3/27/24

Transmission line protection scheme selection for HV lines with IBRs: Utility example

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Relay Settings & Config in Project Delivery Engineering

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Agenda

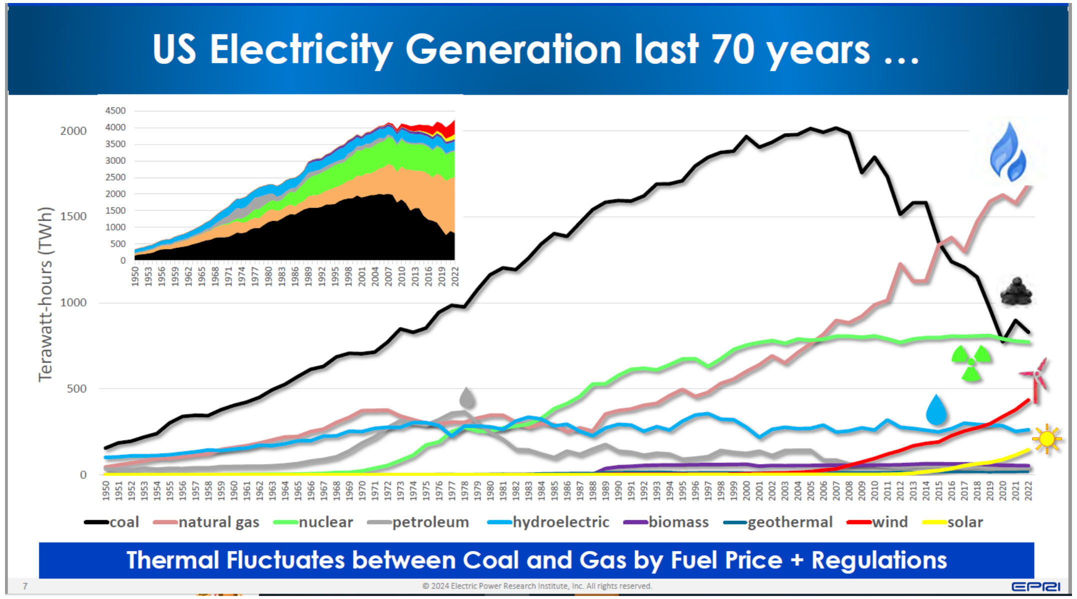
- The “What”- Defining the problem statement : Background and introduction
- The “Why” – Why do we need a tool: Protection scheme comparison
- The “How” – How do we apply the decision ladder: Utility project example
- Benefits – Project benefits and ability to scale up to apply to portfolio

01

Background & Introduction

Sections I and II of paper

ENERGY TRANSITION: US, MISO SOUTH, ENTERGY



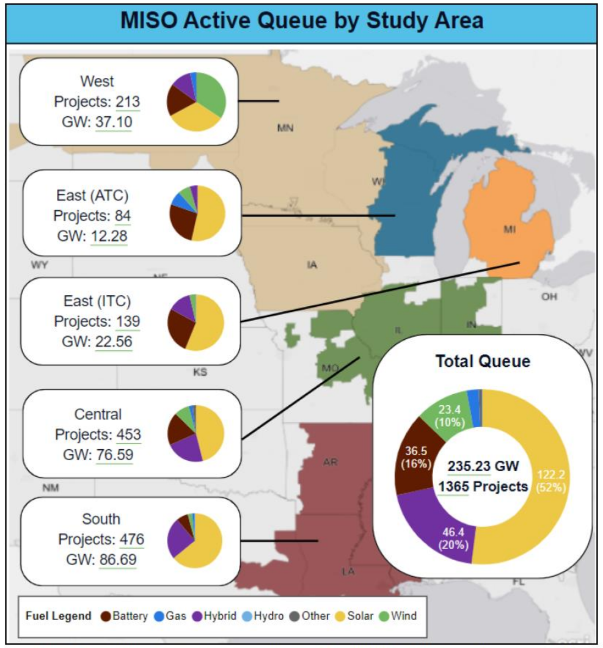
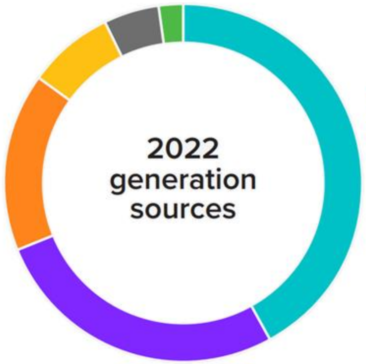


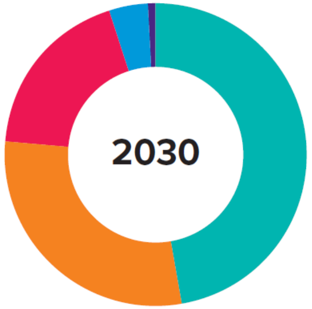
Figure 2.4-2: Active Generation Interconnection Queue by Fuel Type as of August 8 ,2023

Entergy's generation mix



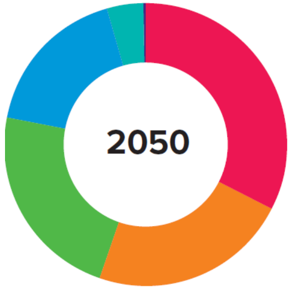
- 42% Modern gas
- 27% Nuclear
- 16% Purchases
- 8% Legacy gas/oil
- 5% Coal
- 2% Renewables

Utility generation mix percentages



53% Carbon-Free Energy

Gas	47%
Nuclear	29%
Solar	19%
Wind	4%
Hydro	1%



96% Carbon-Free Energy

Solar	33%
Nuclear	23%
ZCER	23%
Wind	17%
Gas	4%
Hydro	0.1%

OVERVIEW OF ENTERGY'S LINE PROTECTION PHILOSOPHY

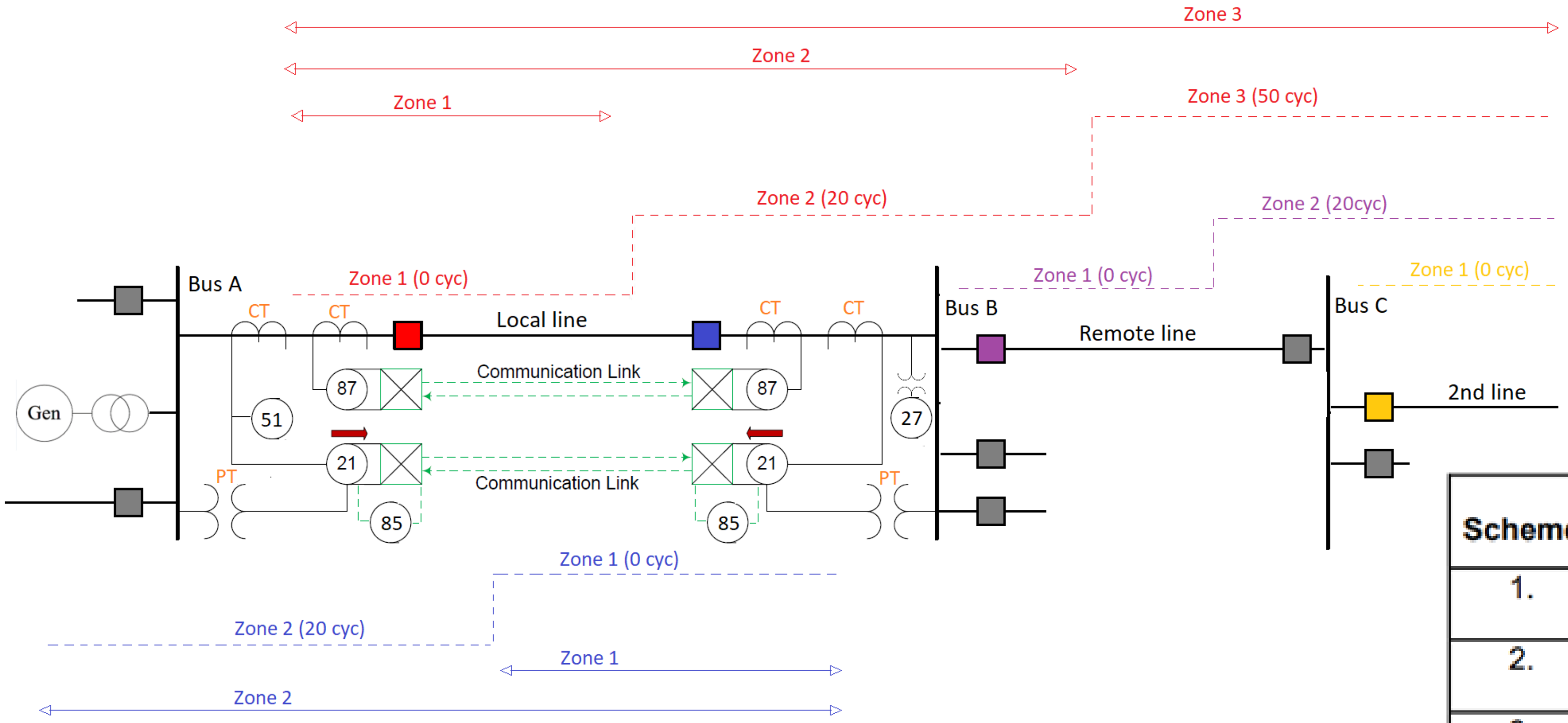
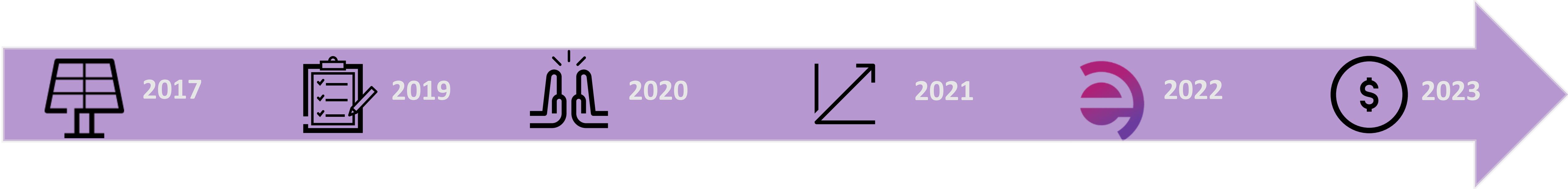


Fig. 1. Schematic summary of different line protection schemes

Entergy's line design standard options

Scheme	Pilot Protection Scheme Description
1.	21P/POTT/DTT , FIBER/MW/MUX 21BU /POTT/DTT, FIBER/MW/MUX
2.	21P/POTT/DTT, 87L BU/DIFF/POTT/DTT, FIBER/MW/MUX
3.	21P/POTT/DTT, 87L /DIFF/POTT/DTT, FIBER/MW/MUX
4.	87L /DIFF/POTT/DTT, FIBER/MW/MUX 87L /DIFF/POTT/DTT, FIBER/MW/MUX
5.	87L /DIFF/POTT/DTT, FIBER/MW/MUX
6.	21P DCUB/DTT PLC (3F) 21BU
7.	21P DCB PLC (ON-OFF) 21BU
8.	21P DCB PLC (ON-OFF) DTT PLC 21BU
9.	21P , 21BU , NO PILOT

TIMELINE SUMMARY OF SOLAR IBR RELAY CHALLENGES



2017

Entergy gets its first set of solar interconnect projects.

Engineering gets involved with writing scopes on the first batch of facility studies.

2019

Handful of projects go into SG4 and SG5.

Engineering documents lessons learned for future projects. Relay teams learn more on limitations of existing models, distance relays.

2020

TPD makes Engineering aware of the waves of MISO DPP projects in the next 3 years.

Based on lessons learned and volume, relay teams stack hands to switch to differential protection as a standard for IBRs.

2021

TPD receives 144 MISO DPP studies- 3x from 2020 cycle and 4x from 2019

Relay team standardizes and streamlines protection philosophy for interconnects.

2022

Entergy rebrands, launches Path to Premier with a focus on Leading in ESG and Advancing customer centricity

Application guide released for line protection (with a focus on distance elements) for IBRs with advanced logic to improve relay performance.

2023

MISO DPP list grows to 369. 2.5x from 2021 and 10x from 2019.

Project sponsors challenge scopes to be more efficient with project spend.

Relay team implements recommendations from vendor's application guide. Evaluates scaling up the solution.

PROTECTION CHALLENGES ON LINES WITH IBRS

IBR response to faults

- Managed by using fast switching of power electronics devices dependent upon manufacturer specific and often proprietary control system design
- Depends on pre-fault operating conditions, which in turn depends on variable factors such as weather
- IBRs may disconnect during external faults due to the sensitivity of harmonics, particularly in weak systems

Polarization

- Negative sequence polarization has been used as it is immune to load and mutual coupling from parallel lines. IBRs do not produce sufficient negative sequence.
- Source impedance depends on the IBR control system, the mho expansion can be anywhere on the R-X plane - threatening protection reliability

Model

- Manufacturers and utilities must perform detailed simulations to define voltage-current relationship

Directionality

- Phase angle is hard to determine due to lack of codes and compliance standards

Current

- Non-universal short circuit current characteristics
- Highly controlled resulting in low magnitude fault currents
- Low fault current jeopardizes the ability to have current supervision or fault detectors

Voltage

- Relationship between residual voltage and inverter current is non linear due to the controls within IBR

Impedance

- Distance based impedance relays cannot be applied on short lines
- Controlled current output increases the source impedance impairing the application of impedance relays
- A low short circuit current IBR appears as a high impedance source behind the relay for a forward fault resulting in high Source Impedance Ratio (SIR)
- Oscillating impedance seen by relays due to varying response from IBR can result in zone drop outs

How do we scope at a portfolio level-
(a) with scope, schedule and cost certainty
(b) without increasing risk to the system?

. . . Let's look at our options

02

Protection scheme comparison

Continuing Sections II of paper

DEFINING PROTECTION PRINCIPLES

- **Local trip**: ability to detect and clear faults at local terminal.
- **Dependability**: the degree of certainty that a relay or relay system will operate correctly.
- **Security**: the degree of certainty that a relay or relay system will not operate incorrectly
- **Selectivity**: max continuity of service with min system disconnection.
- **Speed**: minimum fault duration, consequent equipment damage and system instability.
- **Simplicity**: minimum protective equipment and associated circuitry to achieve the protection objectives.
- **Economics**: maximum protection at minimal total cost.

PROTECTION FUNCTIONS COMPARISON

Protection function	Local tripping		Dependability		Security		Selectivity		Speed		Simplicity		Economics	
Differential (87)	✓	—	✓	—	✓	—	✓	—	✓	—	✓	—	X	▼
Distance (21) + Dual pilot (85) + Advanced logic	✓	▼	✓	▼	✓	—	✓	—	✓	—	X	▼	X	▼
Distance (21) + Pilot (85)	X	▼	X	▼	X	▼	✓	—	✓	—	✓	—	✓	—
Overcurrent (51 and 67)	X	▼	X	▼	X	▼	X	▼	X	▼	X	▼	✓	—
Undervoltage (27)	✓	—	✓	—	✓	—	X	—	X	—	✓	▼	✓	▼

Favorable   Acceptable   Unfavorable

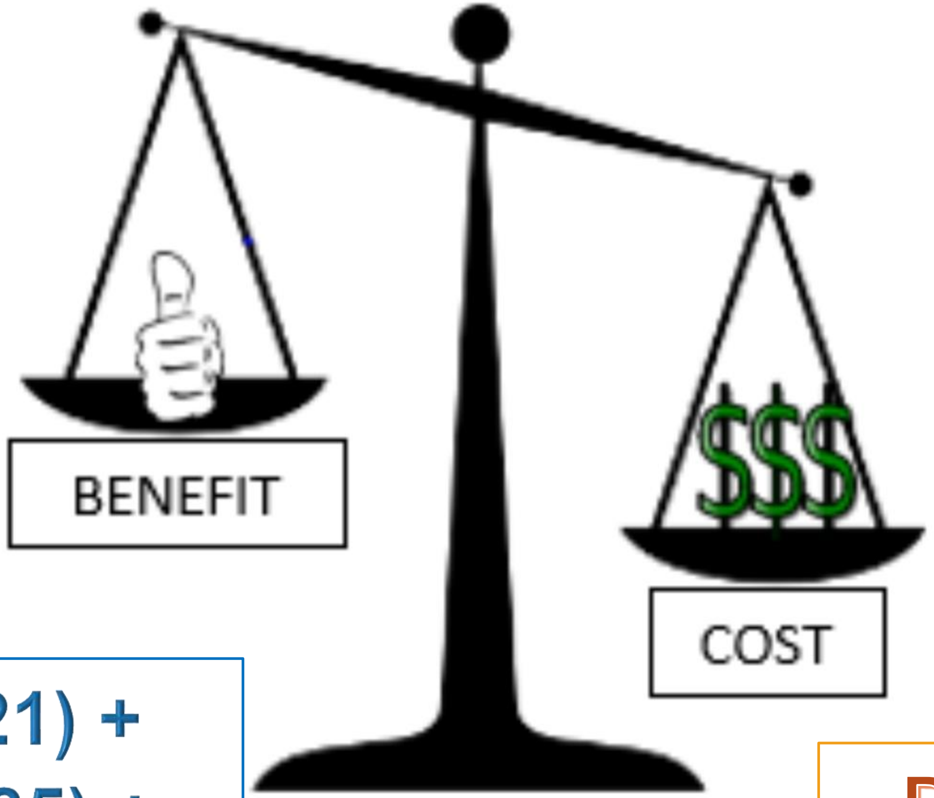
PROTECTION SCHEME COMPARISON FOR DIFFERENT CONTINGENCIES

Relay type	N-1 conditions											
	Loss of 1 relay		Loss of 1 comm channel		Loss of 1 relay function		Loss of 1 PT		Loss of 1 DC set		Loss of 1 line source	
	Contingency	Backup	Contingency	Backup	Contingency	Backup	Contingency	Backup	Contingency	Backup#	Contingency	Backup
Dual 87L-DIFF/POTT/DTT, Fiber/Mux,	87L	87L	Comm on diff	Comm on pilot and P2	Differential	Step distance	Loss of line PT	Differential will still work	Loss of station DC	Remote step distance	Solar only source to the fault	Differential trip
21P1, 21P2, POTT/DTT Fiber/Mux	21P	21BU	Comm on P1	Comm on P2	Step distance	Remote step distance	Loss of line PT	Remote step distance	Loss of station DC	Remote step distance	Solar only source to the fault	Echo conversion to trip
21P, POTT/DTT Fiber/Mux, 21BU	21P	21BU	Comm on P1	No Back up	Step distance	Remote step distance	Loss of line PT	Remote step distance	Loss of station DC	Remote step distance	Solar only source to the fault	Echo conversion to trip
21P/21BU No pilot	21P	21BU	NA	NA	Step distance	Remote step distance	Loss of line PT	Remote step distance	Loss of station DC	Remote step distance	Solar only source to the fault	Non directional under voltage

*- Schemes using DCB or schemes not using 4xx relays are at additional risk for N-1 conditions.
- Assuming most stations only have 1 DC battery set.

Favorable | Acceptable | Unfavorable

ENGINEERING DECISION



Distance (21) +
Dual pilot (85) +
Advanced logic

Dual differential
(87L)

03

Decision points for alternate protection schemes

Sections III of paper

DECISION POINTS FOR ALTERNATE PROTECTION SCHEMES

- While 87L (differential) is an excellent transmission line protection scheme for systems with IBRs when there is existing reliable communication scheme to support the scheme. Alternatives must be explored in cases when panel replacements with dual differential scheme does not make economic sense.
- Below is a proposed decision ladder to help with scheme selection and help reduce the cost of upgrades for projects with IBRs

Decision ladder for IBR interconnect protection

Order of confidence to rely on distance panel for IBRs
Ability to not lose a strong source for the loss of one breaker or for a single contingency
Dual POTT scheme without SPOF
Dual differential protection on remote lines closer to IBRs
IBR GSU with a strong ground source
Ability to leverage vendor recommended advanced logic
At least one end of either remotes is connected to the grid providing "favorable" conditions
Strong grid
Electrically long lines
No mutual lines impacting apparent ground impedance
No known long term system constraints
No existing protection deficiencies

Project scope: Utility example

Project scope summary-

- As part of generator interconnection agreement (GIA), Entergy Mississippi LLC (EML) entered into an agreement with MISO and a customer.
  - Seeking interconnection for a 100 MW solar photovoltaic generator to connect on Entergy's 115kV transmission line.
  - The interconnection of the customer resulted in the need of a new three breaker switch station, to be owned and operated by EML.

Facility study shortfalls-

- The facility study at the time only included the point of interconnect station and the immediate remote ends.
  - Facility study process failed to identify the need to expand the scope of study beyond immediate remote station (remote bus 1), which is an in-and-out station, to the next bulk station (station with 3 or more sources)
    - As part of PEP, relay impact on line 3 was analyzed.
  - Facility study process also failed to include transfer breaker at remote end (remote bus 2) and the impact of interconnection while fed through transfer/bypass breaker.
    - As part of PEP, relay impact for transfer breaker (at remote bus 2) was also analyzed.

PROJECT HIGH LEVEL OVERVIEW

Remote of remote bus

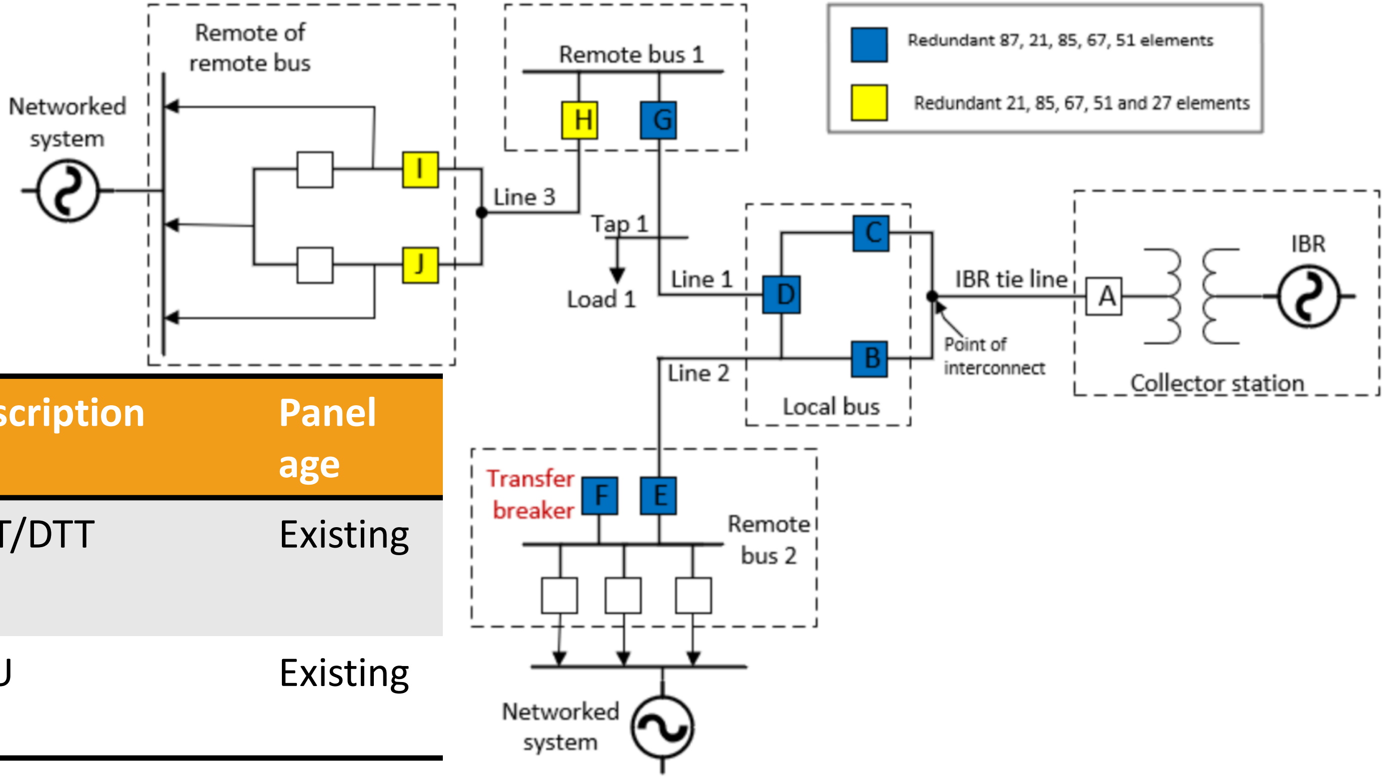
Panel location	Panel description	Panel age
Breakers I & J (Line 3)	21P1, 21P2 POTT/DTT	Existing

Remote bus 1

Panel location	Panel description	Panel age
Breaker H (Line 3)	21P1, 21P2 POTT/DTT	Existing

Local bus

Panel location	Panel description	Panel age
Bkr B&C (IBR tie)	Dual 87L-DIFF/POTT/DTT	New
Bkr C&D (Line 1)	Dual 87L-DIFF/POTT/DTT	New
Bkr B&D (Line 2)	Dual 87L-DIFF/POTT/DTT	New



Remote bus 2

Panel location	Panel description	Panel age
Breaker E, Line 2	21P, POTT/DTT 21BU	Existing
Transfer bkr F	21P, 21BU No pilot	Existing

04

Benefits of decision ladder

Sections IV of paper

DECISION LADDER USAGE: PROJECT EXAMPLE

Remote bus 2 transfer breaker panel:

- Transfer breaker panel did not have any comm scheme reducing our confidence to use existing panel without hardware upgrades.
- Grid management's preference was to operate any line, including line 2 on bypass when needed without any protection limitations for different system configurations.
- This will avoid radial conditions and reliability risks to Entergy customers.
- This flexibility will also not jeopardize the reliability of interconnection points tapped on the line.
- Bypass panel mirroring the protection scheme of the line panel was the most preferred solution for maintenance.
- Benefits of panel upgrade to standard option outweighed the cost of major hardware upgrades on existing panel.

Line 3 panel:

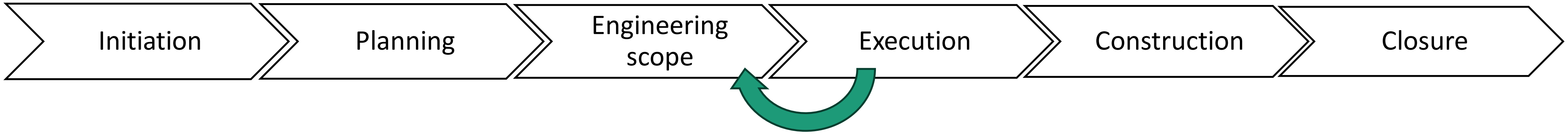
- Line 3 panel checks all the boxes on proposed confidence ladder for us to retain the existing panel and apply settings revisions to provide acceptable protection.
- Per recommendation in application guide, Station C-Station D will rely on echo conversion to trip logic on weak infeed for ("unfavorable") conditions where it cannot detect and trip for a fault locally.
  - Station C would have to rely on undervoltage trip as a backup function.

This will result in significant cost savings of over **$500k**

Applicability	Order of confidence to rely on distance panel for IBRs
✓	Ability to not lose a strong source for the loss of one breaker or for a single contingency
✓	Dual POTT scheme without SPOF
✓	Dual differential protection on remote lines closer to IBRs
✓	IBR GSU with a strong ground source
✓	Ability to leverage vendor's advanced logic app guide
✓	At least one end of either remotes is connected to the grid providing "favorable" conditions
✓	Strong grid
✓	Electrically long lines
✓	No mutual lines impacting apparent ground impedance
✓	No known long term system constraints
✓	No existing protection deficiencies

BENEFITS TO PROJECT PORTFOLIO

- ✓ Communicate uniformly across different customers interconnecting.
  - ❑ Provides scope, cost and schedule certainty on projects



- ✓ Clear strategy for fast paced, high volume engineering scoping.
- ✓ Tool to leverage in risk vs benefit discussion for different project solutions.
- ✓ Easy to interpret tool for leaders, project managers and other stakeholders.
- ✓ Helps drive scoping decisions with the ability to feed into automation tools.
- ✓ Provides basis for leveraging past capital investments without a blanket solution that could be expensive.
- ✓ Helps project cost savings on the portfolio of projects which helps customers.

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