Oak Ridge National Laboratory

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Networked Microgrids: System Protection Constraints

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Outline

- Review of Existing Tools and Projects
- Protection of Networked Microgrids
- Approach to Protection Design
- Example Constraint for Protection Design
- Integration of Protection Constraints with OD&O
- Validation

Review of Existing Microgrid Design Tools

	REopt	MDT	ROMDST	MADRA	LPNORM	Proposed OD&O
Optimization of Design	X	X	X	X	X	X
Multiple Microgrid Controllers		/				X
Adding Lines and Hardening Lines		X	X		X	X
Three-phase Unbalanced Power Flow					X	X
Microgrid Reconfiguration			/		/	X
Fault Analysis and Protection Design						X
Transients during Switching						X
Market Models	X	/	/	/		X
Regulatory Framework	X		/	X	/	X
N-1 Reliability Analysis of Microgrid		X	X	X	/	X
Resilience Scenario Analysis	X	X			X	X
Open-Source			X	X	X	X

Review of Existing Protection Projects

- Review of protection, microgrid protection, and networked microgrid protection projects
- Identification of needs
  - Protection for microgrids / networked microgrids is an emerging field. Unlike other protection arenas, there is little utility / industry experience to draw from.
- None of these are in an optimization framework
  - There is extra complexity in an optimization framework because there is not a fixed network topology. Optimal design is a fluidly changing network design that has to include protection
- ORNL Examples:
  - Applying model-based adaptive relay to EPB networked microgrid
  - Distributed FLISR and self-healing grids on Duke microgrid
- ORNL Deliverable – To be completed December 2018

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

- 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 from a protection standpoint
- 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.

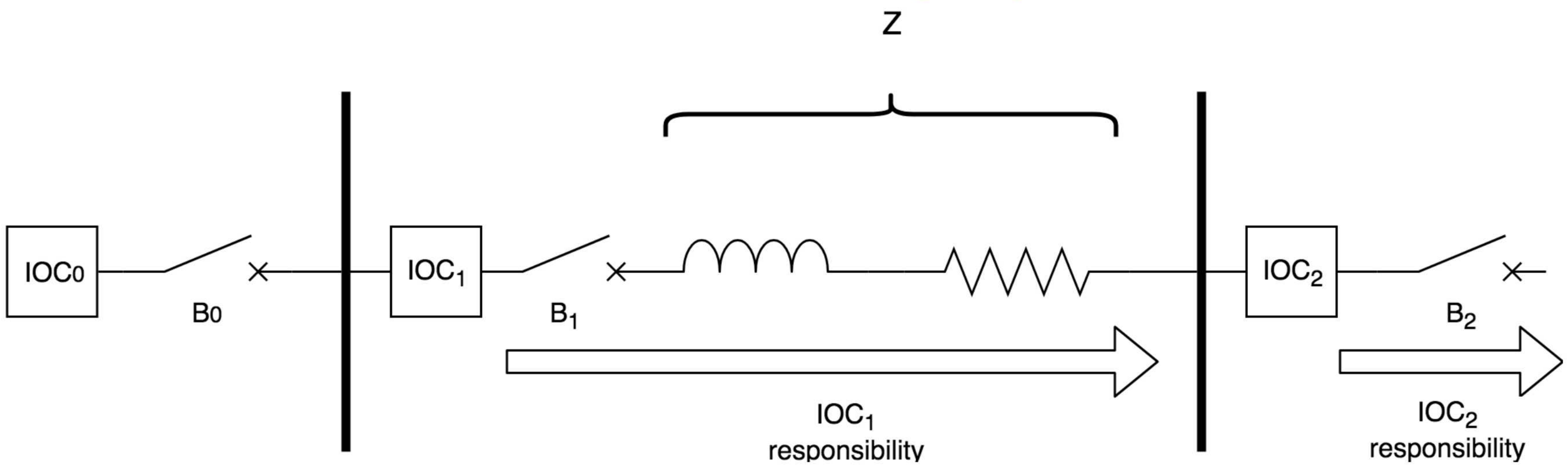
- The product of the optimization will not be a design for a protected system. A detailed protection system will still need to be designed (see validation section)

Example formulation: Instantaneous Overcurrent (50)

- Determine the minimum distance between Instantaneous Overcurrent (IOC) elements on a radial system to add as a constraint to the design tool
- IOC elements may be part of reclosers, relays, etc.
- Simple example using a radial circuit with no downstream DER

Problem statement: How close can two IOC elements be such that the upstream IOC element does not trip for a fault downstream of the downstream IOC element?

Example formulation: Instantaneous Overcurrent (50)



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, …, 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

Example formulation: Instantaneous Overcurrent (50)

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.

Example formulation: Instantaneous Overcurrent (50)

For a fault current of 300 A and a CT accuracy of 5%, the minimum detectable current difference is 15 A (1).

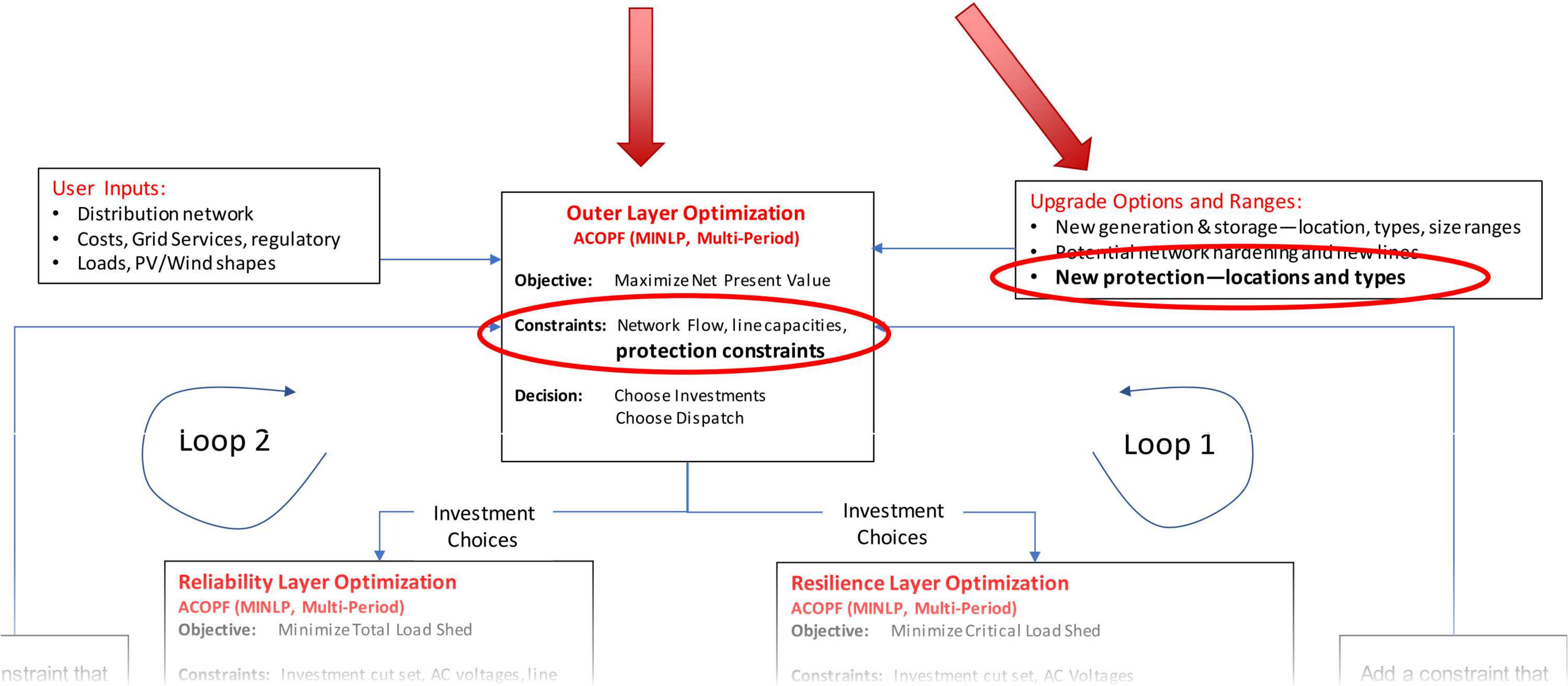
For a Setting Resolution of .1 and a CT ratio of 500/5 = 100, the minimum coordination current difference is 10 A (2).

At 300 A fault current on a 7.62 kV system, Z_1 = 7,620 / 300 = 25.4 Ω

Using the greater of (1) and (2), the minimum impedance between IOC elements is $15*25.4^2 / (7{,}620 - 15*25.4) = 1.33\ \Omega$

Protection Constraint Integration With OD&O

- Protection design determines:
  - Investment options – protection devices, protection schemes
  - Costs of the protection investments
  - Constraints of the potential protection investment locations



Protection Investment Problem

Reclosers and switch locations are a decision variable

Those decision variables are constrained by the ability to ensure the system is protected

		Decision variables	Constraints
t=0	Technology investment decisions	• Generation investment (Diesel, Solar, Wind) • Storage investment • Branch investment • Switchgear investment	• Upper-bound on budget • Investment location constraints • Protection coordination constraints
t=1	Operating decisions	• Power dispatch for generators • Battery control • Switchgear operations	• 3-Phase Power flow physics • N-1 security constraints • Thermal, voltage and generator limits • Ramping constraints • Battery state of charge • Battery efficiency curves • Resilience and reliability constraints • Generator minimum up/down-time • Stability constraints
	Time Coupling Constraints		
t=2	Operating decisions		
t=T	Operating decisions		

Example formulation: Instantaneous Overcurrent (50)

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- For overcurrent protection, distance constraint applies to the investment variable $w_{i,j}^{s} \in \{0,1\}$ - Binary variable 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 $w_{2,3}^{s}$ cannot equal 1 because it is too close
  - New constraint: $w_{1,2}^{s} + w_{2,3}^{s} \leq 1$
- Explicit constraint in outer problem for the subset of lines that can have switches together
  - Based on impedance matrix (***Y***), connectivity and impedances are known. Process the matrix for constraints of sections that cannot have switches at the same time

Investment variables:

$w_{ij}^{s} \in \{0,1\}$ - Binary variable indica

$w_{ij}^{l} \in \{0,1\}$ - Binary variable indica

$w_{i}^{b} \in \{0,1\}$ - Binary variable indicat

$w_{i}^{g} \in \{0,1\}$ - Binary variable indica

$g_{i}^{pv} \in \mathbb{R}$ - The amount of photovolta

$g_{i}^{w} \in \mathbb{R}$ - The amount of wind gener

Time dependent variables:

$w_{ij}^{t} \in \{0,1\}$ - Binary variable indica

$x_{g}^{t} \in \{0,1\}$ - active/inactive status f

$y_{g}^{t} \in \{0,1\}$ - start-up status for gene

$z_{g}^{t} \in \{0,1\}$ - shut-down status for ge

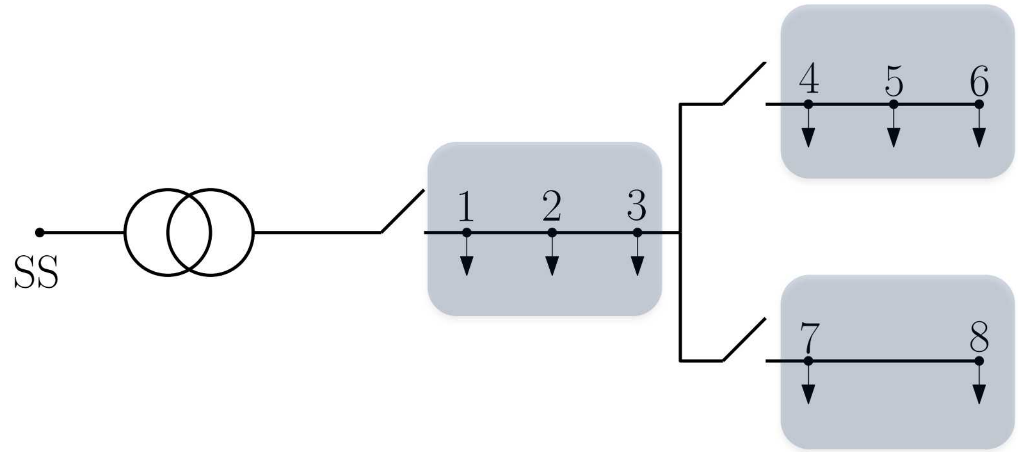
- This constraint is only for coordinating over-current protection
  - Other investment options, such as relays with communication-assisted protection ($w_{i,j}^{cs}$), will be added with different constraints
  - $c_{i,j}^{cs}$ (cost of investment $w_{i,j}^{cs}$) > $c_{i,j}^{s}$ (cost of investment $w_{i,j}^{s}$)
  - Additional constraints for communication requirements

OD&O Protection Constraint Data Flow

- Inputs
  - Circuit topology and impedance matrix (***Y***)
- Protection Constraint Calculation
  - Process ***Y*** for protection constraint matrix (***P***) combinations of lines that cannot both have switches
- Outputs
  - Add protection constraint to OD&O optimization in the form $P \cdot w^s \leq 1$
  - Constraint only impacts the investment variables (what are the investment choices, potential locations, and costs)
- Protection constraint is preprocessed and updated during the optimization when new lines are built

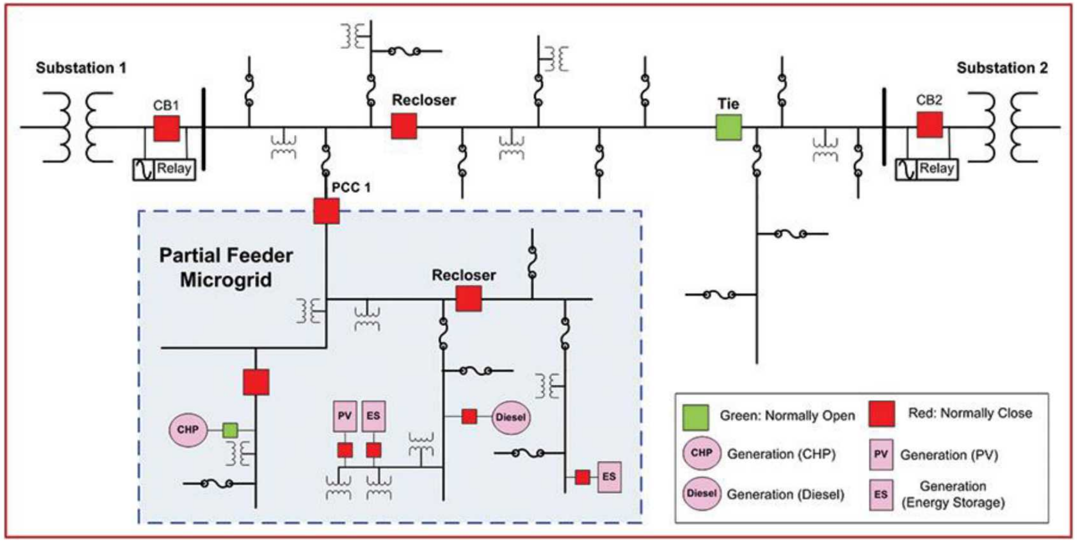
Protection and Reconfiguration Considerations

- Protection constraints apply to the outer problem of OD&O (investment decision)
  - 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 equipment vs. Distribution Automation equipment
  - Safety and isolation (protection) vs. reconfiguration
  - Reconfiguration with switches (automated, load break, fault break, off load)



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?