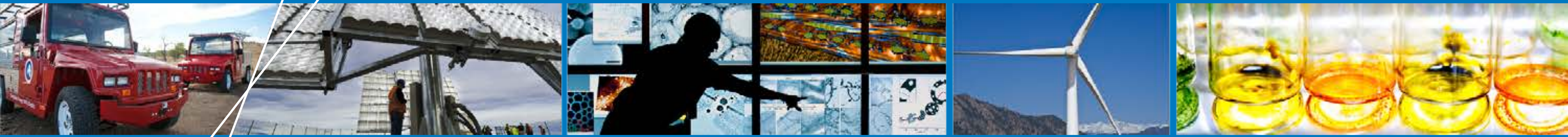
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Security: Microgrid Planning and Design



World Renewable Energy Forum 2012

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Outline

- NREL Approach to Microgrid Design
- CORE Microgrid Design Process
- Microgrid Modeling and Simulation
- Valuing Energy

NREL Approach to Microgrid Design

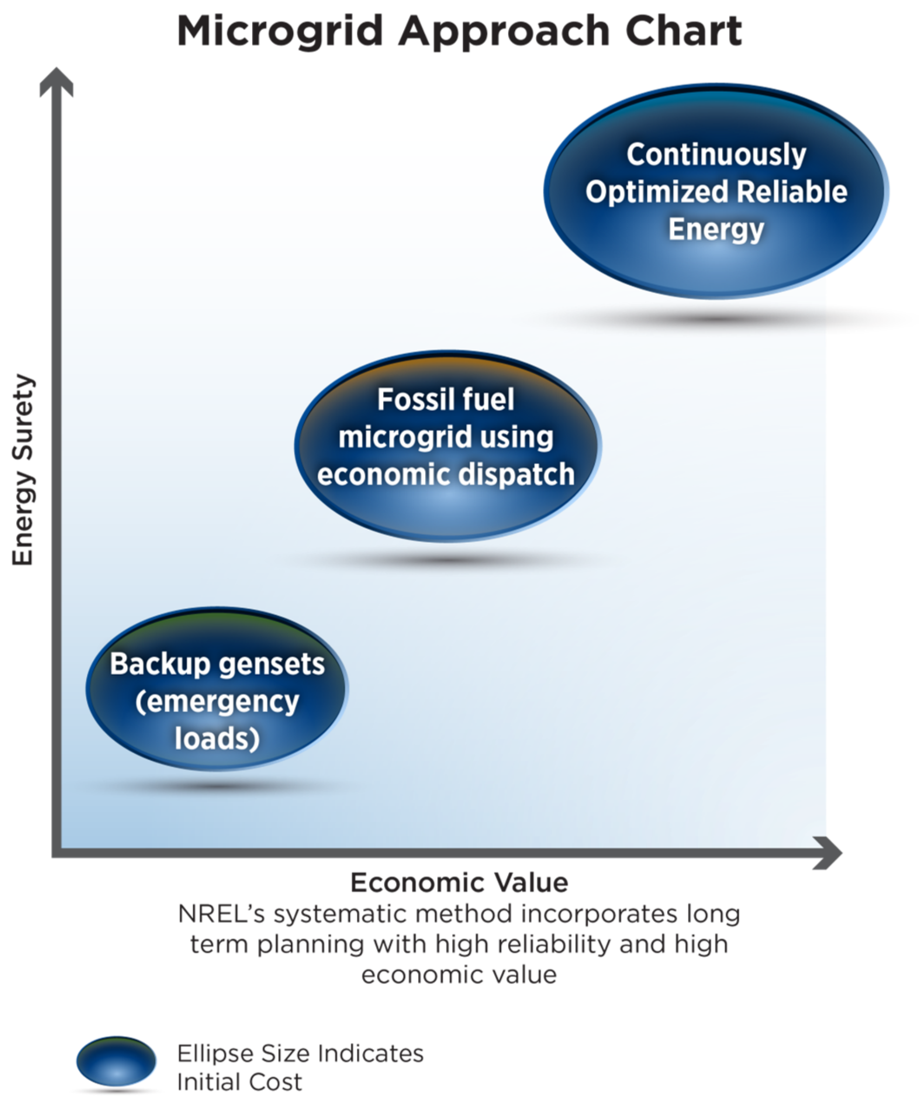
- **Continuously Optimized Reliable Energy (CORE) Microgrids**
- **Differentiating Characteristics:**
  - Integrates into 24/7 operations
  - Can optimize on economics or surety
  - Focuses on fuel diversity
  - Expands/contracts to provide energy for all load coverage spheres
  - Phased approach can allow for gradual addition of components over time
    - ❑ Load prioritization and migration with added generation

Achieving Overarching Goals

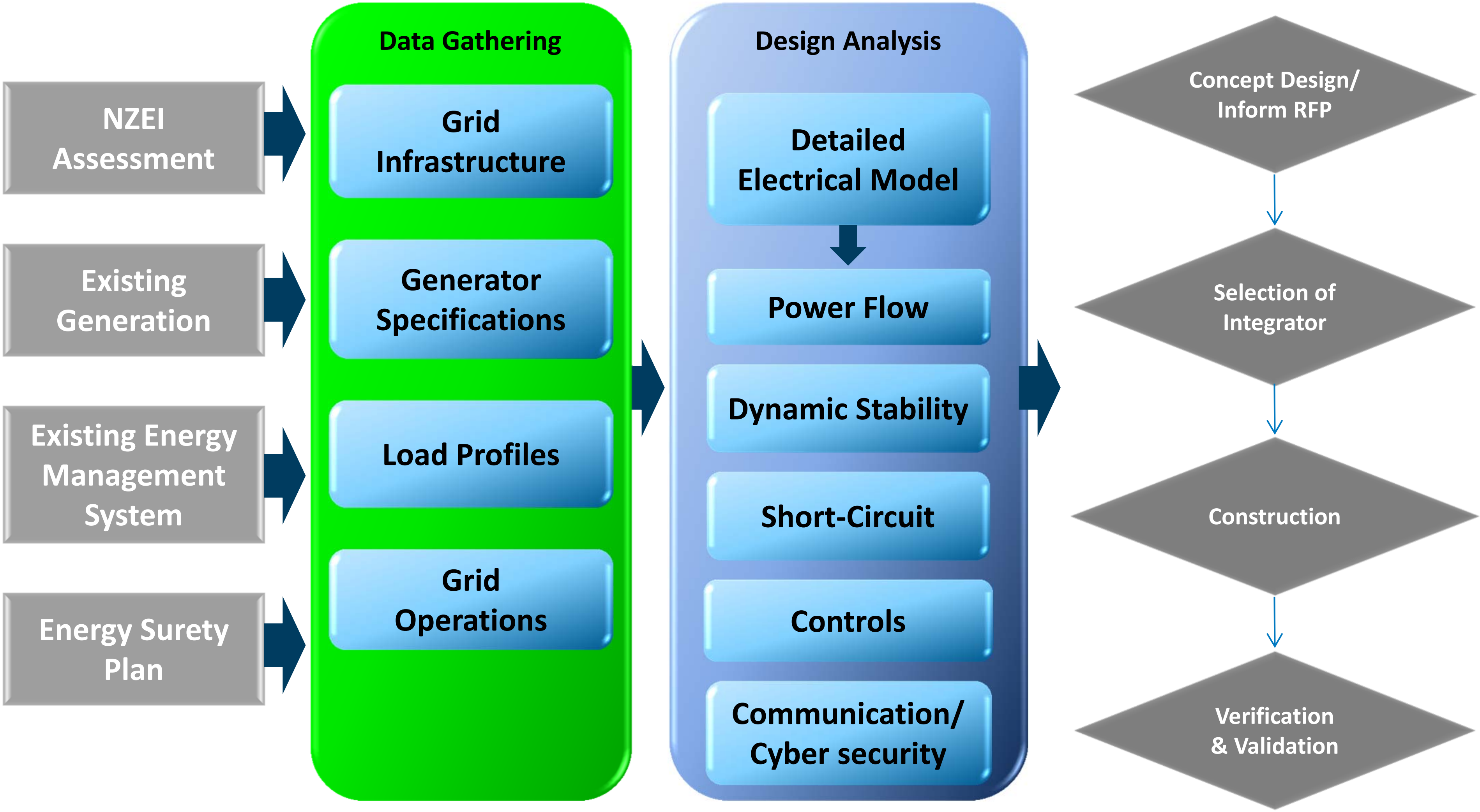
- **Economic Value - Control system to dispatch based on rate structure/generation costs**
  – Primary driver: Economics of generation in context of rate structure
- **Sustainability – integration of renewable energy and energy efficiency technologies**
  – Primary driver: Carbon savings, fuel diversity, emissions goals
- **Energy Surety - Start with critical loads and expand to other load coverage spheres, diversity of generation and fuel types**
  – Primary driver: Ensure reliable operation under different operating scenarios

Key Benefits of CORE Approach

- **Increased energy surety**
  - Diversity of generation assets and fuel sources
  - Generation assets are used daily
- **Increased economic value**
  - Enhanced economic dispatch
  - Reduced lifecycle cost versus initial installation cost



CORE Microgrid Design Process

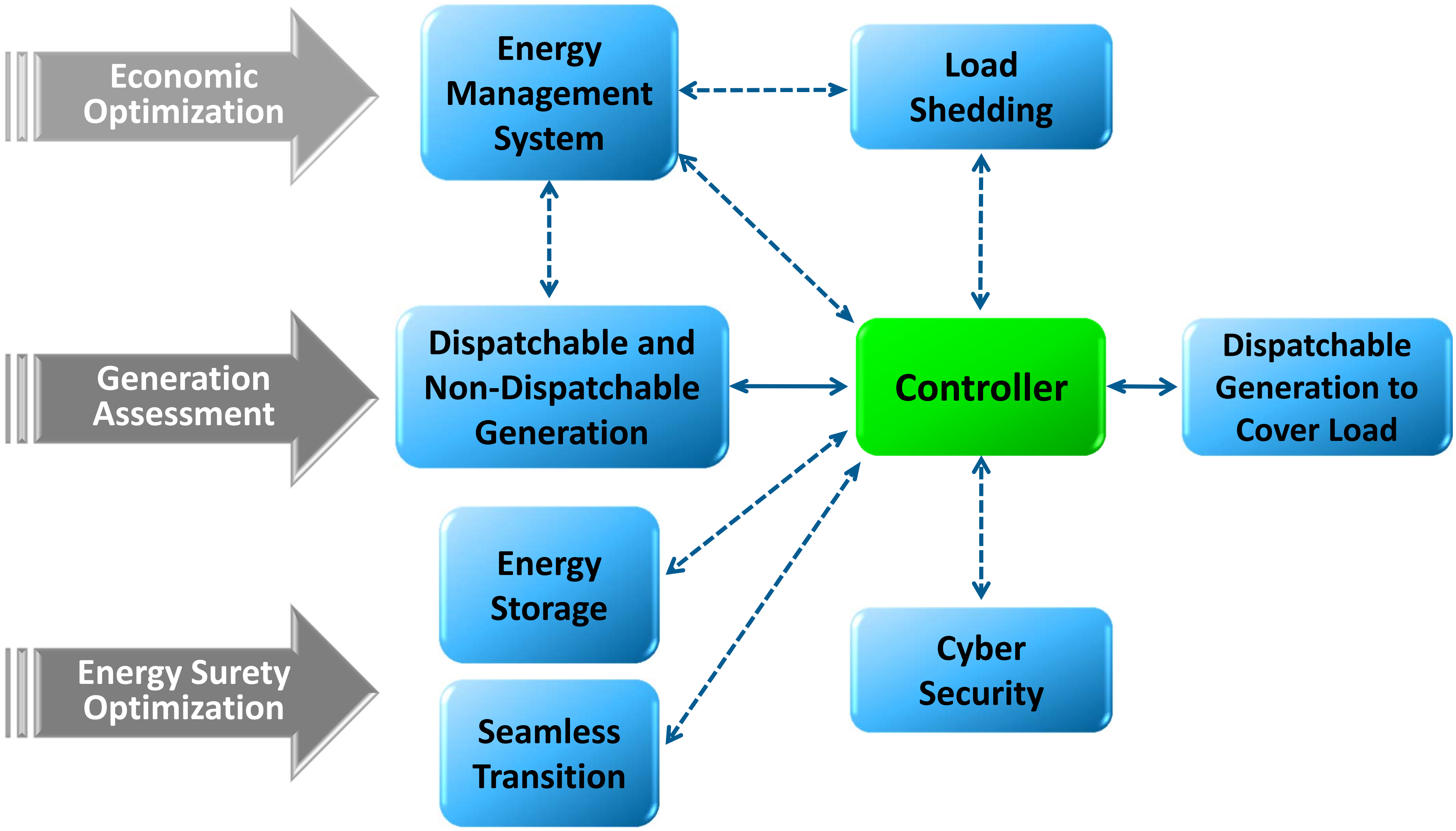


Net-Zero Energy Installations

NZEI systems approach is optimal for microgrid facilitation (energy and security nexus).

- **Maximizes use of sustainable energy technologies**
- **Supplies local generation to electrical loads**
- **Identifies optimal dispatch opportunities**
  - Sale of power (arbitrage), demand response, etc.
- **Characterizes microgrid (microgrid “baseline”)**
  - Base distribution system/grid interface
  - Distributed energy resources (diesel generators/storage and renewable energy combination)

Key Components of a CORE Microgrid



CORE Microgrid Modeling and Simulation

Why was Modeling and Simulation Necessary?

1) **Microgrid design presents unique challenges:**
   - mix of both traditional and new generation equipment
   - grid needs "self-regulation" (of voltage and frequency)
   - advanced controls
2) **Traditional power-flow assessments are inadequate**
   - detailed response characteristics of engines, regulator, and governors needed
   - need to include Renewable technologies
3) **Need to analyze detailed start-up sequence and control**

CORE Microgrid Modeling and Simulation

- **Combination of traditional and new generation equipment**
  - synchronous machines combined with power electronics and
  - non-linear sources (e.g., PV, batteries)
  - In most cases, no standard models are defined (wind is the exception)
- **Traditional power-flow software typically inadequate**
- **Requires breadth and depth of knowledge in:**
  - power systems
  - electrical machinery
  - control systems
  - power electronic converters
  - advanced/novel protection schemes
  - modeling and simulation

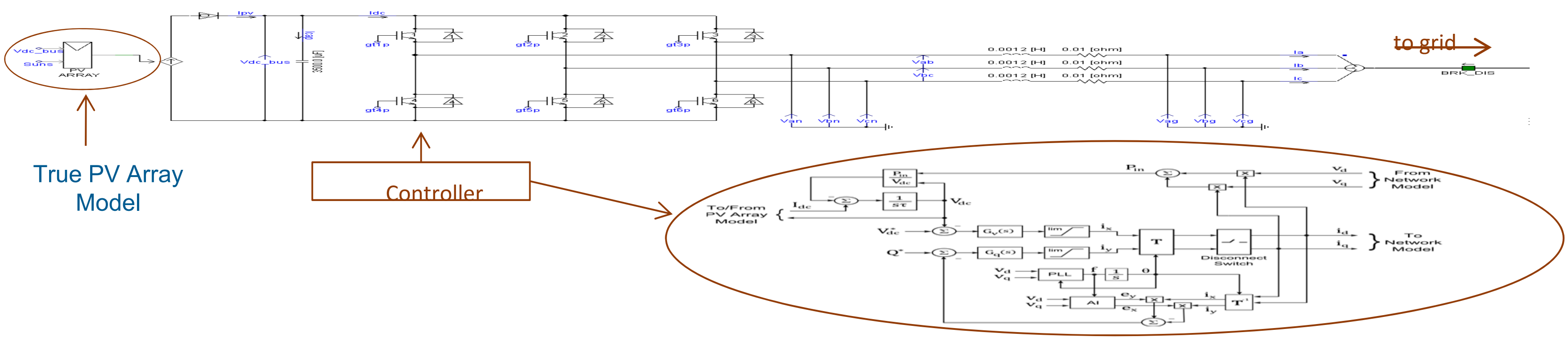
Modeling and Simulation Objectives

1) **Model**
   - Electrical system – transformers, cabling, switches, etc.
   - Generation equipment – diesel, land-fill gas, natural gas engine and controls, PV inverters, etc.
   - Controls – supervisory controller, existing controls
2) **Predict**
   - Simulate operating scenarios and predict performance
3) **Recommend**
   - Generation equipment, supervisory control/operation

PV Inverter Modeling

An advanced PV Inverter model was developed, with the following features:

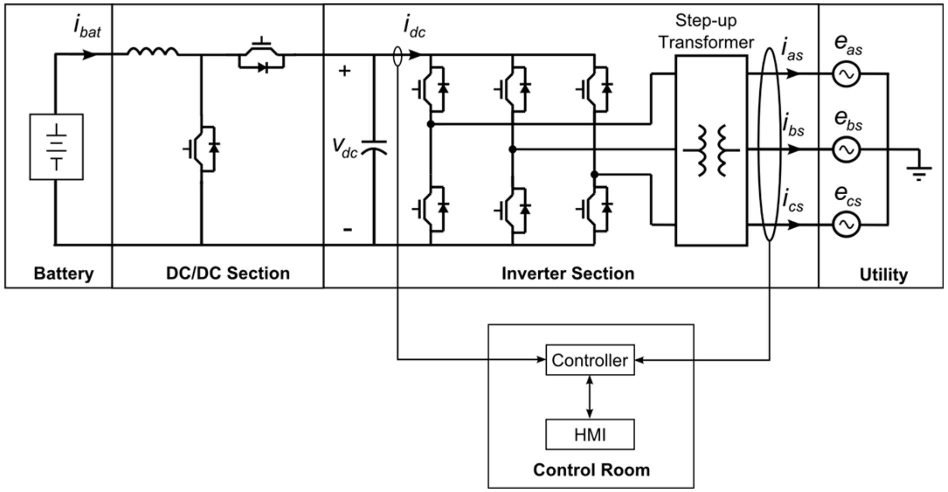
- **True PV array source**
  - Can input actual sun (irradiance) curves
- **Full reactive power control**
  - Supports future inverter designs
  - Allows for arbitrary reactive power command
  - Advanced Anti-Islanding Control
  - Active feedback method



Energy Storage Model

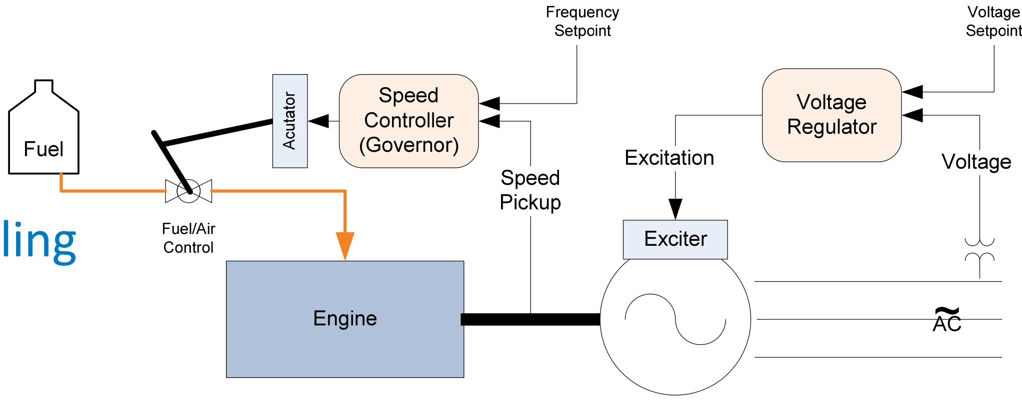
An energy storage model was developed, with the following features:

- **Detailed battery model**
  - Electrical components to represent fast and slow dynamic responses
- **Advanced controls**
  - Fast VAR injection
  - Anti-islanding protection
  - Charge/discharge control

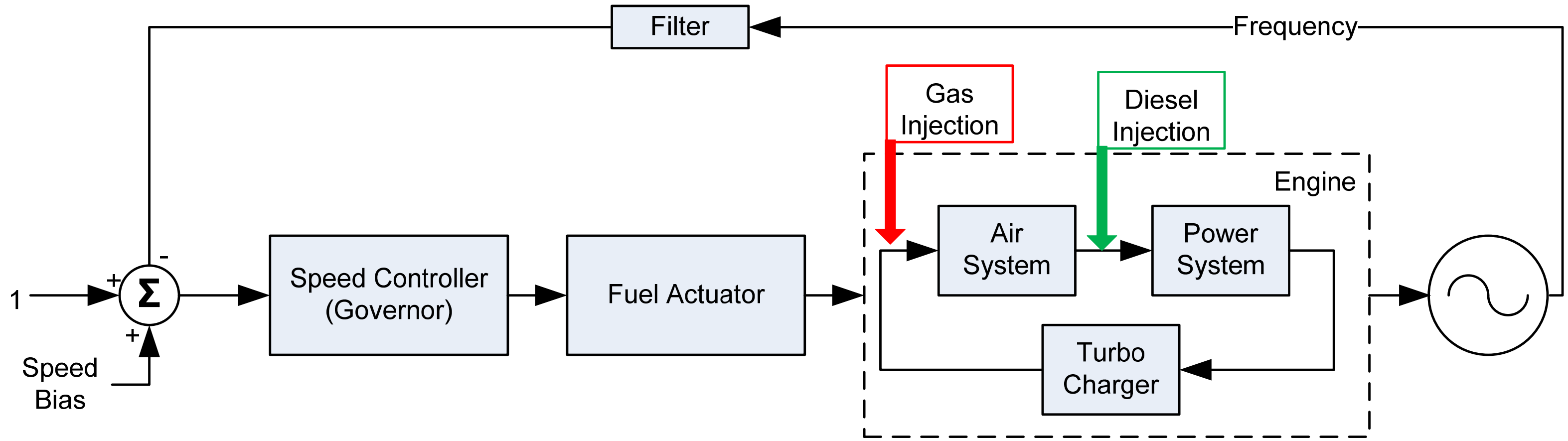


Modeling of Gensets

- **The general gen-set model consisted of an:**
  - electrical machine; fuel-handling system; governor; voltage regulator/exciter



- **Diesel gen-sets operate differently than Land-fill or NG:**
  - diesels have direct fuel injection
  - land-fill and natural gas have an air system



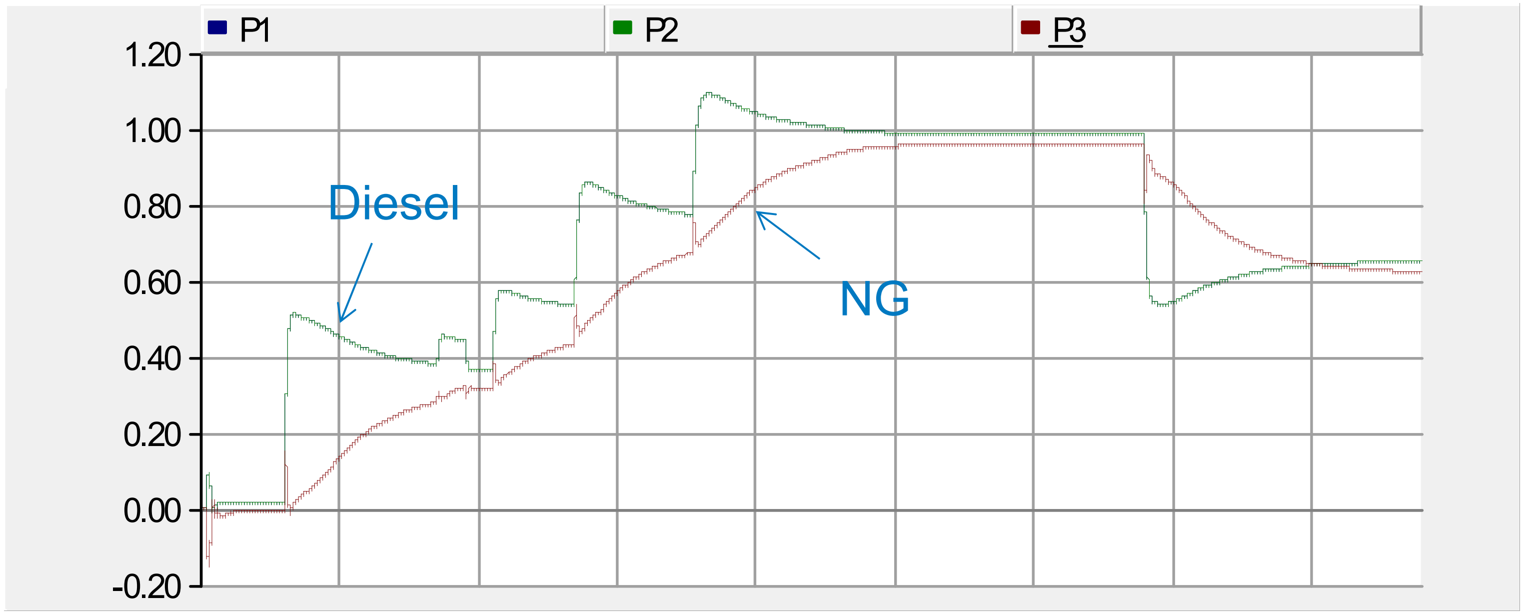
Supervisory Controller

- **Functions**
  - Select the machine group to maintain the microgrid frequency and voltage – the "swing machine."
  - Select other generation assets required to support the load.
  - Restore loads following priority and timing requirements.
  - Control curtailment or restoration of loads using BEMS or load shedding.
  - Manage adjustment of protection settings for island versus grid-connected operation.
  - Pre-programmed contingency responses

Coordination with Baseload Generators

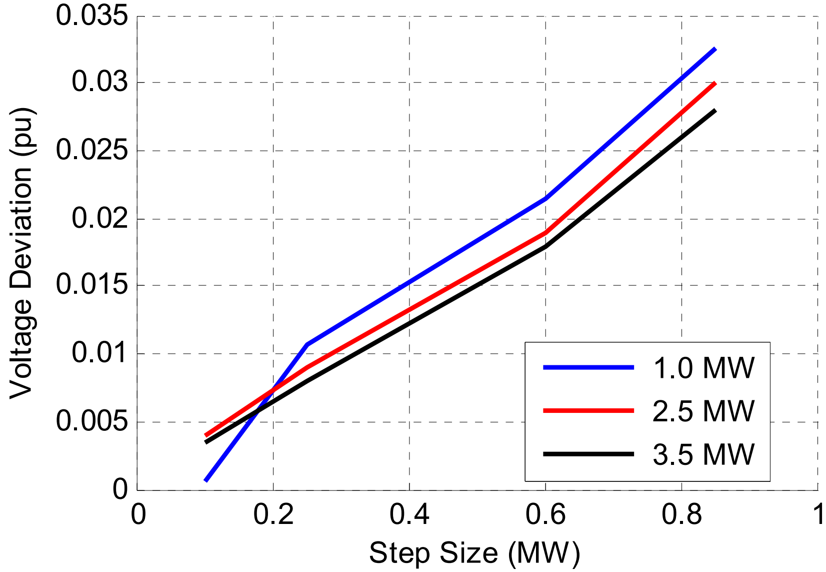
Black-Start: Sequential Addition of All Feeders

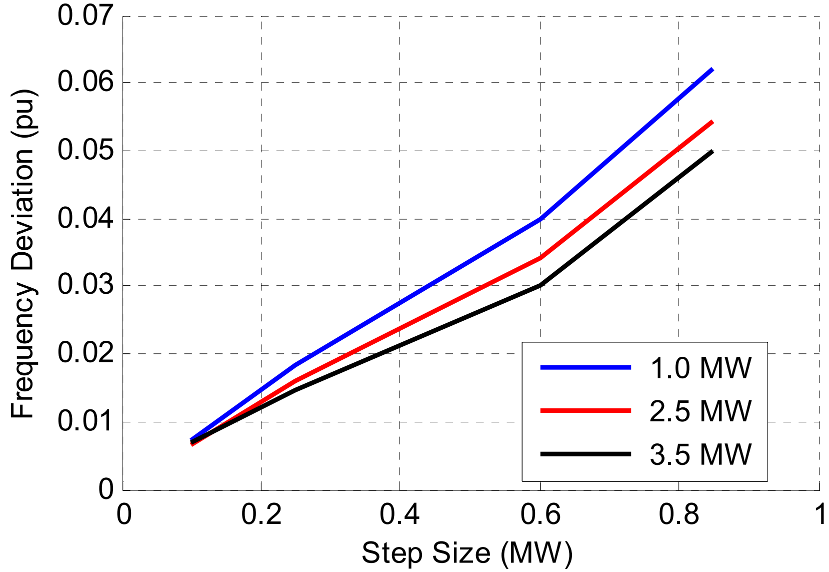
Note: NG operates in baseload mode



Natural Gas Sensitivity Study

Transient Excursions vs Load Step





Valuing Energy Security

- **Macroscopic approach:**
  - Based on Gross National Product or Gross Domestic Product

$$\text{Outage cost}\left(\frac{\$}{\text{kWh}}\right) = \frac{\text{GNP (or GDP) in \$}}{\text{Total annual energy consumption in kWh}}$$

- **Microscopic approach (Customer Damage Function) :**
  - Based on customer survey of outage and cost information
    - ❑ Depends on duration of interruption, situation in which interruption occurs, customer activity
- **Analytical approach:**
  - Based on generation, load and cost models
  - Calculate Expected Energy Not Supplied and Outage Costs

CDF Approach

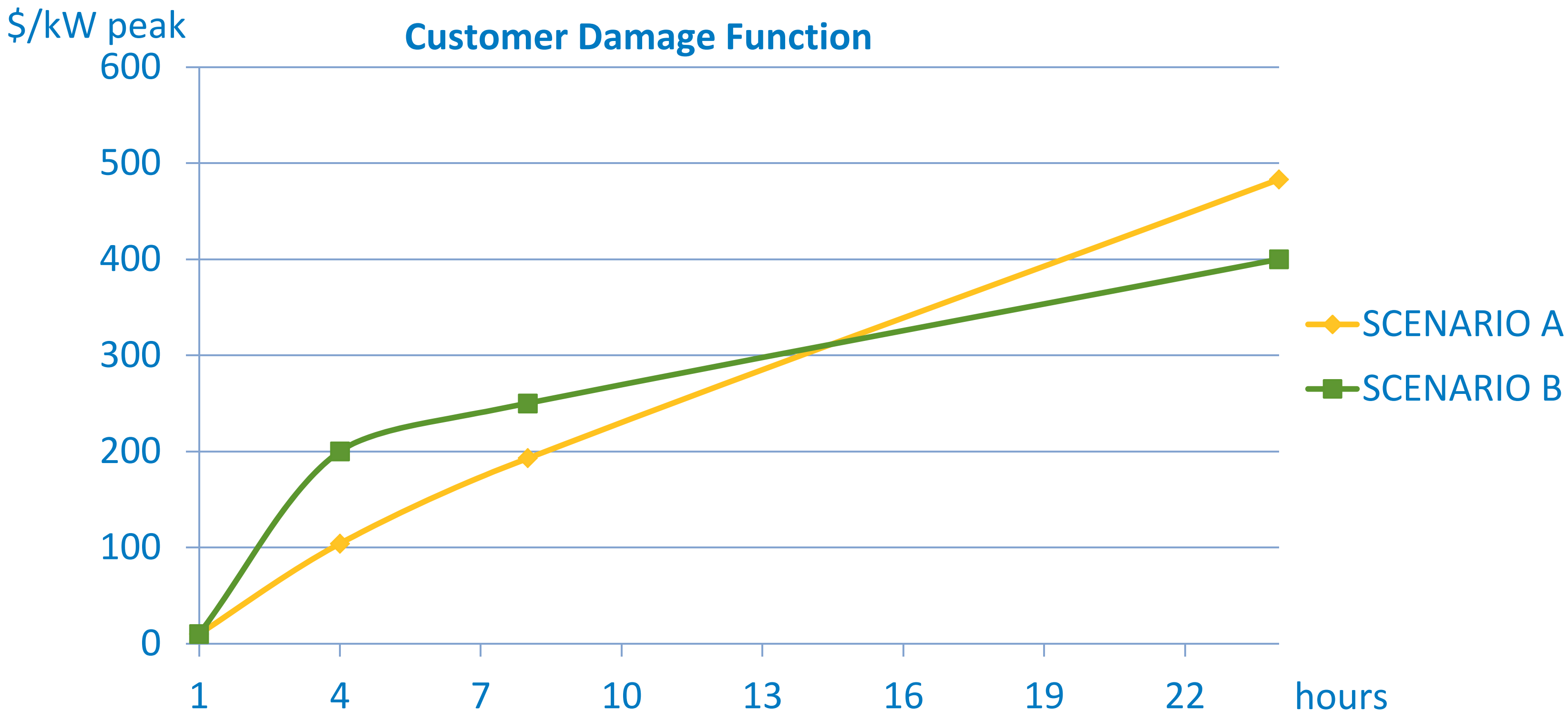
- **Microscopic approach – Customer Damage Function (CDF): developed survey**
  – Surveys exist for residential, commercial, and industrial sectors; none exist for military bases
- **Chose hypothetical scenarios that vary in duration and situation in which interruption occurs (emergency level):**
  – Scenario A
    - ❑ There is a power outage and the lack of power supply lasts for 1 hour, 4 hours, 8 hours or 24 hours. The base is not in an emergency situation.
  – Scenario B
    - ❑ There is an outage and a natural disaster or terrorist attack event is simultaneously going on in the area. The lack of power supply lasts for 1 hour, 4 hours, 8 hours, or 24 hours and the base is under an emergency situation and has to remain operational.

CDF Approach

- **Survey: NREL-designed survey assesses costs of power failure**
  - Suspended mission critical and non-critical operations
  - Impact on relief and rescue missions
  - Personnel sent home from work
  - Overtime for emergency workers
  - Base security impacts
  - Infrastructure impacts (heat, water, sewer, traffic lights)
  - Delays or failures in backup generation
  - Fuel for backup generators
  - Equipment damaged
  - Human lives put in danger
  - Food spoilage
  - Residential impacts
  - Curtailing commercial facility operating hours
- **Costs vary depending on scenario and outage duration**

CDF Approach

- **Once survey completed the data has to be processed in order to create a Customer Damage Function (CDF)**
- **Results: substantial cost difference between Scenarios A and B**
  - Fewer personnel sent home
  - Risk increases: communications, human life put to risk, etc



CDF to Support Financing Energy Security

- **How to use the CDF?**
  - What duration of interruption to prepare for?
  - What duration of interruption should be used to justify Energy Security projects?
  - How unreliable is the grid?
  - What are the statistics of large outage events in the grid?

CDF to Support Financing Energy Security

- **Utility distribution system reliability indices**
  - Consumer or end-user oriented indices
  - Utilities report to Public Utility Commissions (PUCs) reliability performance indices
- **3 most popular customer-oriented indices**

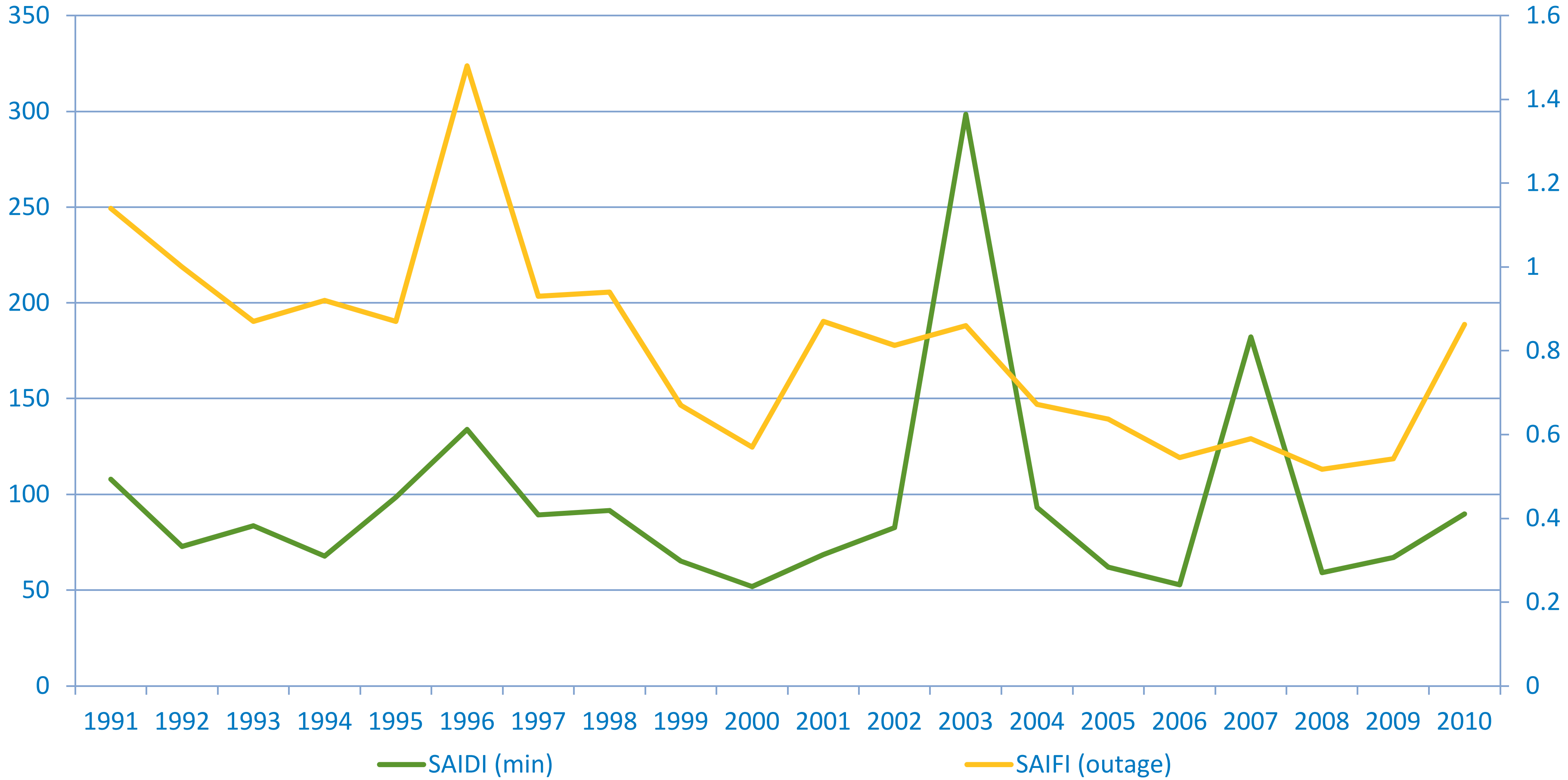
$$\text{SAIDI} = \frac{\text{Sum of customer interruption durations}}{\text{Total number of customers}}$$

$$\text{SAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers served}}$$

$$\text{ASAI} = \frac{\text{Customer hours of available service}}{\text{Customer hours demanded}}$$

CDF to Support Financing Energy Security

- **Example utility SAIDI and SAIFI over 20 years:**
  - Highly variable and no tendency

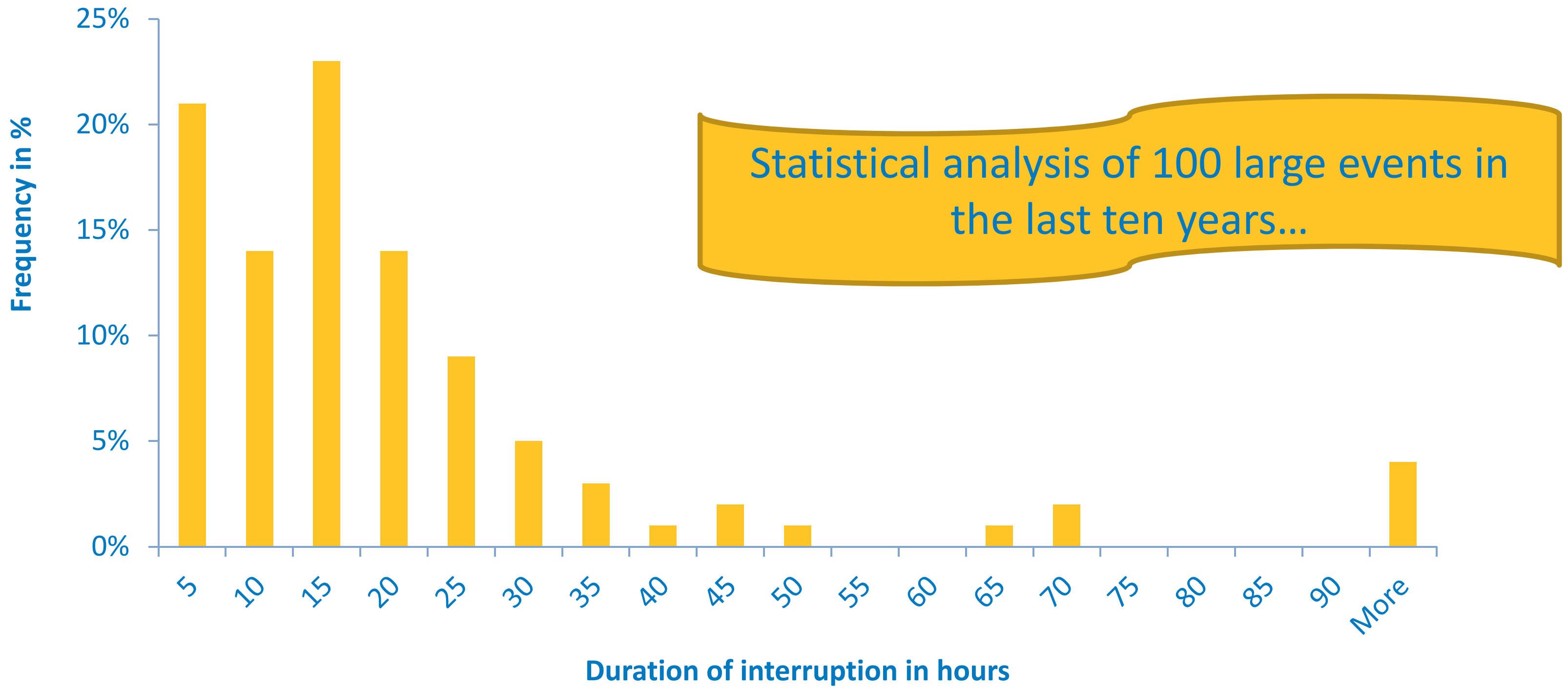


CDF to Support Financing Energy Security

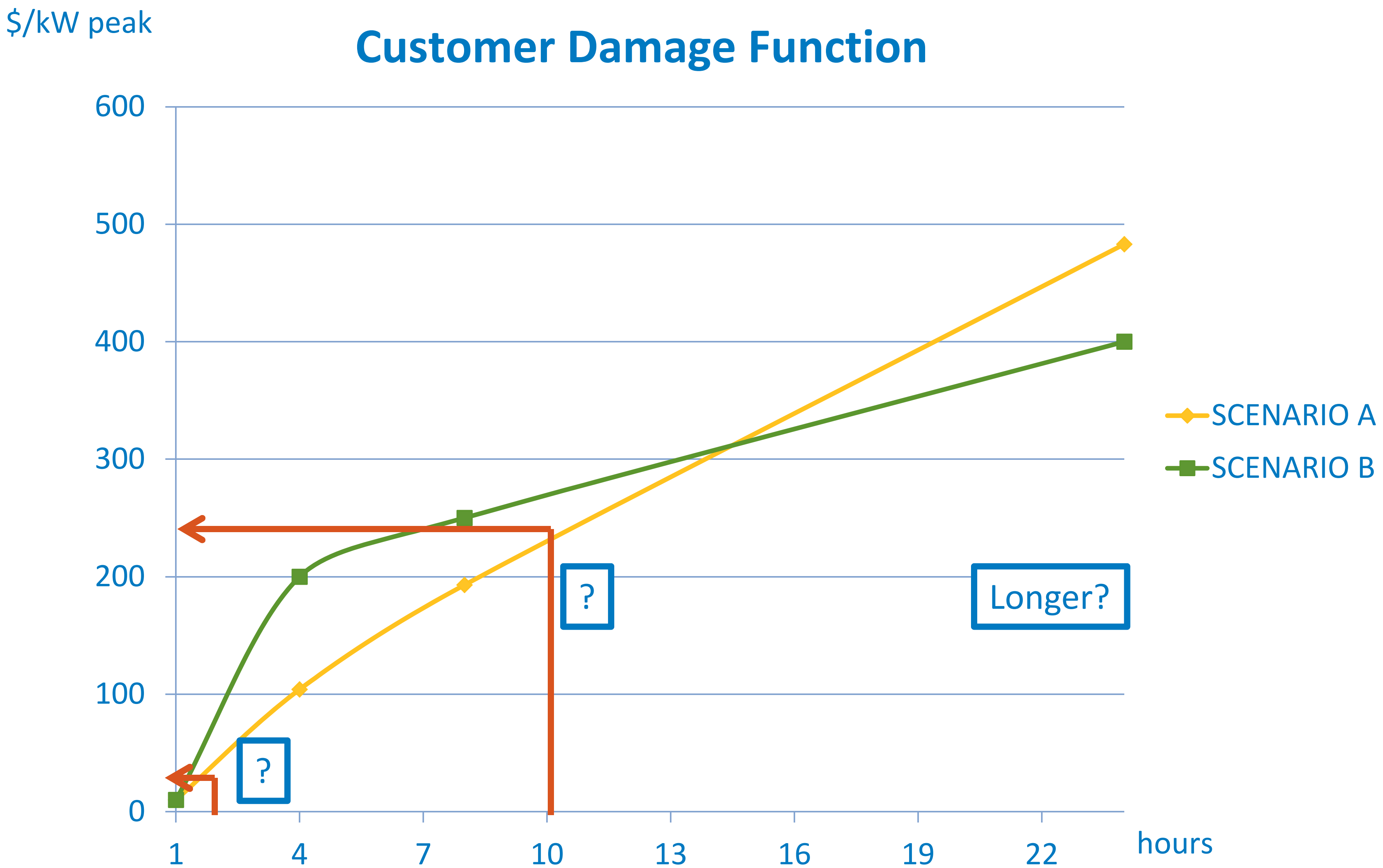
- **Average metrics may not capture key criteria for energy security planning in installations?**
  - Annual average duration and customers affected in the ten largest annual events

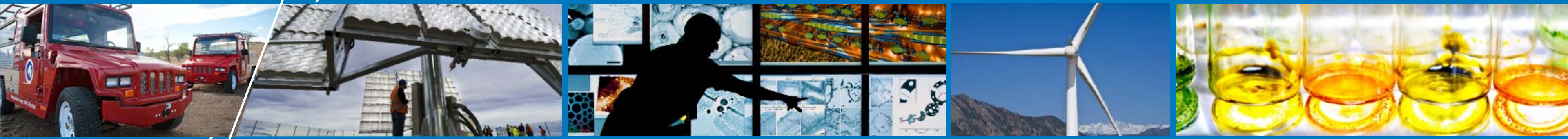
CDF to Support Financing Energy Security

- **Outage duration frequency distribution of example utility's 10 largest annual events over 10 years**
  - What is the risk to be assumed?



CDF to Support Financing Energy Security





Thank you!

Questions?

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