University of Pittsburgh

Panel Session on

Evolution of Power System Designs

Power Electronics Transforming the Power System

November 16, 2015

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UNIVERSITY OF PITTSBURGH
SWANSON school of engineering
Power & Energy Initiative

Program Information

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Session 3 (Conference Room A - 3rd Floor):
Evolution of Power System Designs
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Session Moderator:
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Speakers:
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Deputy Assistant Secretary
James Fields and James Maug - Pitt Ohio Trucking
Chief Operating Officer / Director Building Maintenance and Property Management
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Panel Session Title: "Evolution of Power System Designs"
Title: "Power Electronics Transforming the Power System"

Abstract: The evolving electric power system continues to demand more flexible, reliable, and profitable operation of the power system and grid infrastructure. Existing and future power systems require advanced power electronic technologies applied at transmission and distribution levels, such as STATCOM, SVC, and DC systems, to provide solutions for the reliable, automated, and efficient utilization of the power system. These advanced technologies allow for improved system operation from the consumers' end in the distribution system up through the bulk transmission system with minimal infrastructure investment. Recent system changes and initiatives such as grid and consumer level renewable integration, generation retirement, and efficiency optimization result in need for advanced power electronic solutions. This presentation explores various aspects of power electronics applications at the transmission and distribution level.

Biography: Mr. Sullivan currently manages MEPPI's Power Electronics Product Line, providing both technical and commercial management of Mitsubishi Electric's Flexible AC Transmission Systems (FACTS) and HVDC business in North America. Dan's leadership of system engineering and sales teams ensures technical expertise of all FACTS (SVC/STATCOM) products, including engineering and system design aspects from initial planning stages through design, construction, and commissioning of FACTS systems. Mr. Sullivan has authored technical IEEE papers and publications, and lectured at the University of Wisconsin, University of Pittsburgh, and IEEE tutorials on topics such as Dynamic Reactive Power Control, Static Var Compensators, HVDC, and insulation coordination. Dan is a Senior Member of IEEE, registered Professional Engineer in Pennsylvania, and held leadership roles in PES Subcommittees and Working groups on HV Power Electronics.

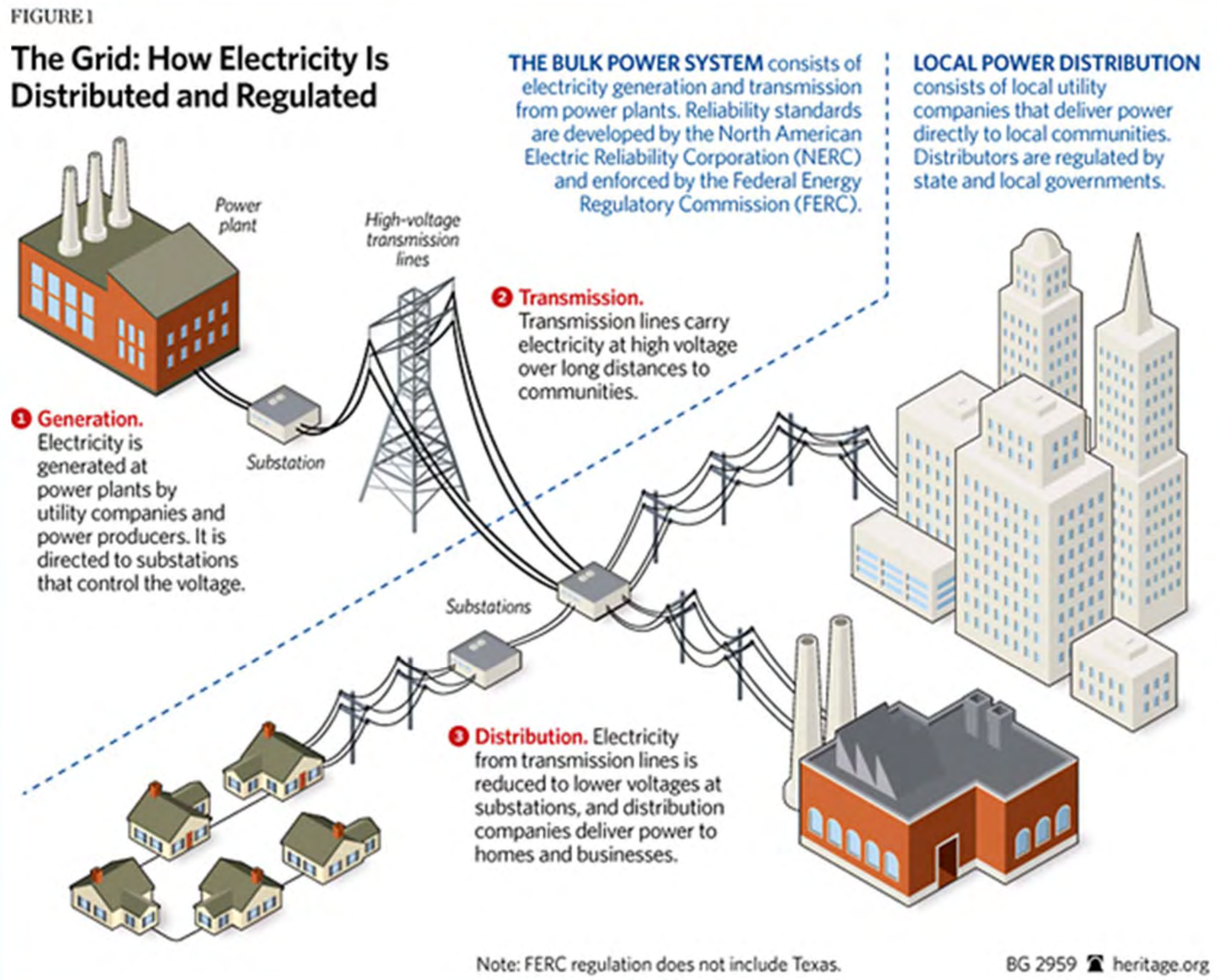
Discussion Agenda

- The Traditional Power System
- Industry trends and evolving power system
- Solutions and equipment applied to cope with evolution
- Distribution Management and Volt Var Optimization
- View of new Power System
- Smart Grid demonstration project at factory
- Planned DC distribution demonstration facility

Traditional Power System

Traditional Grid

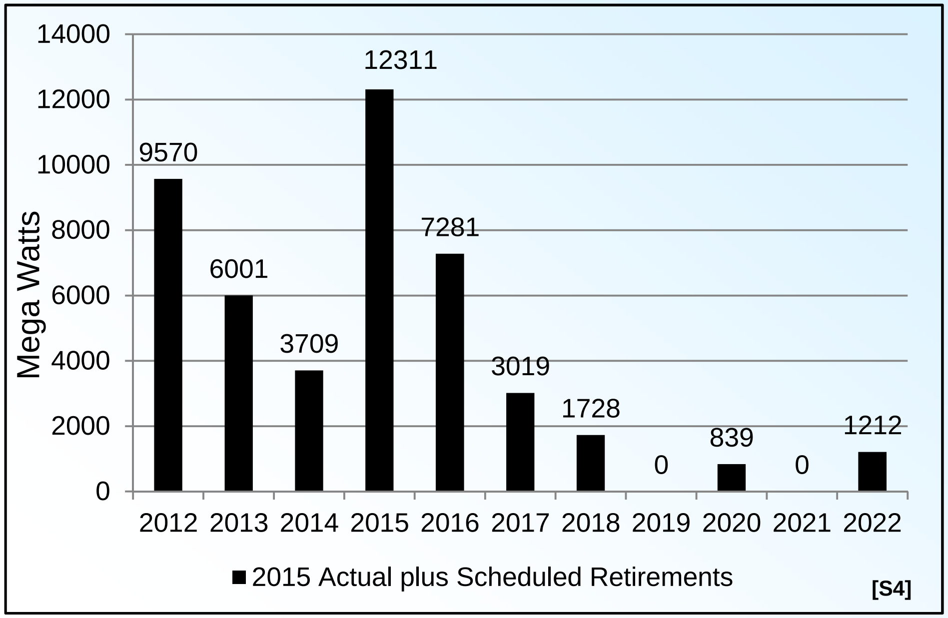
Changes for the Better



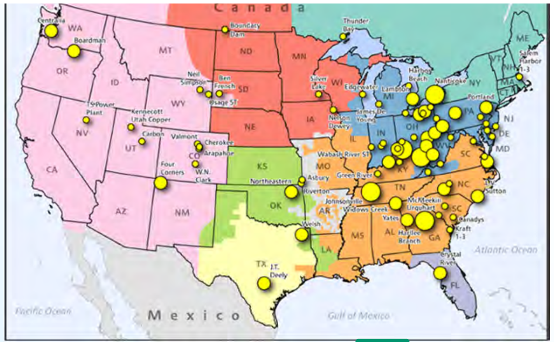
Industry trends and evolving power system

Industry Trend - Generator Retirements

- **Generator retirements due to EPA federal regulations**
- **Projects to address the Clean Power Plan firm up until late 2016 & 2017 (in response to EPA 111d)**

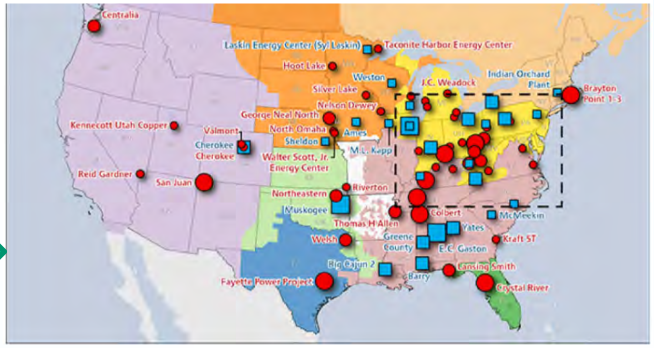


Planned coal retirements 2013 to 2022



26,048 MW Scheduled retirements

Planned coal retirements 2015 to 2022

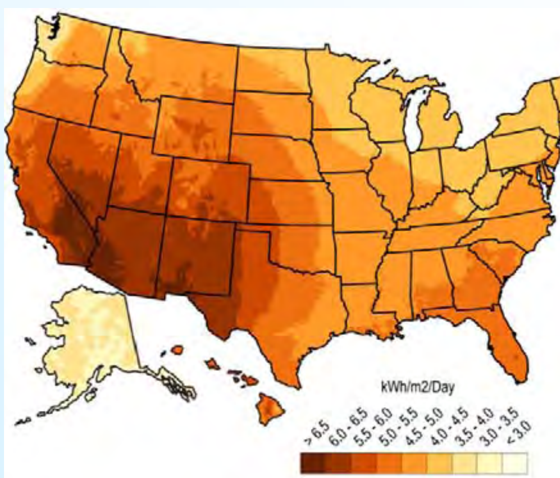


Proactively considering Clean Power Plan (Federal Regulation)

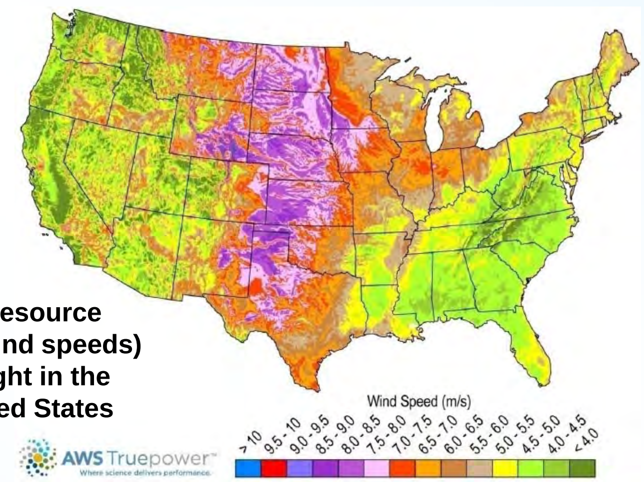
45,669 MW Scheduled & actual retirements

Source: SNL

Industry Trend - Renewable Integration



Map of the mean solar resource available to a PV system that is facing south and is tilted at an angle equal to the latitude of the system



Onshore wind resource (annual average wind speeds) at 80-m hub height in the contiguous United States

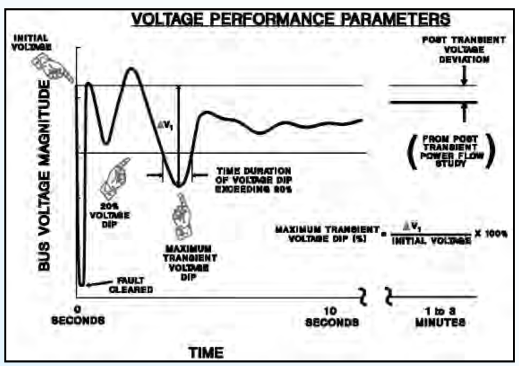
Source: NREL Renewable Electricity Futures Study, Executive Summary, 2012

Source: NREL Renewable Electricity Futures Study, Executive Summary, 2012

Industry Trend – Electric Transmission Reliability

ECAR	ECAR East Central Area Reliability Coordination Agreement	NPCC	Northeast Power Coordinating Council
ERCOT	Electric Reliability Council of Texas	SERC	Southeastern Electric Reliability Council
FRCC	Florida Reliability Coordinating Council	SPP	Southwest Power Pool
MAAC	Mid-Atlantic Area Council	WECC	Western Electricity Coordinating Council
MAIN	Mid-Atlantic Interconnected Network	ASCC	Alaskan Systems Coordinating Council
MAPP	Mid-Continent Area Power Pool		

Source: North American Electric Reliability Council, www.nerc.com



WECC Transient Voltage Dip Criteria

We see SVC/Statcom projects driven by load increased of large industrial loads such as gas processing, mining, and oil extraction

- **Load characteristics**
- **NERC Transmission Planning Standards**
- **Example of system performance criteria**
  - 1-Steady-state voltage following system disturbance (post contingency voltage)
  - 2-Fault induced voltage recovery – examples shown below
    - a) reactive power and control capability shall be provided to facilitate voltage recovery within 1.5 seconds
    - b) the slowest recovering transmission bus voltage must recover to 80% of its pre-fault voltage within 2 seconds (of fault inception).
    - c) provide reactive power and control to facilitate voltage recovery within 1.0 second following a three-phase fault

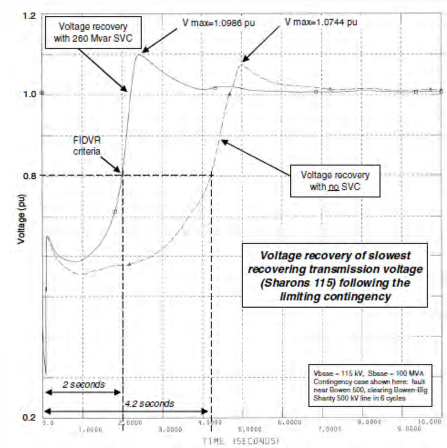


Fig. 6. Illustration of the fault induced delayed voltage recovery (FIDVR) criteria

Source: Sullivan, D.J., et al, "*Managing Fault-Induced Delayed Voltage Recovery in Metro Atlanta with the Barrow County SVC*," Facts Panel Session, IEEE PES Power Systems Conference and Exposition, Seattle Washington, March 2009

Summary of Industry Trends

Trend	Effect	Impacts on Transmission Owners	Possible Solutions
Generation Retirement (Due to Environmental Government Regulation)	Deficiency of real (MW) and reactive (Mvar) resources Need to import more power OR site new generation source (gas turbine or renewable)	Retrofit old generation Add Wind and Solar generation Expand Transmission investment Need for reactive support Distribution voltage instability	SVC, Statcom (Mvar), Synchronous Condenser (Mvar/Inertia/SCmva), HVDC (MW/Mvar) Series Capacitor, Gas Turbine Generators (MW/Mvar)
Renewable Integration	Large-scale Renewable energy often installed far from load center Requires reactive compensation at remote load center to stabilize voltage	Build new transmission to deliver renewable energy to load center OR Utilize existing transmission lines more efficiently	SVC & Statcom (Mvar) HVDC (MW/Mvar) Series Capacitor New Generators, GSU Transformers, GMCBs Energy storage converters
System Reliability	Increasing load concentration & load characteristics Increasing short circuit currents Increase congestion	Need to assess system stability and voltage stability Transmission congestion Voltage variations in transmission system and load centers	B2B HVDC SVC & Statcom (Mvar), Transmission Lines (MW/Mvar), Substation equipment replacement

SCmva = short circuit MVA

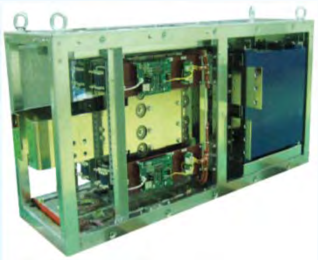
Distribution Management

- **Distribution grid operators are tasked with maintaining a reliable and efficient power delivery system in the face of several challenges and changes**
  - Increasing penetration and adoption of Distributed Energy Resources (DERs)
  - Two-way or multi-directional flows
  - Utilizing Demand Response (DR) and Distributed Generation (DG) in combination with traditional generation for distribution planning
  - Increasing frequency of severe weather events and cyber security threats

Solutions and equipment applied to cope with evolution

➢ Purpose of SVC/Statcom

- ➢ Provide rapid insertion or removal of Vars to support power system voltage during and immediately following system disturbances
- ➢ Avoid voltage collapse or slow voltage recovery following system disturbances
- ➢ Provide steady-state voltage regulation



SVC – rating -100 to +250 Mvar at 230 kV

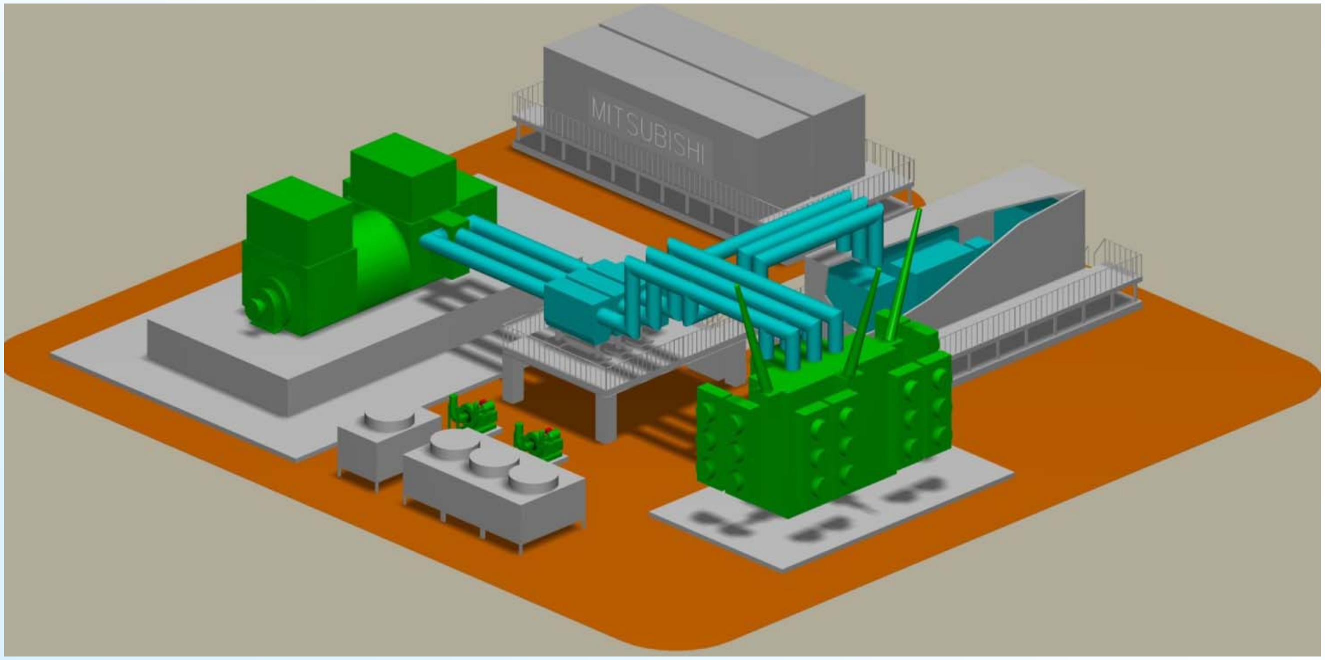
Statcom – rating -450 to +450 Mvar at 275 kV

- **Application:** Voltage Regulation, Dynamic Var Support
- **Project Duration:** 15-18 months
- **USA units in Service:** 23 (Nov. 16, 2015)
- **USA units under Construction:** 5

Synchronous Condenser

- Synchronous Condenser is being considered and/or applied by various regions to provide short circuit MVA and System Inertia
- Increase the System Short Circuit Strength
  - Improves protection system operation and improves system stability with weak interconnections
- Increase System Inertia
  - Improved frequency regulation, especially where renewable generation is being added while existing generation is being retired

Large, air-cooled machines at 100 to 300 MVA

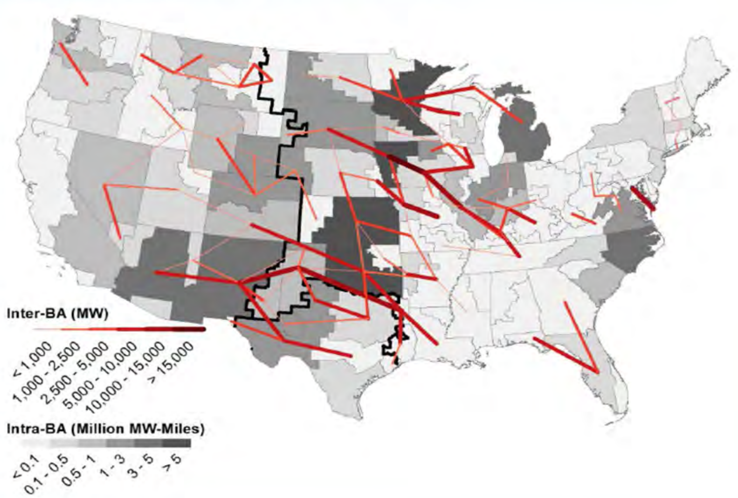


MITSUBISHI ELECTRIC

HVDC

Changes for the Better

- **Line-commutated Current Source Converter (LCC)**
  - Conventional or classic type of HVDC technology, Thyristor switching device
- **Self-commutated Voltage Source Converter (VSC)**
  - Advanced technology, Insulated Gate Bipolar Transistor (IGBT) or Gate-Turn Off (GTO) switching device
- **Applications**
  - Renewable Integration
  - Long distance bulk power delivery
  - Interconnect asynchronous ac systems
  - long submarine or underground cable crossings
  - Preventing increases in short circuit duties
  - Offshore transmission
  - Environmental advantages - reduced tower size, reduced right-of-way (ROW) requirements and reduced visual impact
  - Stabilizing ac systems
  - *Maximizing power control*

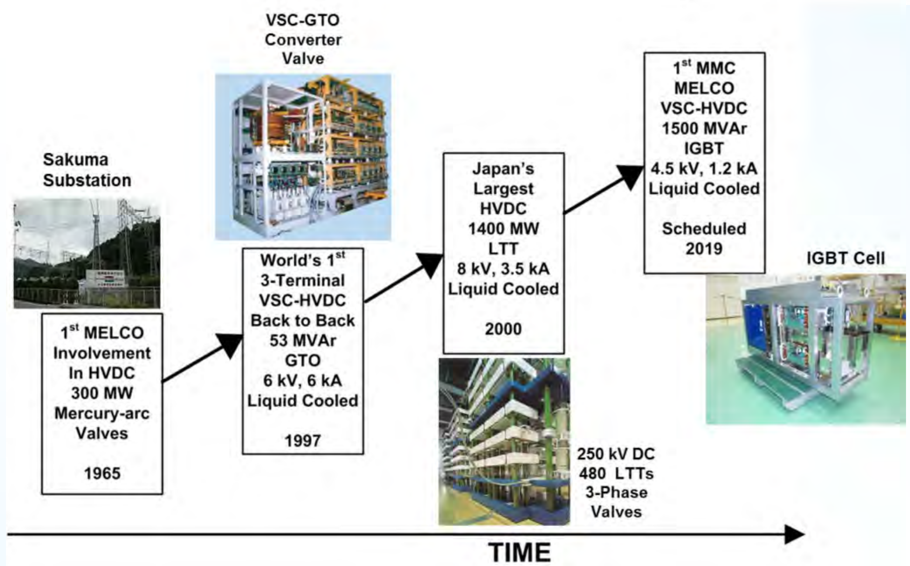


Source: NREL Renewable Electricity Futures Study, Executive Summary, 2012

700 MW, 250 kV HVDC – Japan

used to deliver large amount of electric power from the coal-thermal power plants in Hikoku power system to Kansai electric system.

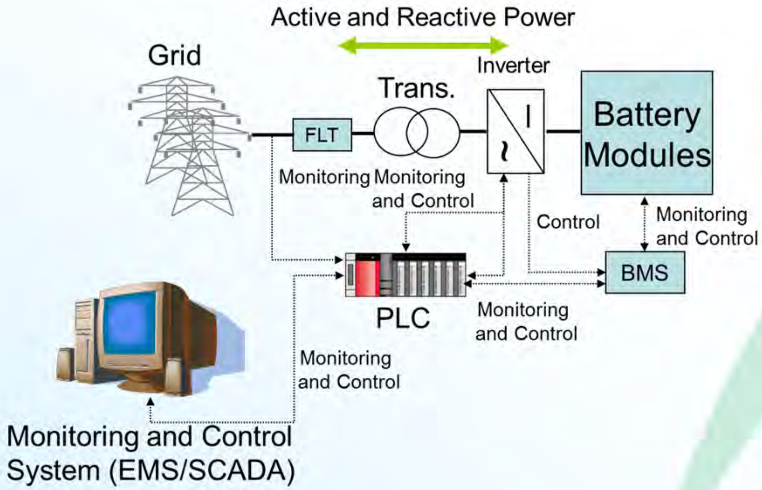
Fig. 11: Kii Channel HVDC and surrou

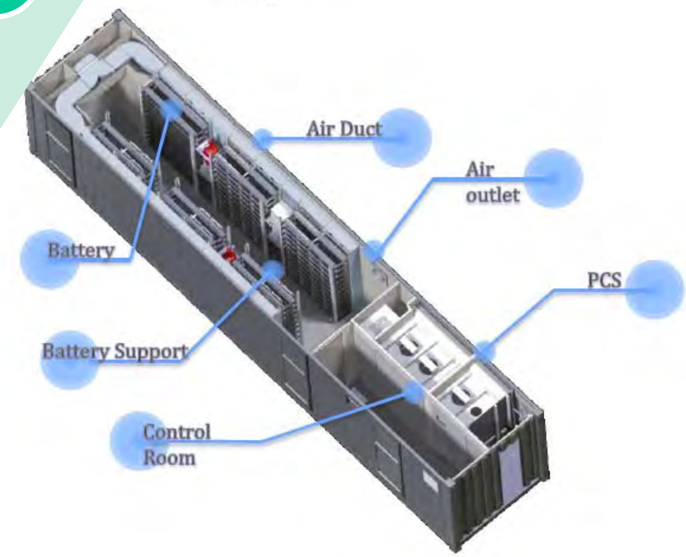


Energy Storage

Table 12-2. Three Classes of Energy Storage

Common Name	Example Applications	Discharge Time Required
Power quality and regulation	Transient stability, reactive power, frequency regulation	Seconds to minutes
Bridging power	Contingency reserves, ramping	Minutes to ~1 hour
Energy management	Load leveling, firm capacity, T&D deferral	Hours





Example Energy Storage System Using Containerized NaS Batteries

System will connect the NAS battery system to its power grid to improve the electricity supply-demand balance, control the grid voltage and smooth the delivery of renewable energy

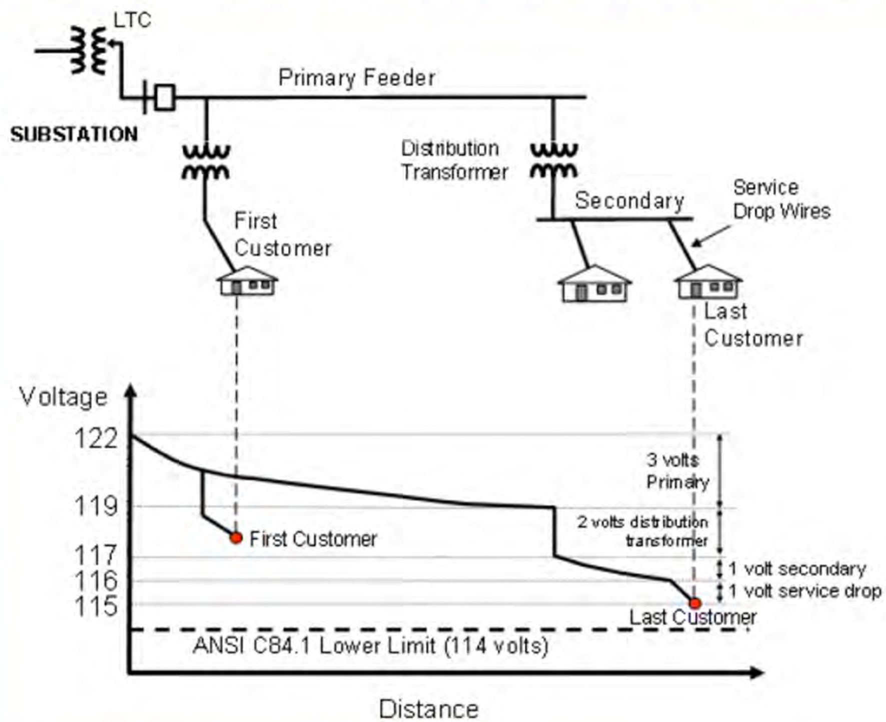
Distribution Management and Volt Var Optimization

Distribution Management

- **Distribution Automation (DA) technologies are critical components in terms of supporting a successful Distribution Management Systems (DMS)**
- **Drivers of DA technologies include:**
  - **Accommodating Distributed Generation (Solar PV), Renewable Generation (Wind) and Storage Options**
    - Help manage intermittent generation, dynamic voltage control, load balancing and black start capabilities (California, North Carolina and Texas are in need of DA solutions)
  - **Smart Grids and Micrografts**
    - Help manage automatic grid connections and islanding capabilities for a set of defined loads (California, New Jersey, New York and Massachusetts are engaged in Case Studies supporting these technologies)
  - **Improvements in Power Quality, Demand Response and Energy Efficiency**
    - Help coordinate protection schemes, automate grid-balancing functions, perform power line monitoring and reduce losses
    - IOUs involved in Case Studies have demonstrated peak demand reductions of 0.8% to 2.4%
    - Recent Pilot Studies show 0.8% energy savings for each 1% voltage reduction
  - **Increase in Grid Resiliency**
    - Respond to system disturbances in a self-healing manner
    - Protect against physical and cyber-attack and natural disaster

Volt VAR Optimization (VVO)

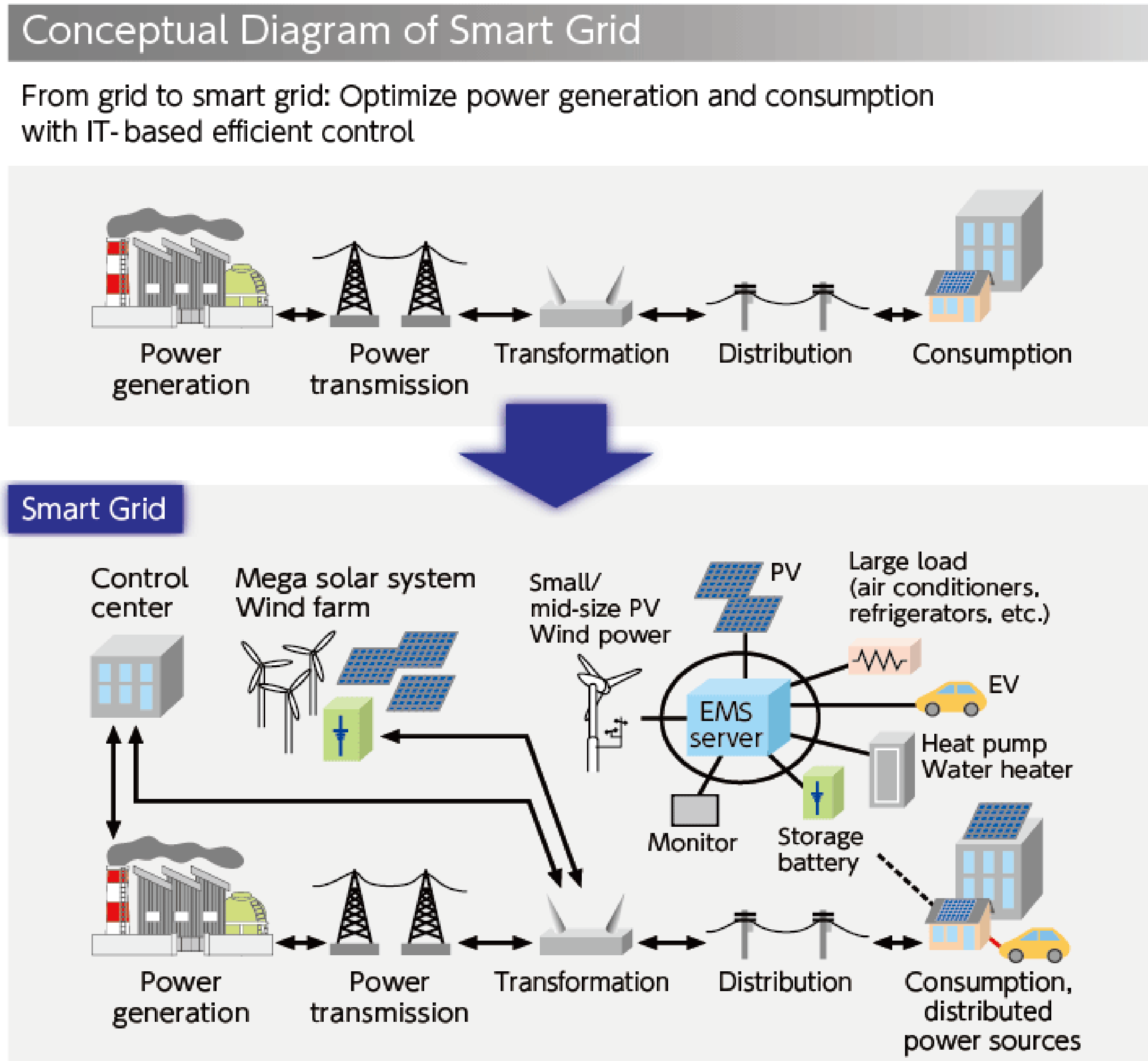
- Volt and VAR control are 2 "levers" that utilities have to maximize asset utilization and meet Conservation Voltage Reduction goals while also reliably and actively managing system demand
- The prime purpose of VVC is to maintain acceptable voltage at all points along the distribution feeder under all loading conditions



Source: Bob Uluski, Volt/VAR Control and Optimization Concepts and Issues, 2011

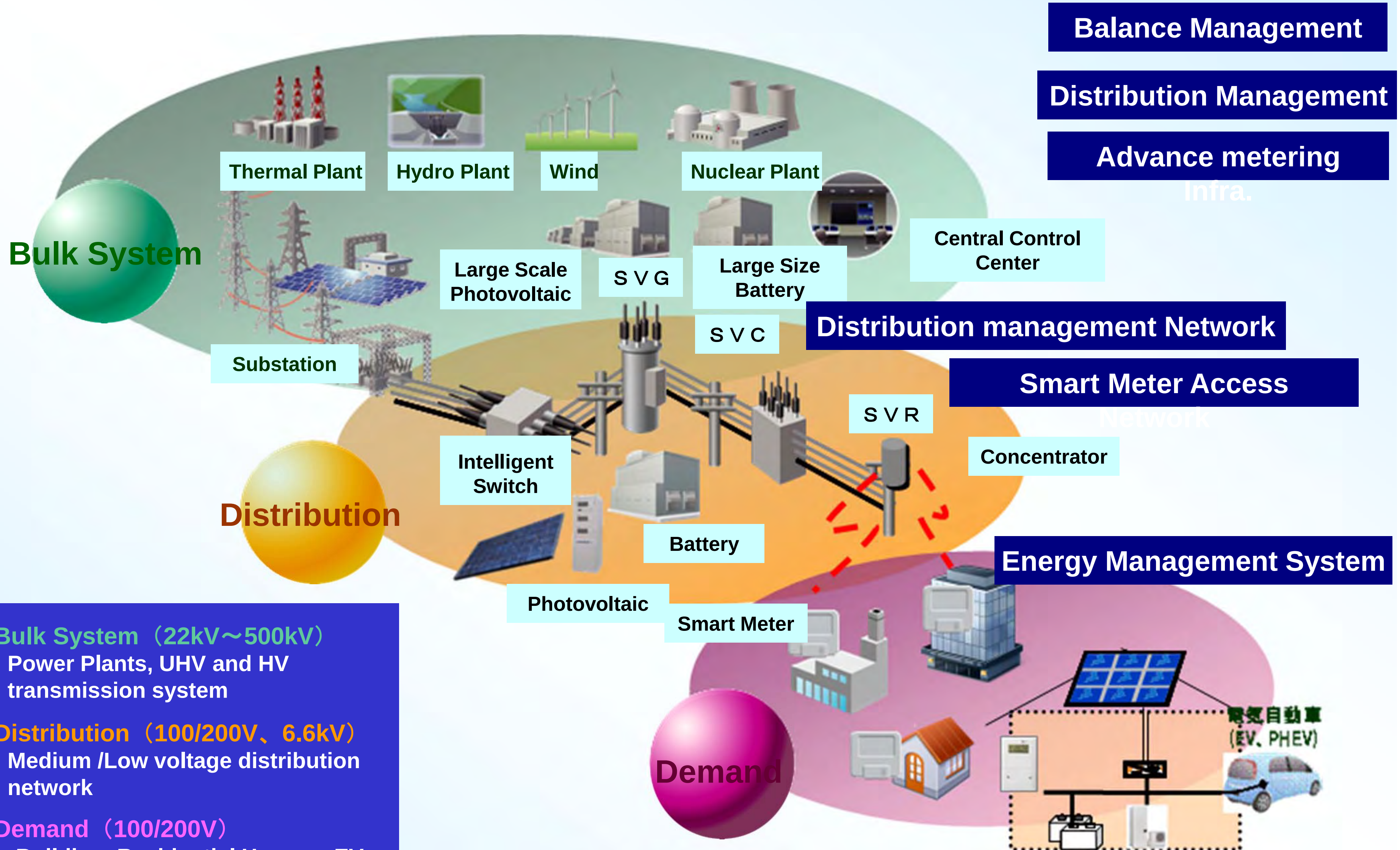
View of new Power System

Grid of the Present/Future



Source: Sumitomo Electric

Evolving System - Smart Grid Test Facility Scope



Bulk System（22kV～500kV）
Power Plants, UHV and HV transmission system

Distribution（100/200V、6.6kV）
Medium /Low voltage distribution network

Demand（100/200V）
Building, Residential Houses, EV

Smart Grid demonstration project at factory

Project Objective

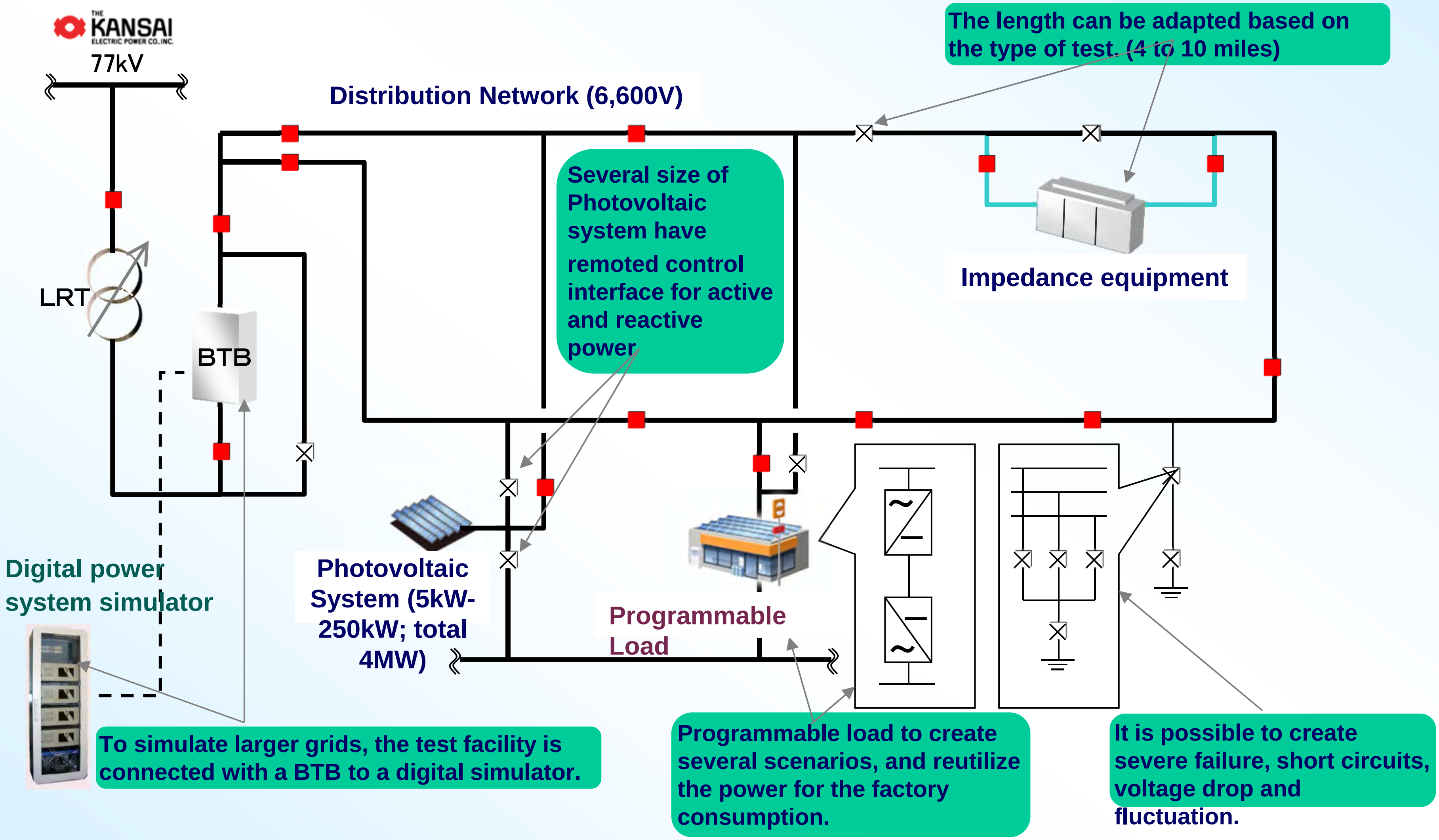
- **The test facility was develop with the intent to have a real analog power system to simulate and verify the performances of algorithms and equipment under the following conditions**

  - Sever power system conditions (earth fault, short circuit, generator fault
  - Political changes (liberalization, interconnection requirements, wheeling rules)
  - Changes in business environment (power system management, regional distributed resources)
  - Climate change (temperature, humidity, solar radiation, wind, etc.)

- **Intent is to find the requirements to keep the future power system economical and stable and to provide and validate solutions in the real field**

Summary of Features

Communication evaluated: high speed optical fiber, metal cable, radio frequency



BTB：Back To Back　　LRT：Load Ratio Transformer

Objective and features

Objective

- **Technologies and equipment validation for the future transmission and distribution networks**
  - power supply and demand balance with high penetration of renewable energy
  - distribution voltage stability in case of a large amount of distributed generators
  - power-saving and energy conservation
  - blackout prevention and outage time reduction
  - demand response in severe power system condition
  - testing of equipment before commercialization

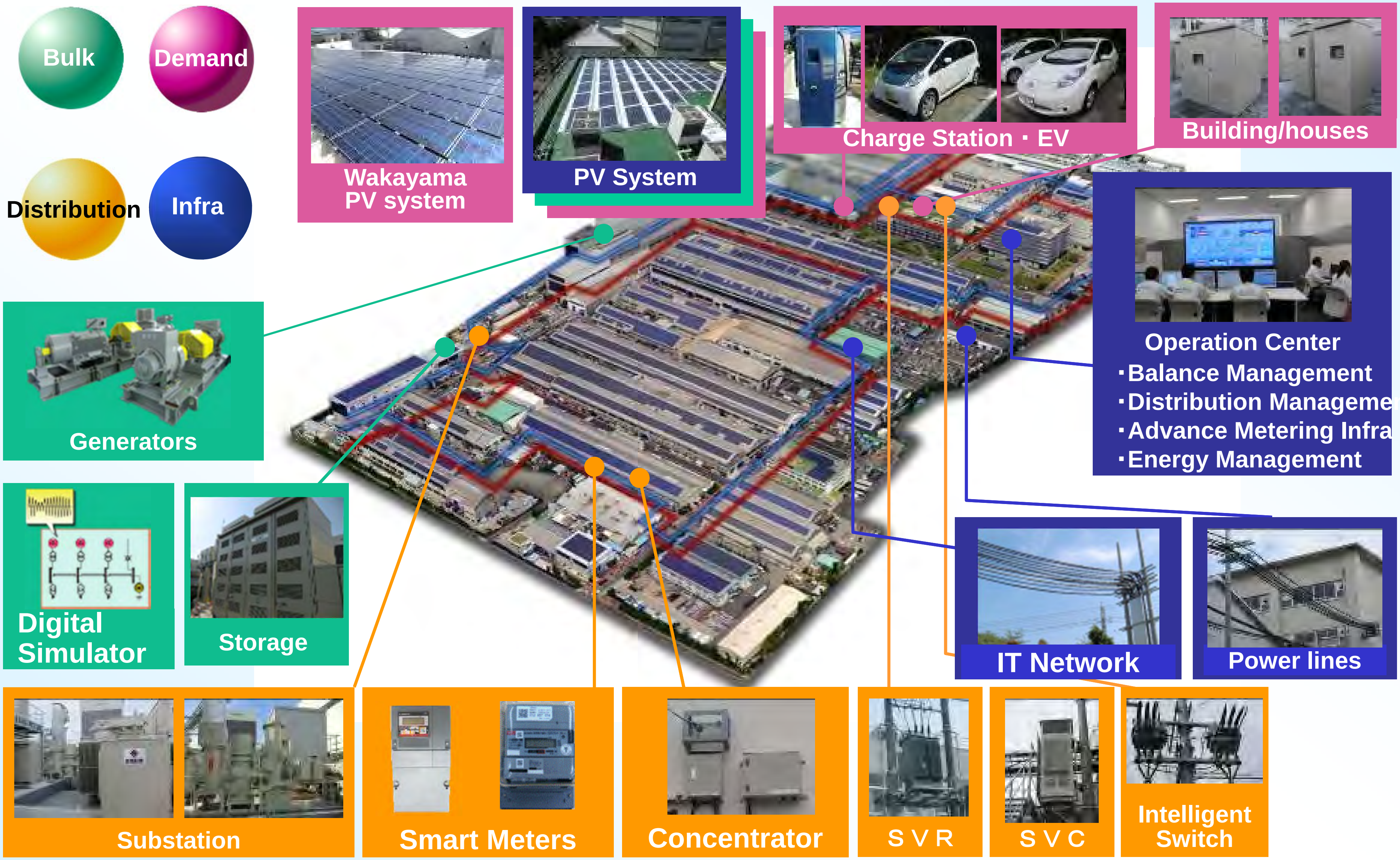
Features

- **The test facilities can be scaled and arranged to simulate several kinds of smart grid configurations and smart communities**
  - **Balance Management Validation Operation**
  - **Distribution Management Validation Operation**
  - **Total Operation**
  - **Special Area, Island Validation Operation**

During each of these operations mode shortage or excess of power, power system troubles such as lighting, voltage drop, short circuit and so on will be tested

Amagasaki Factory - System Overview

Changes for the Better



Planned DC distribution demonstration facility

R&D in MVDC Distribution

➢ Demonstration Facility

Building area	Approx 191sq yd (Gross floor area : Approx 538sq yd)
Construction	Steel construction / Three-story
Construction start	September, 2015
Completion	March, 2016
Operation start	April, 2016
Total investment	4.2 million dollars
Devices	Communication devices, Solar power generation , Wind power generation , DC distribution board (DC380V), DC high speed CB (DC1500V) Batteries, DC load systems, Energy Management Systems (EMS)
System voltage	DC 380V (First step : FY2015) DC1.500V (Second step : FY2016)

Thank You

Changes for the Better

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