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EPRI's Integrated Grid Cost Benefit Analysis Framework

Modeling Distribution System Costs

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NREL Workshop: Benchmarking Distribution Grid Integration Costs under High Distributed PV Penetrations

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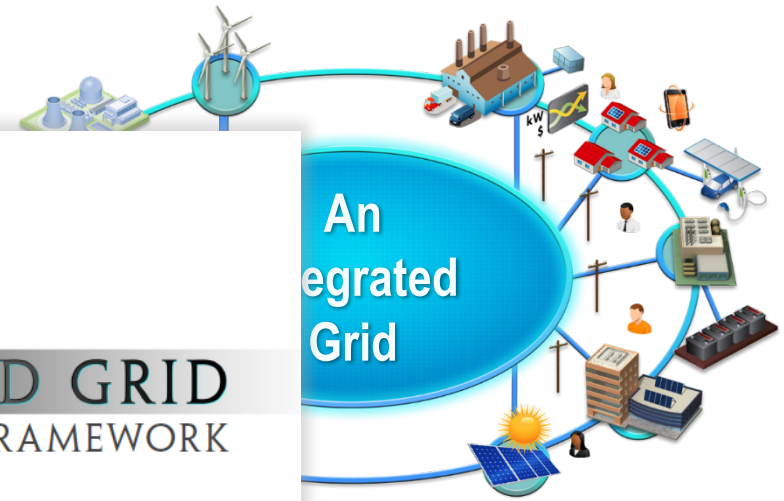
EPRI's Integrated Grid Initiative: The Foundation for a CBA Framework



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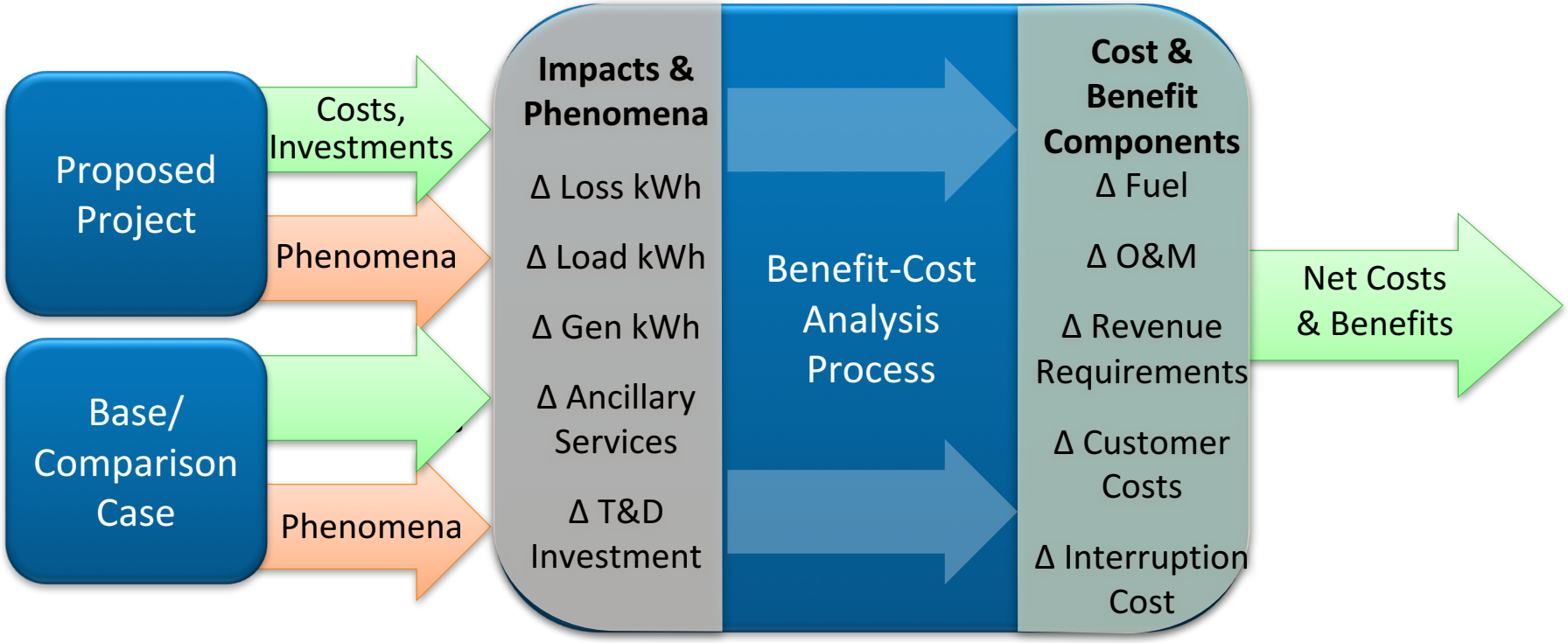
What do we mean by "Benefit-Cost Framework"?



A BCA "Framework" can be expressed in terms of impacts & phenomena to be included, or in terms of cost and benefit components.
A framework also specifies the perspective or point of view.

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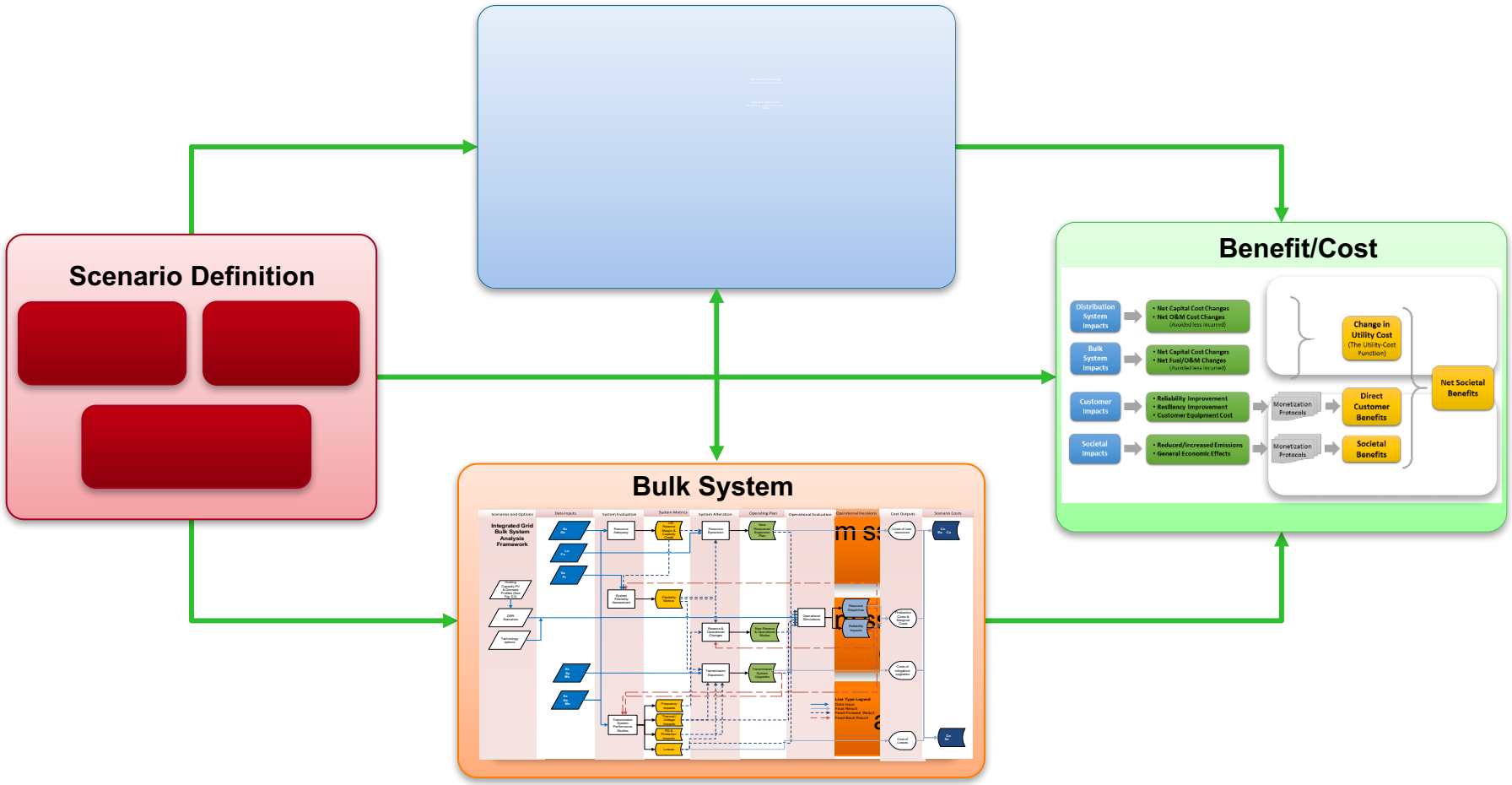
Integrated Grid Methodology

The Integrated Grid's benefit-cost framework contains both bulk system and distribution system elements.



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Categories of Costs and Benefits for Utilities, Customers and Society

Utility-Cost Function

- **Utility Operations**
  (people and how they do their jobs: non-fuel O&M, non-production assets, safety)
- **System Operations**
  (the power system and its efficiency: losses, combustion, dispatch optimization, emissions)
- **Utility Assets**
  (production assets required: GT&D)

Customer Perspective

- **Reliability & Power Quality**
  (frequency and duration of customer interruptions, harmonics, sags/swells, voltage violations)
- **Direct Customer Costs & Benefits**
  (equipment & other direct customer costs)

Societal Perspective

- **Environmental, Other Costs & Benefits**
  (environmental & other costs & benefits otherwise externalized)

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A General Benefit-Cost Analysis Approach

- BCA examines cost changes between at least two alternatives with different physical circumstances.
- Comparing the alternative with the base case reveals physical changes, or impacts. Changes in utility assets and/or expenses may result. Some costs are avoided, while others incurred. Market interactions (price, power flows) may be affected.
- In some cases customers are impacted directly, affecting quality of service. Customers may also affect the system with their DER.
- An analysis can be customer-oriented in utility-planning fashion, or can adopt a societal perspective.

Utility/Market Impacts

Change **in Asset Costs ($)**
[acceleration / deferral, Δ expected life, etc.]

Change **in O&M expenses ($)**
[Δ labor, Δ duty cycles, etc.]

Change **in Energy Costs (¢/kWh)**
[Δ fuel, Δ variable O&M]

AND/OR: Change **in Market Purchases**
[Δ Energy, Δ Capacity, Δ Ancillary Services]

Customer Impacts

Change **in Other Customer Costs**
[Value of Reliability, Power Quality, etc.]

Societal Impacts

Change **in Societal Costs/Benefits**
[Emissions, Economic Impacts]

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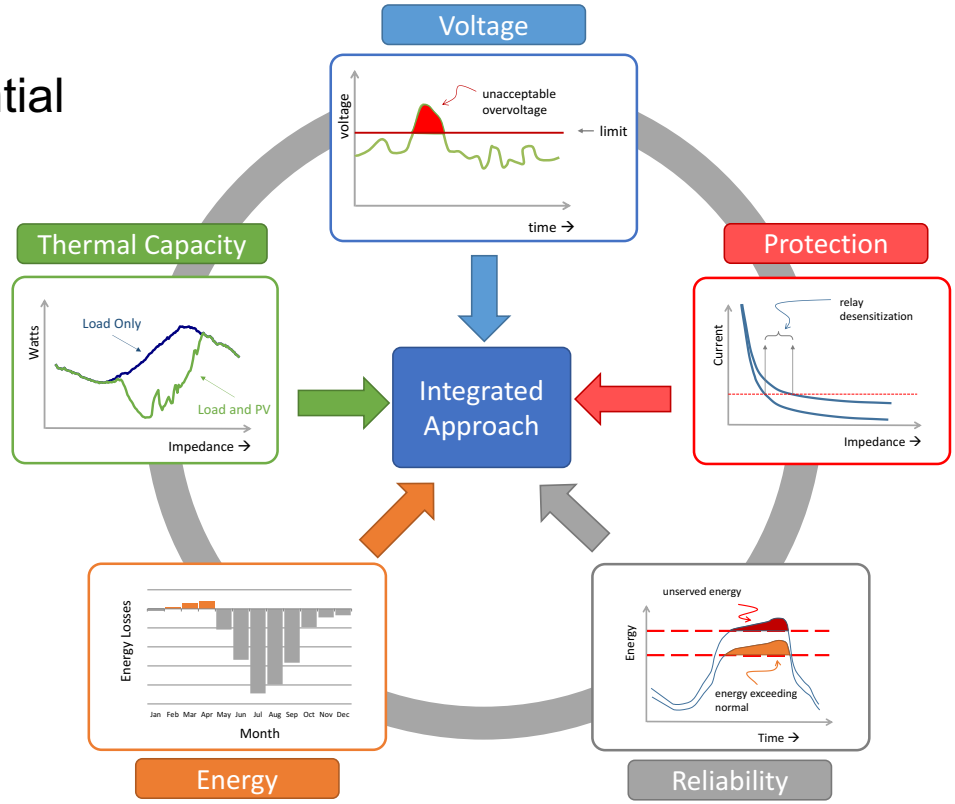
An Integrated Approach for Distribution Analysis

- Hosting Capacity Analysis
  - Voltage/Protection/Reliability components
  - Mitigation required to prevent potential adverse issues
- Thermal Capacity Analysis
  - Capacity component
  - Deferral of system upgrades
- Energy Analysis
  - Energy component
  - Change in losses/consumption
- Benefit-Cost Analysis
  - Benefit and/or cost implications of capacity and energy analyses at a given PV penetration level



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Analysis for Distribution Assessment

Analysis Topic	Area	Description
Transformer Deferral	Thermal Capacity	Analysis of the potential for PV to defer substation transformer upgrades by reducing net feeder demand
Energy	Feeder Losses	Analysis of the reduction in distribution line and transformer losses due to generation sources being located closer to the load
	Energy Consumption	Effect of customer-based PV on delivery voltages
Hosting Capacity and Mitigation	Feeder Voltage	Analysis of overvoltage deviation issues due to PV along with mitigation options and associated costs
	Thermal	Analysis of thermal loading issues due to potential reverse power flow with mitigation options and associated costs
	Feeder Protection	Analysis of protection coordination issues due to changes in fault current along with mitigation options and associated costs

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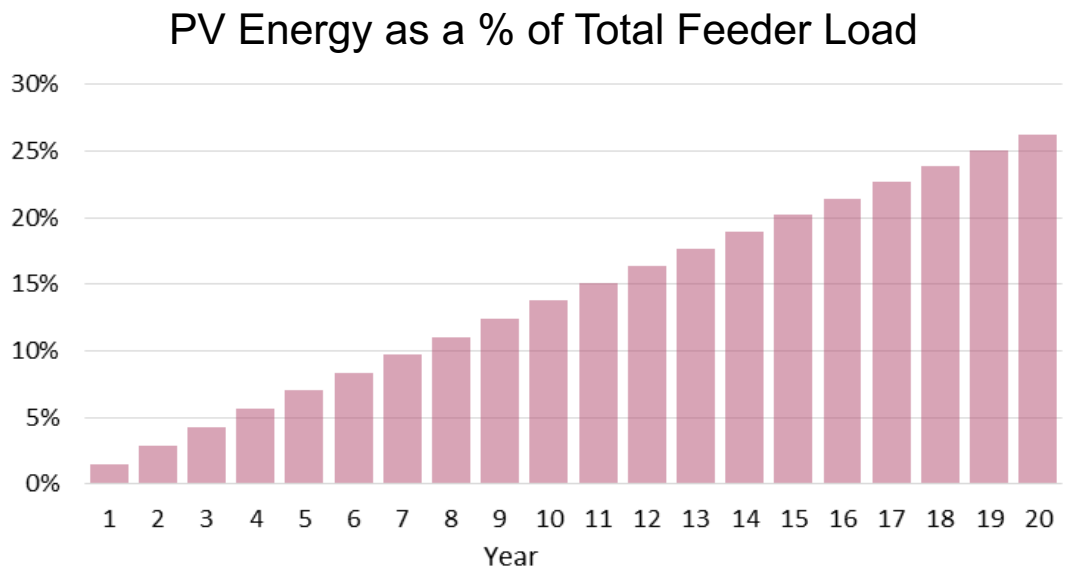
Example: PV's Impact on Distribution Plans

- Example is a 20-year rooftop PV scenario, high penetration, unguided location:



- Circuit analyzed with a detailed technical model; plans maintain voltage, protection, and thermal limitations

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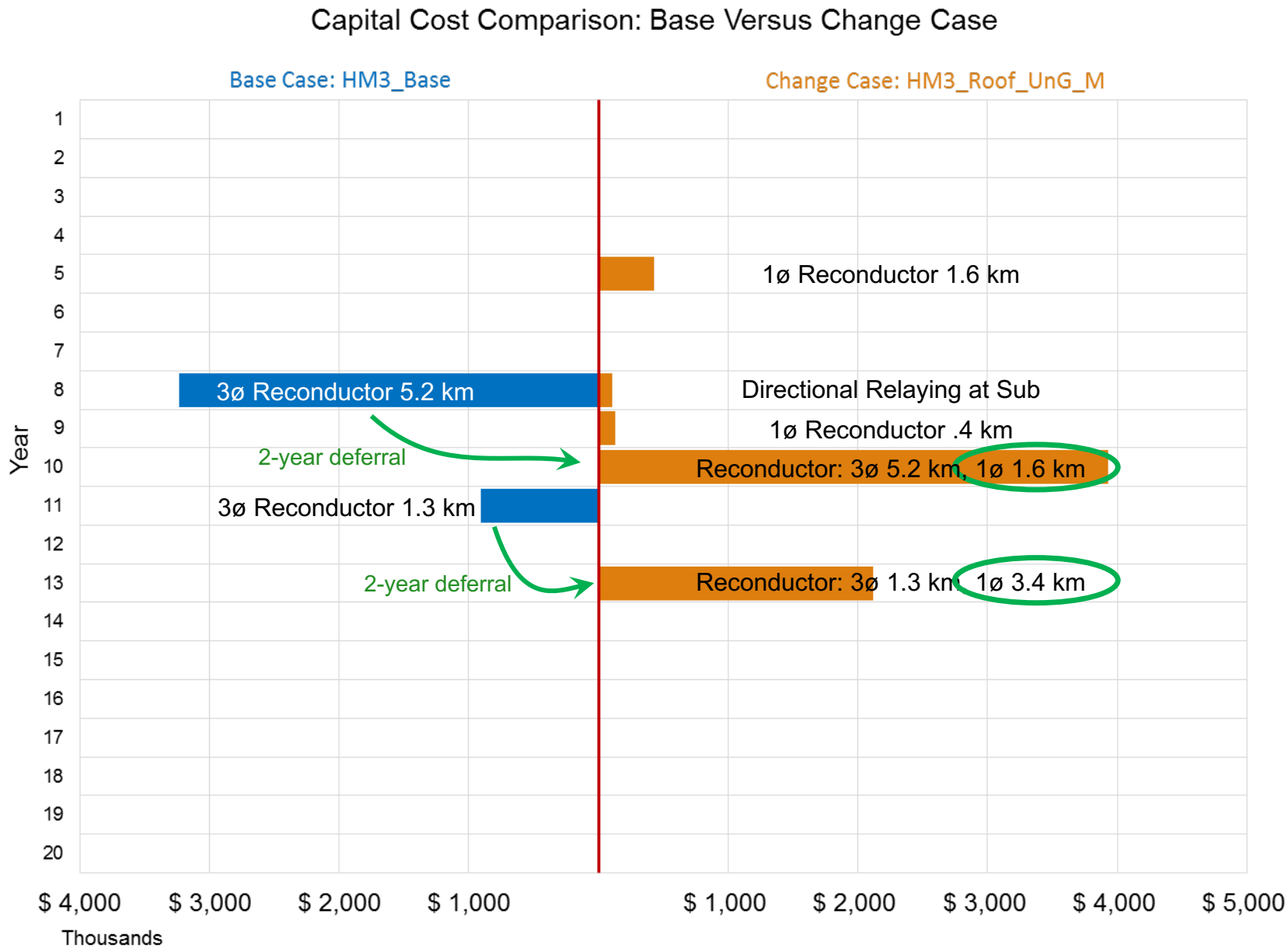
Projects Required to Maintain Circuit Within Limits



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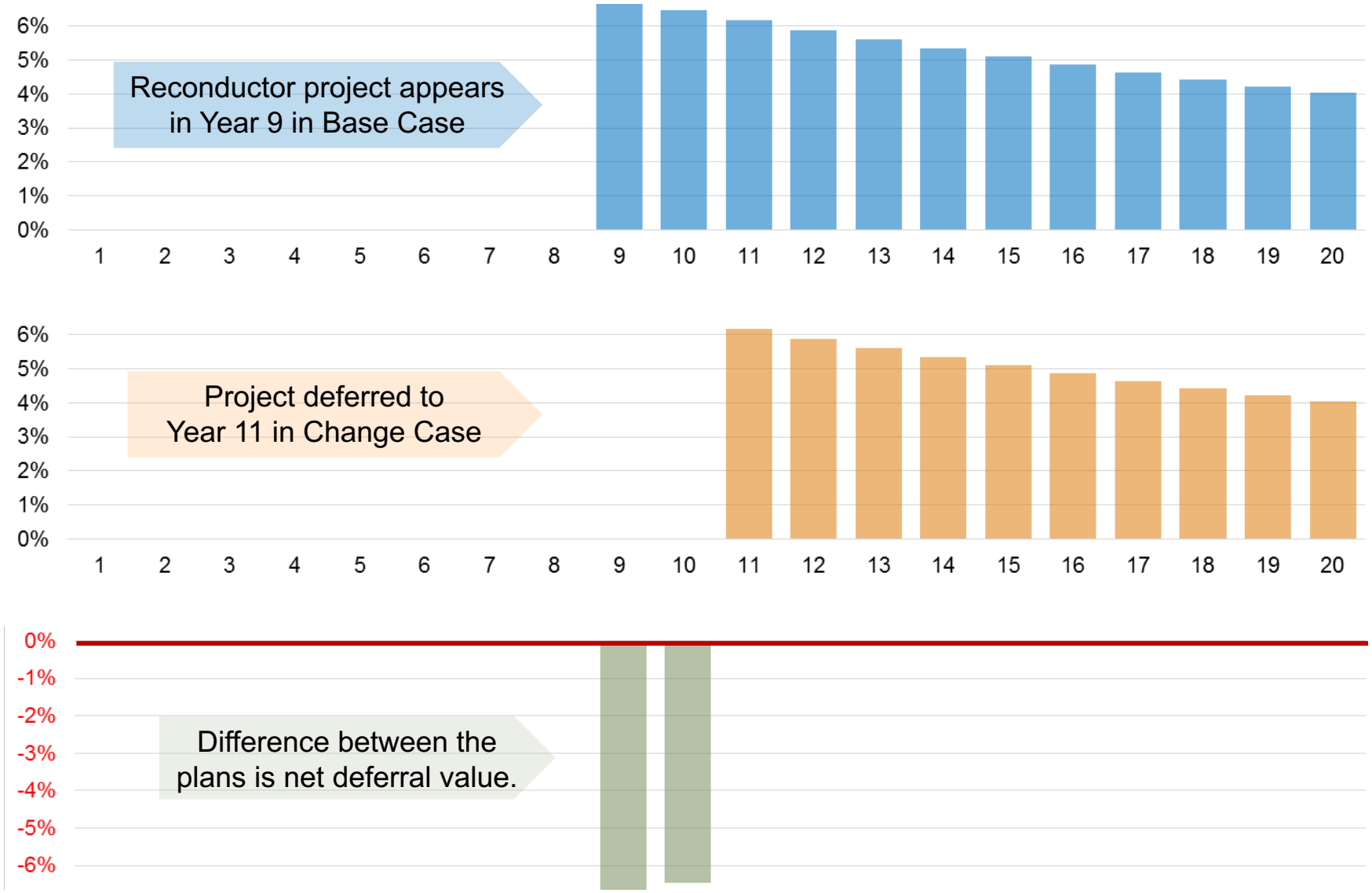
Example: Capital → Economic Present Worth Costs



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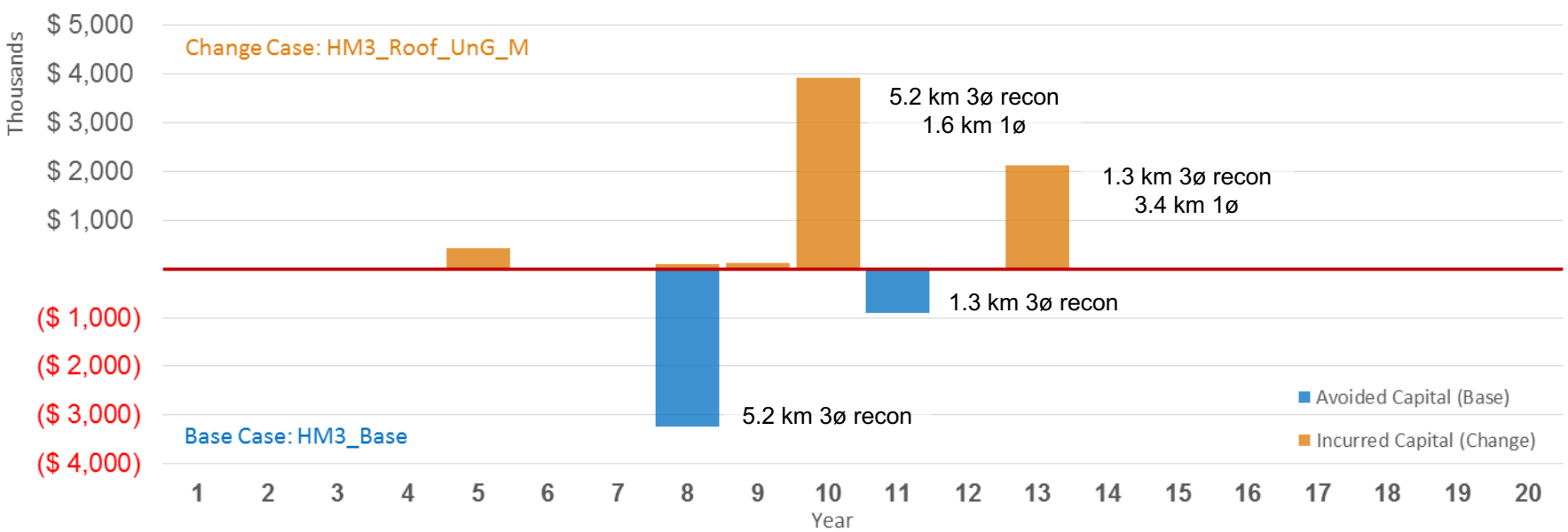
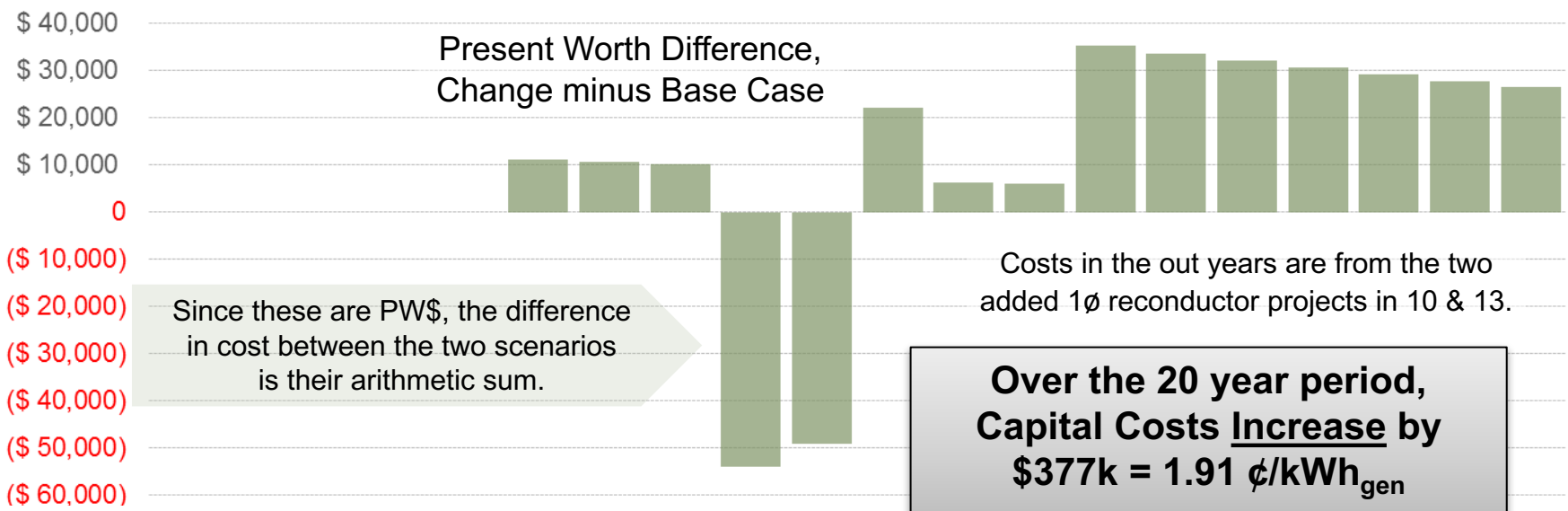
Example: Capital → Economic Present Worth Costs





Since these are PW$, the difference in cost between the two scenarios is their arithmetic sum.

Costs in the out years are from the two added 1ø reconductor projects in 10 & 13.

Over the 20 year period, Capital Costs <u>Increase</u> by $377k = 1.91 ¢/kWh$_{gen}$

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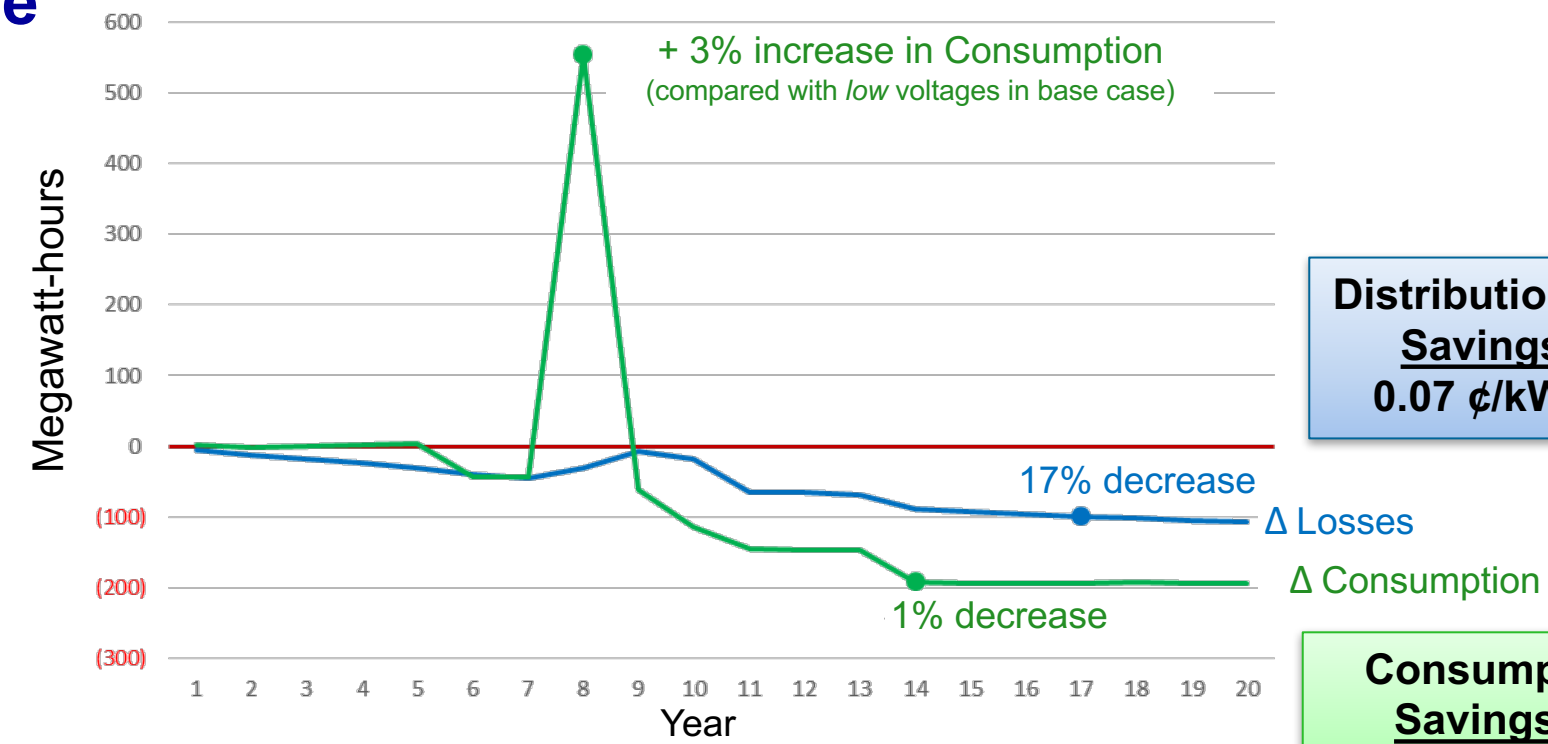
Changes in Load & Losses Between Base and Change Case



Distribution Loss Savings of 0.07 ¢/kWh$_{gen}$

Consumption Savings of 0.08 ¢/kWh$_{gen}$

- Circuit reacts to changing conditions and investments
  - PV reduces line losses, but changes in voltage and voltage control alter both loads and losses.
  - %-Consumption changes are small relative to total load, but are often larger than ΔMWh losses.
  - 3% increase in consumption in year 8 related to a decrease in consumption in the base case due to low voltage. This was corrected when the reconductor project went in-service in year 9.
  - Overall voltage is reduced in the change case because of lower tap settings and lower off-peak voltage. Some of the change in losses is associated with this reduction in voltage.

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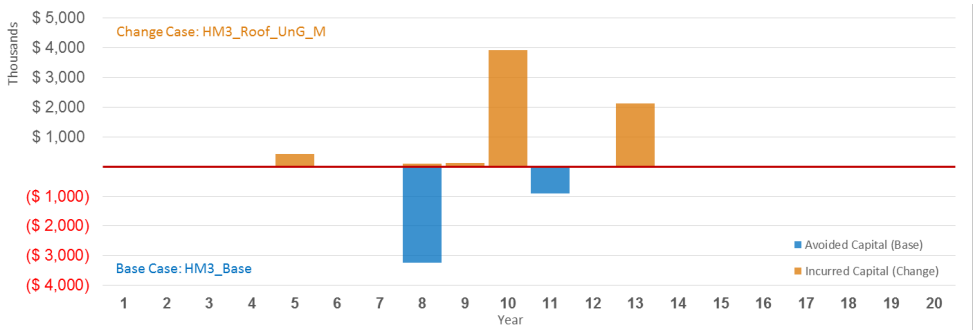
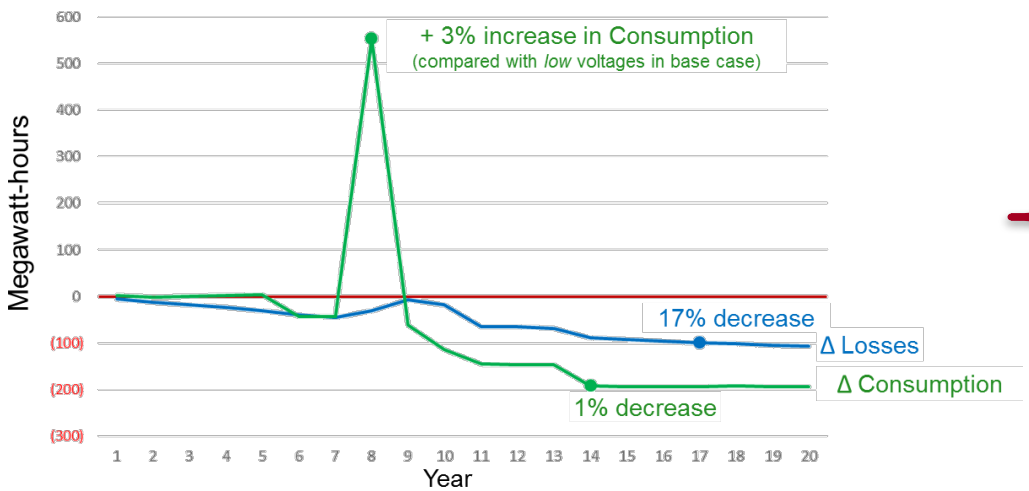
Example Total Net Distribution Value

Feeder HM: Moderate PV, Unguided, Rooftop vs. Base Case (no PV)



$1.91\ ¢/\mathrm{kWh}_{gen}$ — *Capital & O&M Cost*



$-0.07\ ¢/\mathrm{kWh}_{gen}$ — *Distribution Loss Savings*

$-0.08\ ¢/\mathrm{kWh}_{gen}$ — *Energy Consumption Savings*

$= 1.76\ ¢/\mathrm{kWh}_{gen}$ — *Net Distribution Cost*

Note: The full distribution cost would also include an assessment of the value of transformer deferral due to peak demand reduction.

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Sample of EPRI CBA Research and Applications

Title	Year Published
A Systematic Framework for Analyzing the Cost-Benefit of Using Energy Storage to Mitigate Grid Issues	2017
Microgrid Economics and a Cost-Benefit Framework	2017
Comparing the Cost-Benefit of Guided vs. Unguided PV Deployment on Distribution	2016
Time and Locational Value of DER: Methods and Applications	2016
A Framework for Determining the Technical and Economic Impacts of PV System Wide	2015
Guidebook for Cost/Benefit Analysis of Smart Grid Demo Projects	2015
The Economics of Solar PV Plant Variability on Distribution Equipment	2015
The Integrated Grid: A Benefit-Cost Framework	2015
The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources	2014
Understanding the Costs and Benefits of Increasing Grid Penetrations of PV	2014
Methodological Approach for Estimating the Benefits and Costs of Smart Grid Projects	2010

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Some Research Takeaways

Considerations for quantifying the time and locational value of distributed PV

- Identify feeder-specific issues that can be solved with solar
  - *Likely to be the most effective way to increase distributed PV's net distribution system value*
- Determine feeder-specific PV hosting capacity
- Areas with mid-day peak loads and limited remaining head room are more likely to benefit from distributed PV
- Detailed energy analysis at the distribution system is not a high priority due to low cost of energy relative to high cost of capital upgrades
- "Smart Inverter" functions show promise for low cost voltage management and grid support
  - Potential low cost solution; more research needed to determine the "best" functions to use; need updates to codes and standards (IEEE 1547)

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Research Gaps & Next Steps

- Market Signals for DER
  - To achieve optimal economic outcomes, what are the market signals that balance the tradeoffs of increasing hosting capacity (delivery capacity) vs. increasing DER that has to be curtailed?
- Distribution challenges with locational marginal prices
- Centralized control/optimization vs. Market-based DER dispatch
- What is a utility's obligation to serve?
  - How will costs be allocated fairly over time? When first-comers use up the available hosting capacity, is it fair to impose a cost on late-comers?
- Requirements for DER to be used as a capacity resource
  - What capacity contribution does PV provide to distribution?
- Probabilistic-based planning and DER forecasting

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