February 27, 2012

Office of Electricity Delivery & Energy Reliability

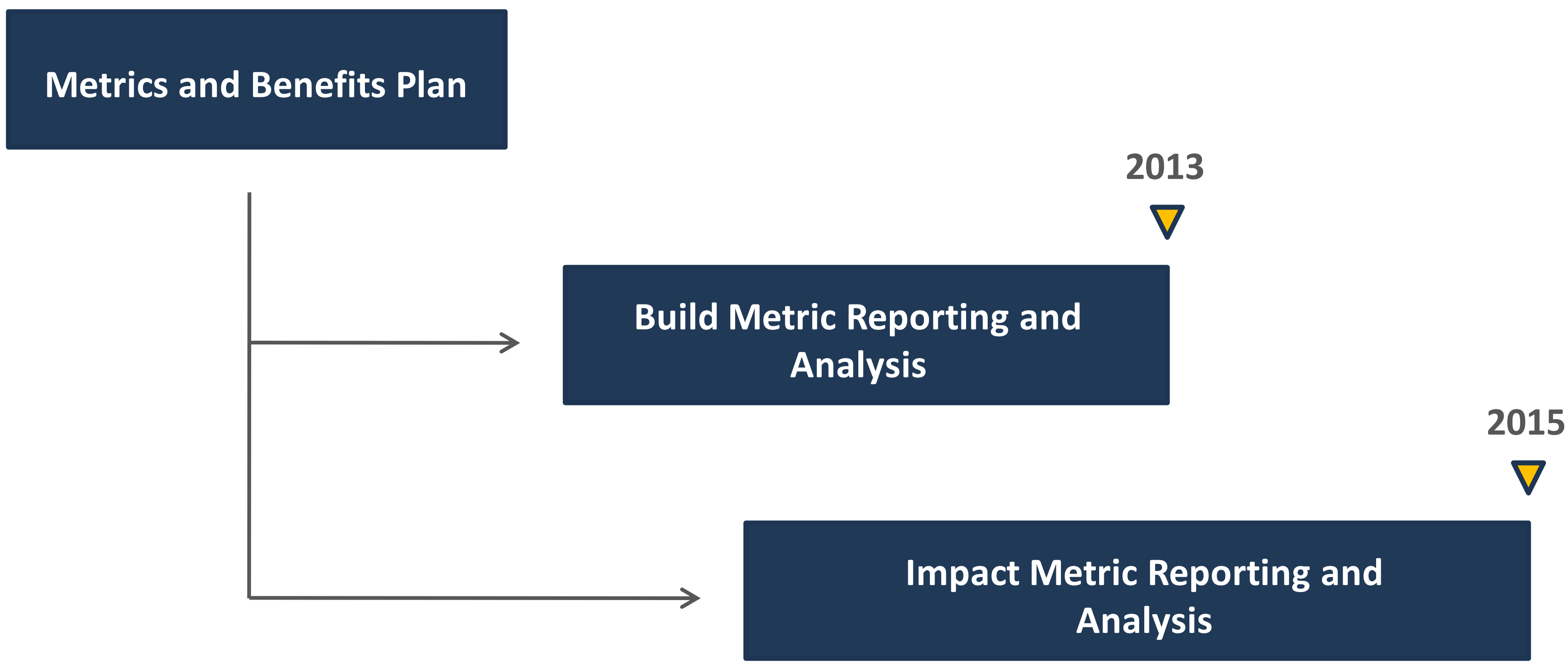
Distribution System Reliability

DOE Analysis Approach

SMARTGRID.GOV
RECOVERY ACT SMART GRID PROGRAMS

Introduction

Build and impact metric data provided by the SGIG recipients convey the type and extent of technology deployment, as well as its effect on grid operations and system efficiency.



Six Primary Analysis Focus Areas

There are six areas where the analysis is focused. This presentation addresses analysis efforts associated with distribution system reliability.

Peak Demand and Electricity Consumption

- Advanced Metering Infrastructure
- Pricing Programs and Customer Devices
- Direct Load Control

Operations and Maintenance Savings from Advanced Metering

- Meter Reading
- Service changes
- Outage management

Distribution System Reliability

- Feeder switching
- Monitoring and health sensors

Energy Efficiency in Distribution Systems

- Voltage optimization
- Conservation voltage reduction
- Line losses

Operations and Maintenance Savings from Distribution Automation

- Automated and remote operations
- Operational Efficiency

Transmission System Operations and Reliability

- Application of synchrophasor technology for wide area monitoring, visualization and control

DOE / Recipient Dialogue

DOE would like to establish a dialogue with recipients to explore distribution system reliability using outage identification, equipment monitoring and feeder switching. The outcome is to share this information across the industry.

DOE's Interests	Recipients' Interests
1. Analysis Approach: Working through issues relating to measuring impacts a. Analytical methodology b. Baseline/Underlying factors leading to results c. How to convey the results and to whom? 2. Lessons-Learned/Best-Practices: Internally and externally conveyed a. What can we learn from each other? b. How do we want to document lessons-learned and best practices for external communication? c. Are there detailed case studies that can be developed?	1. What would you like to address in a group setting? 2. What do you want to learn or share? 3. How would you like to exchange information? a. In smaller or more focused groups? b. How should we structure and support the discussion? 4. Are there issues you are NOT interested in addressing here?

DOE’s Analysis Objectives

This focus area will examine improvements in the reliability of electric distribution systems, i.e., by limiting the scope, frequency and duration of power outages, through the application of technologies that help automate distribution system operations, such as automated feeder switching, equipment health monitoring, and AMI outage notification systems.

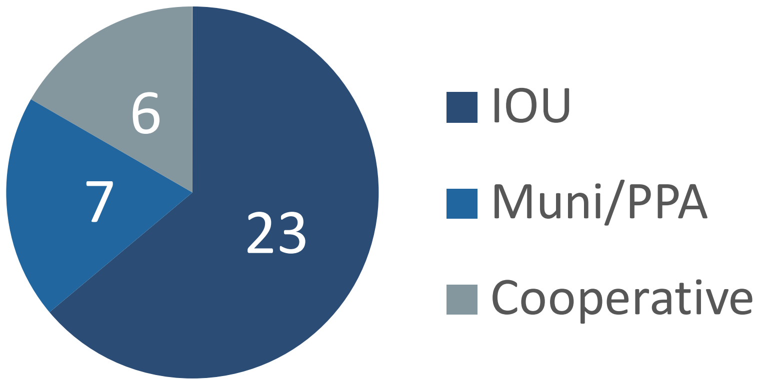
Analysis Objectives

• Determine the improvement in reducing the number and duration of outages from the application of:
  • Outage identification technologies
  • Equipment health and load monitoring sensors
  • Automated feeder switching
• Determine what technology configurations are most important for delivering measurable results.
• Quantify the value of reliability improvements for customers.

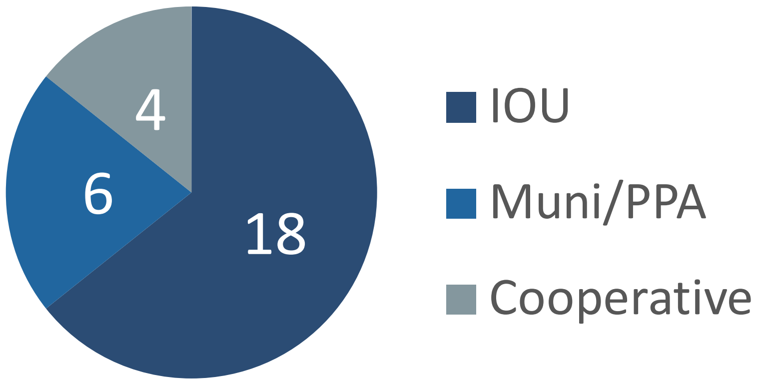
SGIG Projects

SGIG projects are implementing different technology configurations to improve distribution reliability.

23 SGIG Projects Integrating AMI Smart Meter Outage Notifications with Outage or Distribution Management Systems



28 SGIG Projects Implementing Fault Location Isolation Service Restoration (FLISR)



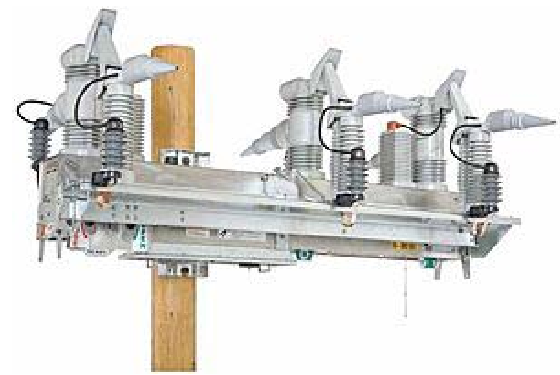
Source: SGIG Build metrics and Navigant analysis

Technologies

SGIG project teams are deploying a variety of different technologies.

Fault Indicators

Automated Feeder Switch

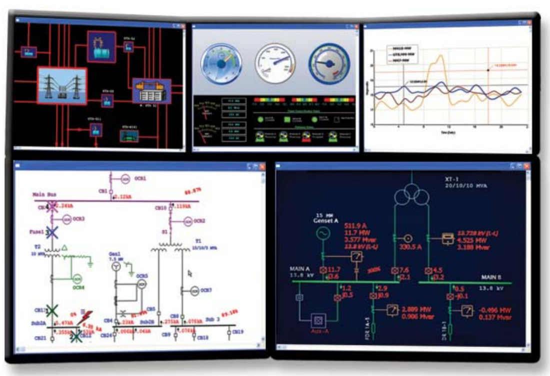


Control package

AMI Smart Meter

Equipment Health Sensor & Monitor

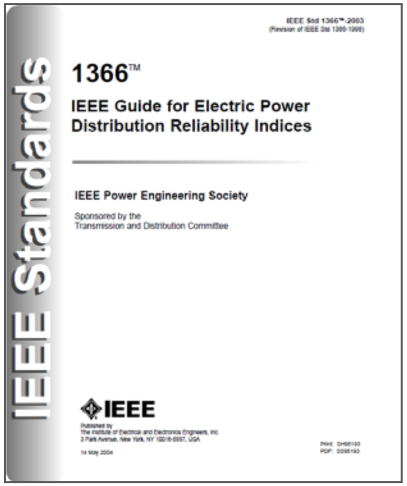
Distribution Management System



Outage Types

Outages are classified by IEEE* into three categories based on the duration of the outage or the number of customers interrupted.

Major Event	An event that exceeds reasonable design and or operational limits of the electric power system. Major events typically interrupt 10% or more of the customer base for 24 hours or more and include named storms.
Sustained Outages	An interruption that lasts five minutes or more.
Momentary Outages	An interruption duration limited to the period required to restore service by a device or less than five minutes.



* IEEE Std 1366-2003 Guide for Electric Power Distribution Reliability Indices

Applications for Outage Management Technology

DOE has observed a combination of technologies within the projects that are implementing applications to respond to outages and restore power.

Outage Identification	Utilizing AMI smart meters, fault indicators, two-way communications and outage management systems (OMS) to identify outages and plan restoration activities.
Remote Feeder Switching	Utilizing outage information and decision support tools operators remotely adjust feeder switch positions to restore power to sections of the feeder that are not damaged.
Fault Location Identification Service Restoration(FLISR)	Utilizing outage information, switching algorithms and feeder switches to reroute power to sections that are not damaged while maintaining acceptable loading conditions.

Applications for System Monitoring Technology

DOE has also observed projects that are using a combination of sensing and monitoring technologies to mitigate equipment failure.

Equipment Health Sensors

Utilizing sensors, two-way communications and distribution management systems to identify condition anomalies which indicate equipment degradation or potential failure.

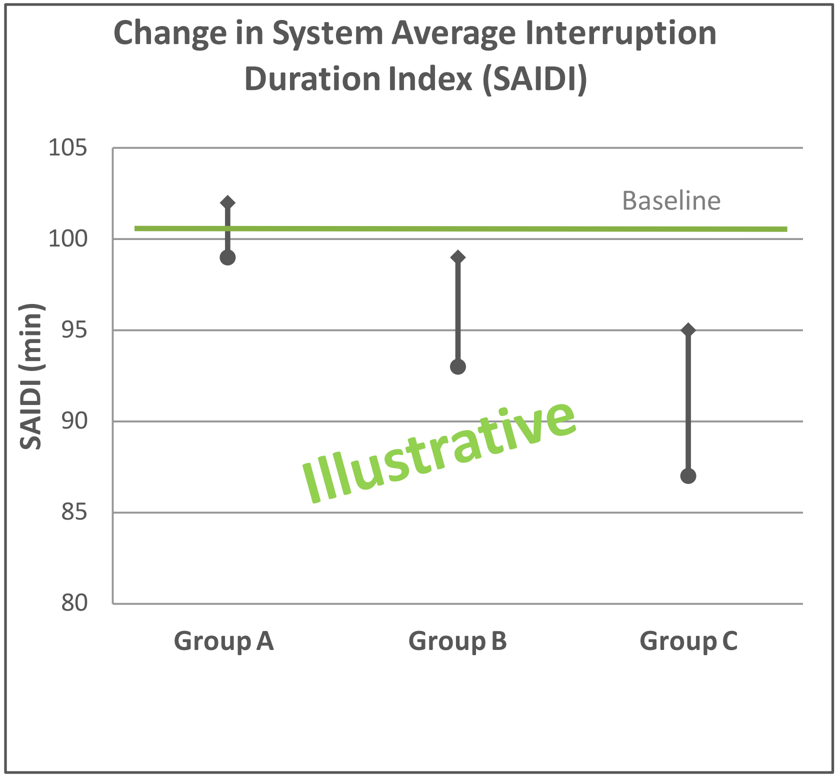
Loading Monitors

Utilizing voltage and current monitors, two-way communications and distribution management systems to identify and mitigate over load conditions.

Functionality and Impact Hypothesis

Our hypothesis is that relative benefits will increase with higher functionality from outage identification, equipment monitoring and feeder switching.

Group	Representative Technology Configurations for Outage Identification and Feeder Switching
A	• AMI smart meters with outage and restoration notification • AMI integrated with OMS
B	• AMI smart meters with outage and restoration notification • AMI integrated with OMS • Remote Feeder Switching
C	• AMI smart meters with outage and restoration notification • Automated feeder switches and with Fault, Location, Isolation, and Restoration (FLISR) capability • DMS integration with AMI or OMS



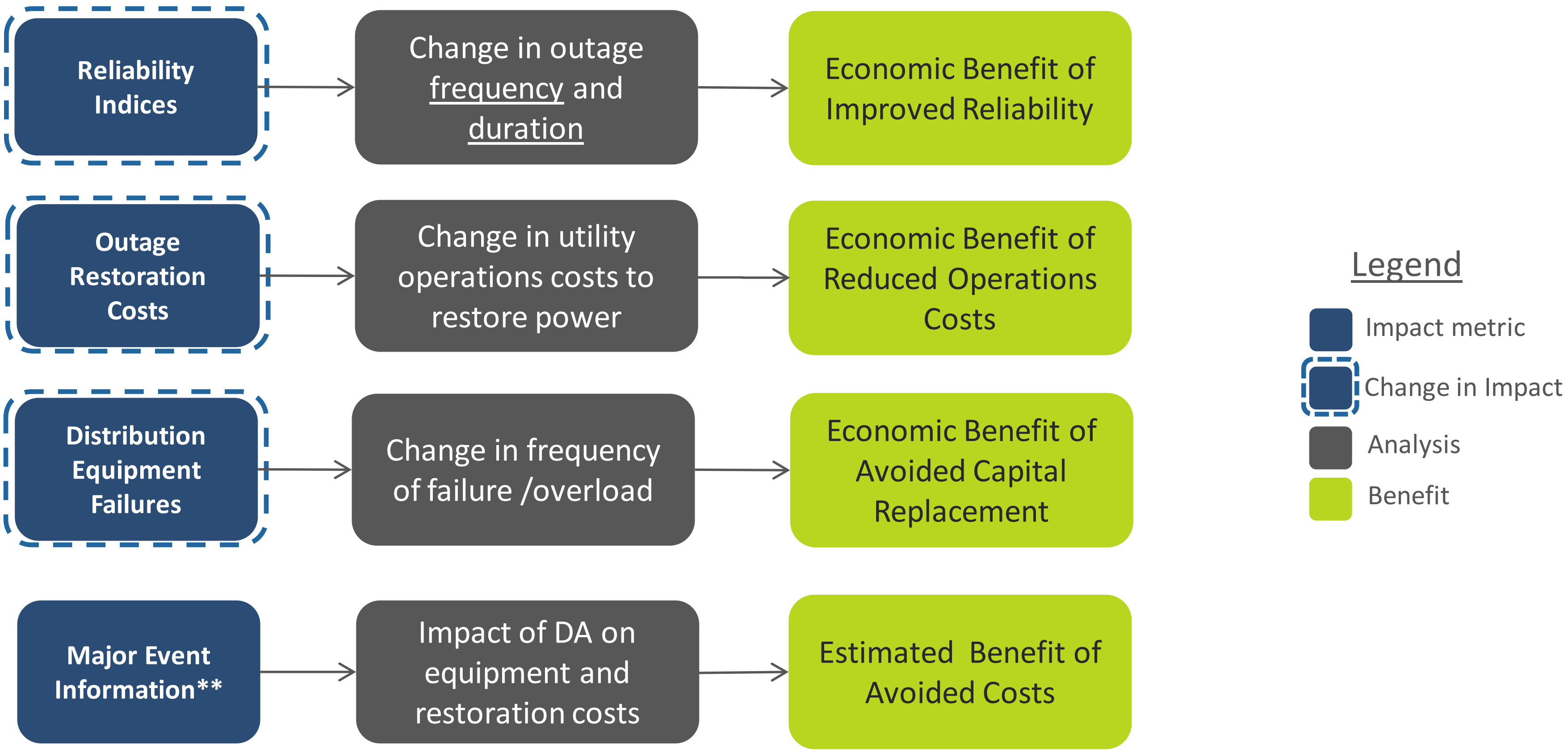
Build and Impact Metrics

Build and impact metrics will track the deployment of technology and how it affects distribution system reliability.

Build Metrics (Technologies)	Impact Metrics
• AMI Smart Meters with Outage and Restoration Notification features • SCADA • Enhanced fault detection technology • Automated feeder switches • Distribution Management System (DMS) • DMS integration with AMI Smart Meters with Outage and Restoration Notification • Others ➢ Equipment health sensors ➢ Loading monitors	• System Average Interruption Duration Index (SAIDI) • Customer Average Interruption Duration Index (CAIDI) • Outage restoration costs • Major event information • Others ➢ System Average Interruption Frequency Index (SAIFI) ➢ Momentary Average Interruption Frequency Index (MAIFI) ➢ Equipment failure incidents ➢ Cost of failed equipment

Logic for Analyzing Reliability

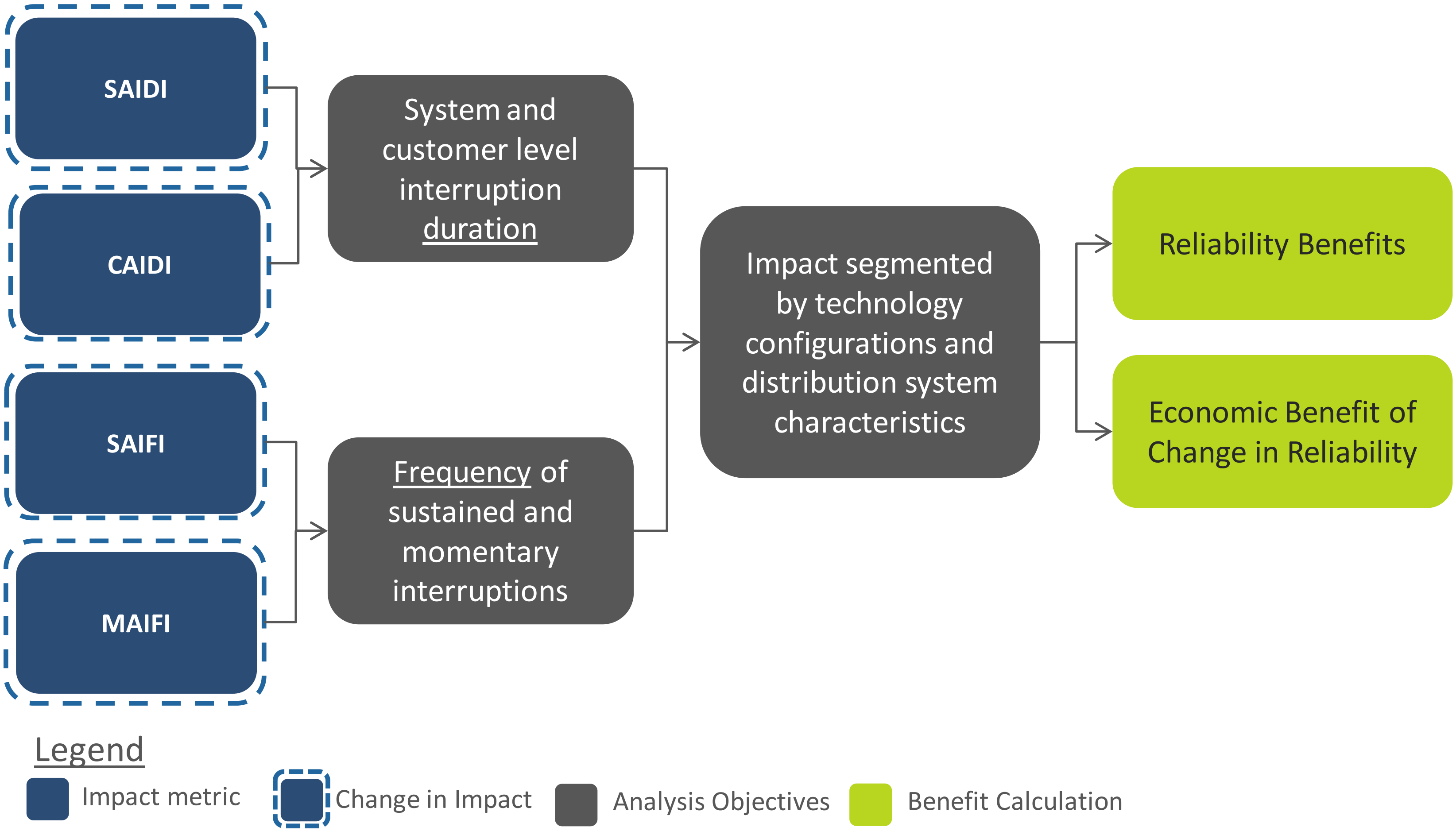
DOE will analyze reliability indices* and other impact metrics to calculate the economic benefits of smart grid technologies.



* IEEE STD 1366-2003 Guide for Electric Power Distribution Reliability Indices
** DOE will collaborate with recipients after events to understand lessons learned and qualitative insights

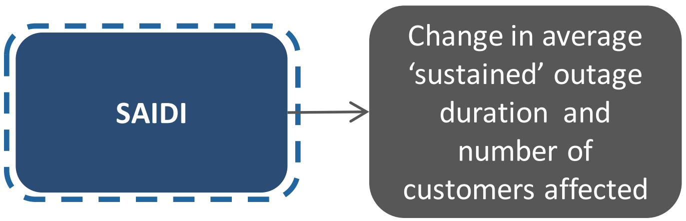
Reliability Indices

Analyzing reliability indices can contribute to determining how outage duration and frequency is changing.



SAIDI – System Average Interruption Frequency Duration Index

DOE will analyze changes in SAIDI to determine outage duration improvements and utilize Value of Service Calculations (VOS) to estimate economic benefit. SAIDI gives the average outage duration for each customer served by a utility.



Projects will report SAIDI using the same calculations and definitions. Using this information we will calculate the average change in outage duration (*minutes*) and the number of customers affected;

Projects will report the index and the number of customers used in the calculation. This data will provide DOE with an understanding of change in duration and number of customers affected. In some cases, small distribution automation projects and pilots will need to estimate a baseline for the portion of the system that is affected.

$$\text{SAIDI} = \sum \frac{\text{Customer Interruption Duration}}{\text{Total Number of Customers Served}}$$

$$\text{SAIDI} = \frac{\sum r_i N_i}{N_T} = \frac{\text{CMI}}{N_T}$$

r_i = Restoration Time for each Interruption Event

N_i = Number of Interrupted Customes for each Sustained Interruption Event during the reporting period

CMI = Customer Minutes Interrupted

N_T = Total Number of Customes Served for the Areas

Legend

Impact metric | Change in Impact | Analysis Objectives | Benefit Calculation

Value of Service Coefficients

DOE will estimate the economic value of reliability improvements by utilizing prior work done by LBNL to develop Value of Service (VOS) coefficients.

Standard Economic Value Calculation

**Value ($) of SAIDI Improvement** = Σ{ [SAIDI (System) * Total Customers Served within a class (#) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]Baseline - [SAIDI (System) * Total Customers Served within a class (#) * Average Hourly Load Not Served During Outage per Customer by class (kW) * VOS by class ($/kWh)]Project}

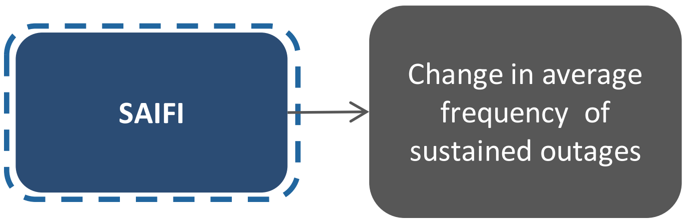
Estimated Average Electric Customer Interruption Costs US 2008$ by Customer Type and Duration (Summer Weekday)*

Customer Type	Interruption Cost	Interruption Duration				
		Momentary	30 mins	1 hr	4 hr	8 hr
Large C&I	Cost Per Average kWh	$173	$38	$25	$18	$14
Small C&I	Cost Per Average kWh	$2,401	$556	$373	$307	$2,173
Residential	Cost Per Average kWh	$21.6	$4.4	$2.6	$1.3	$0.9

*Sullivan J, Michael, 2009 *Estimated Value of Service Reliability for Electric Utility Customers in the US*, xxi

SAIFI – System Average Interruption Frequency Index

DOE will analyze changes in SAIFI to determine outage frequency improvements and utilize VOS Calculations to estimate economic benefit. SAIFI refers to the average number of interruptions that a utility customer would experience.



Some projects are not reporting this metric, because the assets they are deploying will likely not impact the frequency of sustained outages. The key assets that contribute to reducing SAIFI are fault current limiters, micro grids, and energy storage. Based on an analysis of the build metrics there are not any SGIG projects planning to utilize these assets to improve reliability.

Projects will report SAIFI using the same calculations and definitions. Using this information we will calculate the average change in the number of customers affected by sustained outages;

$$\text{SAIFI} = \sum \frac{\text{Total Numer of Customers Interrupted}}{\text{Total Number of Customers Served}}$$

$$\text{SAIFI} = \frac{\sum^{N} i}{N_T} = \frac{\text{CI}}{N_T}$$

r_i = Restoration Time for each Interruption Event

N_i = Number of Interrupted Customes for each Sustained Interruption Event during the reporting period

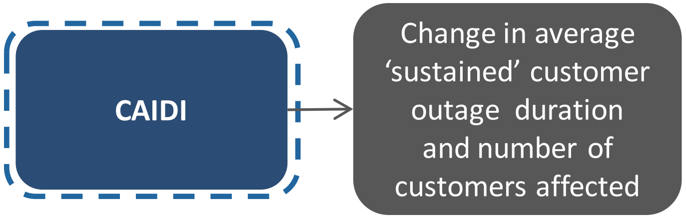
CI = Customers Interrupted

N_T = Total Number of Customers Served for the Areas

Impact metric | Change in Impact | Analysis Objectives | Benefit Calculation

CAIDI – Customer Average Interruption Duration Index

DOE will analyze changes in CAIDI to determine outage duration improvements and utilize VOS Calculations to estimate economic benefit. CAIDI refers to the average outage duration that any utility customer would experience. It can also be viewed as the average restoration time.



Projects will report CAIDI using the same calculations and definitions. Using this information we will calculate the average change in customer outage duration (*minutes*) the number of customers affected;

$$\text{CAIDI} = \sum \frac{\text{Customer Interruption Duration}}{\text{Total Number of Customers Interrupted}}$$

$$\text{CAIDI} = \frac{\sum r_i N_i}{\sum N_i} = \frac{\text{SAIDI}}{\text{SAIFI}}$$

r_i = Restoration Time for each Interruption Event

N_i = Number of Interrupted Customes for each Sustained Interruption Event during the reporting period

Projects will report the index and the number of customers used in the calculation. This data will provide DOE with an understanding of change in duration and number of customers affected. In some cases, small projects or distribution automation pilots will need to estimate a baseline for the portion of the system that is affected.

Impact metric | Change in Impact | Analysis Objectives | Benefit Calculation

MAIFI – Momentary Average Interruption Frequency Index

DOE will analyze changes in MAIFI to determine momentary interruption frequency and utilize VOS Calculations to estimate economic benefit. MAIFI refers to the average number of <u>momentary</u> outages (typically 5 minutes or less) that a utility customer would experience during a given period.

MAIFI → Change in average frequency of momentary interruptions

Projects will report MAIFI using the same calculations and definitions. Using this information we will calculate the average change in the number of customers affected by momentary (less than 5 min) interruptions;

$$\text{MAIFI} = \sum \frac{\text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customers Served}}$$

$$\text{MAIFI} = \frac{\sum \text{IM}_i \text{N}_{mi}}{N_T}$$

IM_i = Number of Monetary Interruptions

N_{mi} = Number of Interrupted Customes for each Momentary Interruption Event during the reporting period

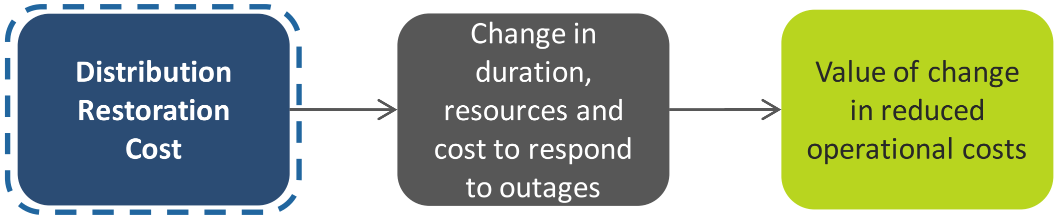
N_T = Total Number of Customes Served for the Areas

Some projects are not reporting this metric, because the assets they are deploying will likely not impact the frequency of momentary outages. The key assets that contribute to reducing MAIFI are fault current limiters, micro grids, and energy storage. Other projects are reporting this metric and hope to observe changes due to automated feeder switching.

Impact metric | Change in Impact | Analysis Objectives | Benefit Calculation

Outage Restoration Costs

DOE will analyze changes in Outage Restoration Costs to calculate utility operational benefits.



$$\textbf{Value (\$)} = [\text{Restoration Cost (\$)}]_{\text{Baseline}} - [\text{Restoration Cost (\$)}]_{\text{Project}}$$

Restoration costs include labor and other allocated overhead expenses such as vehicle costs, fuel and consumables.

Legend

Impact metric | Change in Impact | Analysis Objectives | Benefit Calculation

Major Events

DOE will collaborate with recipients after events to understand how automated and remotely controlled equipment can enhance restoration efforts.

Major Event Information

- Event cause
- Event duration
- Number of customers affected
- Duration customers are affected
- Capital replacement costs
- Average rate of restoration (customers per day)
- Restoration personnel required (internal/contract)

Outage duration and customers affected

Restoration duration and cost

Equipment replacement

Estimated Value of Service (reduced outage duration)

Estimated cost avoided

Estimated Capital Cost avoided

Legend

Information

Analysis Objectives

Benefit Estimate

Additional Analytical Questions

- What other kinds of impacts are project teams expecting, and how should we be looking for them in the metrics data?
- How are utilities operating distribution automation equipment and leveraging data, and how can that shared?
- How are baselines and control group circuits being established?
- How might circuit topology and configuration affect results?
- What kinds of "experiments" can the industry perform together?