sources- variability, intermittency, converters

-Virtual power plant

-Virtual synchronous generator

-Business in ancillary services

In Microgrid

- Distributed energy resource (DER) in the system reduces the physical and electrical distance between generation and loads.
- Bringing sources closer to loads --enhancement of the voltage profile, to the reduction of distribution and transmission bottlenecks, improve reliability, lower losses, and enhancement of the use of waste heat, improvement in resiliency..

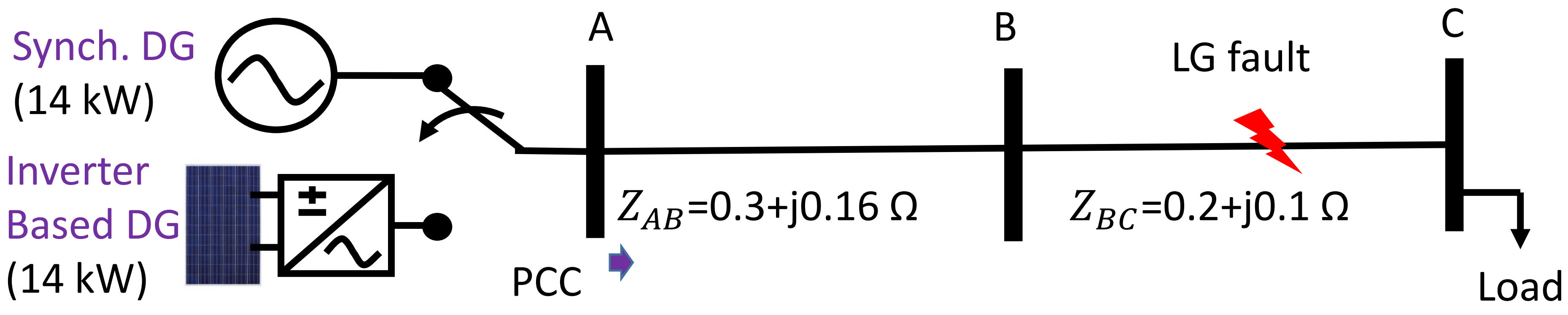
Microgrid Sources

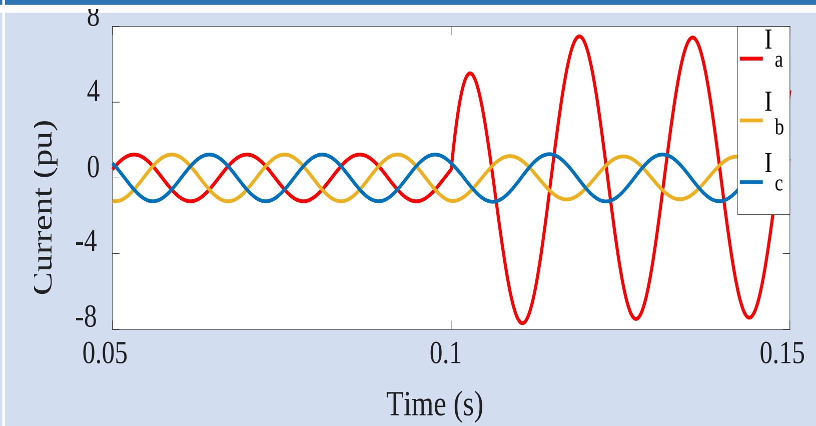
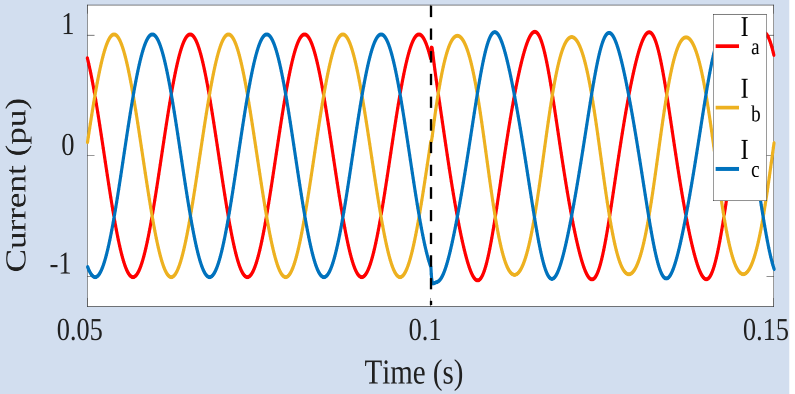
- Grid
- Distributed Generation (DG)-

PV/Wind/ Storage -Converter interfaced

Diesel Generator- Synchronous machine

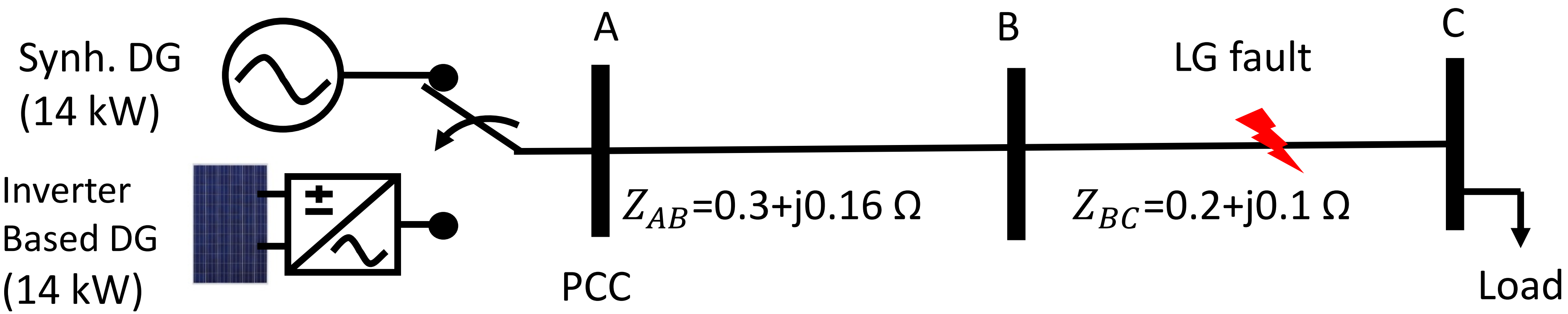
Fault with *Current Controlled Inverter based DG* for LG fault

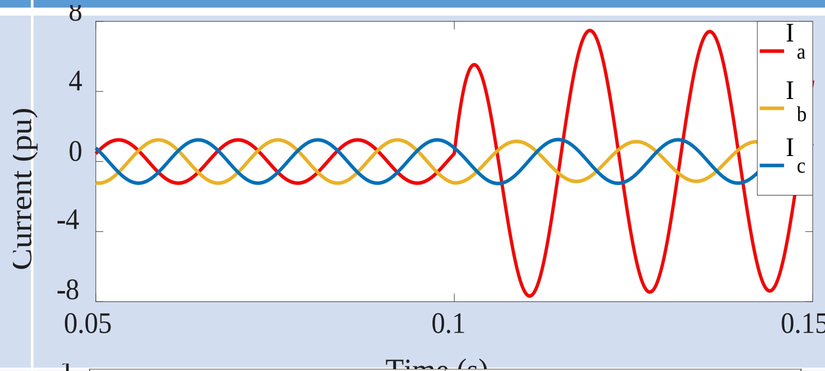
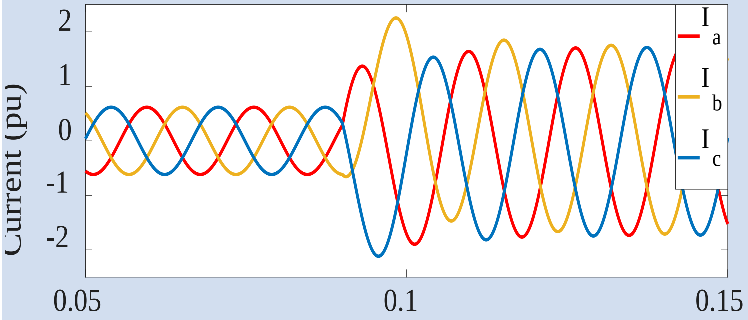


	Synchronous based DG	Inverter based DG
		
I_{a1}(pu)	2.5	1
I_{a2}(pu)	1.6	0
I_{a0}(pu)	1.7	0

- Due to converter current control, current is maintained at 1 pu.
  Conventional protection schemes may not work properly at certain points.

Fault with *Voltage Controlled IBDG* during LG fault



<table>
<tr><th></th><th>Synchronous based DG</th><th>Inverter based DG</th></tr>
<tr><td>Current Waveforms</td><td>
</td><td>
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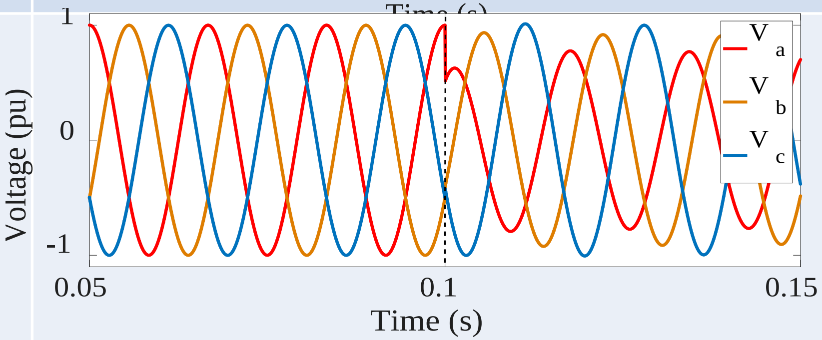
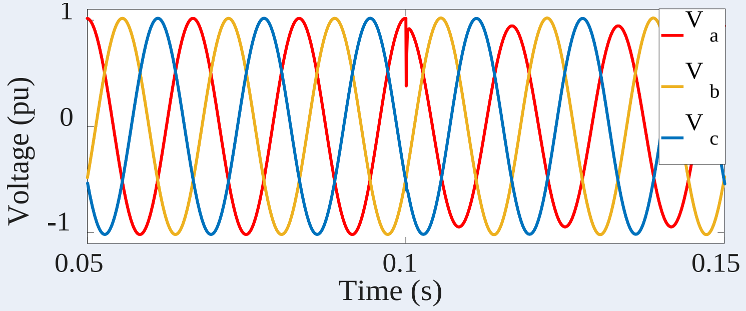
<tr><td>Voltage Waveforms</td><td>
</td><td>
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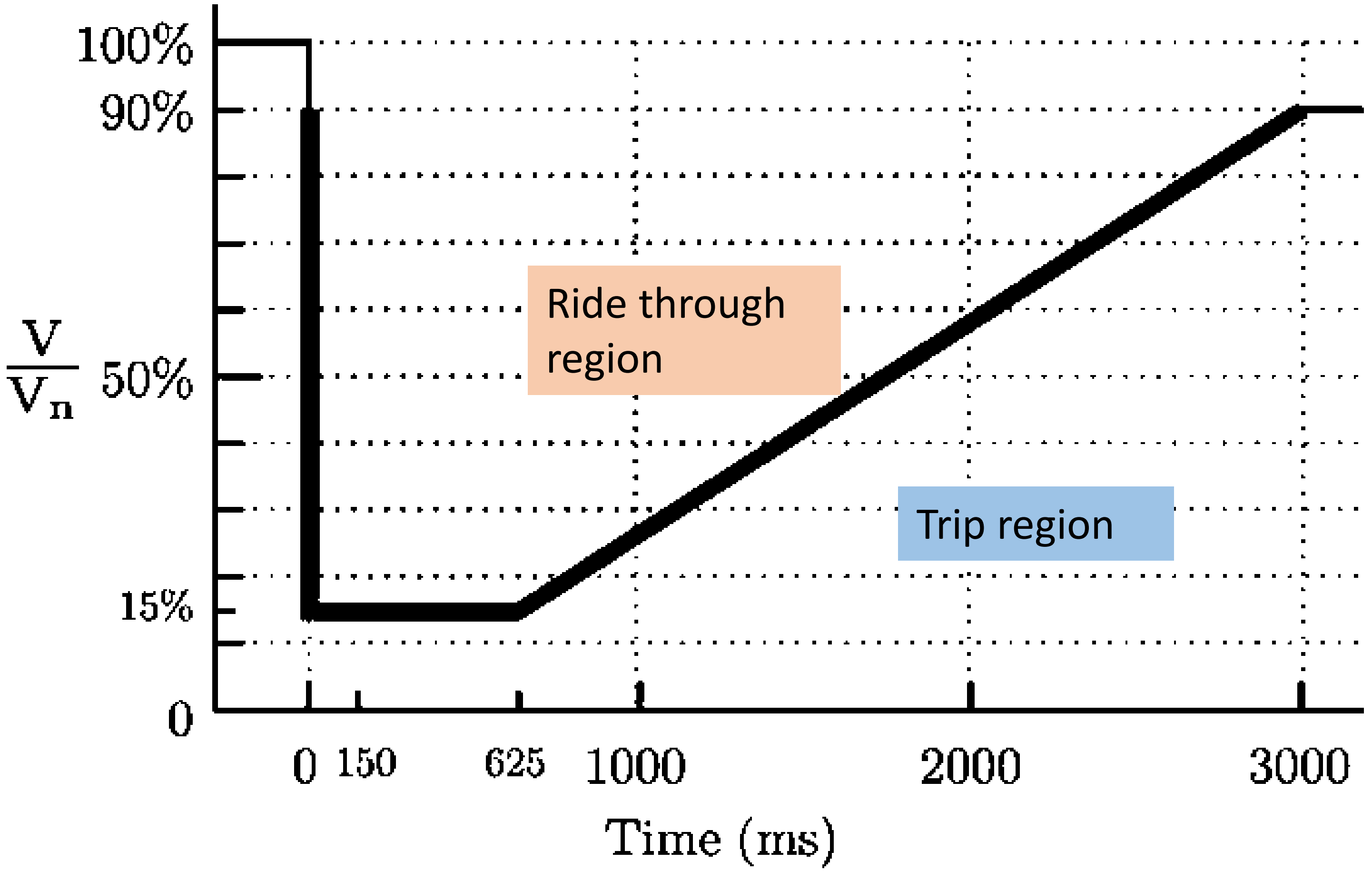
- For converter voltage control, voltage is maintained at PCC and current is limited. conventional protection schemes at points may not work properly.

Impact of different control algorithms in Renewable Sources

- High penetration of DERs –control of a significant number of distributed energy sources– a challenge– numerous control algorithms-
- MPPT—maximum power point tracking algorithm
- Current limiting—
- LVRT
- In all control algorithms (acting so fast), either voltage and/or current get modulated during fault (fault being considered as a disturbance)—affecting performance of conventional relays.

Fault Ride Through

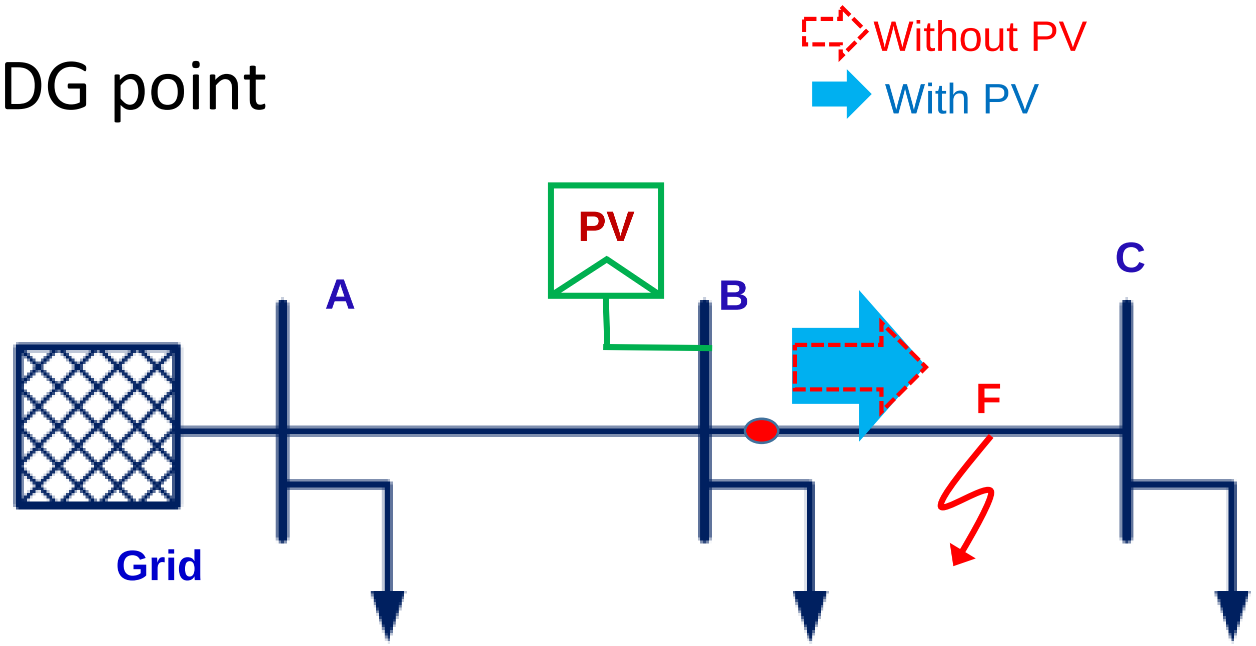


Wind-Turbine Fault Ride-Through Enhancement
Alan Mullane, *Member, IEEE*, Gordon Lightbody, and R. Yacamini, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 20, NO. 4, NOVEMBER 2005

Fault level

- Current increases beyond the DG point

- Circuit Breaker rating

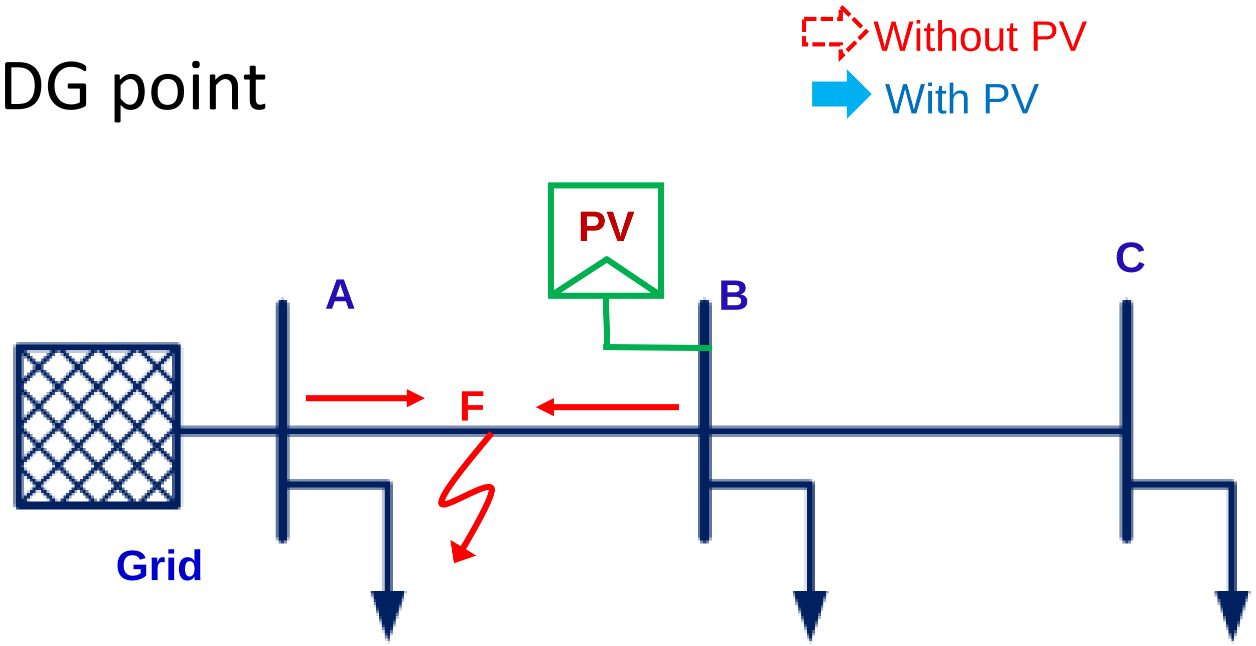


Fault level

- Current increases beyond the DG point

- Circuit Breaker rating

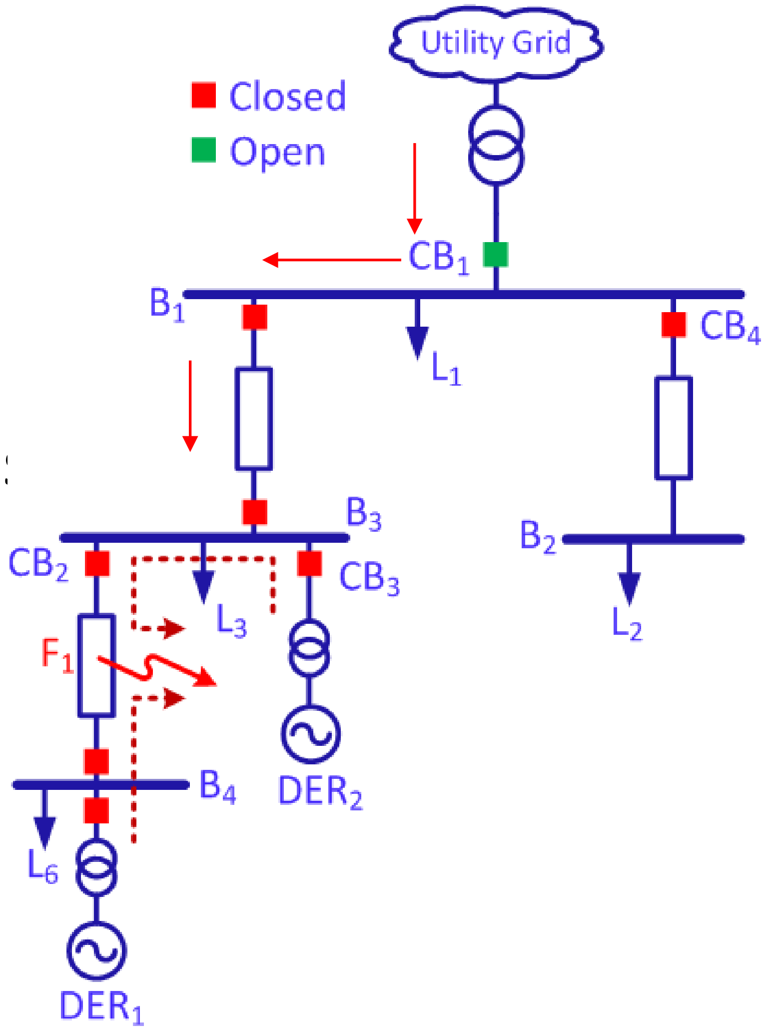
- Bidirectional Current Flow



Fault Level--

- The fault current levels for the **grid-connected** and **islanded modes** of microgrid : much different
- Therefore the available protective devices,

such as **fuse and recloser** are not suitable candidates protection.

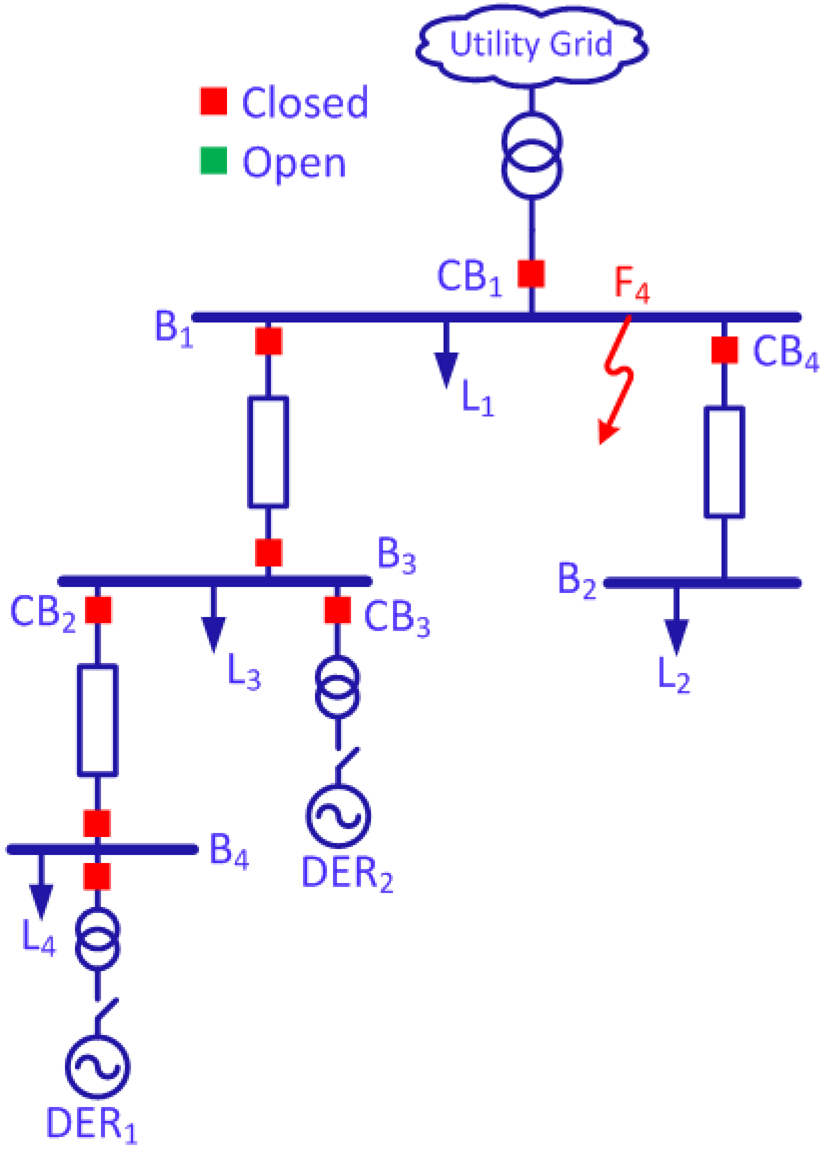


Compared to conventional power system-Microgrid

- Synchronous generator-rotating m/cs –during short circuit acts as a voltage source—leading to 5-6 times of rated current.
- Inverter based distributed generators (DGs) act as a current source—leading to fault current same as rated current
- The fault current level for **grid-connected mode** much higher to

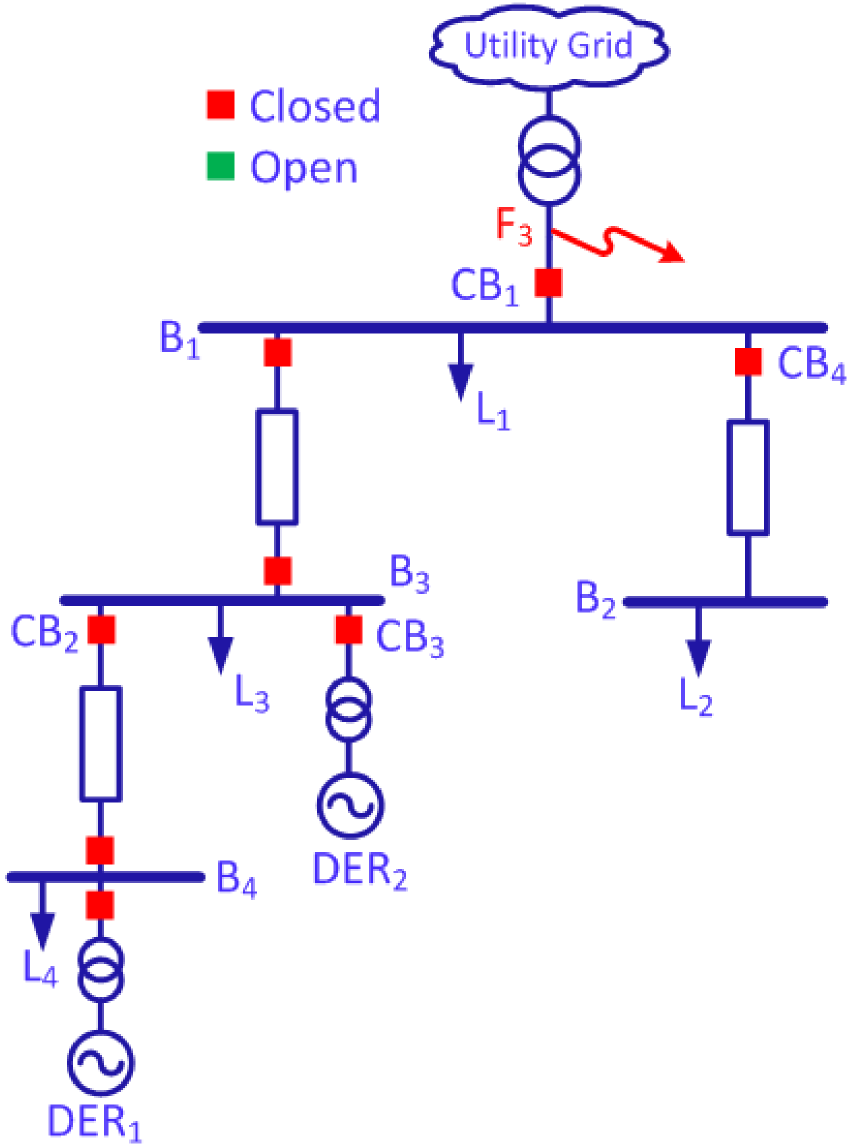
  islanded mode of microgrid operation
- From a protection perspective, a microgrid has a mix of transmission and distribution system features, such as bidirectional fault currents and the need for low cost relays…

Operational Challenge: Isolating Fault contributions from all DERs



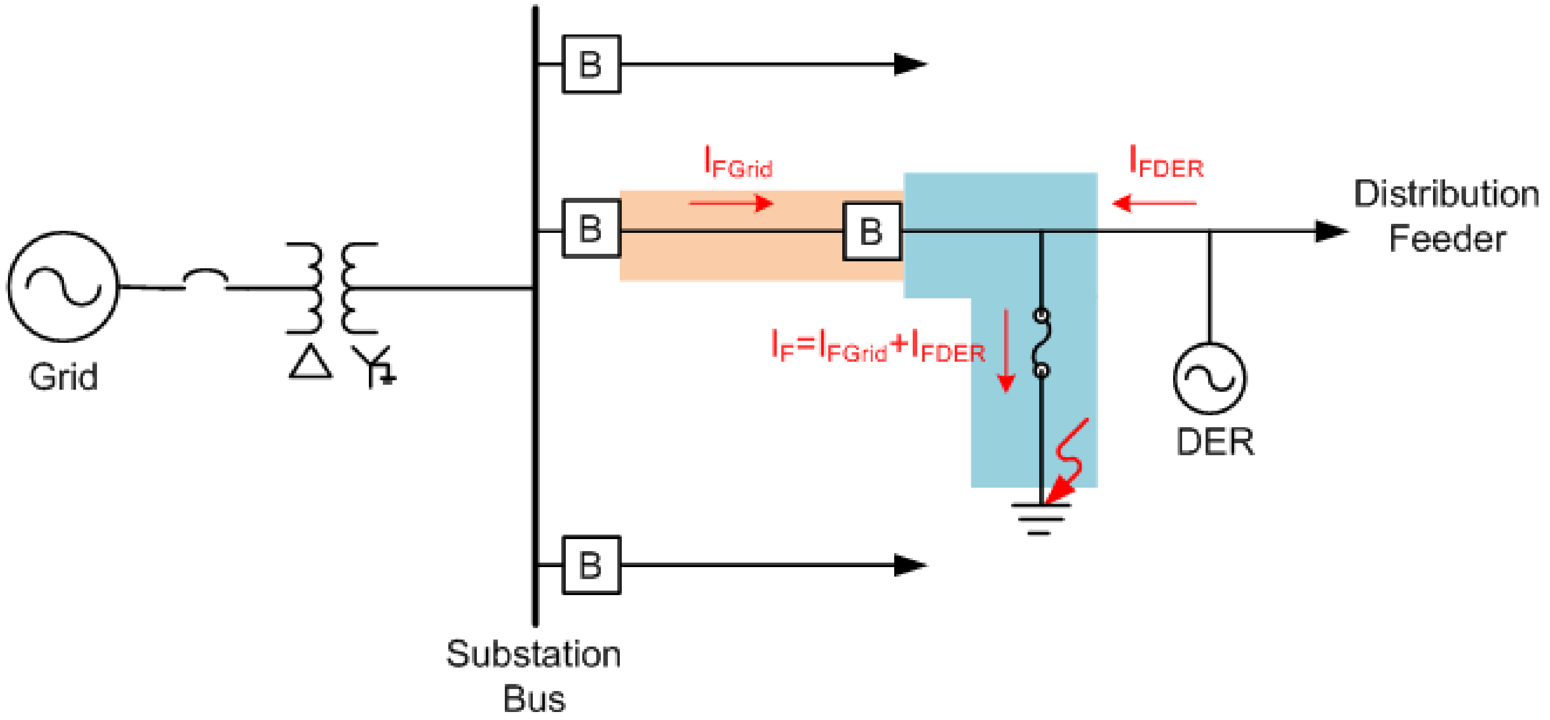
- DER_1 and DER_2 not operating for the instant
- Fault current flows only from utility grid.
- CB_1 should operate and also CB at B_3 or so
- Otherwise, DER_1 and DER_2 can be turned on later with fault.

Operational Challenge-Maintaining DER availability after fault

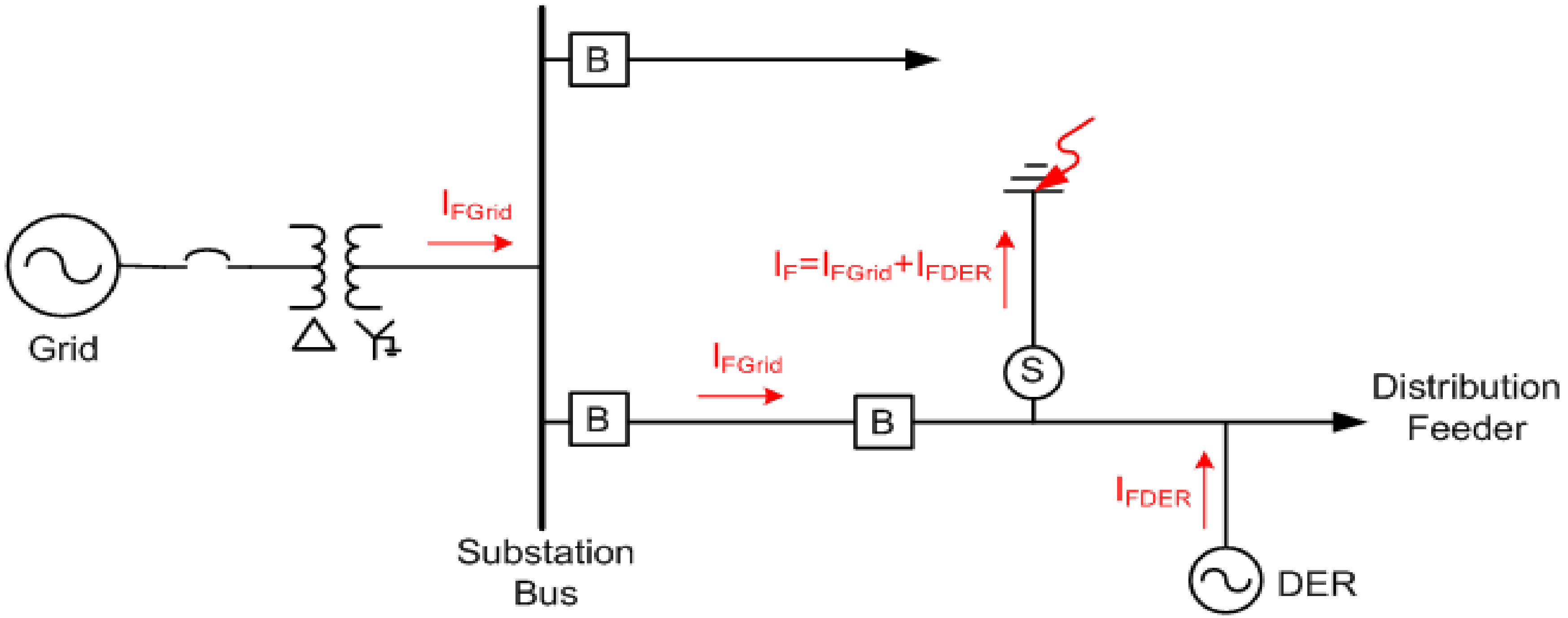


- Permanent fault at F_3
- DER_1 and DER_2 should ride through the fault.
- CB_1 should open to isolate fault contribution from DER_1 and DER_2
- If CB_2 and CB_3 open ---- power at local loads (L_1-L_3) cannot be restored.

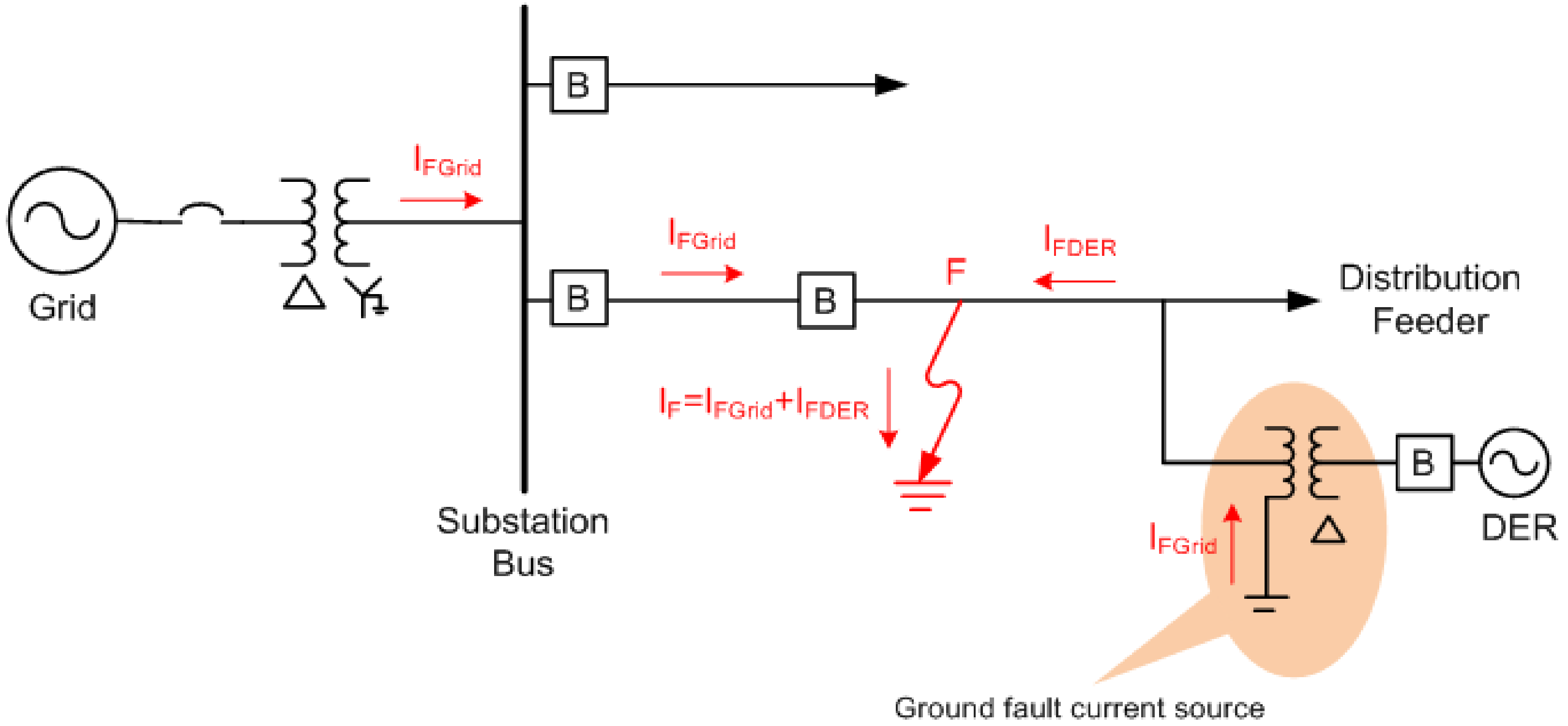
Impact on Fuse Saving Scheme



DERs Impact on Sectionalizer



Impact of PV intertie Transformer Connection

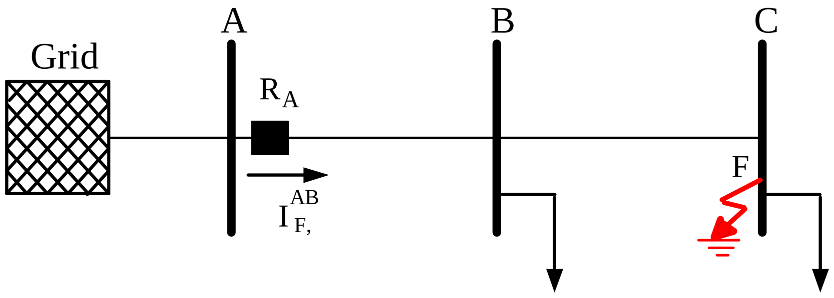


Protection Blinding

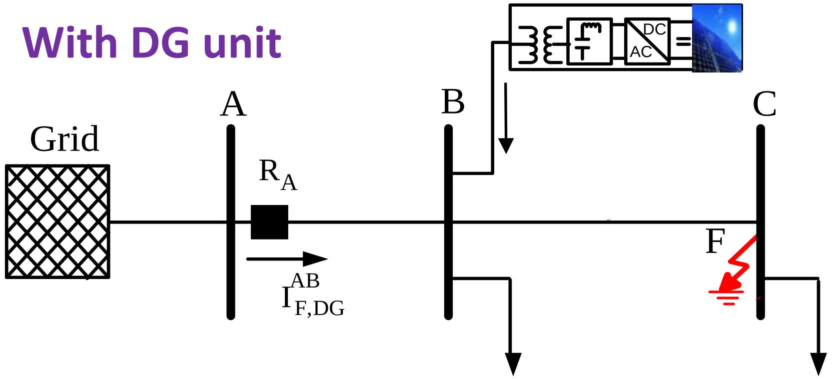
- When a synchronous or inverter based DG is present between the main substation and any fault, fault current contribution from the upstream grid is decreased.

- Sensitivity of the feeder relay reduces. This undesirable effect is known as protection blinding.

Without DG unit



With DG unit

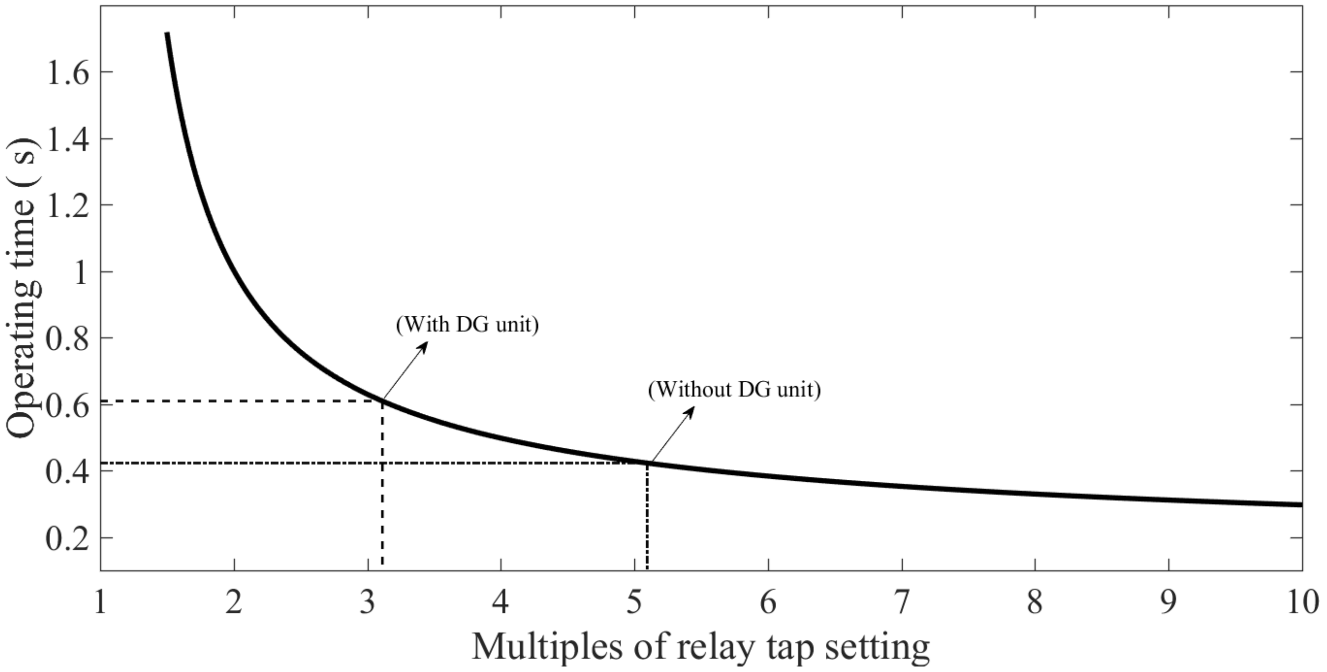


$$I_F^{AB} = \frac{V_{B\_pre}}{Z_{eq\_B} + Z_{BC}}$$

$$I_F^{AB} > I_{F,DG}^{AB}$$

$$I_{F,DG}^{AB} = \frac{V_{B\_pre}}{Z_{eq\_B}\left(1 + \frac{Z_{BC}}{Z_{DG}}\right) + Z_{BC}}$$

Overcurrent relay problem



Due to protection blinding

- Relay R_1 trips at 0.423 s **without the DG unit**
- Relay R_1 trips at 0.609 s **with the DG unit**
- Relay delays the operation for 0.186 s.

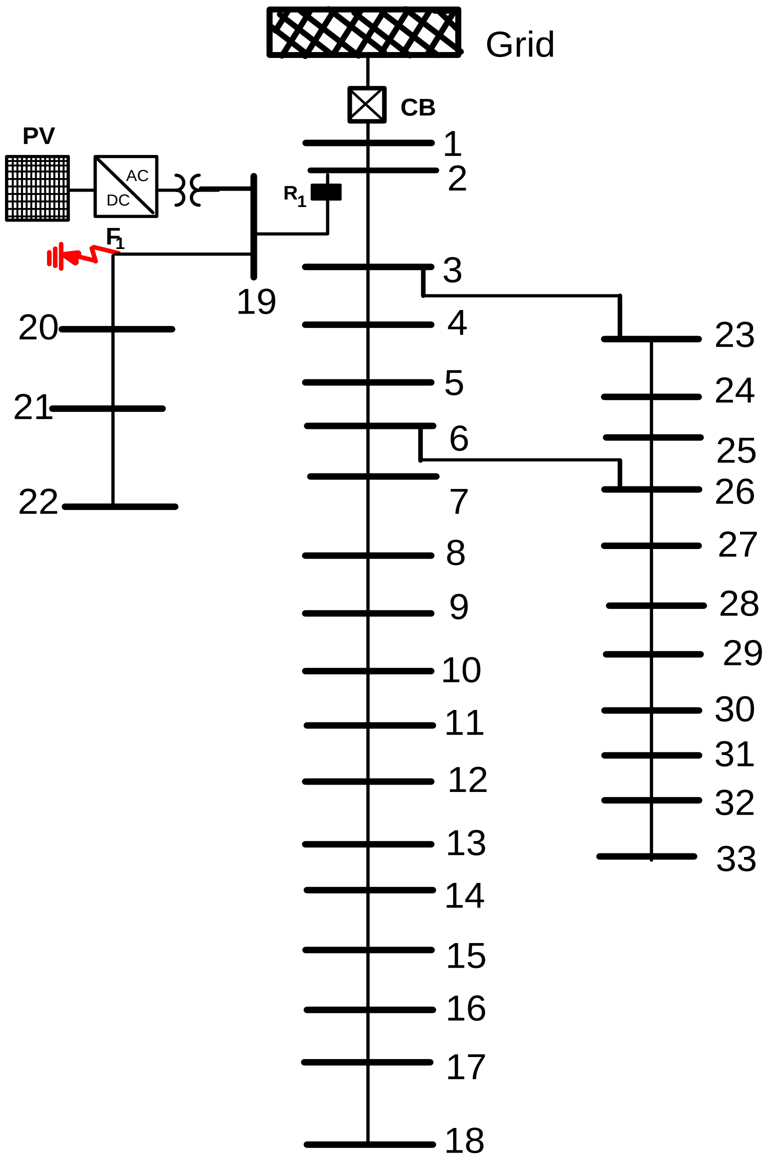
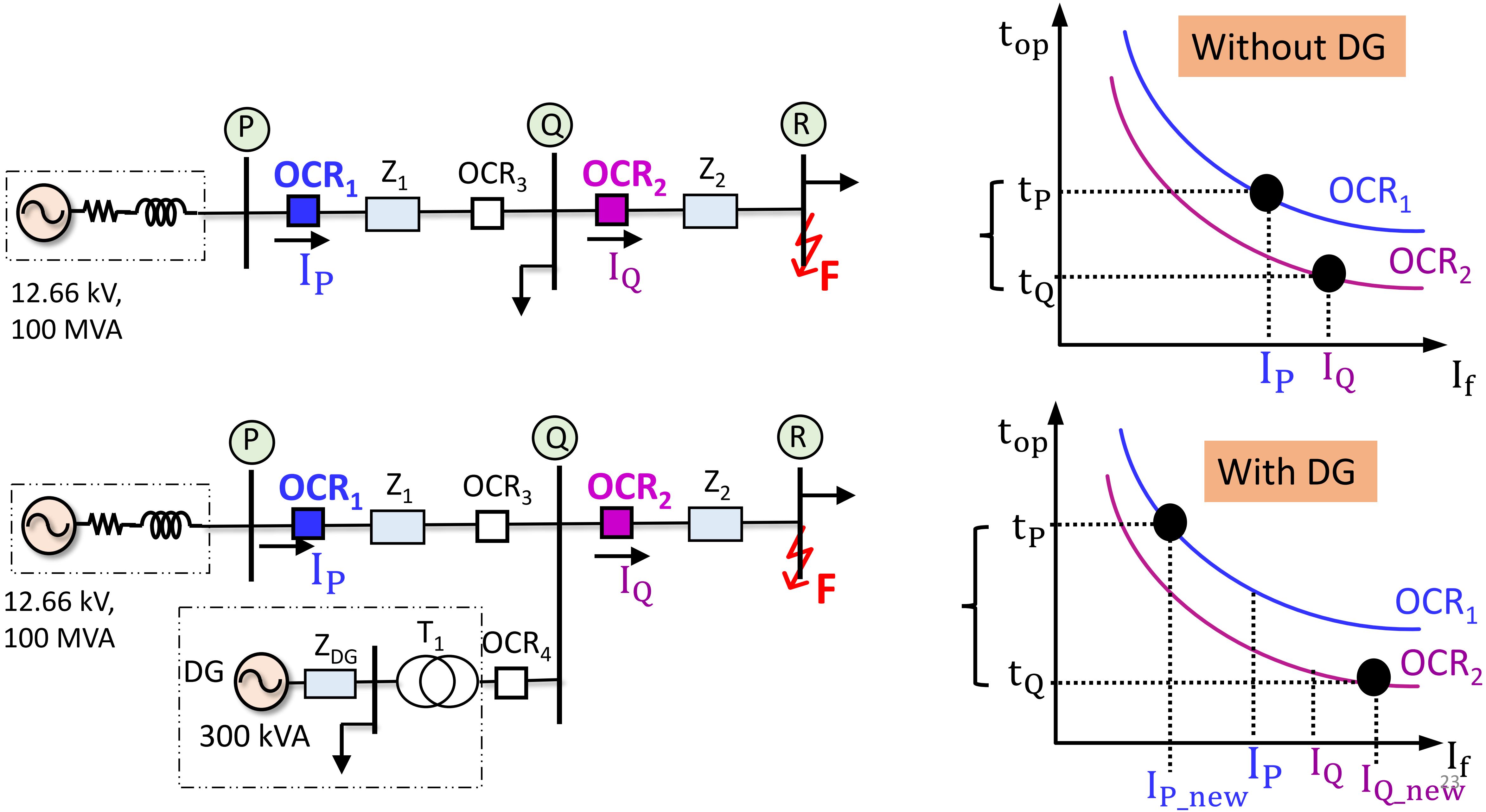
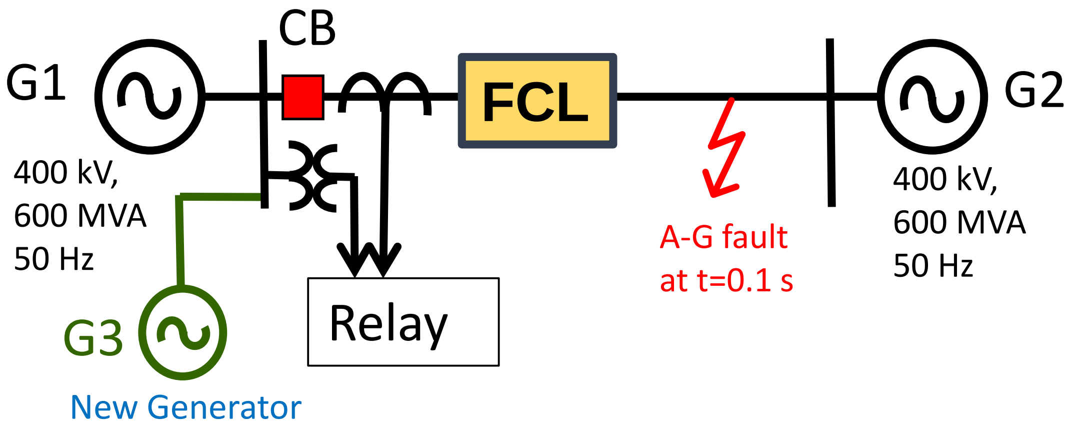


Fig. The 33 bus distribution system

Protection coordination with DG integration



Breaker Issue- with fault current



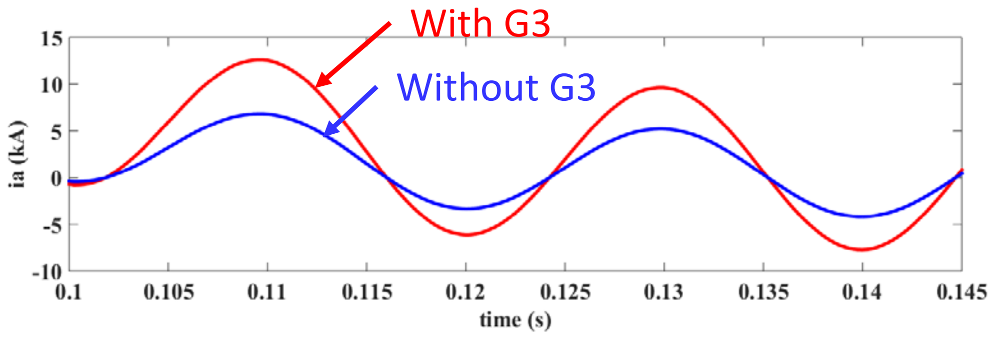


Fig: Current in phase-A during fault with and without G3

Fault current limiter (FCL) --as a solution

- Offers high impedance (Resistive or Inductive or R-L) during fault without disturbing normal operation
- Designed with superconducting materials or solid state technology

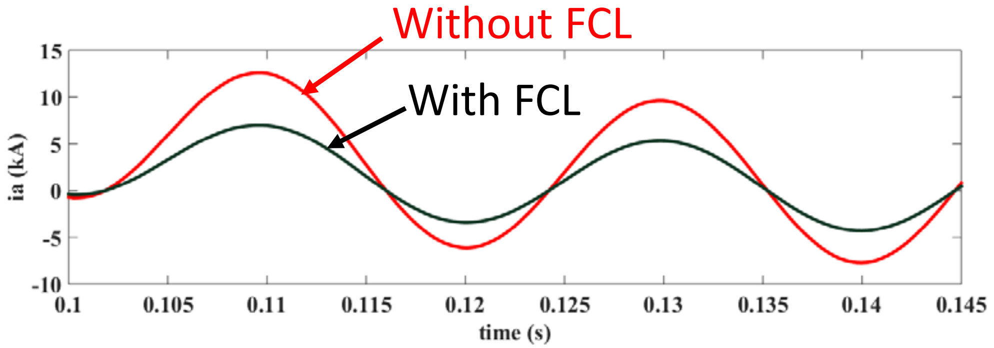
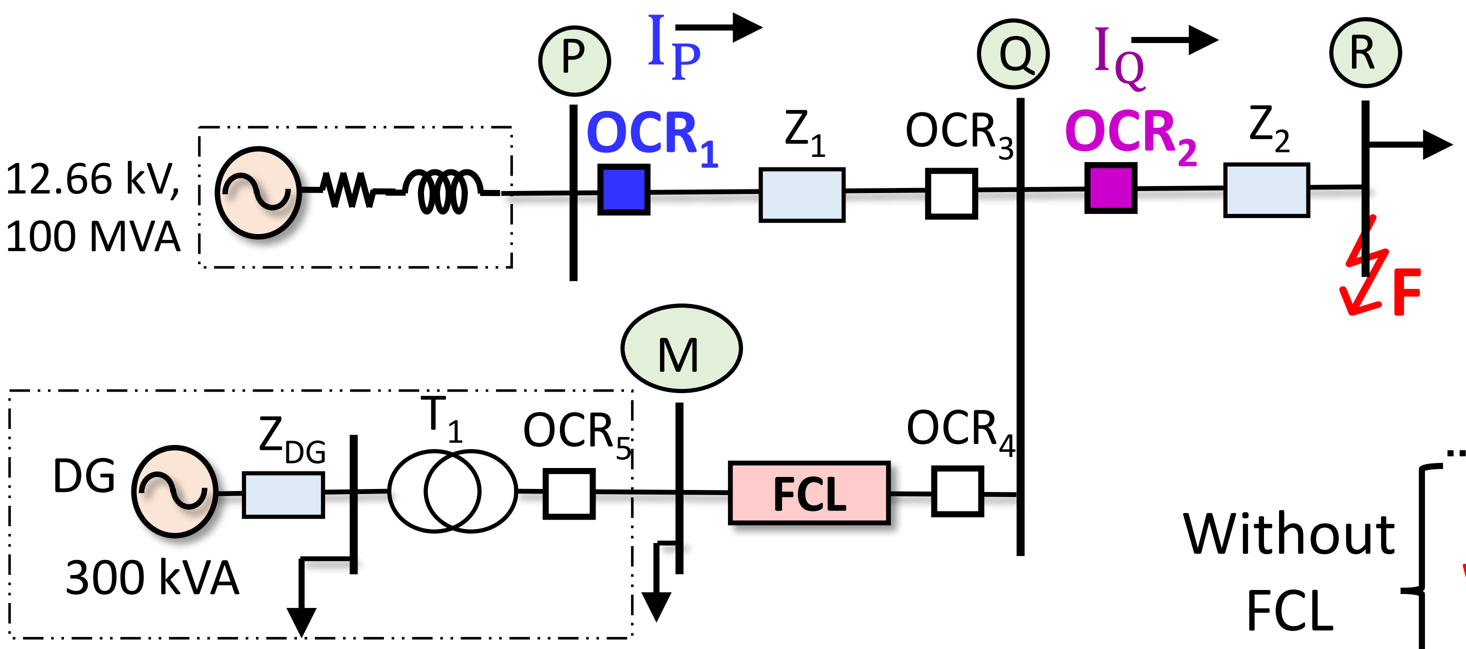
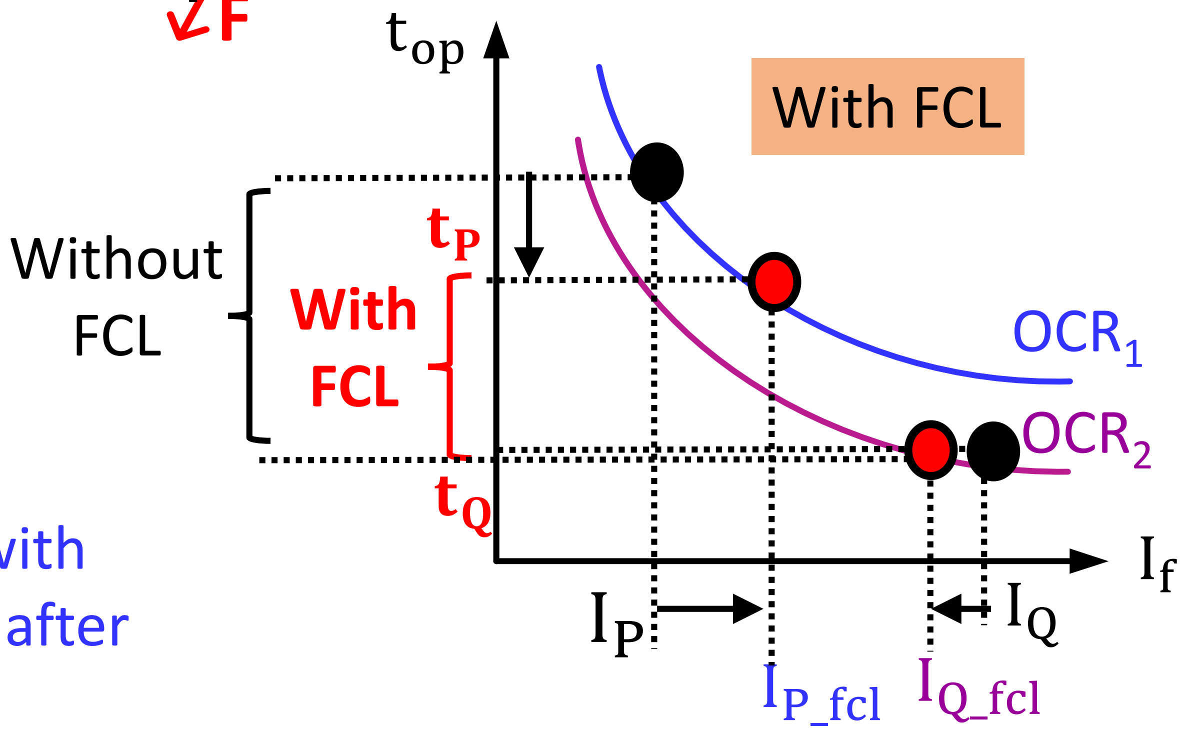


Fig: Current in phase-a during fault with and without FCL

70% reduction in peak of fault current with FCL

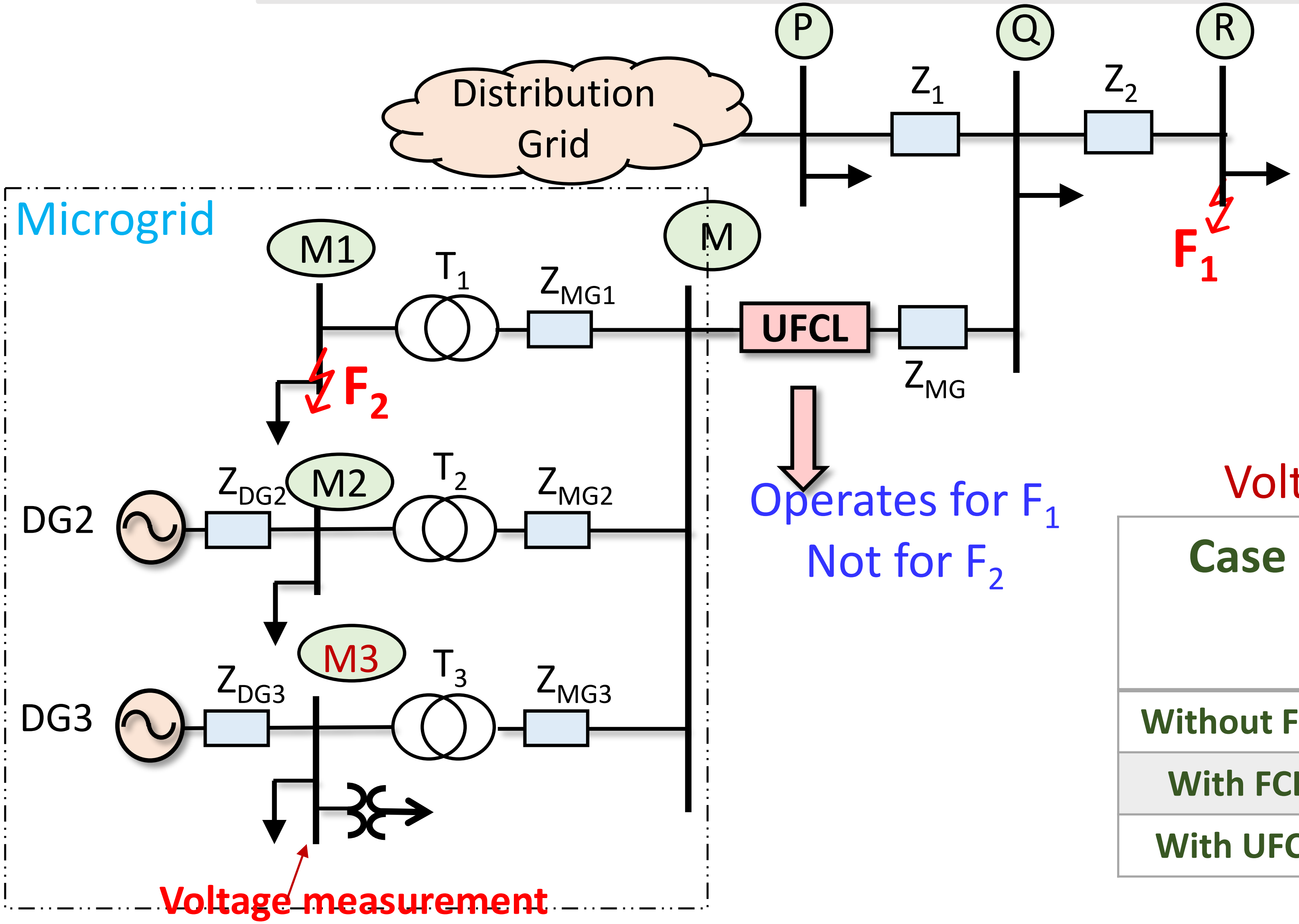
Impact of FCL on protection coordination





Coordination time interval is improved with FCL compared to that of without FCL case after DG integration

Voltage sag comparison with and without FCL and Unidirectional-FCL (UFCL)



A directional unit along with a current comparator triggers UFCL only during upstream faults.

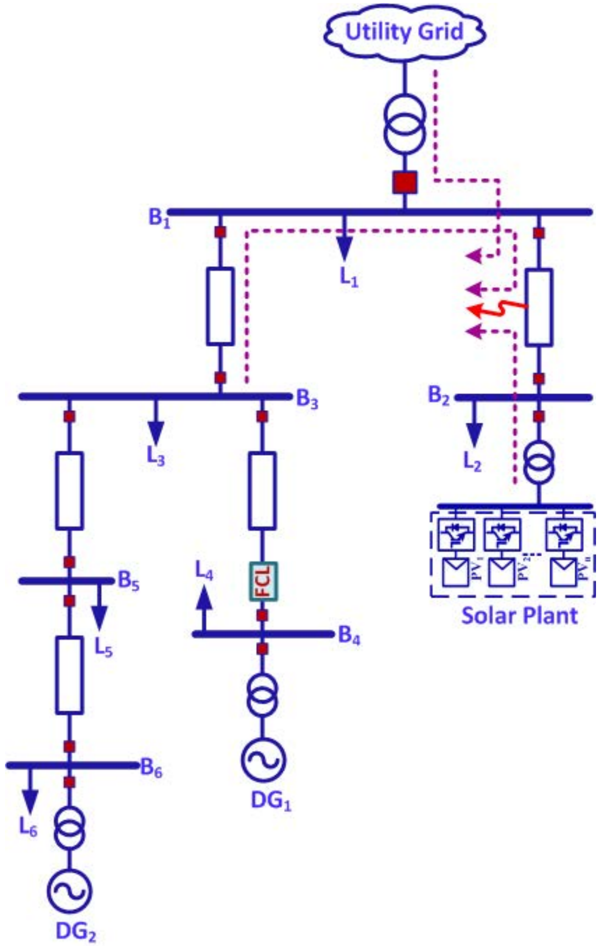
Voltage measured at bus M3

Case	Sag (%) at bus M3	
	Fault at bus R (F_1)	**Fault at bus M1 (F_2)**
Without FCL	57 %	21 %
With FCL	43 %	43 %
With UFCL	43 %	21 %

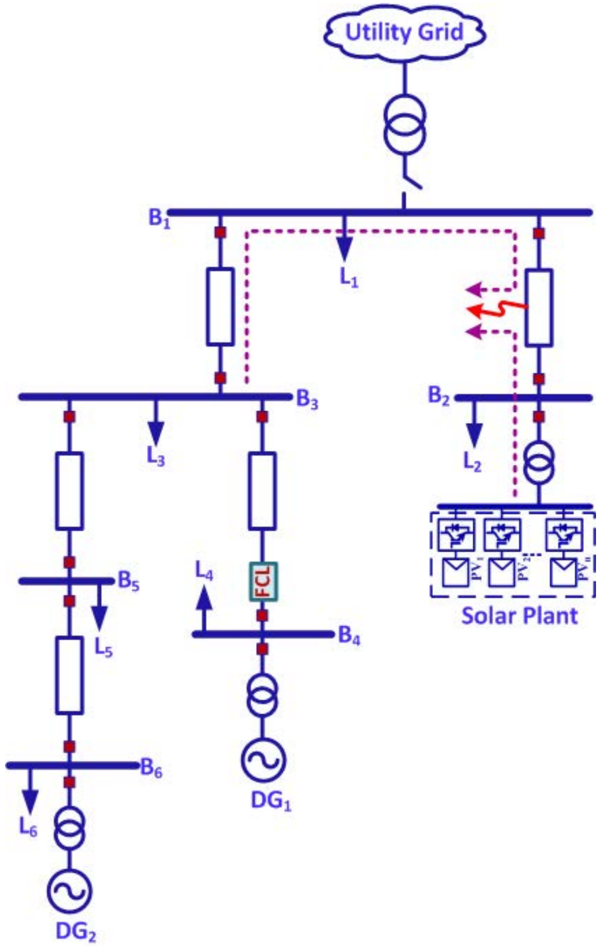
A. Esmaeili Dahej, S. Esmaeili and H. Hojabri, "Co-Optimization of Protection Coordination and Power Quality in Microgrids Using Unidirectional Fault Current Limiters," *IEEE Transactions on Smart Grid*, vol. 9, no. 5, pp. 5080-5091, Sept. 2018.

Challenges with Current based Protection Schemes

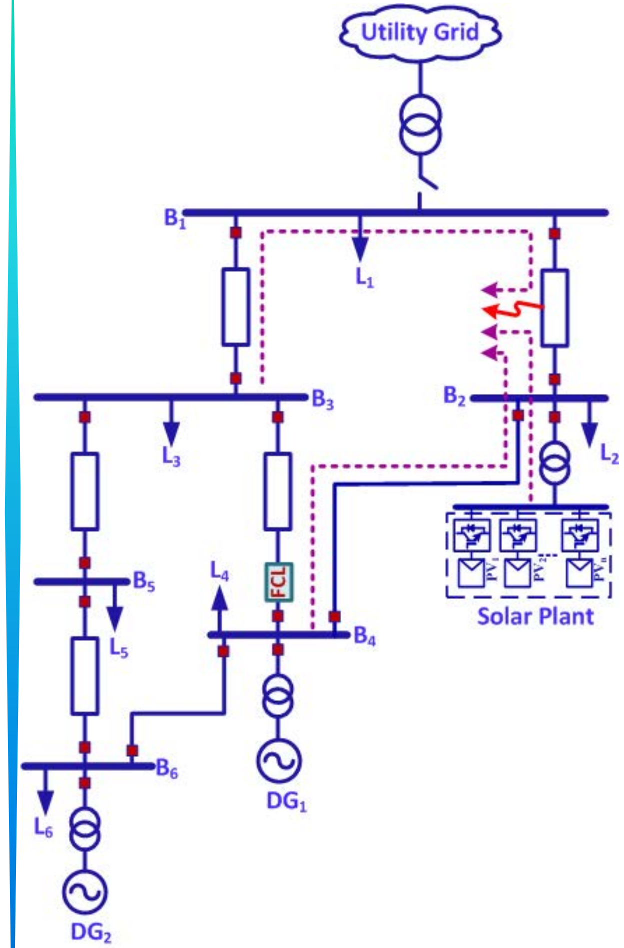
Effect of change in Operating Mode and Network Topology



Grid connected mode
(Radial Topology)



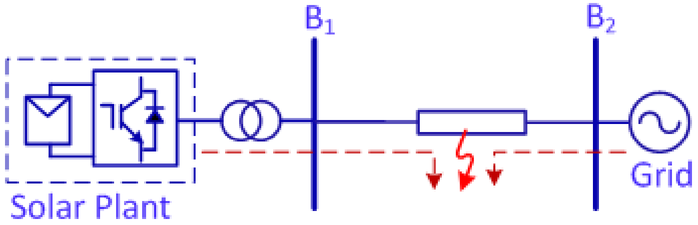
Islanded mode
(Radial Topology)

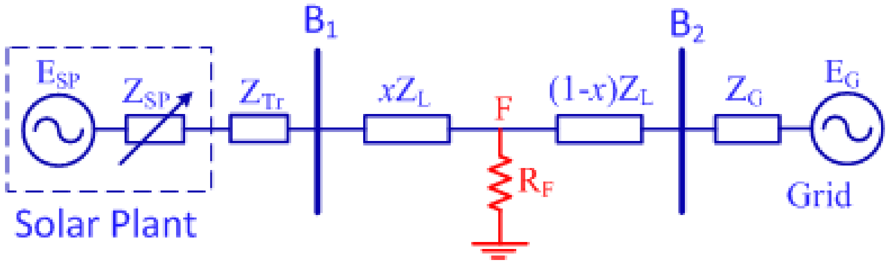


Islanded mode
(Mesh Topology)

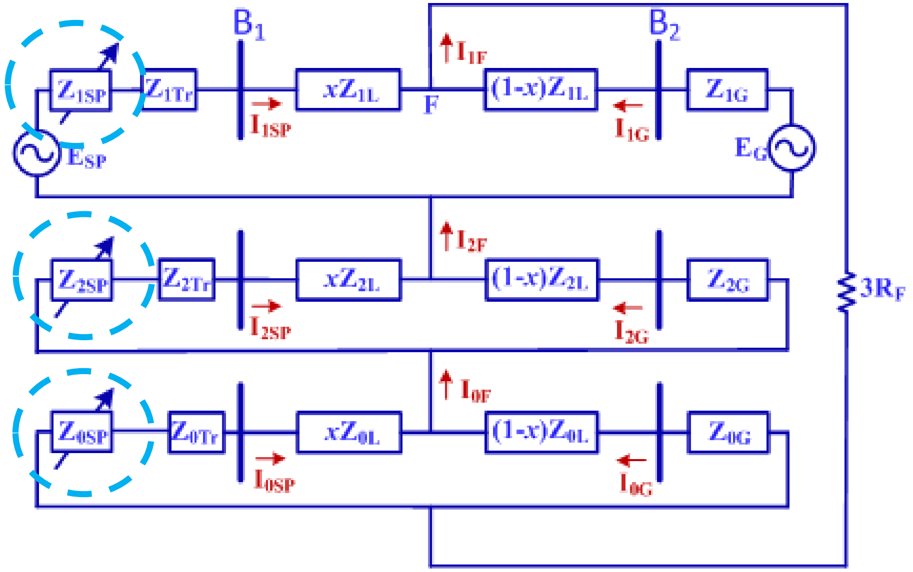
Challenges with Current based Protection Schemes

Effect of variation in interfacing transformer configuration

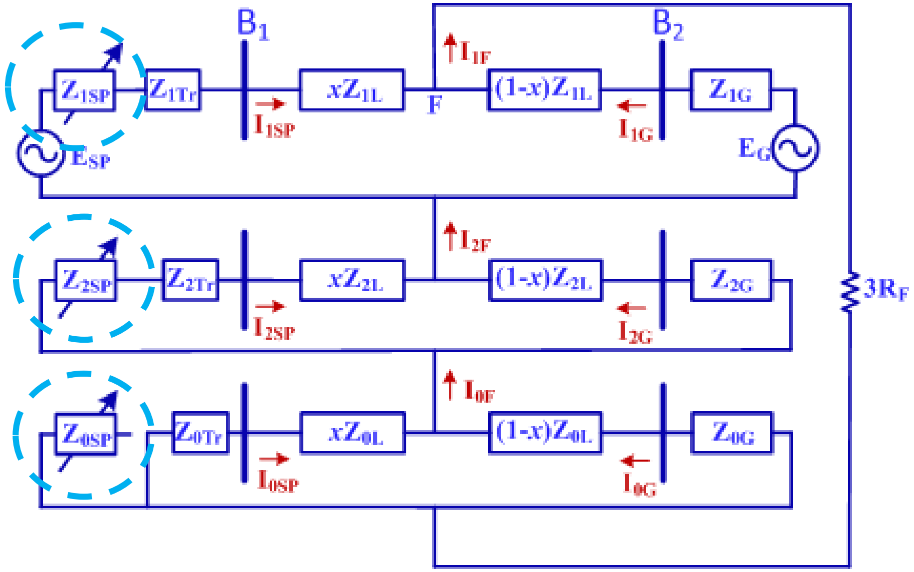




- For L-G fault:



Transformer configuration: YgYg



Transformer configuration: dYg

- Inference: Zero sequence current based protection scheme remains unaffected with dYg connection.

Solutions

- Simris Microgrid—

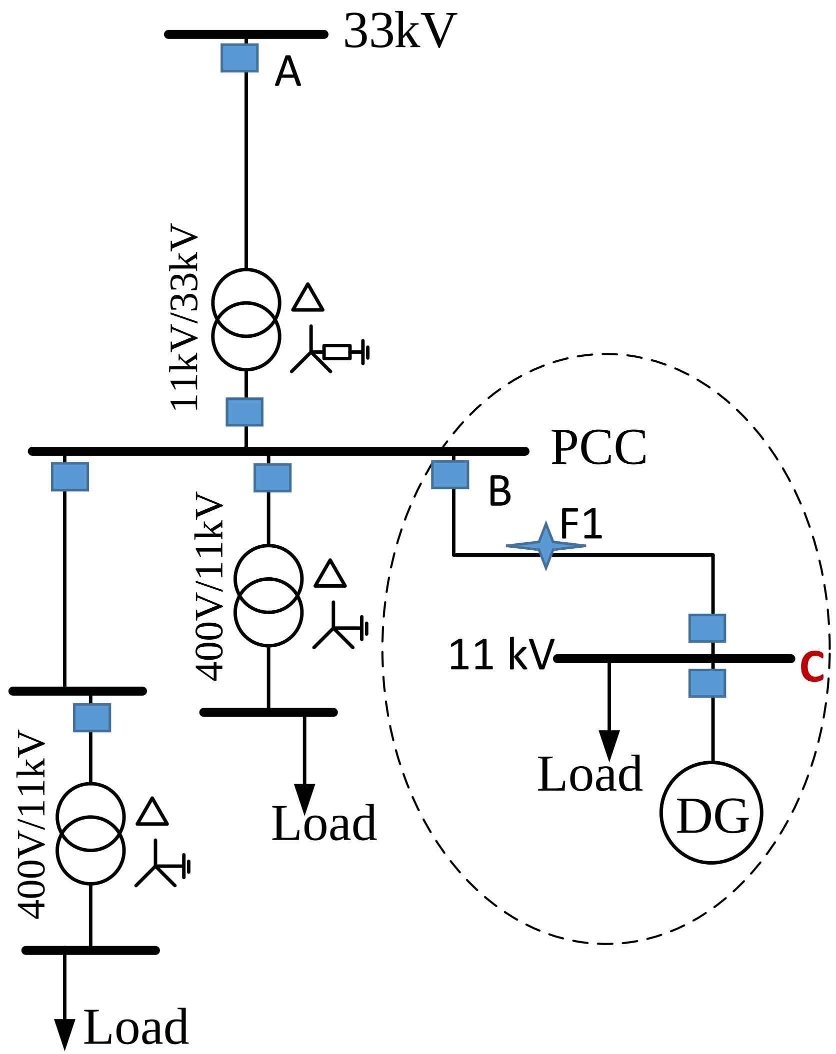
(a) Oversized converter to get the amount of fault current necessary for the conventional directional overcurrent relay to operate–

(b) setting change during transition between grid connection and island *mode*—***adaptive setting***

Overrated converter in practice: Why?

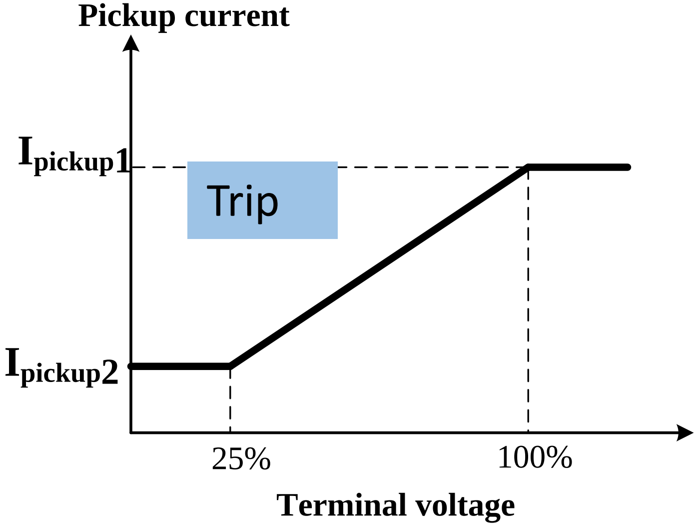
- Converter: installed by a *DG owner* and **protection system-** by grid owner.
- To replace IEDs in distribution grid by a DG owner: to limit converter rating within rated capacity????
- Overrated converter (at DG owner) allows the amount of current to operate the IED (in distribution grid) based on overcurrent principle in the network.

Practical issues and solutions



Strategies— <u>at C</u>

- Overcurrent– issue with converter controlled DG
- Undervoltage-issue with long line
- Voltage restrained overcurrent relay 51VR

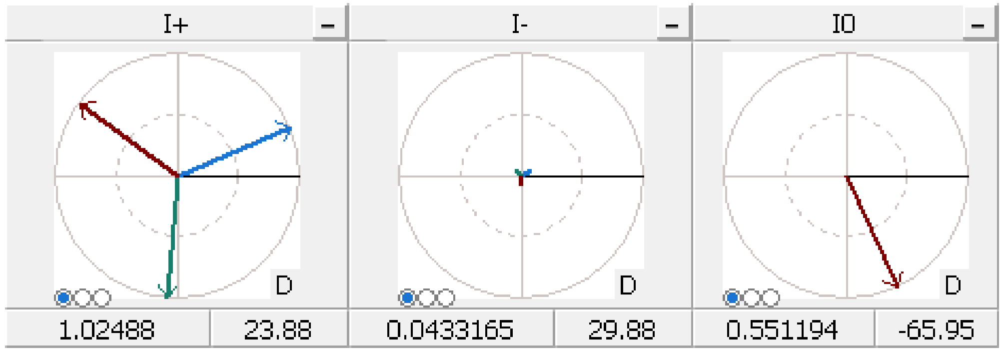


The disadvantage : coordination of these relays in microgrid application is problematic

Challenge with Directional Relaying

Unavailability of Negative Sequence Current from Renewables

- For unbalance faults the negative sequence based directional relay (67NEG) are used.
  - ✓ Independent of load angles and fault resistance.
- Current controlled DG sources produce negligible negative sequence current.



- Ratio of (I^-/I^+) lower than a threshold value disable, 67NEG operation??
- Solution: Magnitude and angle of negative sequence source impedance is used to detect the direction of fault in such situation

A. Hooshyar and R. Iravani, "A New Directional Element for Microgrid Protection," IEEE Trans. Smart Grid, vol. 9, no. 6, pp. 6862-6876, Nov. 2018.

Challenges with fault classification

Effect of Converter Control on sequence current components

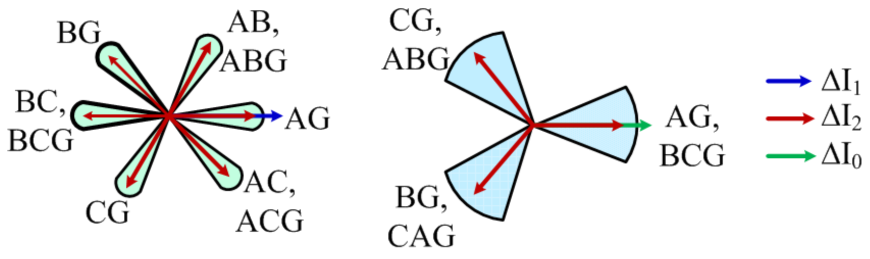
Conventional synchronous generator sources maintain machine voltage during short circuit.

- Characteristics of fault current are determined by the fault property.

Renewable sources connected to a microgrid through voltage source converter (VSC) operates as a current source.

- Sequence currents are controlled by the converter control, produces negligible negative sequence current.

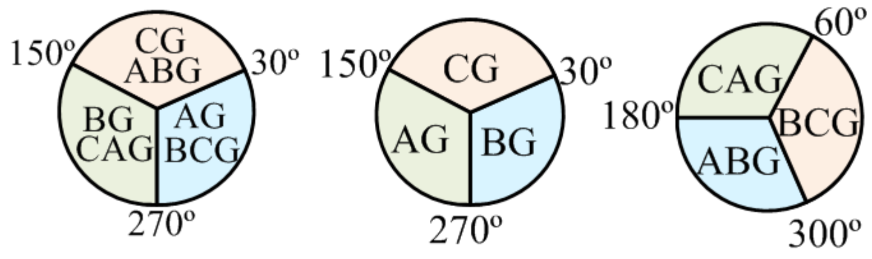
❑ Current Angle based Classifier:



(a) δ_I^+ comparator (b) δ_I^0 comparator

$$\delta_I^+ = \angle\Delta I_2 - \angle\Delta I_1 \qquad \delta_I^0 = \angle\Delta I_2 - \angle\Delta I_0$$

❑ Voltage Angle based Classifier:



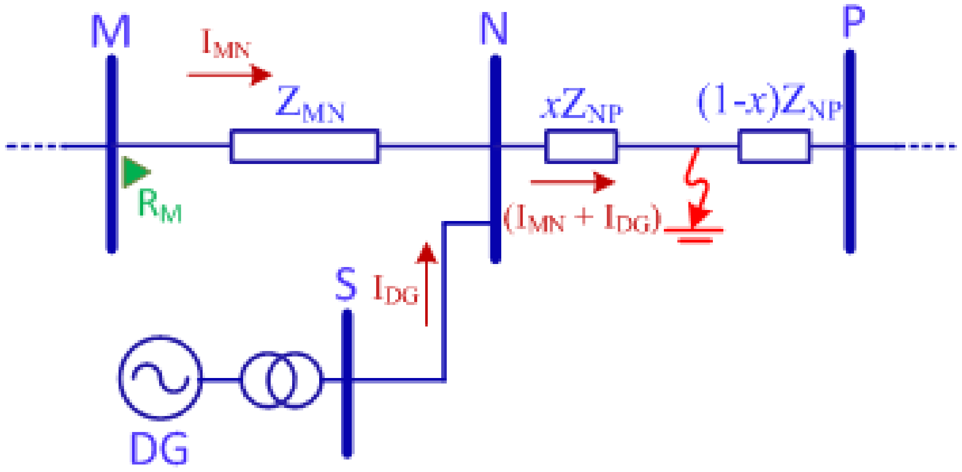
(a) δ_V^0 comparator (b) δ_V^+ comparator

$$\delta_v^0 = \angle V_2 - \angle V_0 \qquad \delta_v^+ = \angle V_2 - \angle V_1$$

A. Hooshyar, E. F. El-Saadany and M. Sanaye-Pasand, "Fault type classification in microgrids including photovoltaic DGs," *IEEE Trans. Smart Grid*, vol. 7, no. 5, pp. 2218-2229, Sept. 2016.

Challenges with Distance Protection

Effect of Infeed Variability



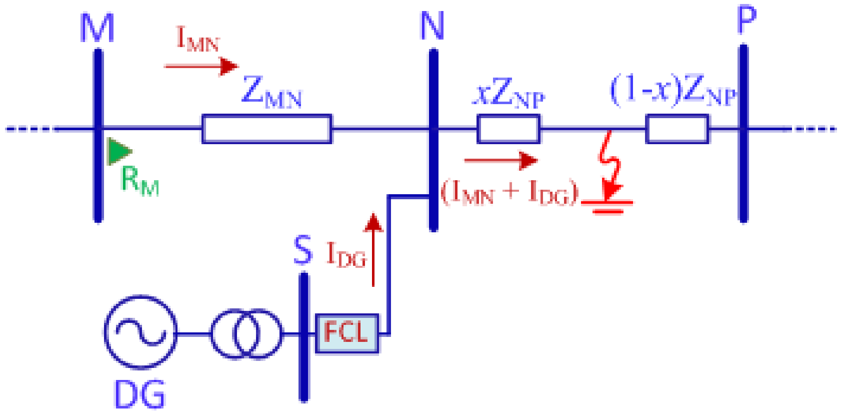
- For solid 3-phase fault:

$$Z_{app} = \frac{V_M}{I_{MN}} = Z_{MN} + xZ_{NP}\left(1 + \frac{I_{DG}}{I_{MN}}\right)$$

→ Varies with number of available operating units, resource intermittency and associated control schemes.

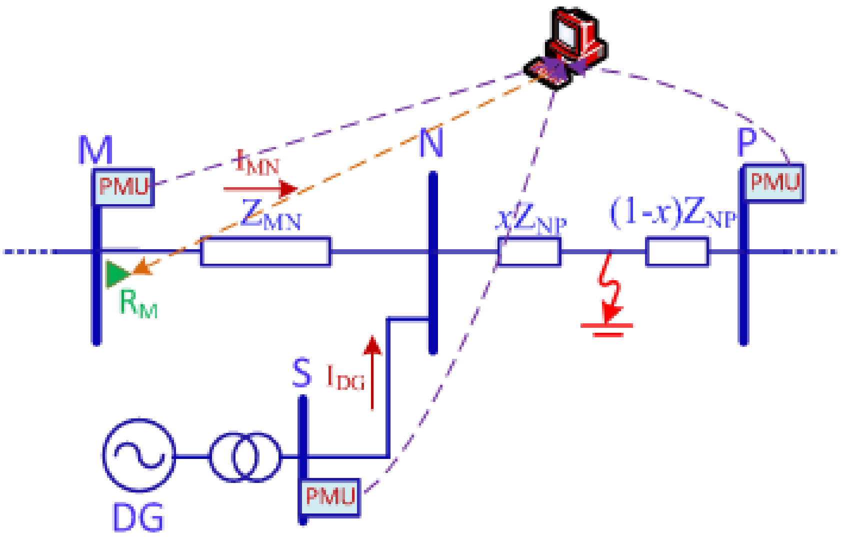
Mitigating the effect of infeed variability

Use of FCL



- Using FCL the infeed current is kept as a constant value and relay can operate with a fixed setting

Centralized Protection



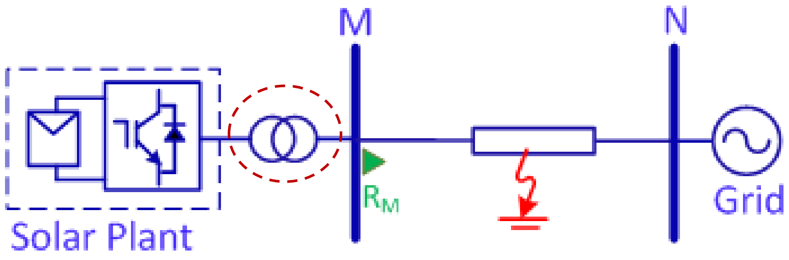
- In this scheme centralized controller collects the data from different generating buses and calculated Thevenin equivalent.
- Updates the relay setting periodically.

Challenges with Distance Protection

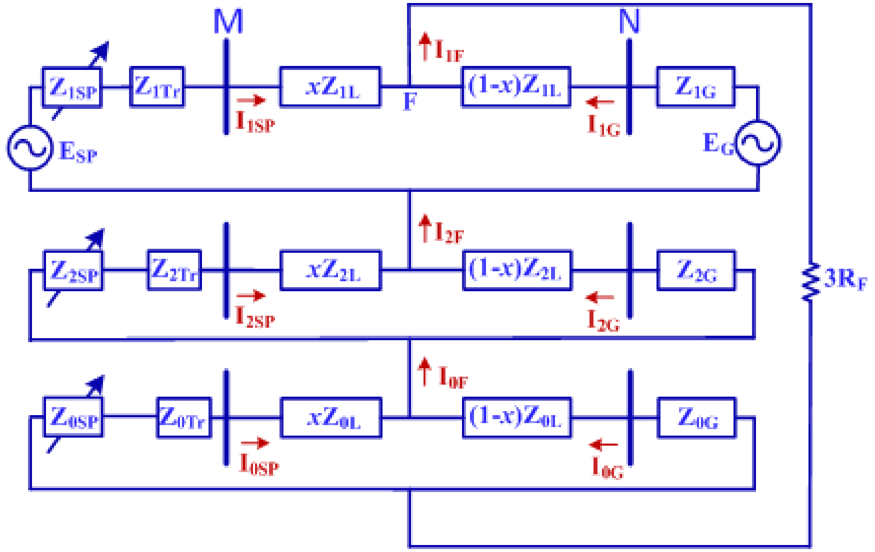
Effect of Interfacing Transformer Configuration

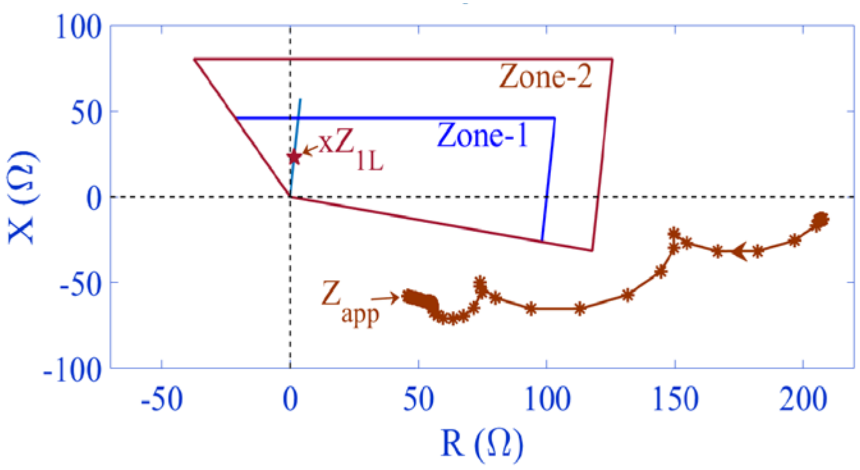
- For phase-A-to-ground fault:

$$Z_{app} = \frac{V_{AM}}{I_{AM} + K_0 I_{0M}}$$



❖ With YgYg type connection:





Challenges with Distance Protection

Effect of Interfacing Transformer Configuration

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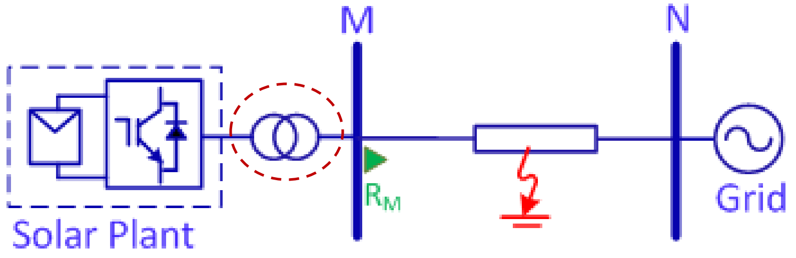
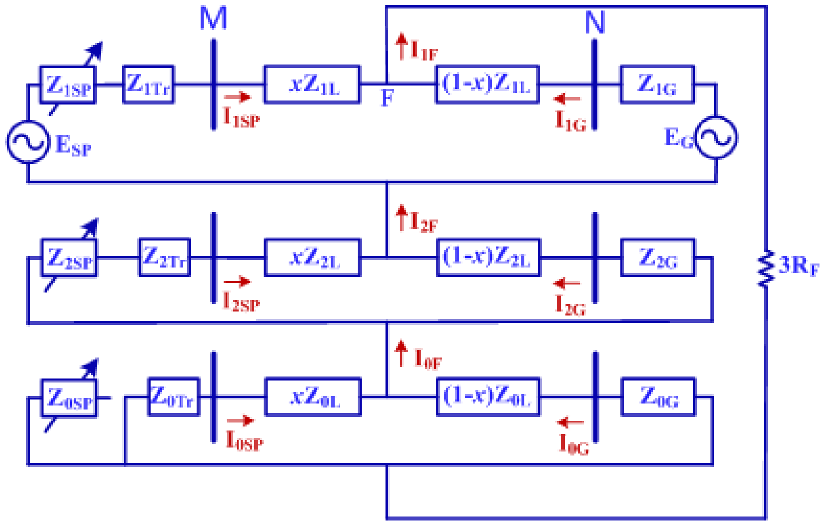
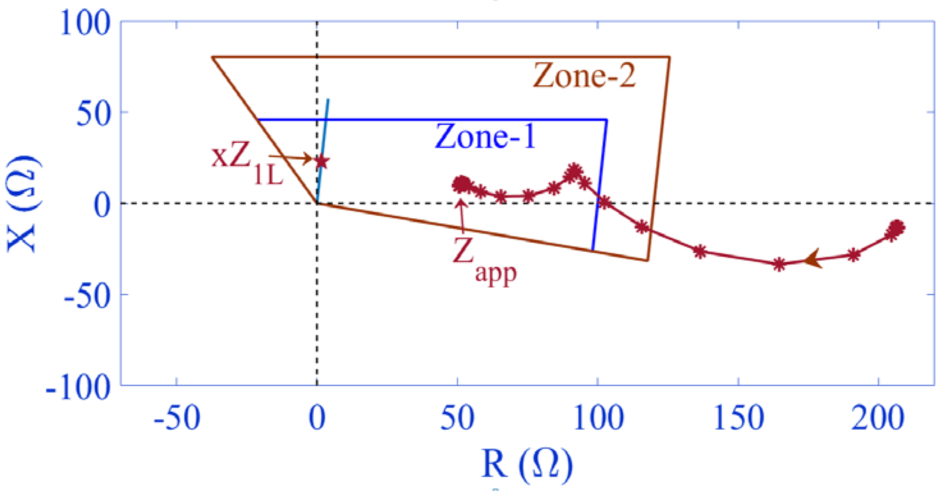


❖ With dYg type connection:





- Performance of distance relay is less affected with dYg type connection

Islanding detection

(i) Passive methods-ROCOF, dV/dT, (ii) Active Methods-harmonic injection, Active frequency drift—try to change the current waveform frequency

- Typically the setting of the ROCOF relay is set to about 0.1–0.2 Hz/s. However, a loss of a large generator on the system or the connection of a large load also causes a similar frequency excursion and may cause the ROCOF relay to operate.

Synchrophasor based technique--

SEL-451

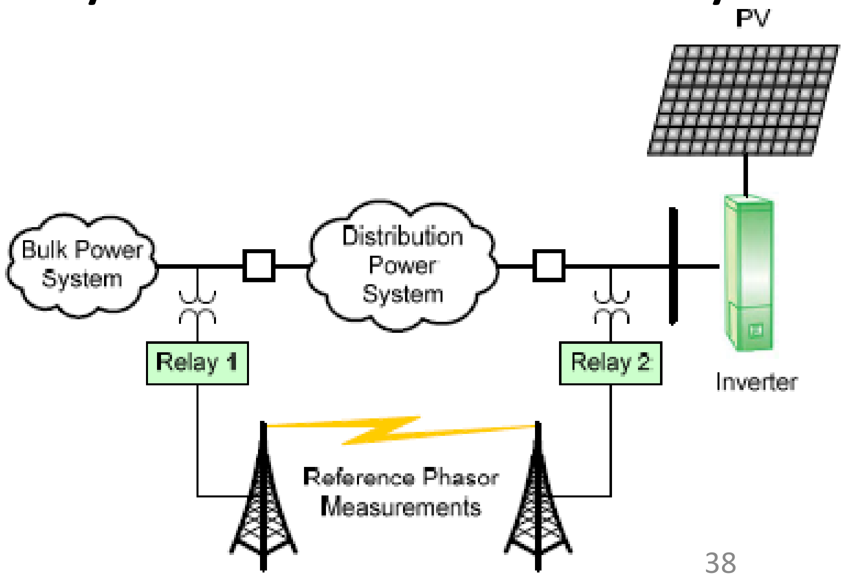
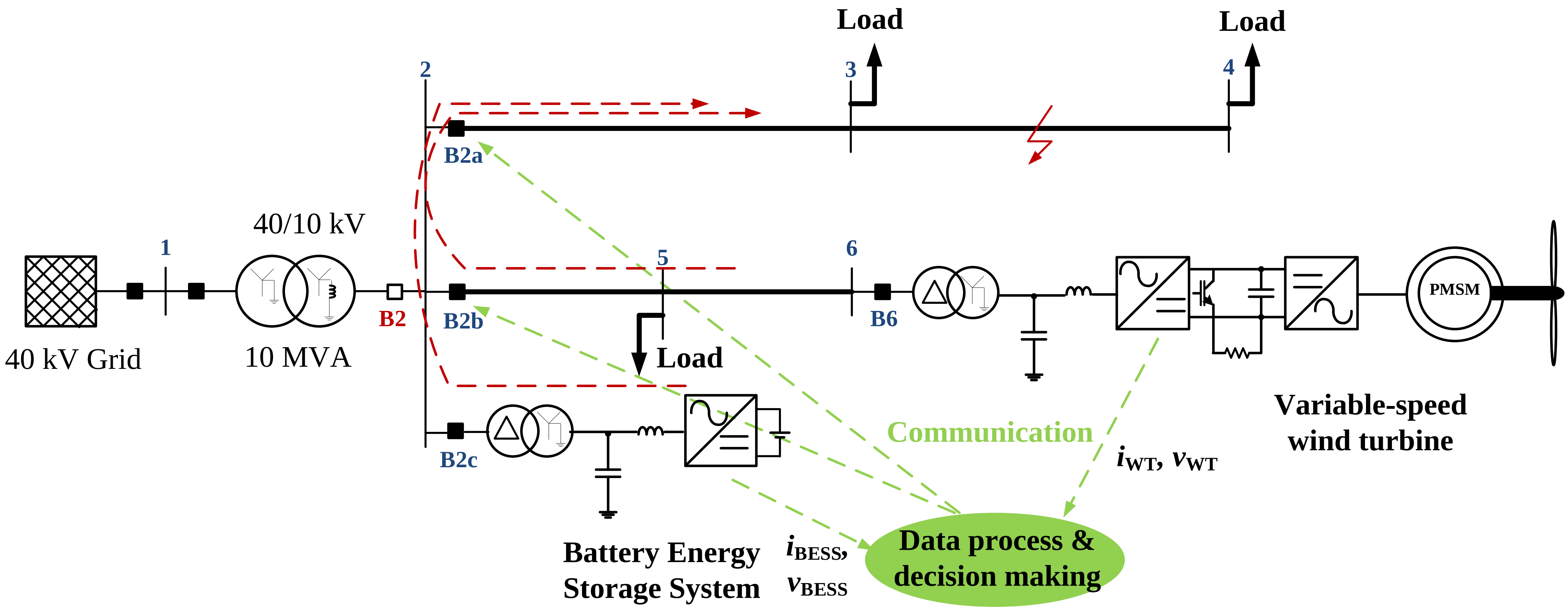


ABB--Centralized Adaptive protection scheme for microgrid



Conclusions

- Functionality of Renewable sources--
- Limitations of conventional protection schemes--Current based protection—Directional, Distance….
- Scope for new developments- new principles in protection schemes
- **CIGRE Protection Task Force– on Characterizing source during fault**
- ***Not limited to Microgrid-***

Contributed by–

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Thank You