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2019 Microgrid R&D Program Meeting

Networked Microgrids: System Protection Constraints

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Outline

- Review of Existing Tools and Protection Projects
- Protection of Networked Microgrids
- Constraints for Protection Design in Networked Microgrids
- Integration of Protection Constraints with OD&O
- Validation

Previous Deliverables

Sandia National Labs	Oak Ridge National Lab
Report on existing microgrid design tools	Report on state of the art microgrid protection methods

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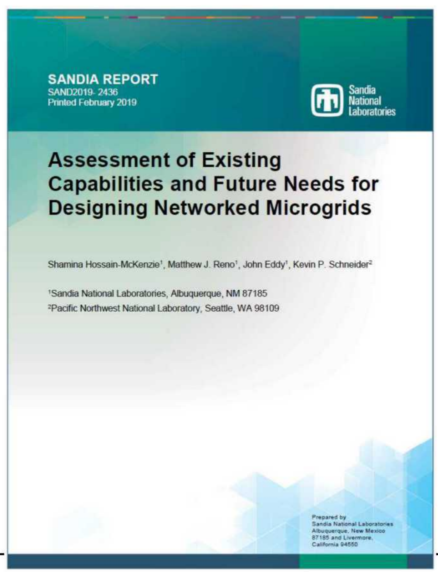
Report on existing microgrid design tools

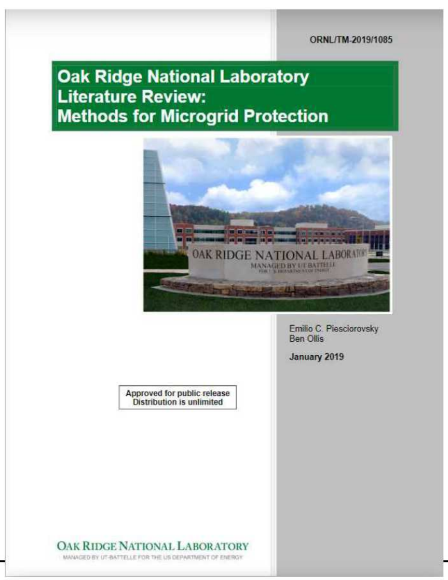
- Surveyed MDT, DER-CAM, ROMDST, MADRA, Reopt, and LPNORM
- Current design tools are limited in their capabilities for multiple microgrid controllers, protection design, and transient analysis.



Oak Ridge National Lab

Report on state of the art microgrid protection methods

- Surveyed 15 microgrid projects across North America
- No consensus on protection method across projects



Overview

- Objective: Incorporate protection considerations into networked microgrid design
- Networked microgrid designs must be protectable if industry is to adopt them. Wide variety of protection options
  - Example: Overcurrent/fuses vs. Communication based approaches
- Protection can be a significant portion of a microgrid's cost, so optimization with cost as an objective should consider protection
- First networked microgrid design effort to include protection considerations

Networked Microgrid Protection

- Differences for networked microgrid protection than microgrid protection
  - Networked microgrids may involve utility assets – this changes the rules and standards for protection
  - Potentially multiple owners with the requirement to coordinate communications and controls for adaptive and pilot protection
  - More variations in topologies and reconfigurations
  - Each microgrid may involve different types of generation
  - Switching transients (inrush) when connecting islanded microgrids to additional loads or other microgrids
- This project considers existing microgrid protection techniques (leveraging other DOE research), but the protection schemes may have to be modified to address these differences

Approach

- Objective to develop a general method for optimally placing protection equipment based upon constraints such as cost, coordination requirements, and fault current limits
- Do not attempt to rigidly define a networked microgrid protection system that will work for all
- Supply constraints to optimization so that tool does not produce a design that is infeasible to protect
- Develop optimization constraints for different protection functions and schemes:
  - 50 (instantaneous overcurrent), 51 (timed overcurrent), 87 (differential protection), 27 (undervoltage), 59 (overvoltage), etc.
  - Example: How far apart do the protection elements (50) need to be to ensure coordination?

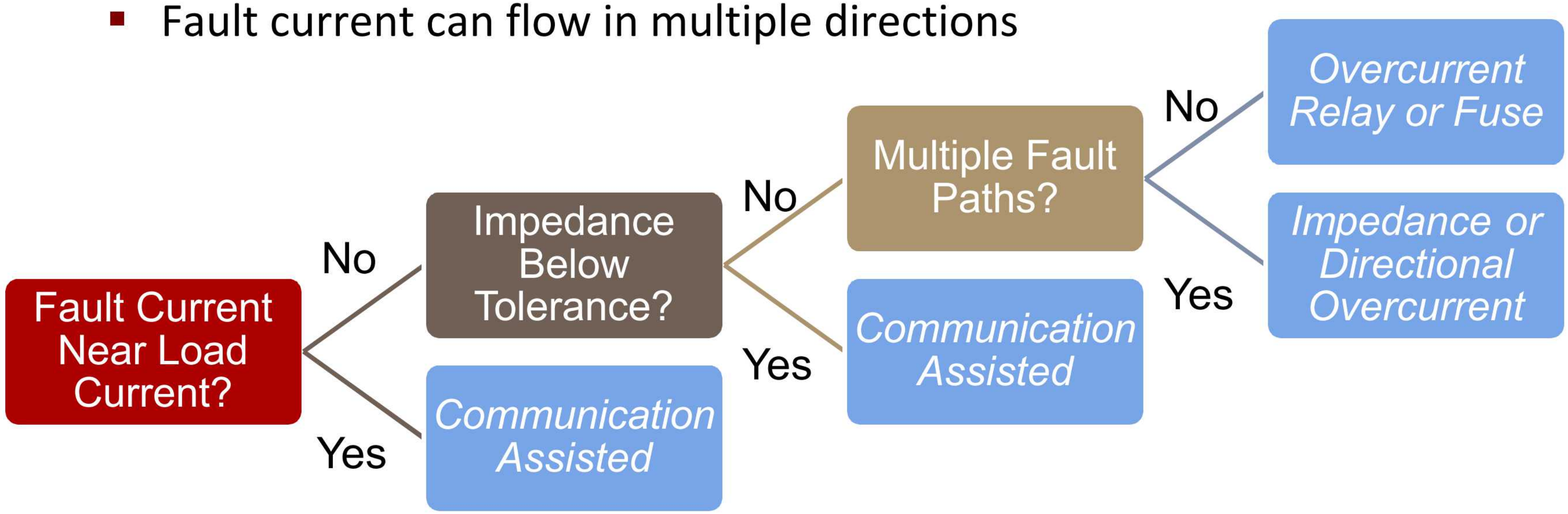
Approach (cont.)

- Develop cost estimates based on scheme:
  - Differential, Direct Transfer Trip, Pilot Schemes, etc.

- The product of the optimization will not be a design for a protected system. A detailed protection system will still need to be designed (see validation section)

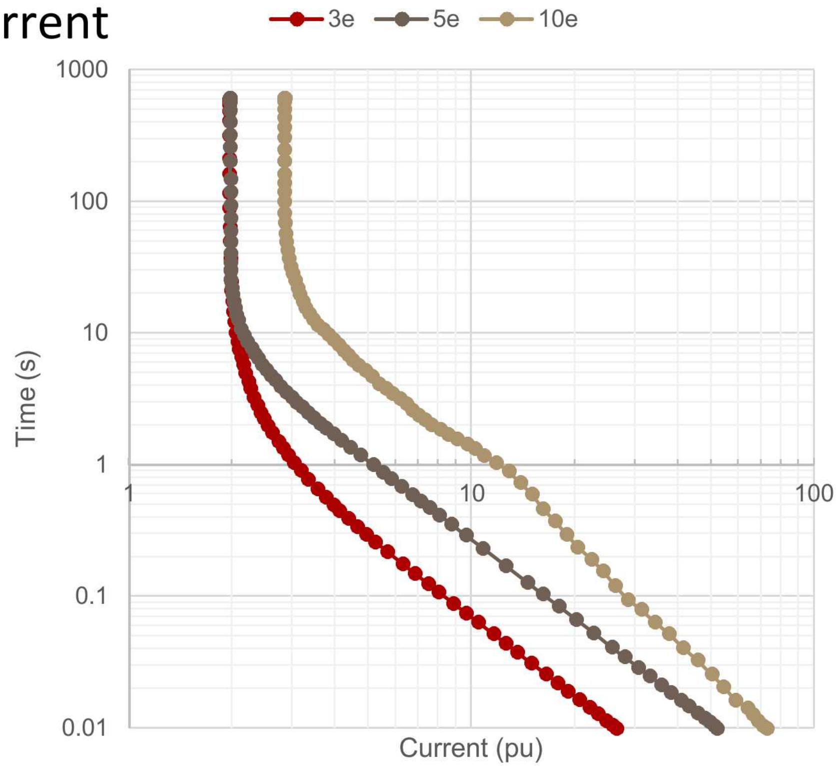
Protection Scheme Decision Tree

- Each microgrid topology is analyzed for fault behavior
- Limiting factors considered:
  - Available fault current less than 3x full load current
  - Network impedance between protective devices below the detection minimum
  - Fault current can flow in multiple directions



Available Fault Current Constraint

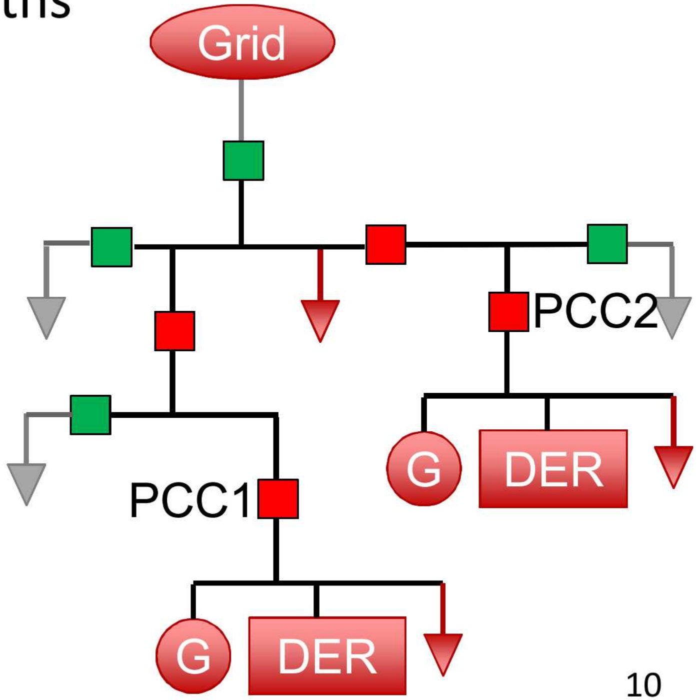
- If the available fault current in a microgrid is small, it becomes difficult to differentiate a fault from a load change
- Rules of thumb for fault current contribution:
  - Rotating generators – 10x rated current
  - Inverters – 1.5x rated current
- Initial target of 3x rated current



*S&C SMD Power Fuses, Minimum Melting, TCC 153-1 - https://www.sandc.com/en/support/time-current-characteristic-curves/

Number of Fault Paths

- Considered when fault current is significantly higher than load current and impedance between protective devices is larger than the detection minimum
- Radial systems with a single source are easier to protect
- Meshed networks or multiple generation buses can cause fault current to have multiple directions and paths
- Coordination is difficult without directional overcurrent capabilities or using impedance protection
- Traditional overcurrent or fuses can be used when only one path exists



Distance Constraint

- The ability of relays to distinguish faults inside their protection zone and an adjacent zone is limited by:
  - The accuracy of the relay and CT
  - The resolution of the trip settings
- The distance threshold is derived from the fault current levels and the protection equipment specifications

For coordination on a radial circuit with radial flow:

$I_{PU\_0} > I_{PU\_1} > \ldots > I_{PU\_n}$

Minimum detectable current ΔI_{MIN} is the greater of:

$K_{SR} * K_{CT}$ (Setting resolution * CT ratio)

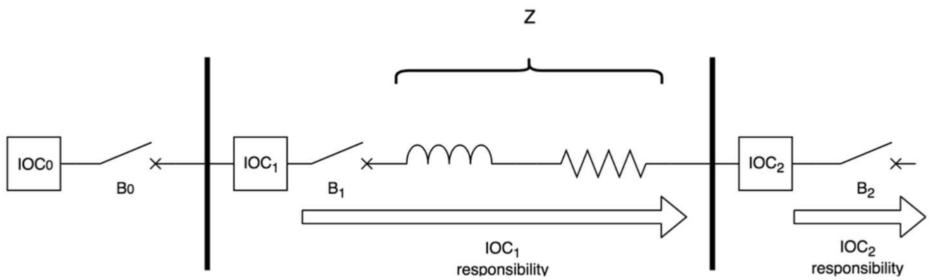
$K_{CTA} * I_{F\_n}$ (CT Accuracy * Fault Current)

$K_{CTA} * I_{PCT}$ (same as above max current is assumed)

Minimum Impedance in terms of known quantities is given by:

$Z_{MIN} = \Delta I_{MIN} * Z_1^2 / (V_S - \Delta I_{MIN} * Z_1)$

Other constraints: minimum relay pick-up settings, CT accuracy range, etc.



IOC_0 – Feeder IOC element (often owed by transmission)

IOC_1 – First IOC element for coordination

IOC_2 – First downstream IOC element for coordination

$B_0, B_1, \ldots, B_n$ – Breakers controlled by IOC elements

I_{PU_n} = Pickup current for IOC_n

I_{PCT} = Current transformer primary rating

I_{SCT} = Current transformer secondary rating

K_{CTA} = CT accuracy

K_{SR} = Pick-up dial setting resolution

K_{CT} = I_{PCT} / I_{SCT}

Z_S = Source Impedance

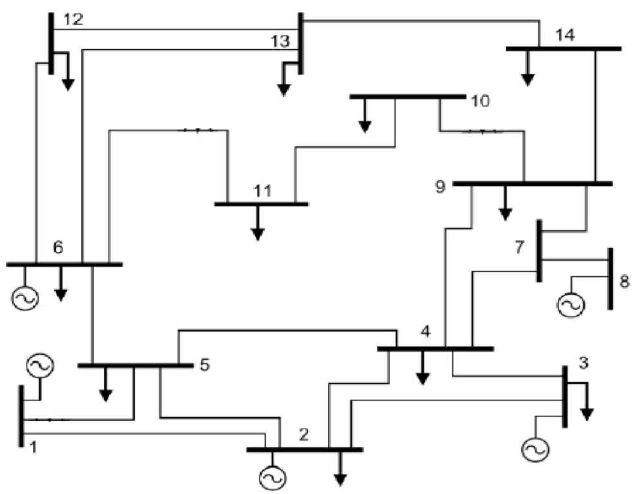
Z_n = Series impedance from source to IOC_n

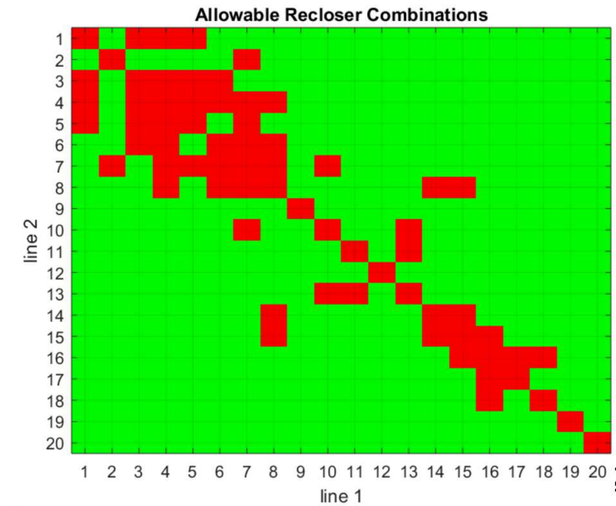
I_{F_n} = Fault current at IOC_n

Distance Constraint Implementation

- The distance constraint applies to the investment variable $w_{i,j}^{s} \in \{0,1\}$ - indicating if a switch is built on line (*i,j*). If $w_{1,2}^{s} = 1$ (adding a switch to line 1-2), then adjacent line switch investment $w_{2,3}^{s}$ may be too close: $w_{1,2}^{s} + w_{2,3}^{s} \leq 1$
- Process the network model and the bus admittance matrix $Y_{bus} \in \mathbb{C}^{n \times n}$
- Let $\wp_{a,b}$ be the shortest path (impedance) from line a to line b.
  - For radial systems, there is a single path, but meshed systems will have many potential paths.
- Once these paths have been determined, any pair with a shortest path impedance of less than Z_{min} will classified as an **invalid pair**.
- Using the Impedance-Based Recloser Proximity Constraint Determination Algorithm, the following constraints are determined for the IEEE 14 bus system

$w_3^s + w_1^s \leq 1$
$w_4^s + w_1^s \leq 1$
$w_4^s + w_3^s \leq 1$
$w_5^s + w_1^s \leq 1$
$w_5^s + w_3^s \leq 1$
$w_5^s + w_4^s \leq 1$
$w_6^s + w_3^s \leq 1$
$w_6^s + w_4^s \leq 1$
$w_7^s + w_2^s \leq 1$
$w_7^s + w_4^s \leq 1$
$w_7^s + w_5^s \leq 1$
$w_7^s + w_6^s \leq 1$
$w_8^s + w_4^s \leq 1$
$w_8^s + w_6^s \leq 1$
$w_8^s + w_7^s \leq 1$
$w_{10}^s + w_7^s \leq 1$
$w_{13}^s + w_{10}^s \leq 1$
$w_{13}^s + w_{11}^s \leq 1$
$w_{14}^s + w_8^s \leq 1$
$w_{15}^s + w_8^s \leq 1$
$w_{15}^s + w_{14}^s \leq 1$
$w_{16}^s + w_{15}^s \leq 1$
$w_{17}^s + w_{16}^s \leq 1$
$w_{18}^s + w_{16}^s \leq 1$





Protection Constraint Integration With OD&O

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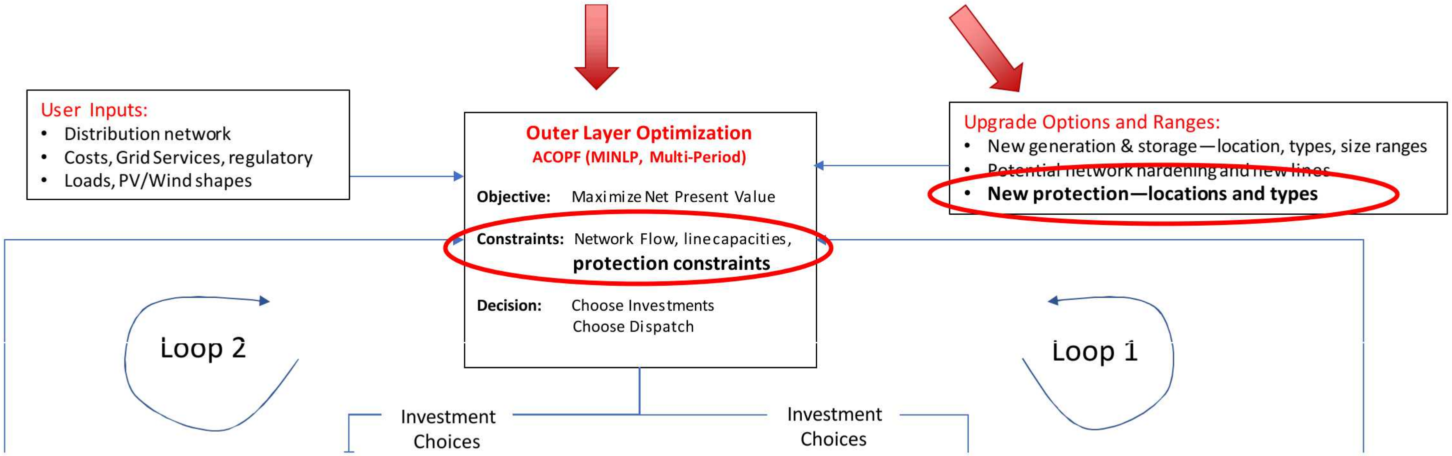
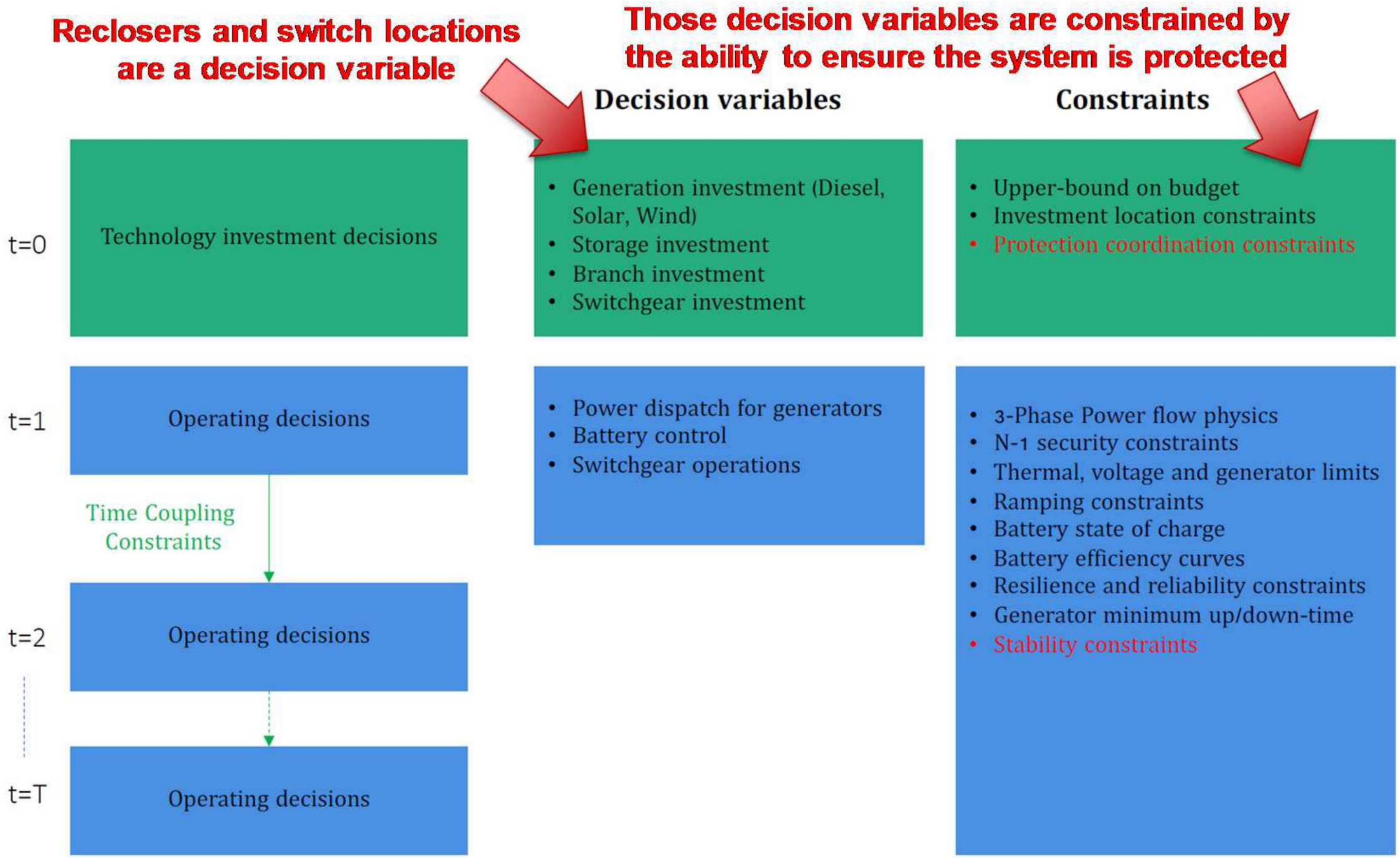
- Protection design determines:
  - Investment options – protection devices, protection schemes
  - Costs of the protection investments
  - Constraints of the potential protection investment locations
- Protection constraints apply to the outer problem of OD&O
  - Those investment decisions of protection devices feed into the OD&O inner problem (optimal reconfiguration for SAIFI and resilience)
  - The inner problem assumes that protection operates and is correctly coordinated, isolating as little of the network as possible



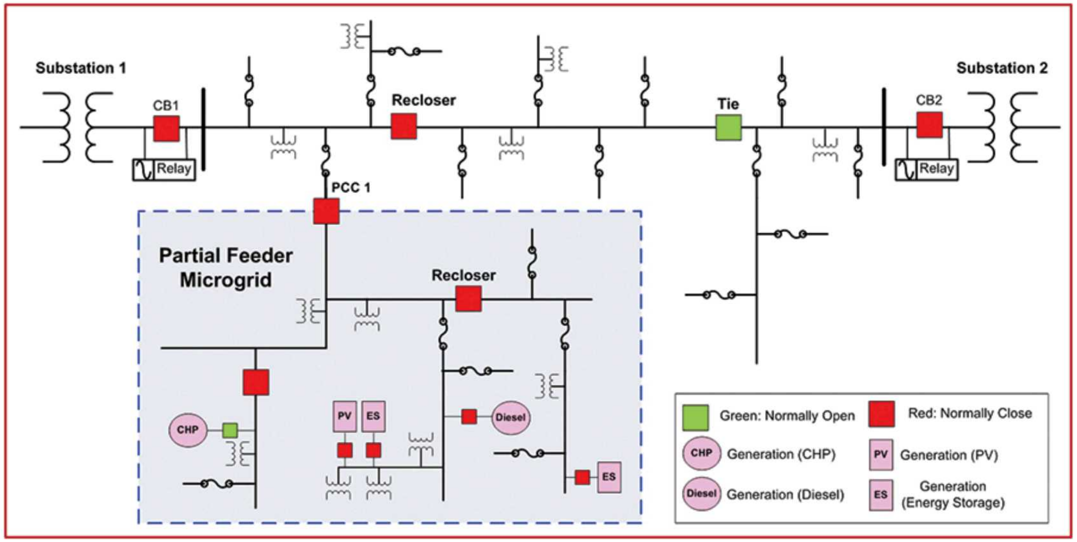
Protection Investment Problem

- Based on the network Y_{bus} and the selected protection scheme:
  - Add protection constraint to OD&O optimization in the form $P \cdot w^s \leq 1$
  - Determine costs associated with that protection scheme



Validation

- Once the tool creates a design, a detailed protection system will need to be developed for that design
- The protection system will then be evaluated using simulation
- The constraints will be considered validated if an adequate protection scheme can be developed for design



QUESTIONS?