Reliability/Resilience-Based Metrics and Planning

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Overview of this presentation

- Reliability Metrics Definitions, Momentary Interruptions, Data Availability
- Major Events (IEEE Std. 1366 definition)
- Reliability vs. Resilience, Resilience Metrics
- Resilience: What Matters and How Can It Be Valued?
- Reliability Value-Based Planning
- The Interruption Cost Estimate (ICE) Calculator
- Recent LBNL Research on the Value of Reliability to Customers
- Resources

Electricity reliability is measured by the annual average amount of time and frequency that the lights are out

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System Average Interruption Duration Index

$$\text{SAIDI} = \frac{\text{total duration of sustained customer interruptions } (\geq 5\text{min each})}{\text{number of customers served}}$$

Customer Average Interruption Duration Index

$$\text{CAIDI} = \frac{\text{SAIDI}}{\text{SAIFI}}$$

System Average Interruption Frequency Index

$$\text{SAIFI} = \frac{\text{frequency of sustained customer interruptions } (\geq 5\text{min each})}{\text{number of customers served}}$$

Momentary Average Interruption Frequency Index

$$\text{MAIFI} = \frac{\text{frequency of momentary customer interruptions } (< 5\text{min each})}{\text{number of customers served}}$$

SAIDI, SAIFI, and CAIDI represent aggregations of customers' experiences of power interruptions

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Example: Circuit 3 Outage History

Circuit	Customers Served	Outage Number	Customers Interrupted	Outage Duration in Minutes	Customer-Minutes Interrupted
Circuit 3	3,000	1	1,500	90	135,000
Circuit 3	3,000	2	750	150	112,500
Circuit 3	3,000	3	3,000	120	360,000
Circuit 3	3,000	4	750	150	112,500
Total	**3,000**		**6,000**		**720,000**

Example: SAIFI Calculations (Assume system serves 2,000,000 customers)

Circuit	Customers Interrupted	Circuit Customers Served	Circuit SAIFI	System Customers Served	System SAIFI
Circuit 1	1,000	500	= 1,000/500 = 2.0	2,000,000	= 1,000/2M = 0.0005
Circuit 2	4,000	2,000	= 4,000/2,000 = 2.0	2,000,000	= 4,000/2M = 0.0020
Circuit 3	6,000	3,000	= 6,000/3,000 = 2.0	2,000,000	= 6,000/2M = 0.0030

Example: SAIDI Calculations (Assume system serves 2,000,000 customers)

Circuit	Customer-Minutes Interrupted	Circuit Customers Served	Circuit SAIDI	System Customers Served	System SAIDI
Circuit 1	120,000	500	= 120,000/500 = 240.0	2,000,000	= 120,000/2M = 0.060
Circuit 2	480,000	2,000	= 480,000/2,000 = 240.0	2,000,000	= 480,000/2M = 0.240
Circuit 3	720,000	3,000	= 720,000/3,000 = 240.0	2,000,000	= 720,000/2M = 0.360

Source: DTE Electric Company's Distribution Operations Five-Year (2018-2022) Investment and Maintenance Plan Final Report, January 31, 2018

Momentary Interruptions

The adoption of Advanced Metering Infrastructure (AMI) has made monitoring and recording information on momentary interruptions easier and more accurate than was feasible previously.

momentary interruption event: An interruption of duration limited to the period required to restore service by an interrupting device.

NOTE 1—Such switching operations must be completed within a specified time of five minutes or less. This definition includes all reclosing operations that occur within five minutes of the first interruption.

NOTE 2—If a recloser or circuit breaker operates two, three, or four times and then holds (within five minutes of the first operation), those momentary interruptions shall be considered one momentary interruption event.

Source: IEEE Std. 1366-2012

Momentary Interruptions: Significance to Customers

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- The economic costs to customers that are caused by momentary interruptions stem from the disruption or *down-time* required to recover from the interruption, *not from the very small amount of time that the power was actually interrupted.*
- Historically (i.e., ~20 years ago), these disruptions were due to the susceptibility of older electronic controls, especially those controlling industrial processes, to both power quality and momentary interruptions (the “blinking” VCR).
- Today, the electronic controls for industrial processes routinely have built-in capabilities to ride-through power quality events and in some instances also momentary interruptions. In addition, many firms susceptible to these types of disruptions have also installed dedicated equipment to protect their processes (e.g., UPS and back-up generation).
- As a result, today momentary interruptions are generally less of an issue for many (but not all) industrial firms and processes.

The US Energy Information Administration collects and publishes electricity reliability statistics annually

Annual Electric Power Industry Report, Form EIA-861 (2015)

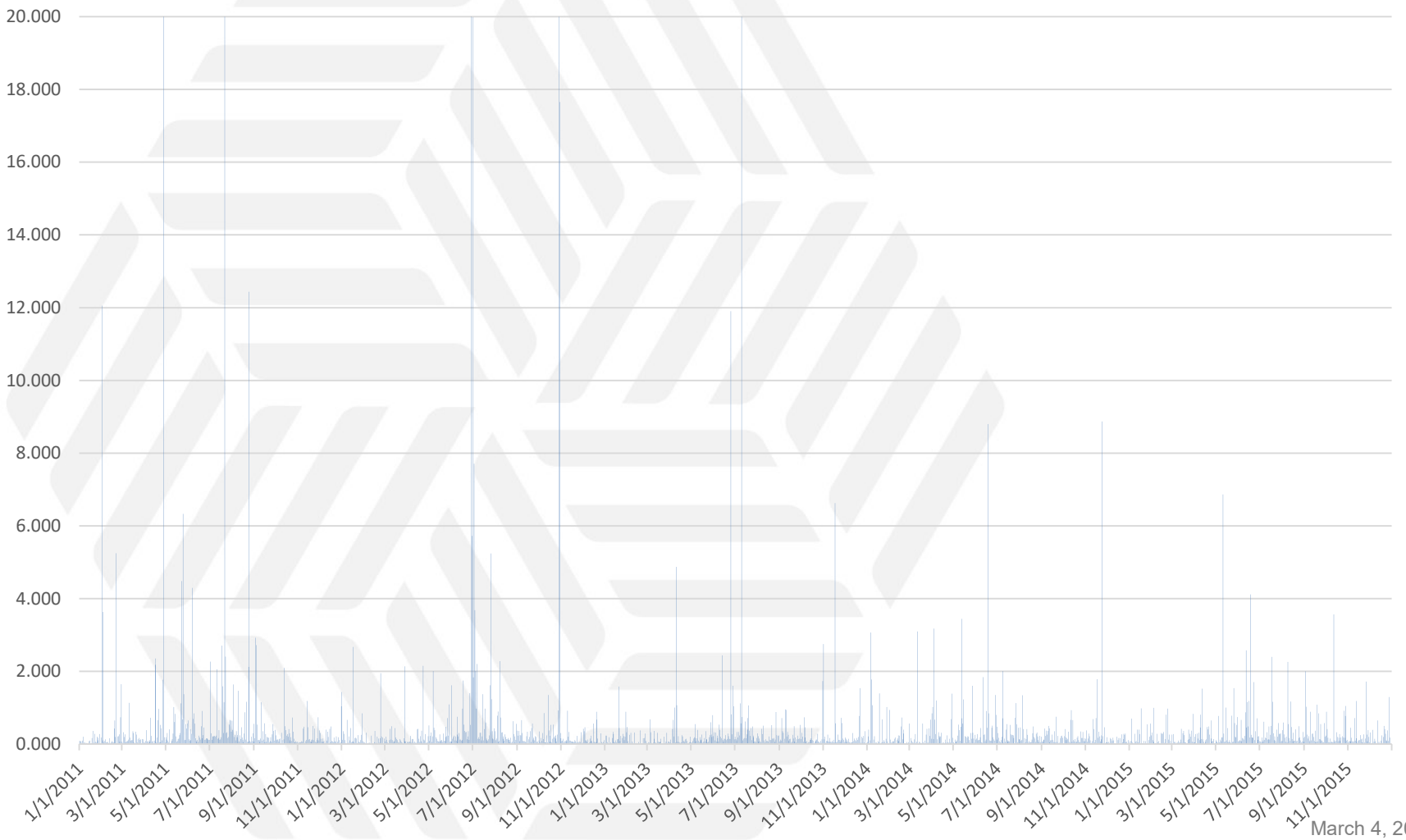
IEEE Standard 1366	Investor Owned	Cooperative	Municipal
Number of utilities reporting	137	296	117
% of U.S. sales by type of utility	51%	47%	43%
SAIDI with Major Events	237	302	115
SAIDI without Major Events	136	159	50
SAIFI with Major Events	1.4	2.8	0.9
SAIFI without Major Events	1.2	2.1	0.7

https://www.eia.gov/electricity/data/eia861/

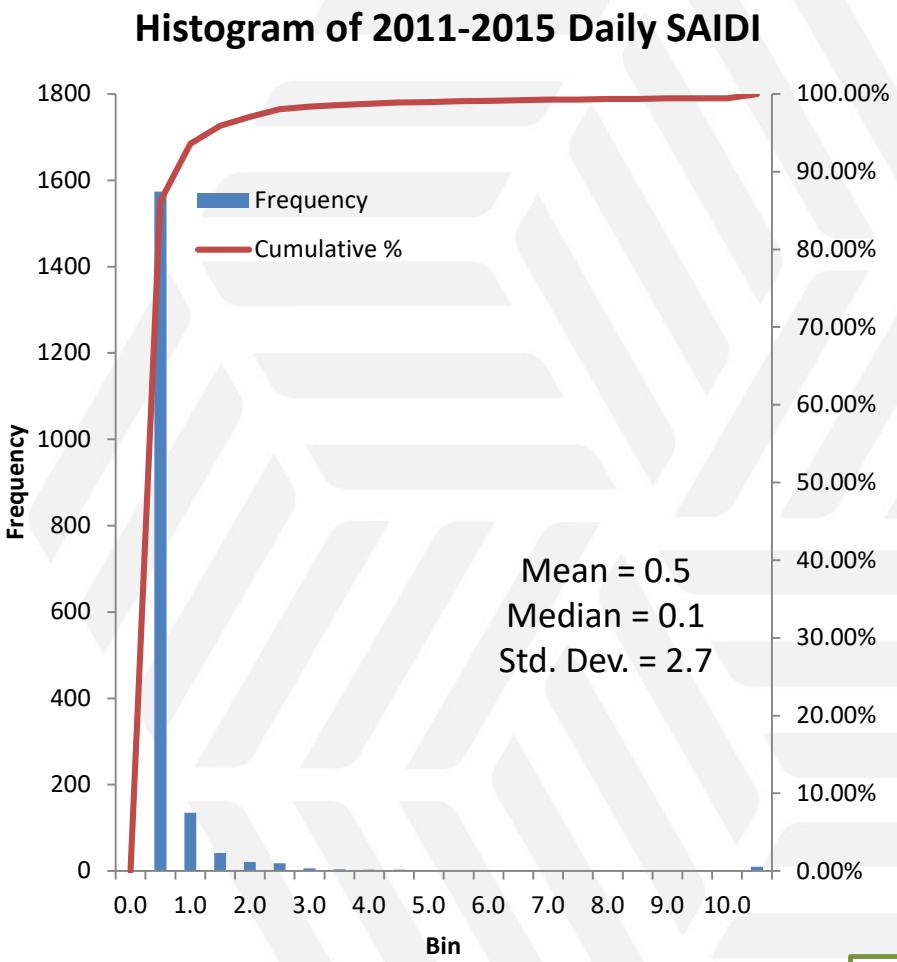
Major Events - IEEE Standard 1366

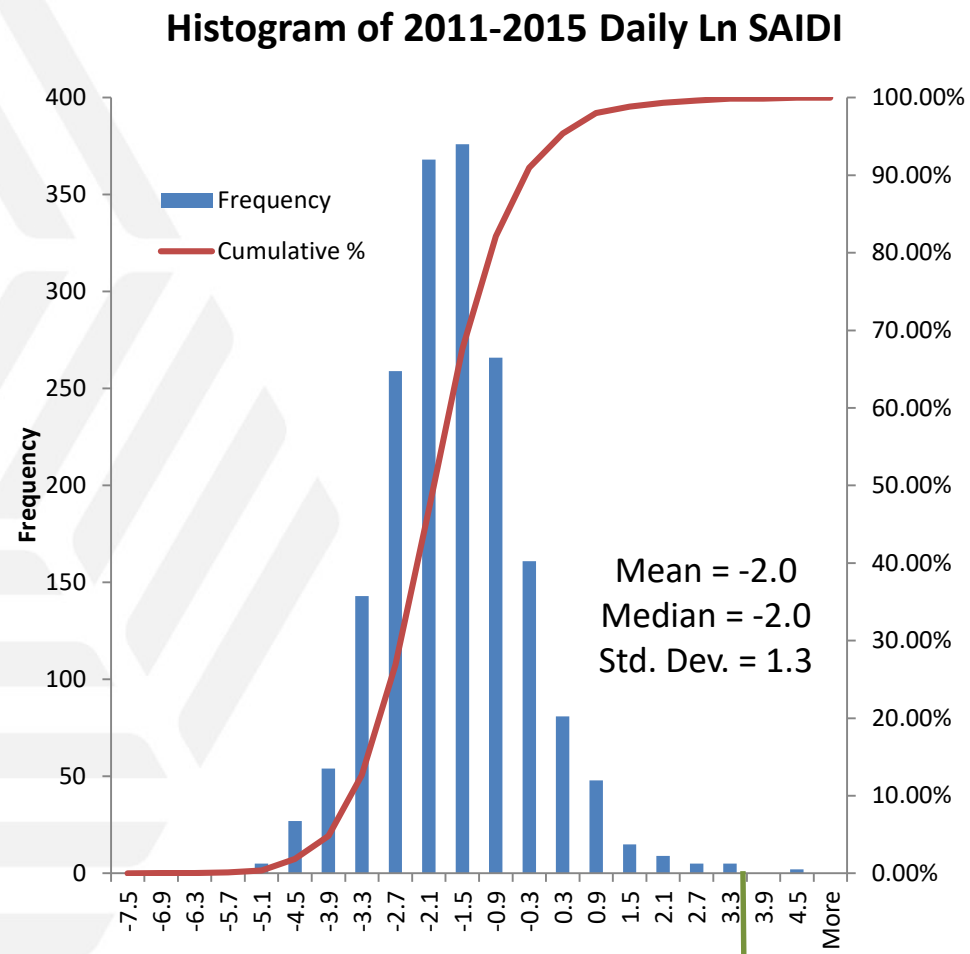
- First developed in 1998 to define reliability indices; amended in 2003 to add a consistent approach for segmenting Major Event Days (amended again in 2012; MED definition unchanged)
- Uses 2.5*beta to estimate a threshold daily SAIDI, Tmed, above which a Major Event Day is identified
  - Tmed = exp (α+2.5β)
  - Beta = log-normal standard deviation
  - Alpha = log-normal statistical mean
- For a ***normal*** distribution:
  - Multiplying beta (the standard deviation) by 2.5 covers 99.379% of the expected observations (assuming a one-sided confidence interval)
  - For a year of daily observations, this translates to an expectation of 2.3 Major Event Days per year
- *But, utility daily SAIDI data are not "perfectly" normally distributed.*

Daily SAIDI for 5 years (2011-2015)



Daily SAIDI Re-Ordered from Lowest to Highest

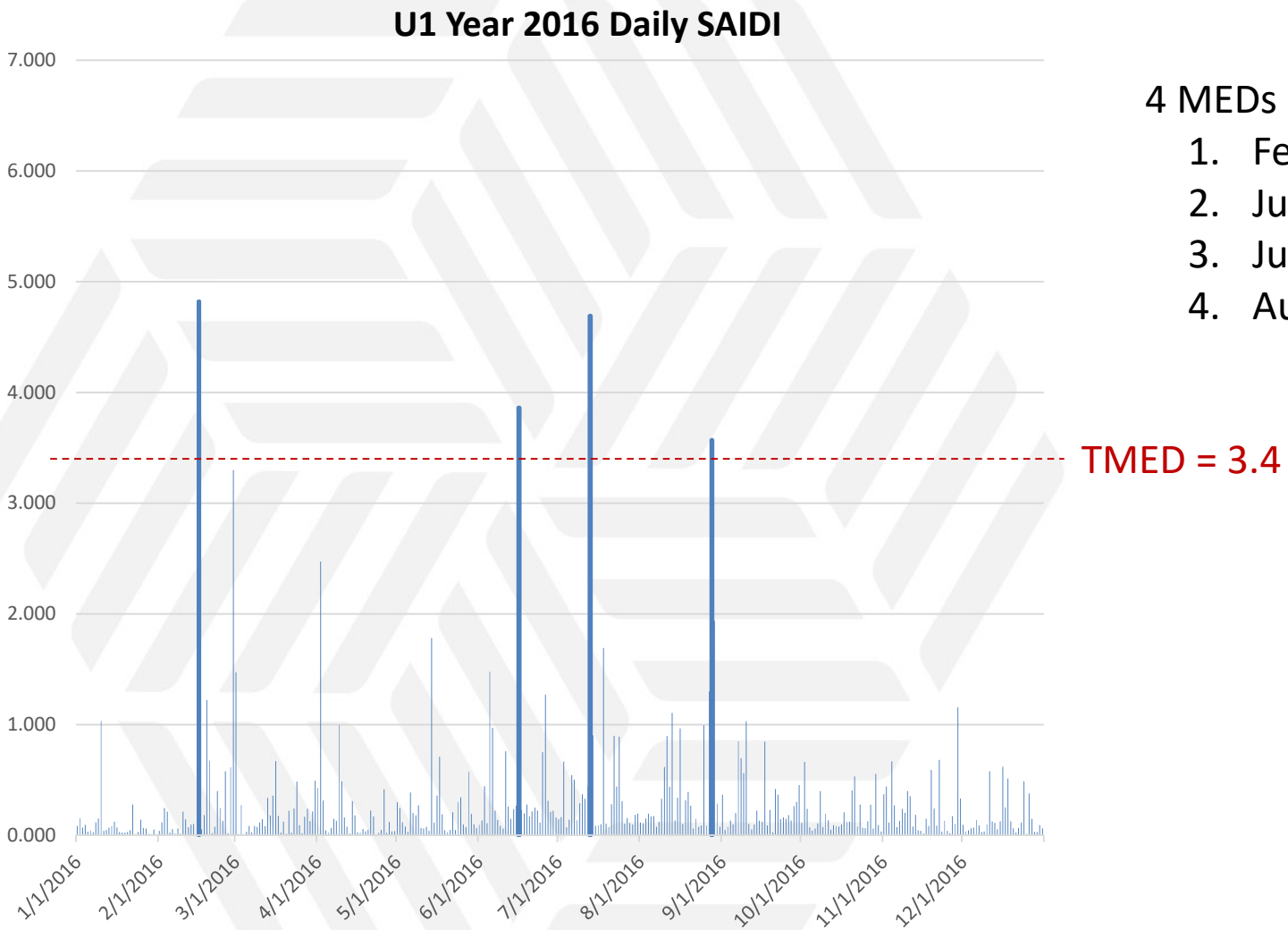




$$Tmed = e^{(mean + (2.5*std.\ dev.))}$$

Tmed = 3.4

Daily SAIDI for 2016 → 4 MEDs



4 MEDs in year 2016:

1. Feb 16
2. Jun 16
3. Jul 13
4. Aug 28

Reliability vs. Resilience: features, metrics, actions

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	Reliability	Resilience
Common features/ characteristics	Routine, expected, normally localized, shorter duration interruptions of electric service Larger events will make it into the local headlines	Infrequent, unexpected, widespread/long duration power interruptions, often with significant corollary impacts Almost always "event" based Always national headline worthy
Metrics	Well-established, annualized (SAIDI, SAIFI, MAIFI), with provisions for "major events" Rarely include non-electricity impacts	Familiar, but non-standardized, and generally event-based (number of customers affected; hours without electric service) Routinely also include non-electricity impacts (e.g., costs to firms; health and safety impacts)
Actions to improve	1. Plan and prepare; 2. Manage and endure event(s); 3. Recover and restore; and 4. Assess, learn, and update plan.	No qualitative difference But generally larger in scope/cost (see next slide)

Reliability vs. Resilience: decision-making

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	Reliability	Resilience
Entities involved in decision-making	Primarily electric utility and its regulator or oversight board	Electric utility and regulator or oversight board; sometimes acting in response to state legislative direction or Governor's orders Routinely in conjunction with parties that have responsibilities for other critical infrastructures, including local, regional, state, or federal agencies/authorities, and communities/elected officials
Factors affecting decision-making	Actuarial records on frequency of exposure – widely understood risks: insurable Well-understood/tested practices/approaches Understood to be an expected cost of doing business	No actuarial basis to establish likelihood of occurrence – widely varying perceptions of risk/exposure: "un-insurable" risk Limited opportunities to test strategies Large dollar amounts/extraordinary expenditures may require special approval/vote Political leadership critical

Grid Modernization Lab Consortium metrics: Resilience

GMLC Resilience Metrics	Data Requirements
Cumulative customer-hours of outages	customer interruption duration (hours)
Cumulative customer energy demand not served	total kVA of load interrupted
Avg (or %) customers experiencing an outage during a specified time period	total kVA of load served
Cumulative critical customer-hours of outages	critical customer interruption duration
Critical customer energy demand not served	total kVA of load interrupted for critical customers
Avg (or %) of critical loads that experience an outage	total kVA of load severed to critical customers
Time to recovery	
Cost of recovery	
Loss of utility revenue	outage cost for utility ($)
Cost of grid damages (e.g., repair or replace lines, transformers)	total cost of equipment repair
Avoided outage cost	total kVA of interrupted load avoided
	$ / kVA
Critical services without power	number of critical services without power
	total number of critical services
Critical services without power after backup fails	total number of critical services with backup power
	duration of backup power for critical services
Loss of assets and perishables	
Business interruption costs	avg business losses per day (other than utility)
Impact on GMP or GRP	
Key production facilities w/o power	total number of key production facilities w/o power (how is this different from total kVA interrupted for critical customers?)
Key military facilities w/o power	total number of military facilities w/o power (same comment as above)

Resilience (1): What Matters and How Can It Be Valued?

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1. What types of resilience "events" are of concern to the utility, its regulators, and its stakeholders?
   - Ice storms?
   - High wind/lightning events?
   - Extreme cold/coupled with a gas supply disruption event
   - Others?

2. To what extent are utility-led actions to address these events—at least to some degree—already considered in reliability planning by the utility? For those that are not, why not?

Resilience (2): What Matters and How Can It Be Valued?

3. For those actions that already are considered in reliability planning (at least to some degree), what, if anything, more or different should be done as part of current development and review processes for utility reliability plans?

   Different spending levels?

   Different spending targets/objectives?

   Different performance metrics?

4. What should be the basis for these suggested changes? What objectives should they serve?

Resilience (3): What Matters and How Can It Be Valued?

5. What information or perspectives are currently missing from today's discussions that would be helpful for informing future decisions on these suggested changes?

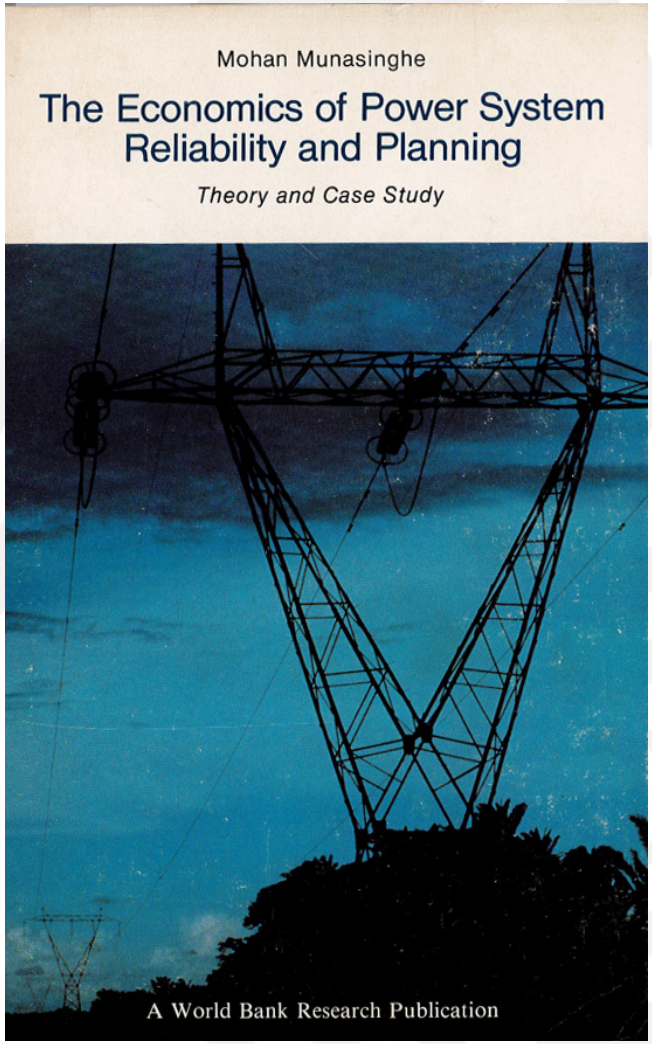
   Specifically, should additional information on the value of activities to improve reliability/resilience be incorporated in these discussions?

   What values? To whom? How should they be estimated? How should they be incorporated?

6. For warranted actions that are not currently considered in reliability planning—what (if any) additional factors should be taken into account in order to plan for them?

   How should they be incorporated into or considered in relation to current utility reliability planning activities?

Value-Based Reliability Planning is a means for taking the cost of interruptions borne by customers into utility planning decisions (1)



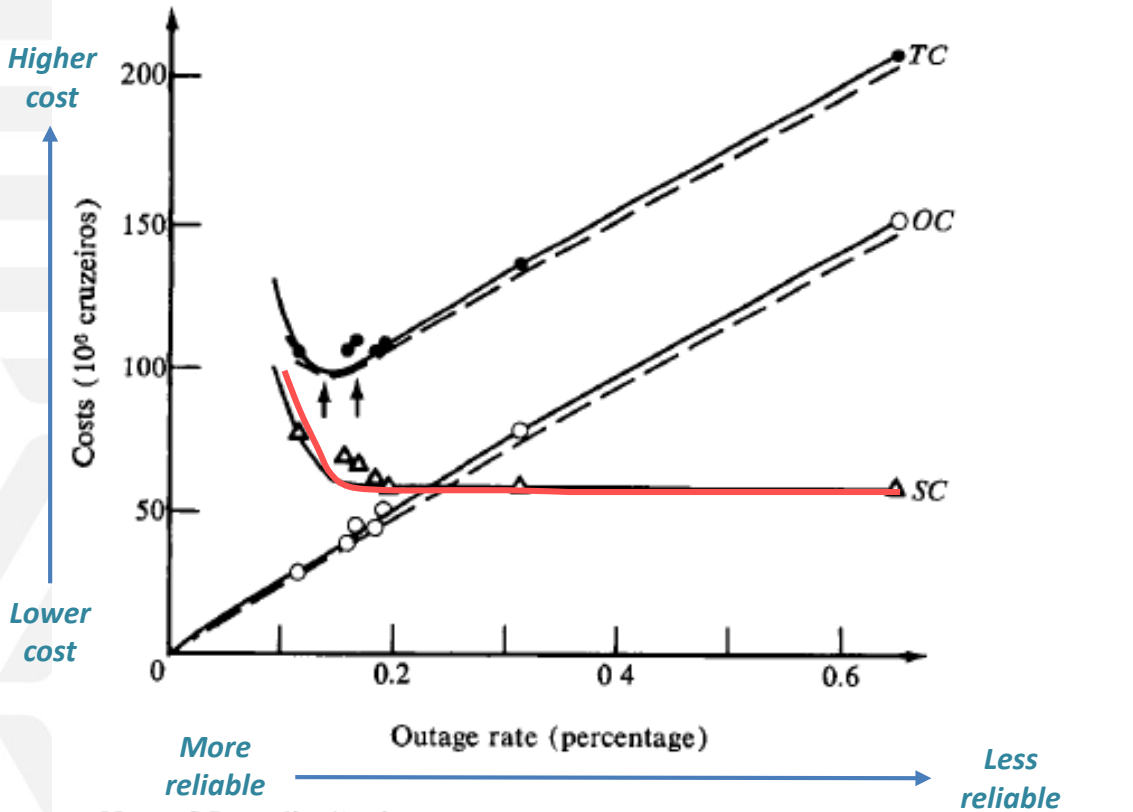
Reliability value-based planning was developed to guide the design of “green field” power systems.

The objective is to minimize the total cost to society of providing reliable electric service.

The societal cost factors include both the cost of building a power system and the costs that unreliability imposes on customers.

Value-Based Reliability Planning is a means for taking the cost of interruptions borne by customers into utility planning decisions (2)

Figure 13.1. *Optimization of the Outage System: Costs Versus Outage Rate*



Note: SC = distribution system supply costs; OC = global outage costs; and TC = total costs. The plotted data points and solid lines refer to efficiency priced costs; the broken lines indicate the costs in terms of social prices.

Value-Based Reliability Planning is a means for taking the cost of interruptions borne by customers into utility planning decisions (3)

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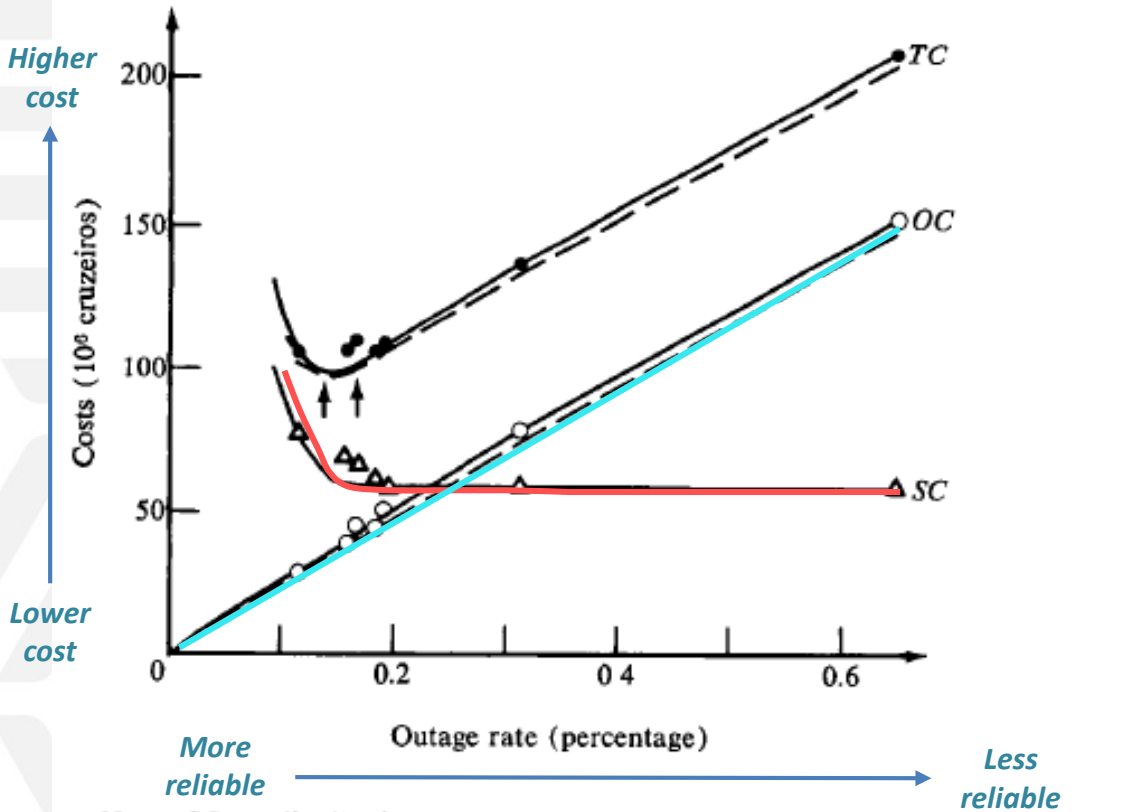

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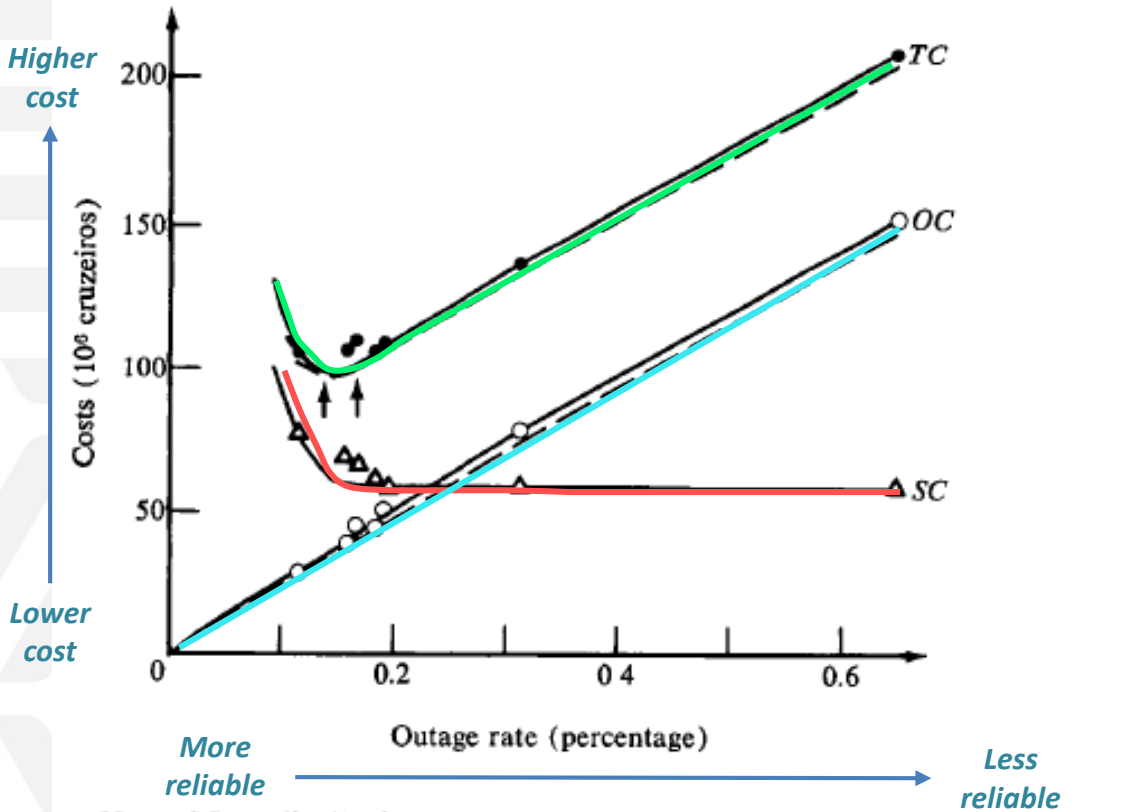

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Value-Based Reliability Planning is a means for taking the cost of interruptions borne by customers into utility planning decisions (5)

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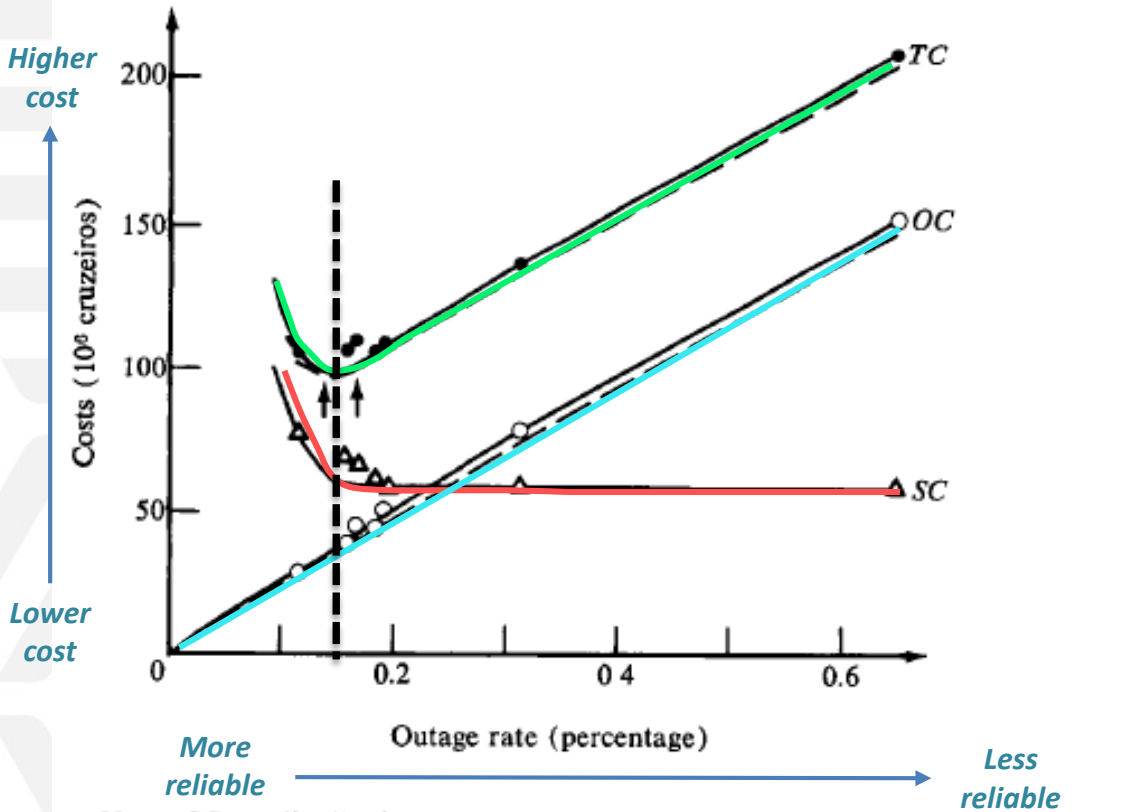
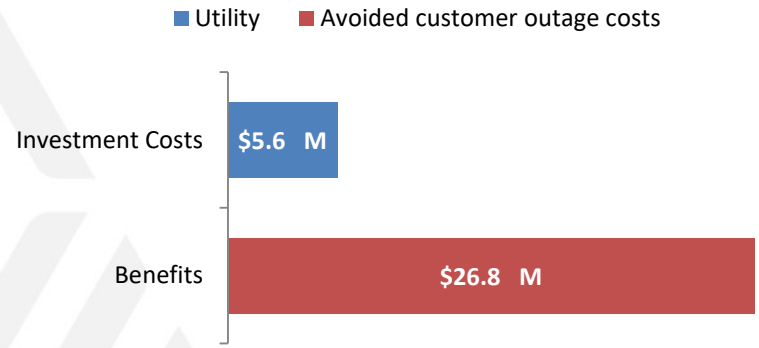


Note: SC = distribution system supply costs; OC = global outage costs; and TC = total costs. The plotted data points and solid lines refer to efficiency priced costs; the broken lines indicate the costs in terms of social prices.

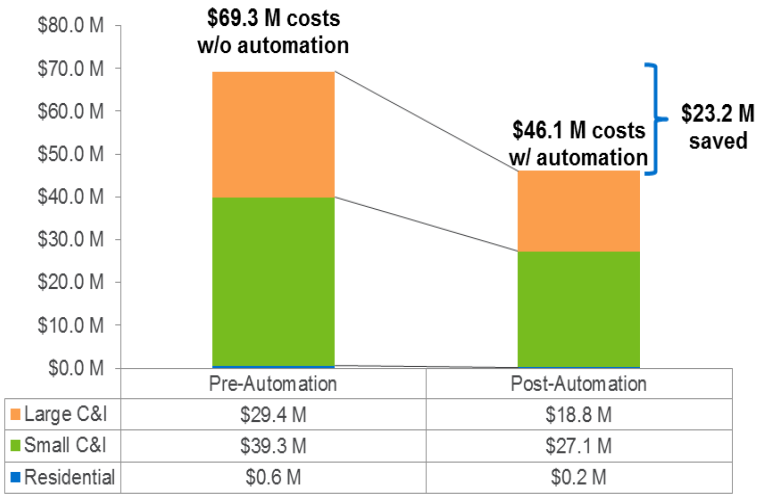
Value-Based Reliability Planning example: Distribution Automation

- Utility: EPB of Chattanooga
- Customers Impacted: 174,000 customers (entire territory)
- Investment: 1,200 automated circuit switches and sensors on 171 circuits
- Reliability Improvement: 2010-2015
  - SAIDI ↓45% (from 112 to 61.8 minutes/year)
  - SAIFI ↓51% (from 1.42 to 0.69 interruptions/year)

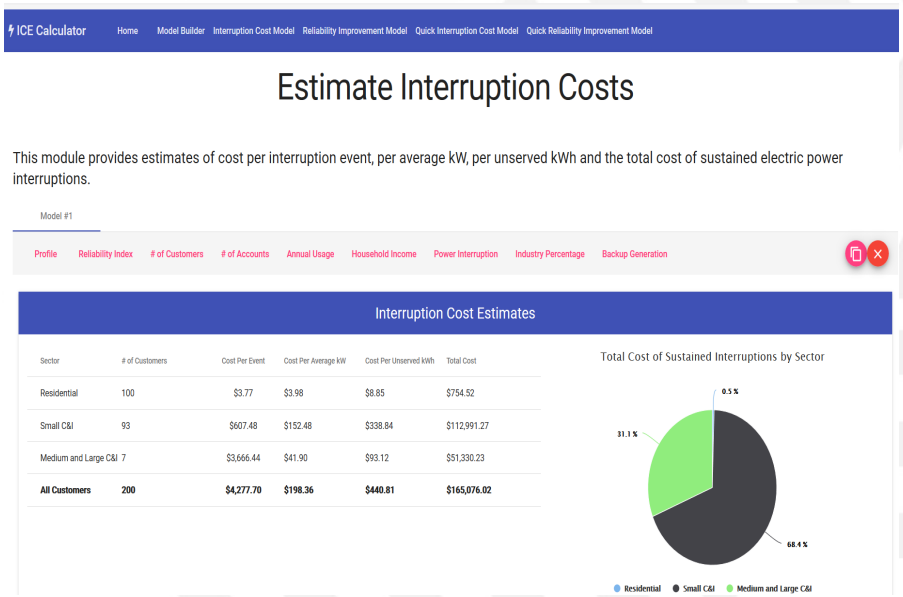
Annual Costs and Benefits



Avoided Cost of Severe Storm



Interruption Cost Estimate (ICE) Calculator



- ICE Calculator is an interactive tool for estimating customer interruption costs for a circuit, region, or utility service territory
- The ICE Calculator was developed using customer survey responses from 34 utility-sponsored Customer Interruption Cost (Value of Lost Load) studies

http://www.icecalculator.com/

The Costs of Power Interruptions

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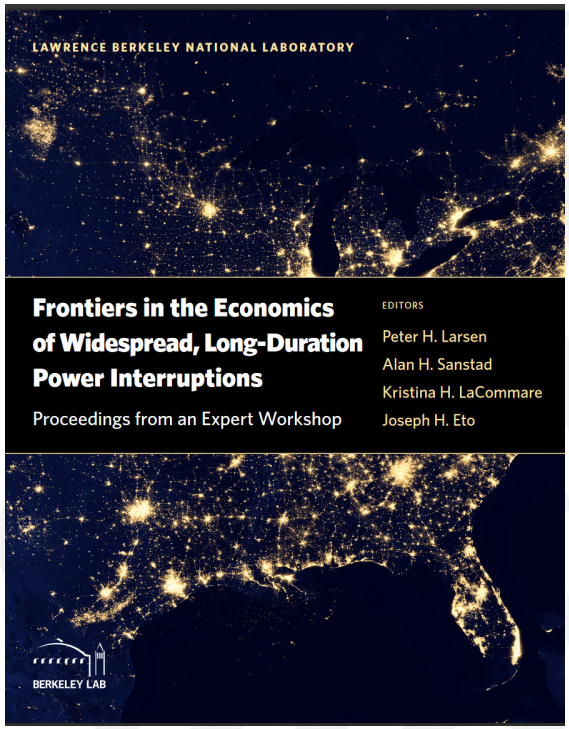
Varies by type of customer and depends on when and for how long their lights are out

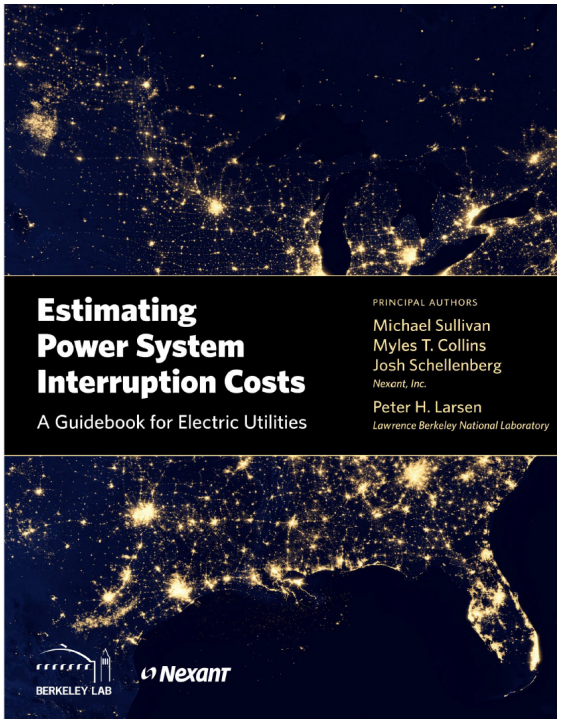
Interruption Cost	Interruption Duration				
	Momentary	30 minutes	1 hour	4 hours	8 hours
Medium and Large C&I					
Morning	$8,133	$11,035	$14,488	$43,954	$70,190
Afternoon	$11,756	$15,709	$20,360	$59,188	$93,890
Evening	$9,276	$12,844	$17,162	$55,278	$89,145
Small C&I					
Morning	$346	$492	$673	$2,389	$4,348
Afternoon	$439	$610	$818	$2,696	$4,768
Evening	$199	$299	$431	$1,881	$3,734
Residential					
Morning	$3.7	$4.4	$5.2	$9.9	$13.6
Afternoon	$2.7	$3.3	$3.9	$7.8	$10.7
Evening	$2.4	$3.0	$3.7	$8.4	$11.9

Recent LBNL Research:
Economic Costs to Customers of Power Interruptions



Guidance to utilities designing surveys to assess the direct costs of power interruptions

Review of state of the art in estimating the direct *and indirect* costs of widespread, long-duration power interruptions



https://emp.lbl.gov/research/electricity-reliability

Some themes to keep in mind

"What's measured improves"
— Peter F. Drucker

"Delegating your accountabilities is abdication"
— Michael E. Gerber

"Not everything that can be counted counts,
and not everything that counts can be counted"
— Albert Einstein

Resources

- LaCommare, Kristina Hamachi, Peter H. Larsen, and Joseph H. Eto. *Evaluating Proposed Investments in Power System Reliability and Resilience: Preliminary Results from Interviews with Public Utility Commission Staff*, 2017. https://emp.lbl.gov/sites/default/files/lbnl-_1006971.pdf

- Larsen, Peter H.. "A Method to Estimate the Costs and Benefits of Undergrounding Electricity Transmission and Distribution lines." *Energy Economics* 60, no. November 2016 (2016): 47-61. https://emp.lbl.gov/sites/default/files/lbnl-1006394_pre-publication.pdf

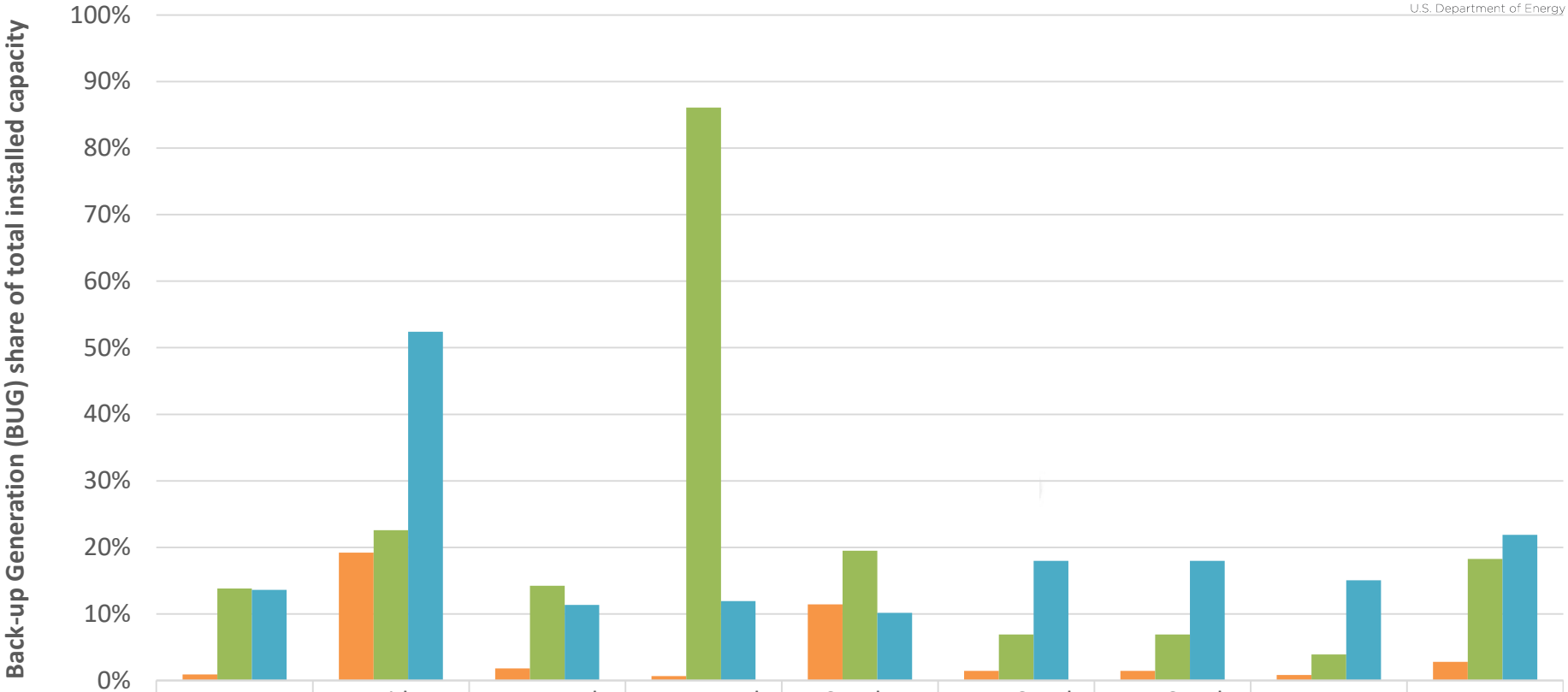
- Larsen, Peter H., Kristina Hamachi LaCommare, Joseph H. Eto, and James L. Sweeney. *Assessing Changes in the Reliability of the U.S. Electric Power System*., 2015. https://emp.lbl.gov/sites/default/files/lbnl-188741.pdf

- Eto, Joseph H., Kristina Hamachi LaCommare, Michael D. Sohn, and Heidemarie C. Caswell. "Evaluating the Performance of the IEEE Standard 1366 Method for Identifying Major Event Days View Document." *IEEE Transactions on Power Systems* 32, no. 2 (2016).

- Sullivan, Michael J., Josh A. Schellenberg, and Marshall Blundell. *Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States*., 2015. https://emp.lbl.gov/sites/default/files/lbnl-6941e.pdf

- https://emp.lbl.gov/research/electricity-reliability

Installed Capacity of Back-up Generation



	New England	Mid-Atlantic	East North Central	West North Central	South Atlantic	West South Central	East South Central	Mountain	Pacific
Residential	1%	19%	2%	1%	11%	1%	1%	1%	3%
Commercial	14%	23%	14%	86%	19%	7%	7%	4%	18%
Industrial	14%	52%	11%	12%	10%	18%	18%	15%	22%

Source: Frost and Sullivan. 2015. "Analysis of the US Power Quality Equipment Market." Lawrence Berkeley National Laboratory.