Frankfurt (Germany), 6-9 June 2011

Introduction and Schedule

Mark McGranaghan
EPRI

Smart Distribution Systems
for a Low Carbon Energy Future Workshop

6 June 2011

Objective

The workshop is designed to illustrate requirements for the distribution management system of the future through examples of advanced distribution system applications that are being implemented around the world. These applications include advanced voltage and reactive power control, integration of distributed resources, demand response, real time state estimation for optimizing performance, automatic reconfiguration, integration of advanced metering, etc. The tutorial will include a focus on modeling requirements for the distribution system of the future to support real time simulations, voltage control, new load models, and integration of distributed resources.

Schedule

- ***Development of the Smart Distribution System –***
  Mark McGranaghan: mmcGranaghan@epri.com
  Bob Uluski: ruluski@epri.com

- ***Smart Distribution Roadmap at Hydro Québec –***
  Georges Simard: Simard.Georges@hydro.qc.ca
  Christian Perreault: perreault.christian@hydro.qc.ca

- ***Active Distribution Network Concepts –***
  Bob Currie: robert.currie@smartergridsolutions.com
  Graham Ault: g.ault@eee.strath.ac.uk

Schedule

- ***Advanced Distribution Management at EDF –***
  Sébastien Grenard: sébastien.renard@edf.fr

- ***Integration of Distributed Renewables and Electric Vehicle Charging in Ireland –***
  Andrew Keane: *andrew.keane@ucd.ie*

- ***Model Requirements for Smart Distribution –***
  Roger Dugan: *rdugan@epri.com*
  Andrew Keane: *andrew.keane@ucd.ie*

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Development of the Smart Distribution System

Mark McGranaghan
VP, Power Delivery and Utilization
Bob Uluski
Technical Executive
Electric Power Research Institute

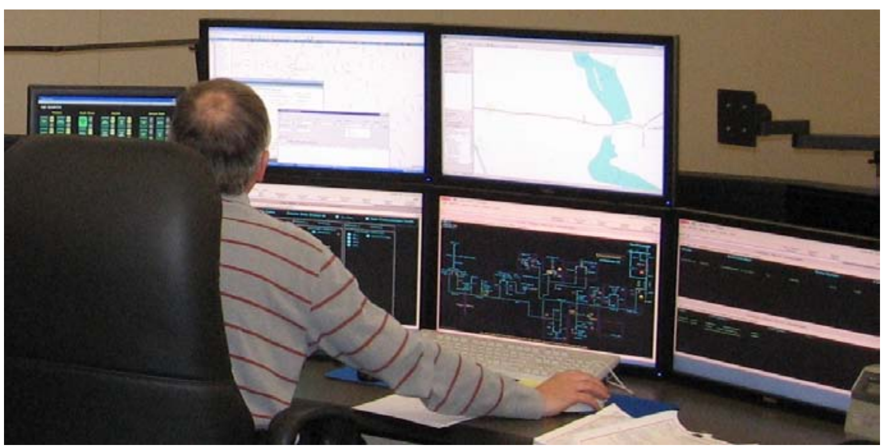
Smart Distribution Systems for a Low Carbon Energy Future Workshop

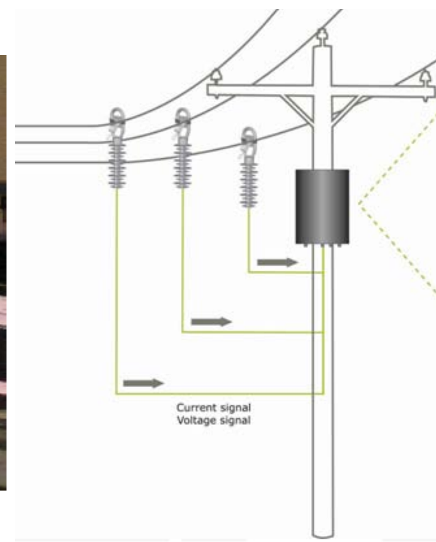
6 June 2011

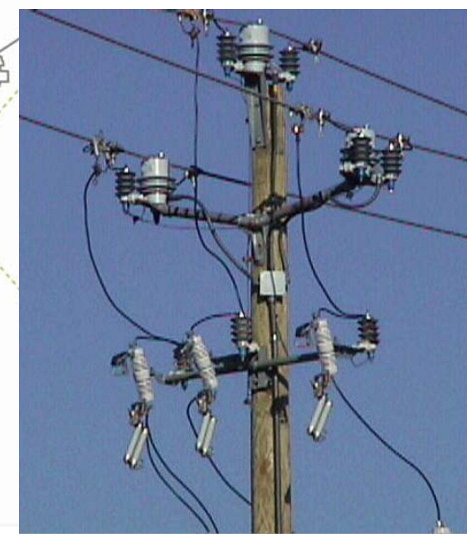
- **What is “Smart Distribution”?**
- **Building blocks for smart distribution**
- **Smart Distribution Applications**
  - **What they are**
  - **How they work**
  - **Benefits they provide**

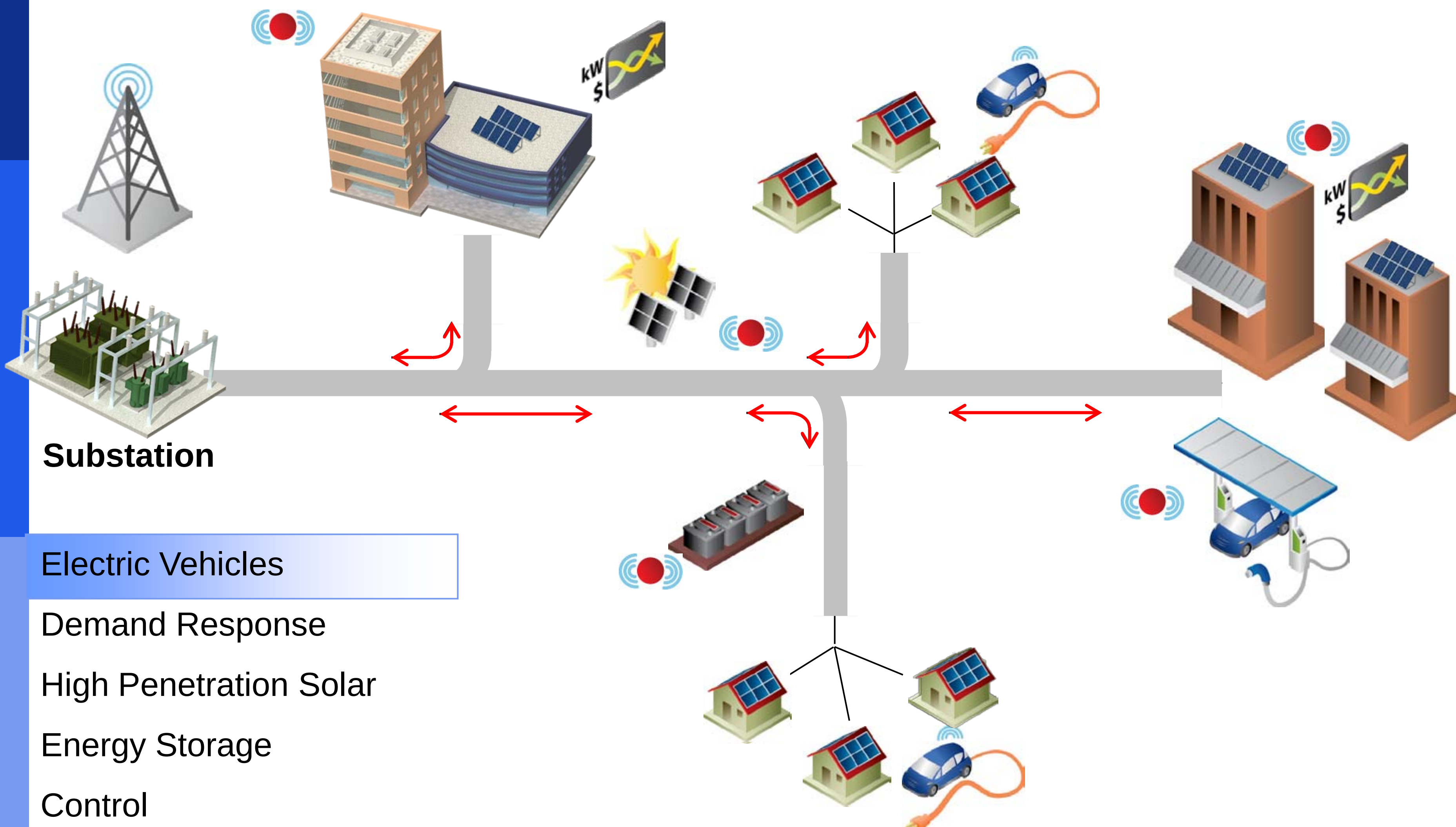
What is Smart Distribution?

Continuous monitoring of distribution assets located in substations and out on the feeders, and control of these assets for improved efficiency, reliability, and performance, without compromising safety and asset protection







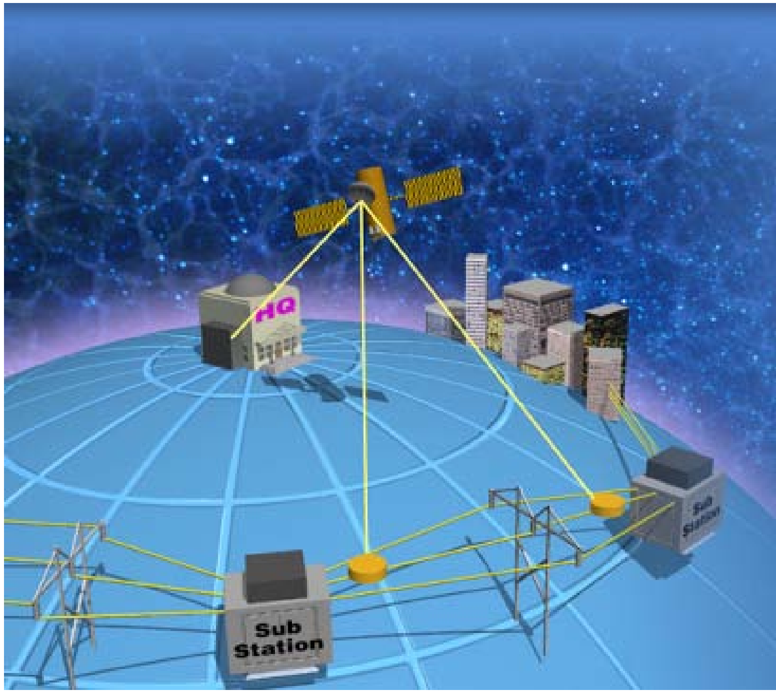


- Electric Vehicles
- Demand Response
- High Penetration Solar
- Energy Storage
- Control

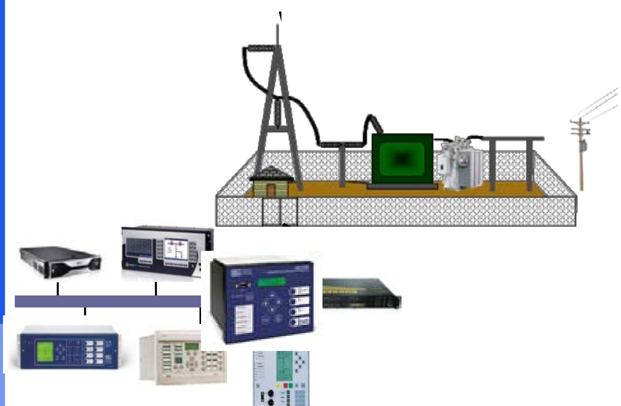
Characteristics of the Smart Distribution Grid – The Intelligrid Vision

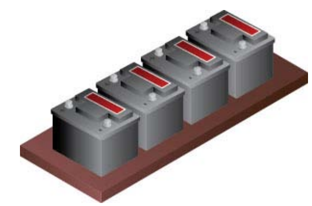
Makes use of communications, computing & power electronics to create a system that is:

- *Self-Healing* and *Adaptive*
- *Interactive* with consumers and markets
- *Optimized* to make best use of resources and equipment
- *Predictive* rather than reactive, to prevent emergencies
- *Distributed* across geographical and organizational boundaries
- *Integrated*, merging monitoring, control, protection, maintenance, EMS, DMS, marketing, and IT
- *More Secure* from attack



Building Blocks for Smart Distribution





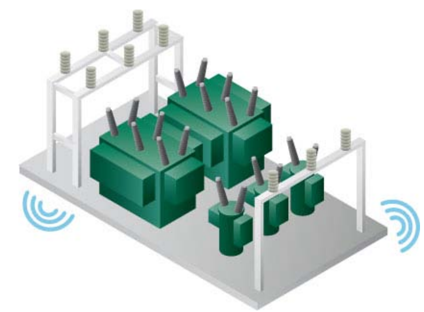
Smart

ADA

Key Smart Distribution Applications

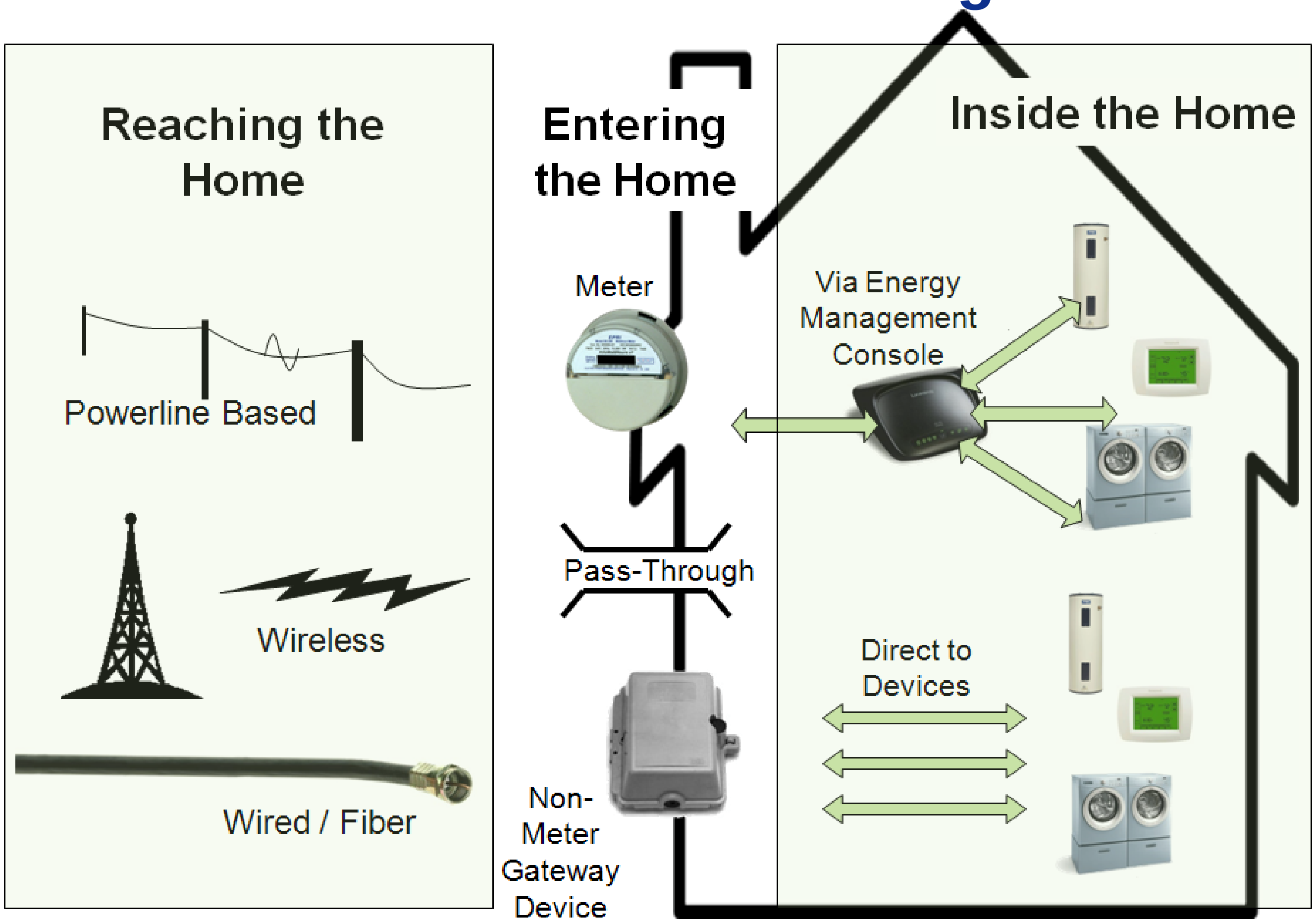
- Demand-side Integration and Empowering Customers
  - Price Signals & Technology

- Improving Reliability and Power Flow
  - Automatic Reconfiguring or "Self-Healing"
  - Advanced Volt/VAR Control

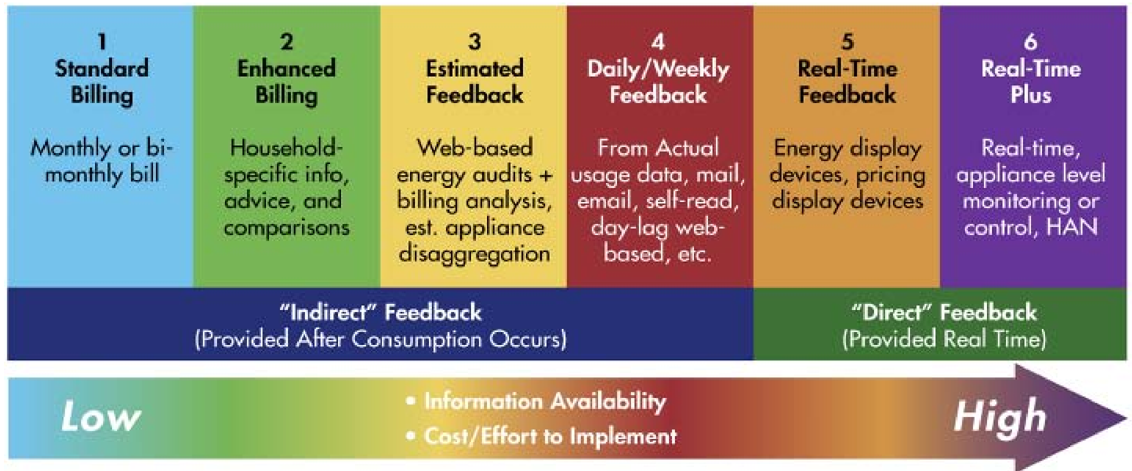


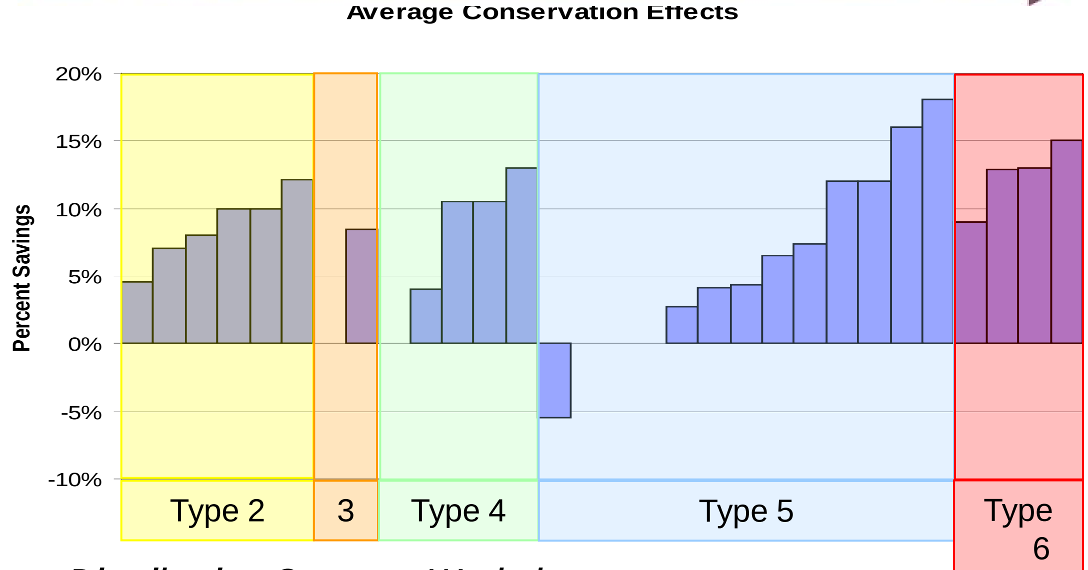
- Reducing Green House Gases
  - Deploying Renewables
  - Optimizing Operation of Centralized Generation

Demand Response
Diverse Architectures and Technologies



Consumer Feedback Mechanisms





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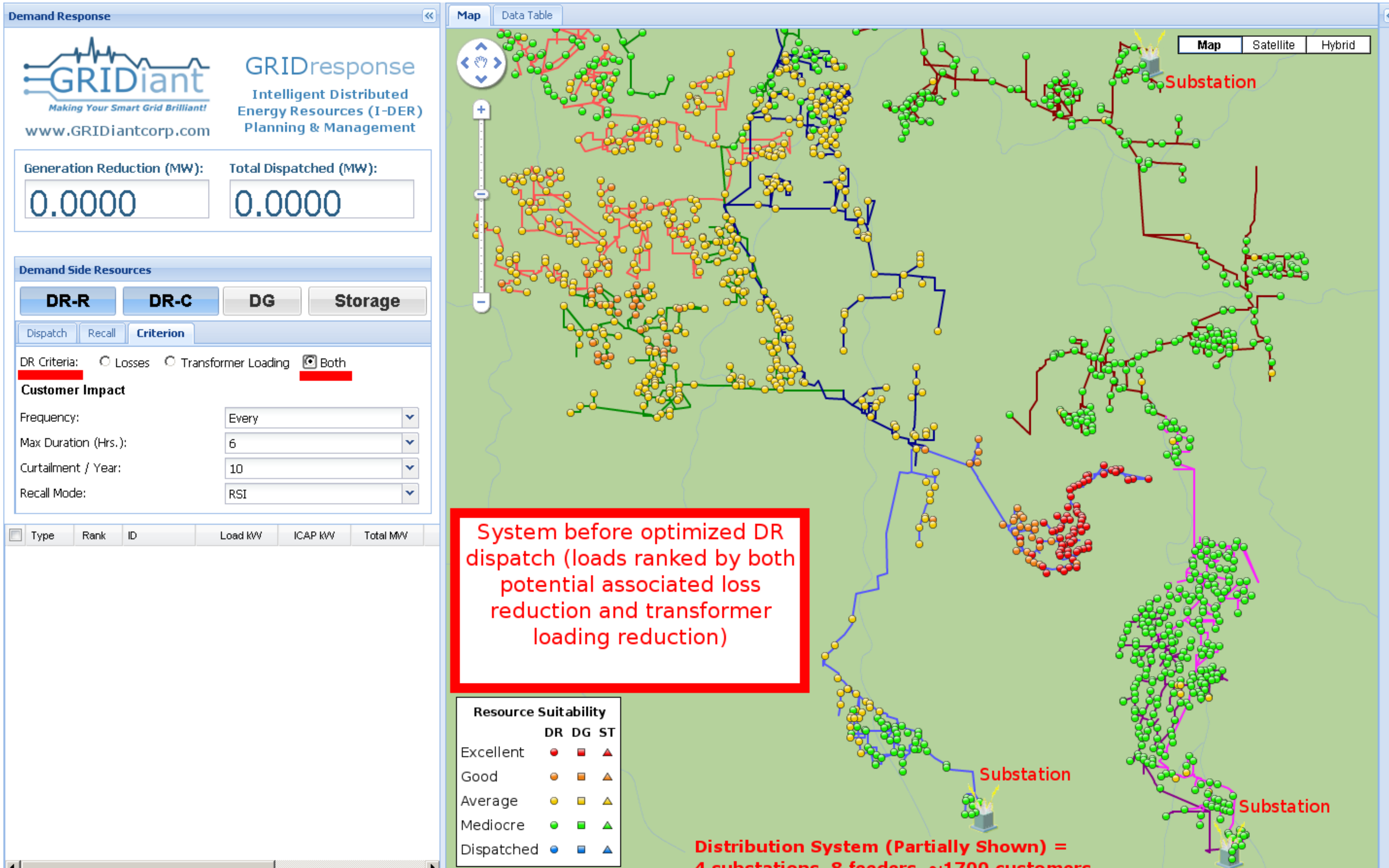
Enabling Technology Variables

Evaluations – Technologies Provided for Free and for Purchase

Web	Web + IHD Basic	Web + IHD	Web + IHD + PCT
			
			 


Demand Response
GRIDiant
Making Your Smart Grid Brilliant!
www.GRIDiantcorp.com
GRIDresponse
Intelligent Distributed Energy Resources (I-DER) Planning & Management
Generation Reduction (MW):
0.0000
Total Dispatched (MW):
0.0000
Demand Side Resources
DR-R
DR-C
DG
Storage
Dispatch
Recall
Criterion
DR Criteria:
Losses
Transformer Loading
Both
Customer Impact
Frequency:
Every
Max Duration (Hrs.):
6
Curtailment / Year:
10
Recall Mode:
RSI
Type
Rank
ID
Load kW
ICAP kW
Total MW
Map
Data Table
Map
Satellite
Hybrid
Substation
Substation
Substation
System before optimized DR dispatch (loads ranked by both potential associated loss reduction and transformer loading reduction)
Resource Suitability
DR DG ST
Excellent
Good
Average
Mediocre
Dispatched
Distribution System (Partially Shown) = 4 substations, 8 feeders, ~1700 customers

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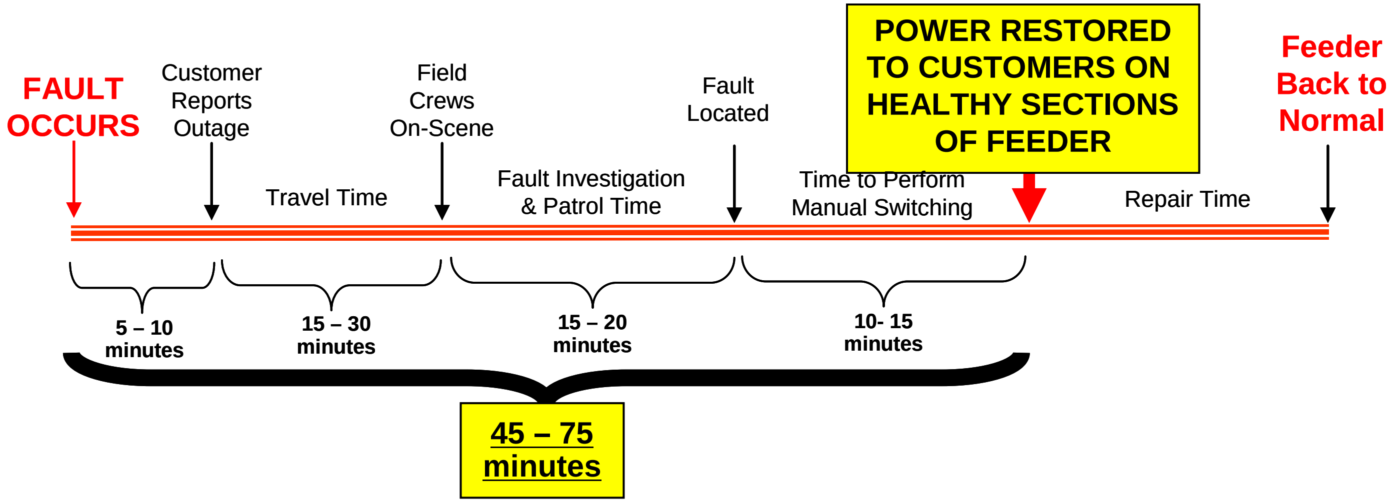
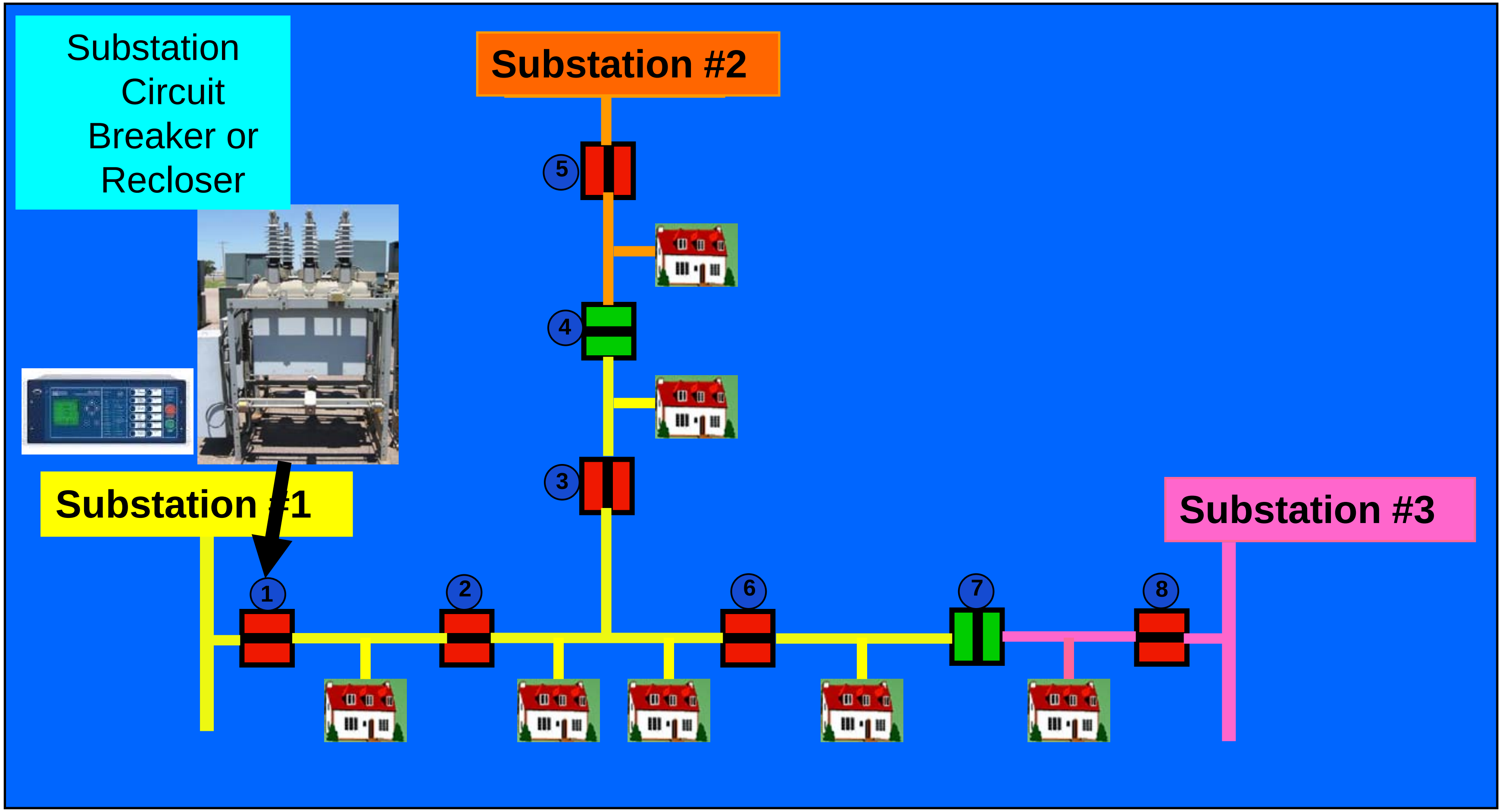
"FLISR" – A Smart Distribution Application for a "Self Healing" Grid

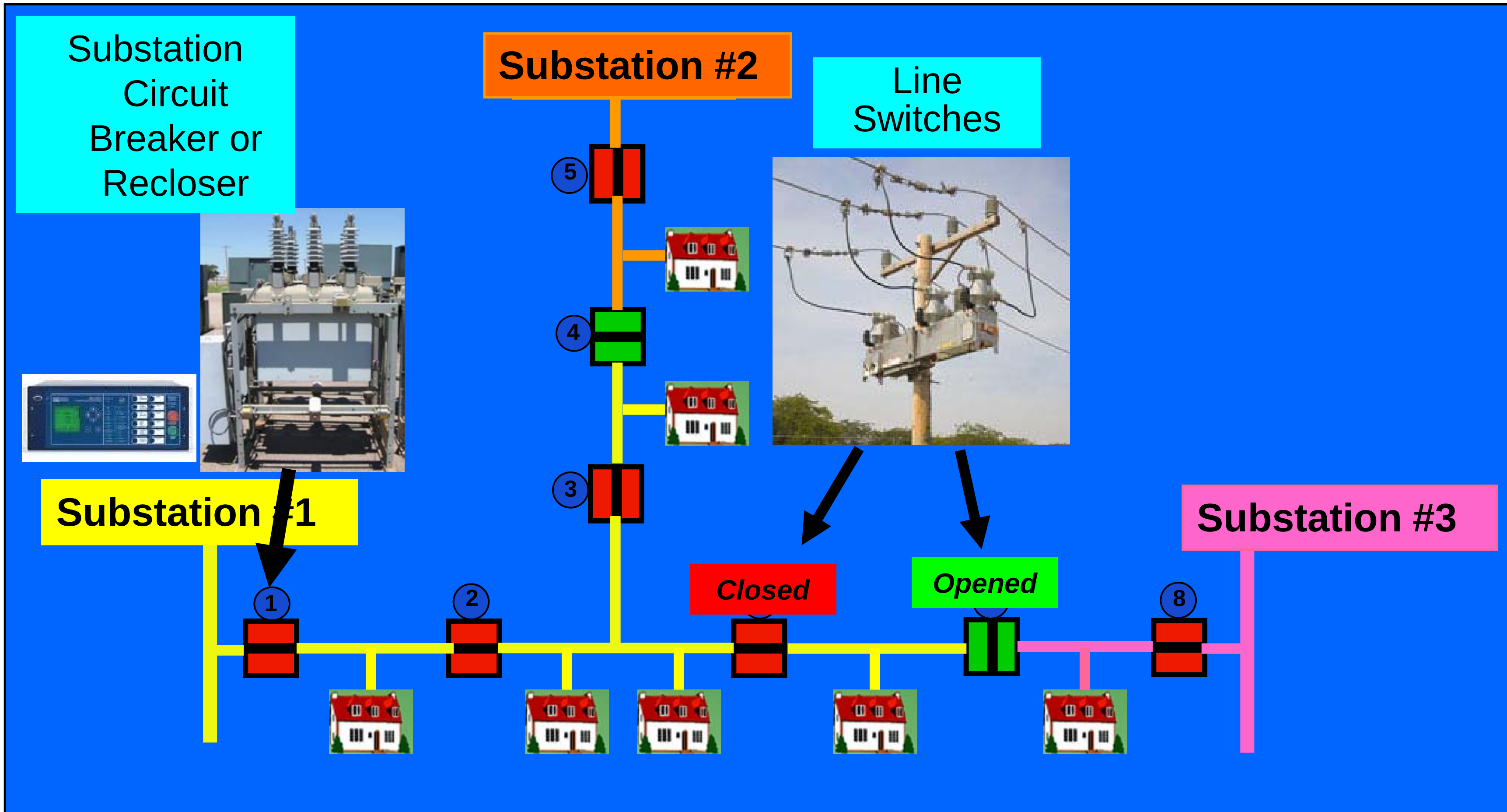


- Fault Location, Isolation, and Service Restoration
- **Use of automated feeder switching to:**
  - Detect feeder faults
  - Determine the fault location (between 2 switches)
  - Isolate the faulted section of the feeder (between 2 feeder switches)
  - Restore service to "healthy" portions of the feeder

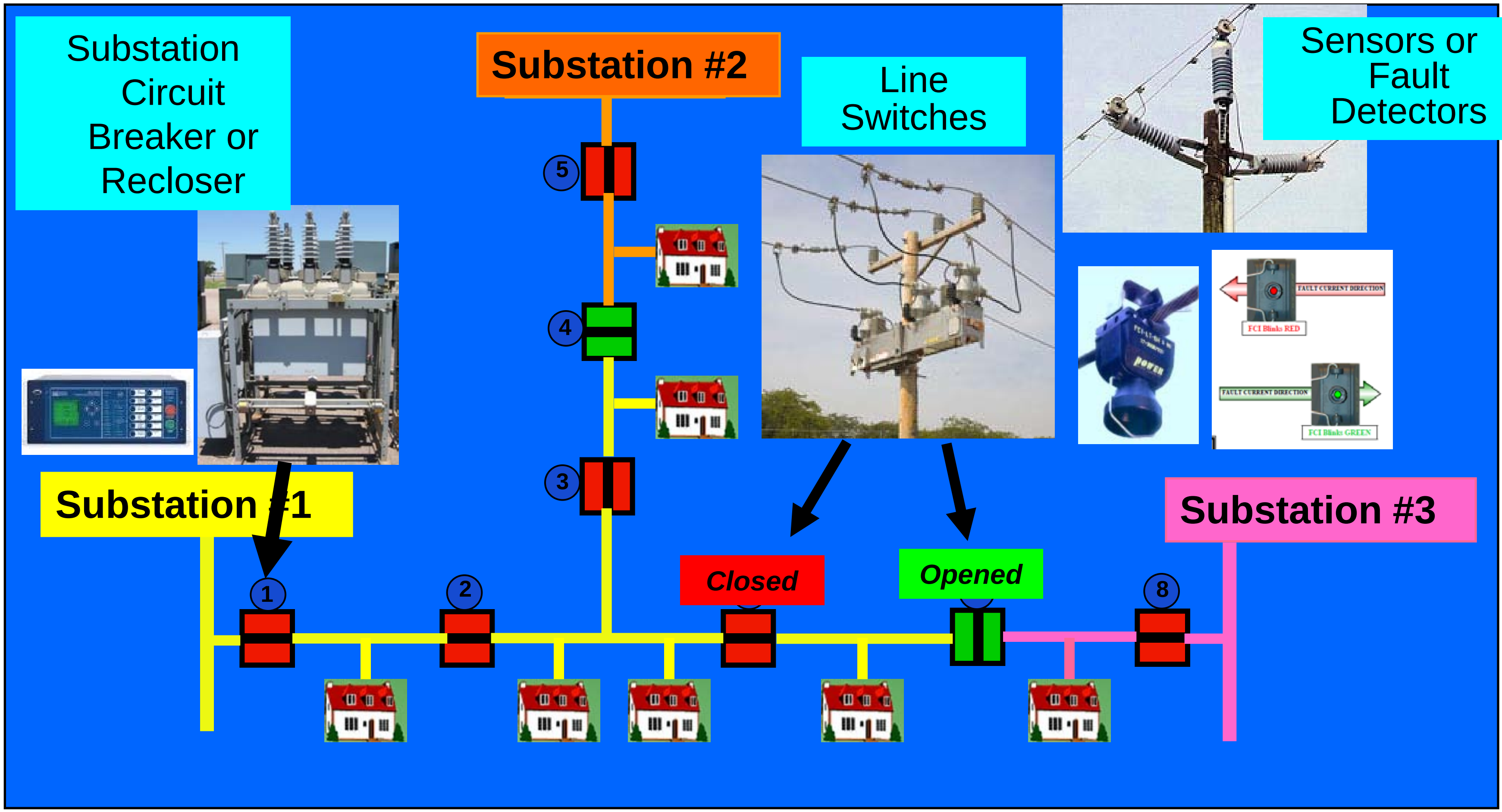
FLISR Components



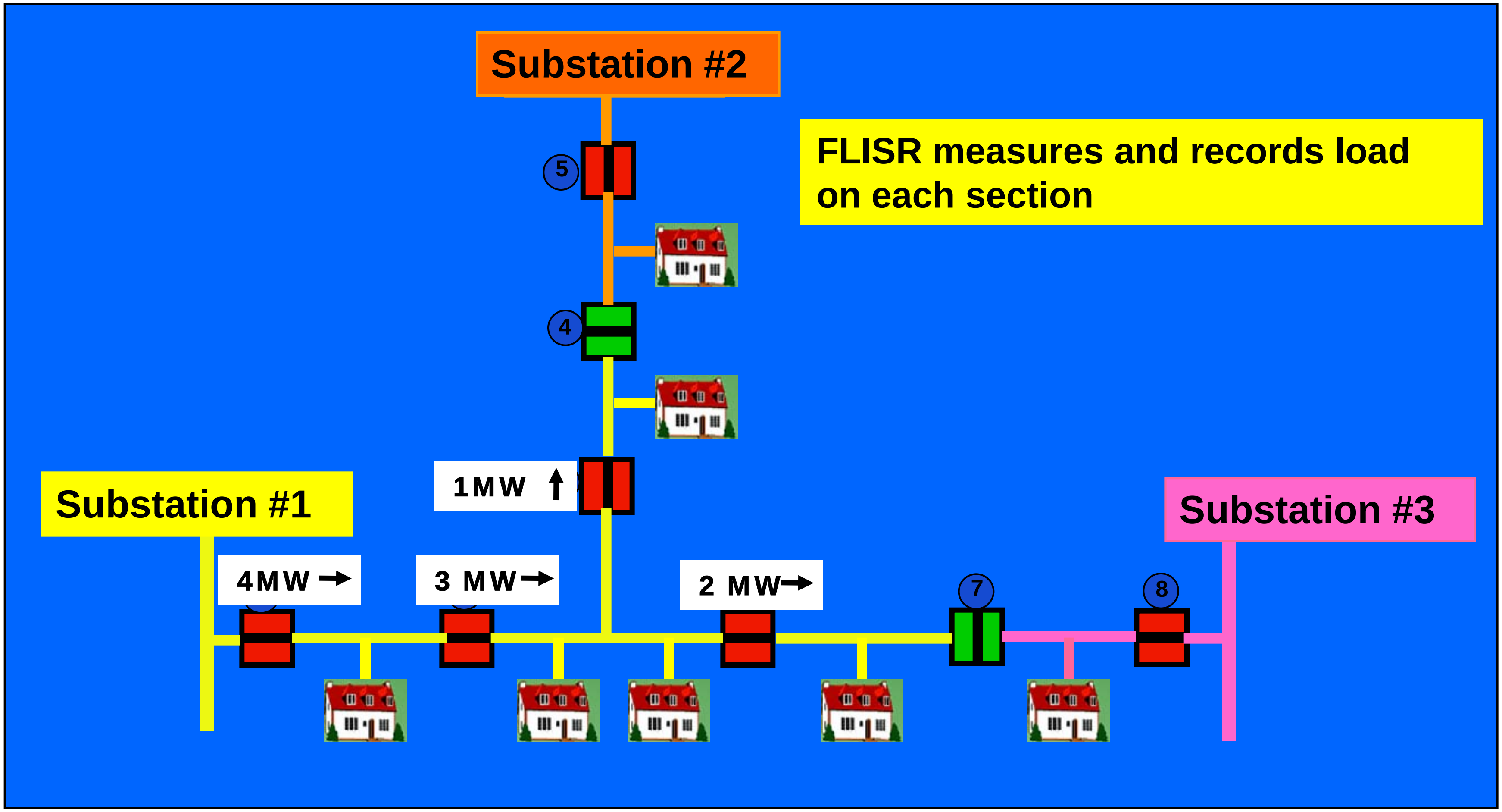
FLISR Components



FLISR Components



FLISR – Normal Operation



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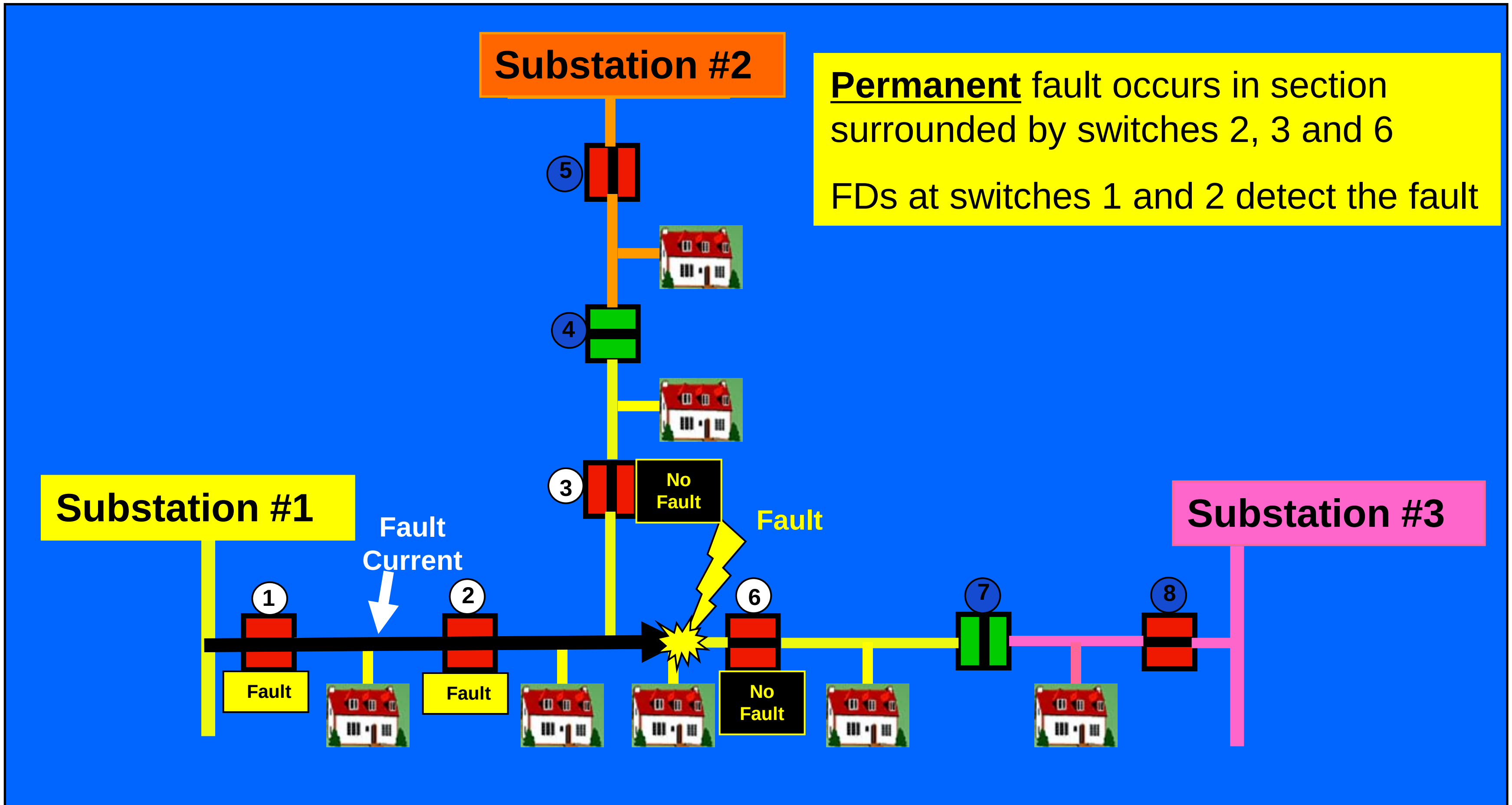
FLISR Operation – A Fault Occurs



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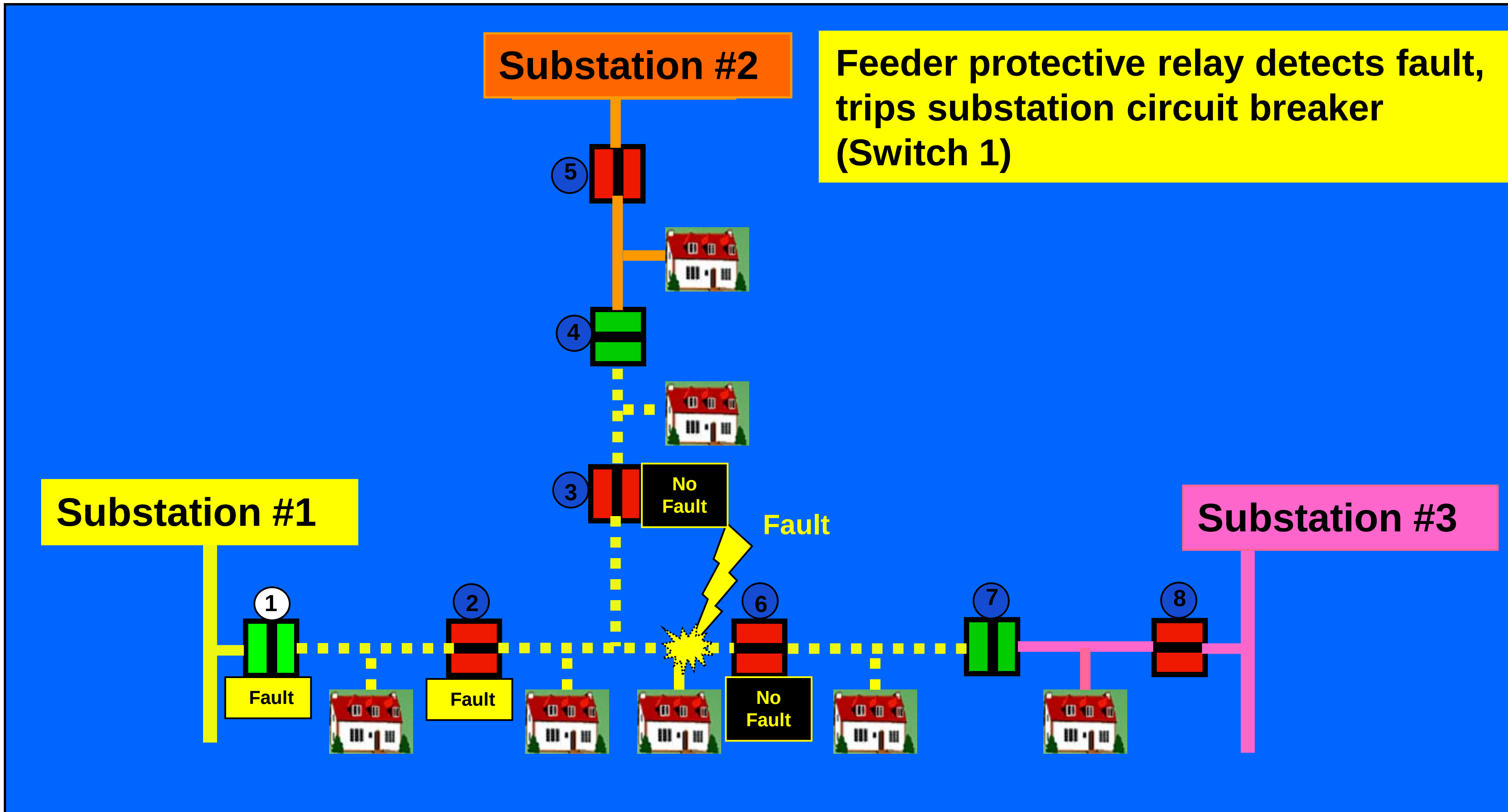
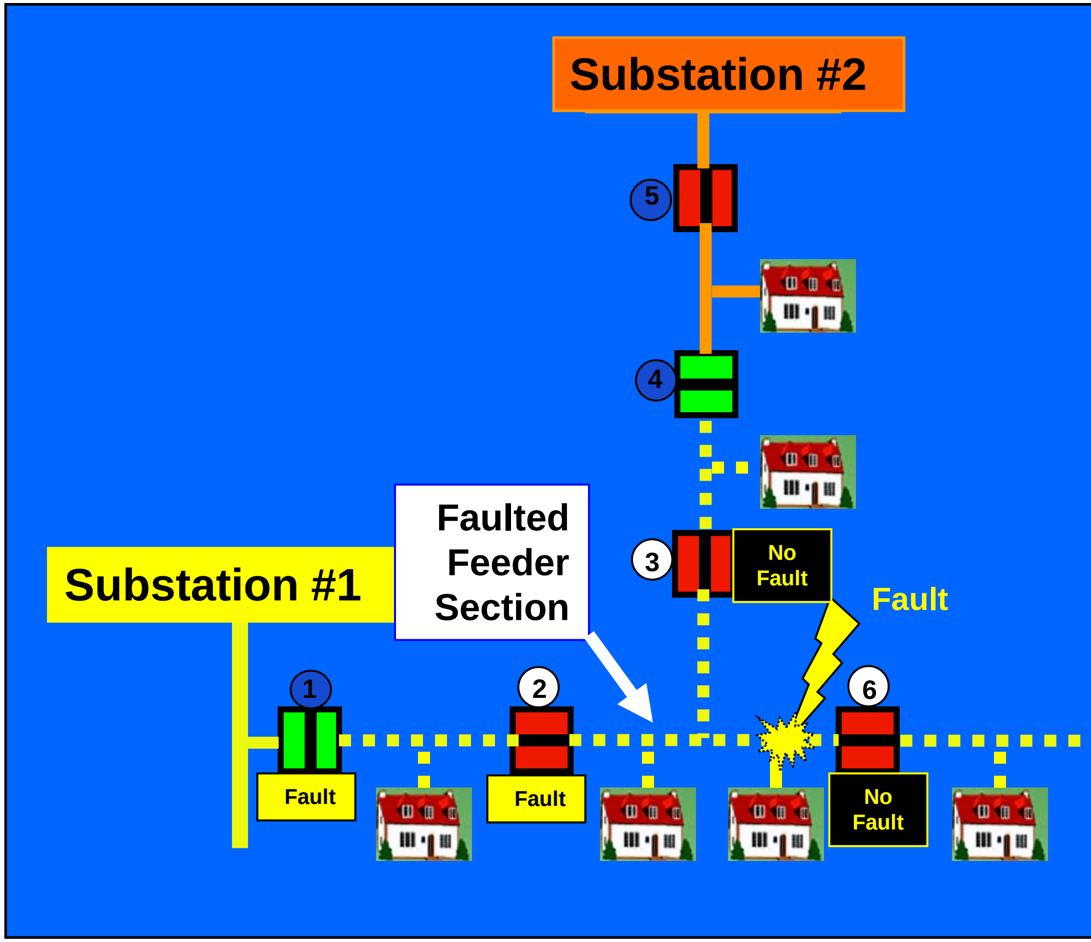
FLISR Operation – Feeder Protection Operates



FLISR Operation – Locate the Fault

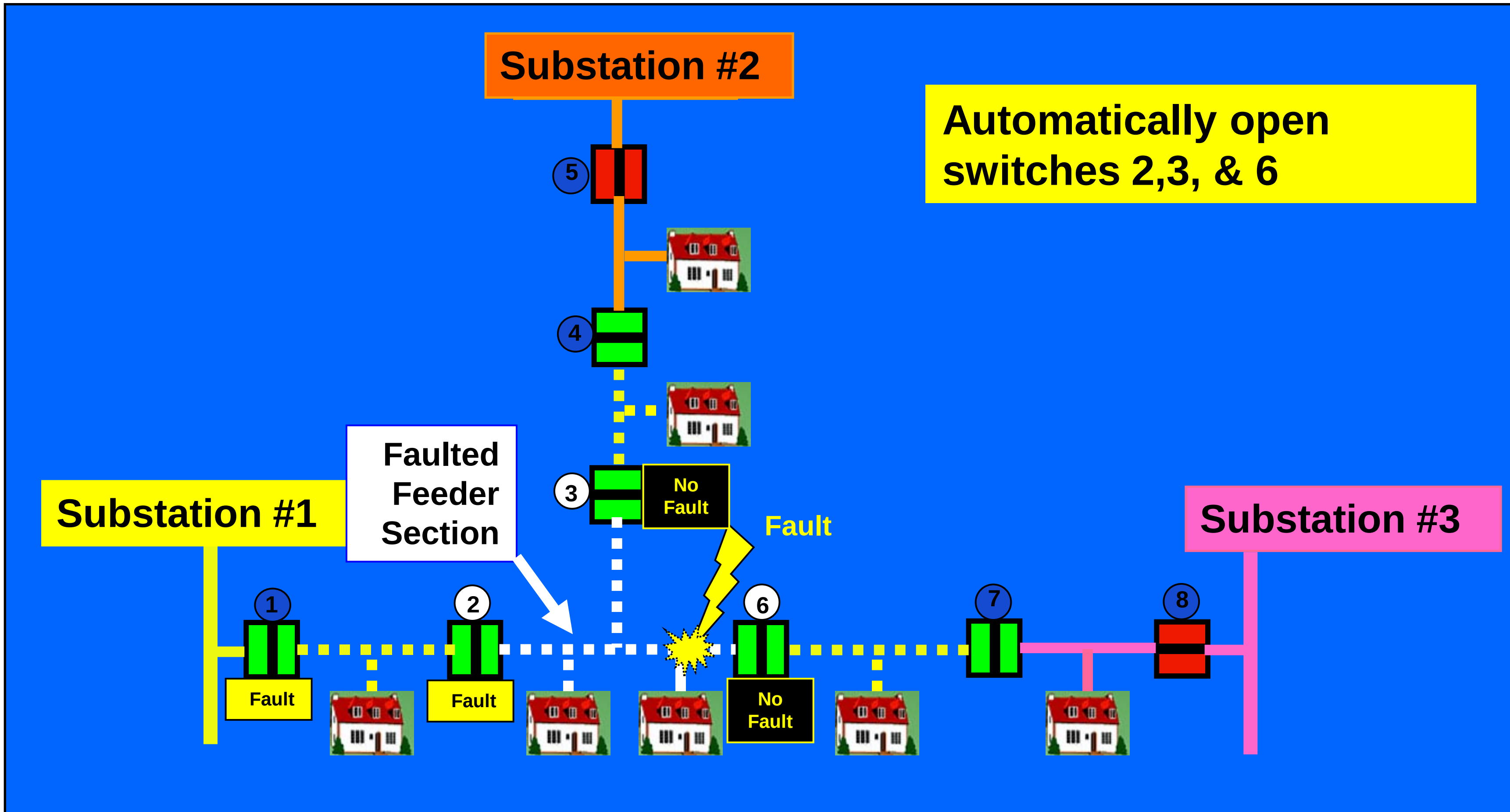


FDs 1 & 2 saw a fault

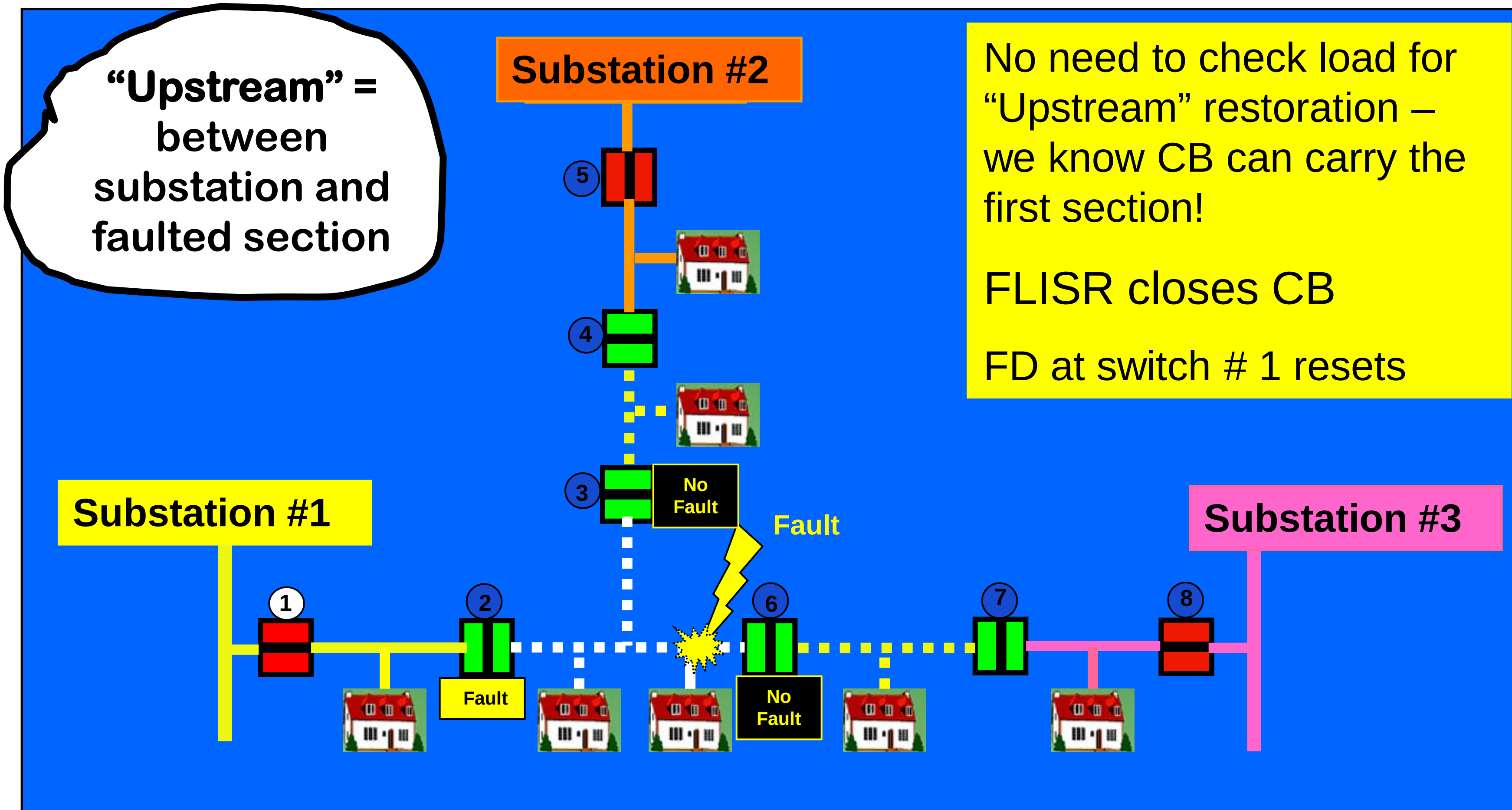
FDs 3 and 6 did not see the fault

Fault must be in section between switches 2,3, & 6

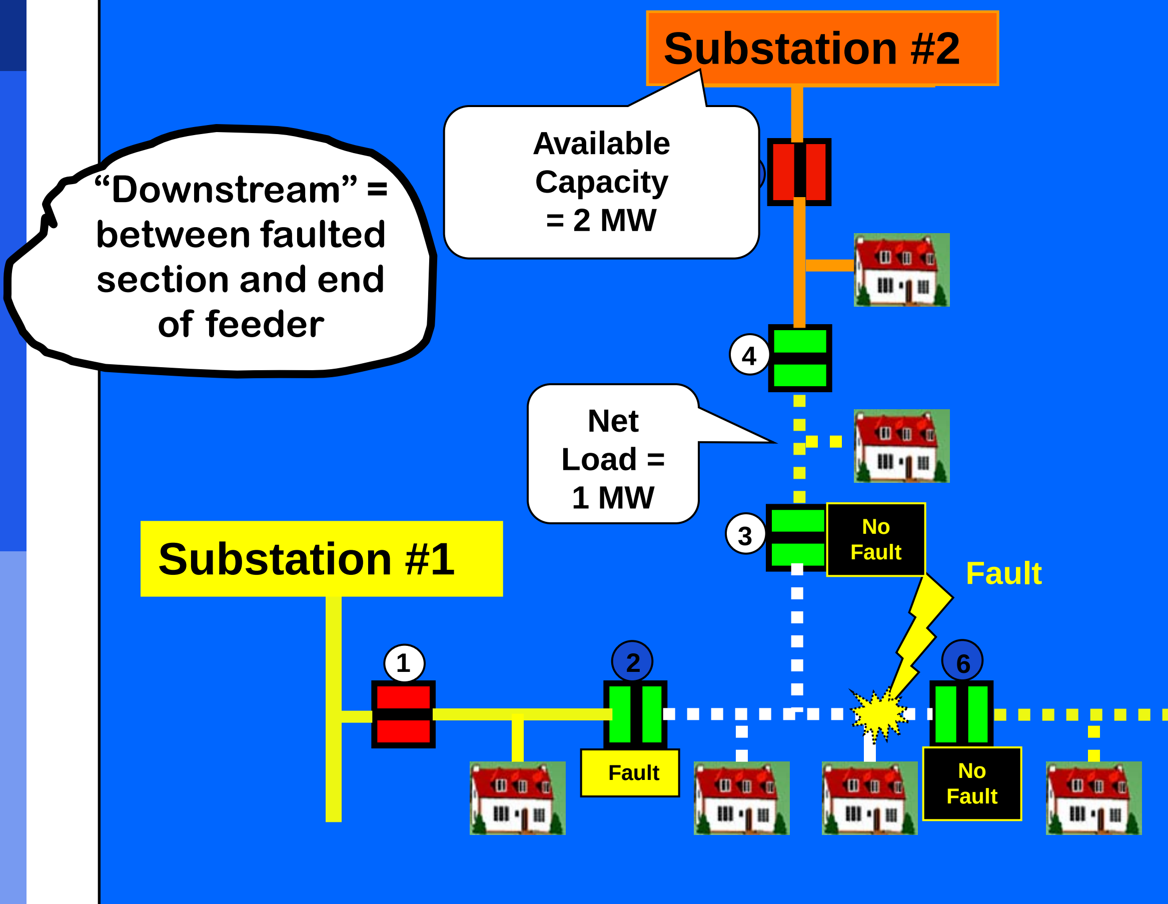
FLISR Operation – Isolate the Fault



FLISR Operation – Upstream Restoration



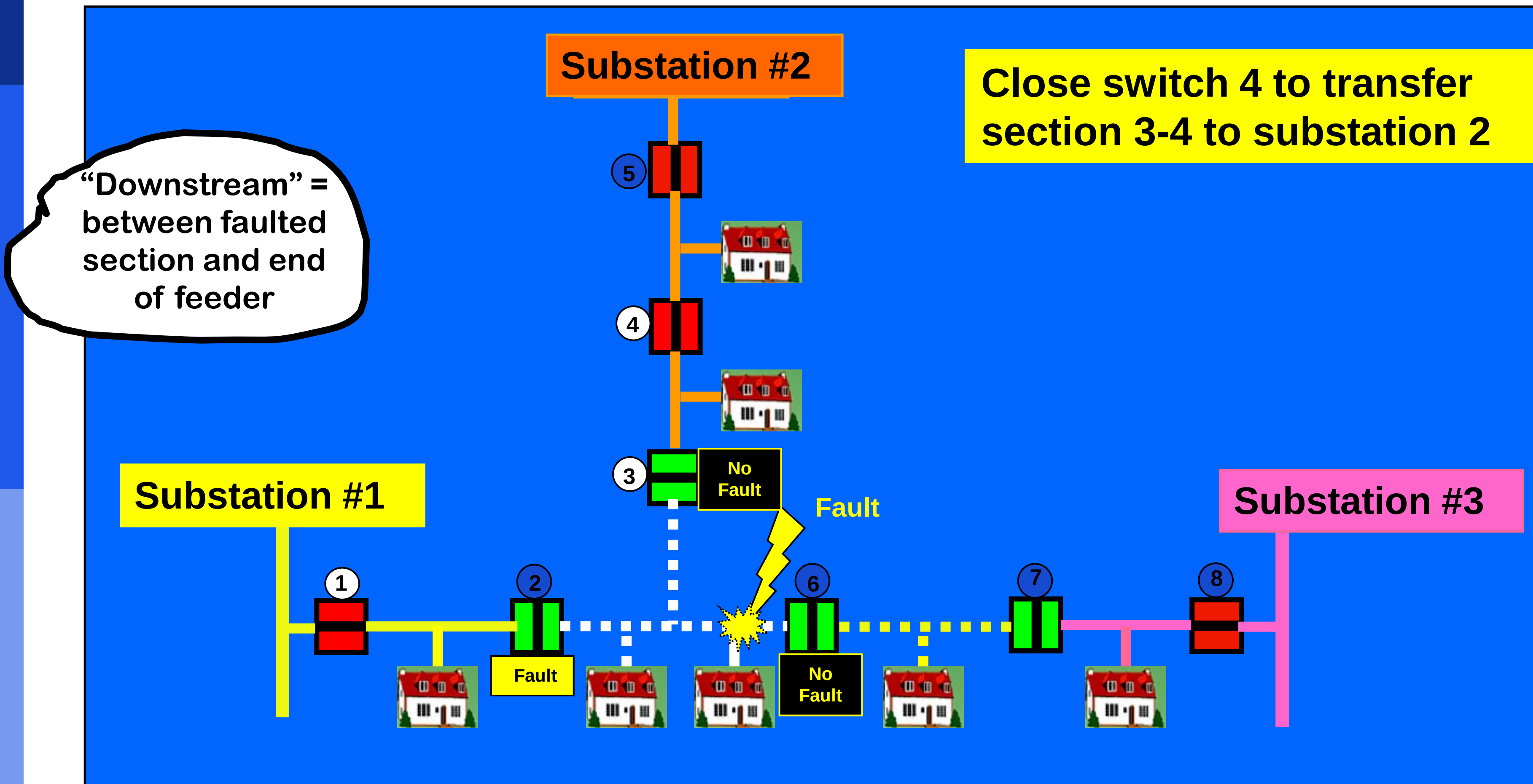
FLISR Operation – Downstream Restoration



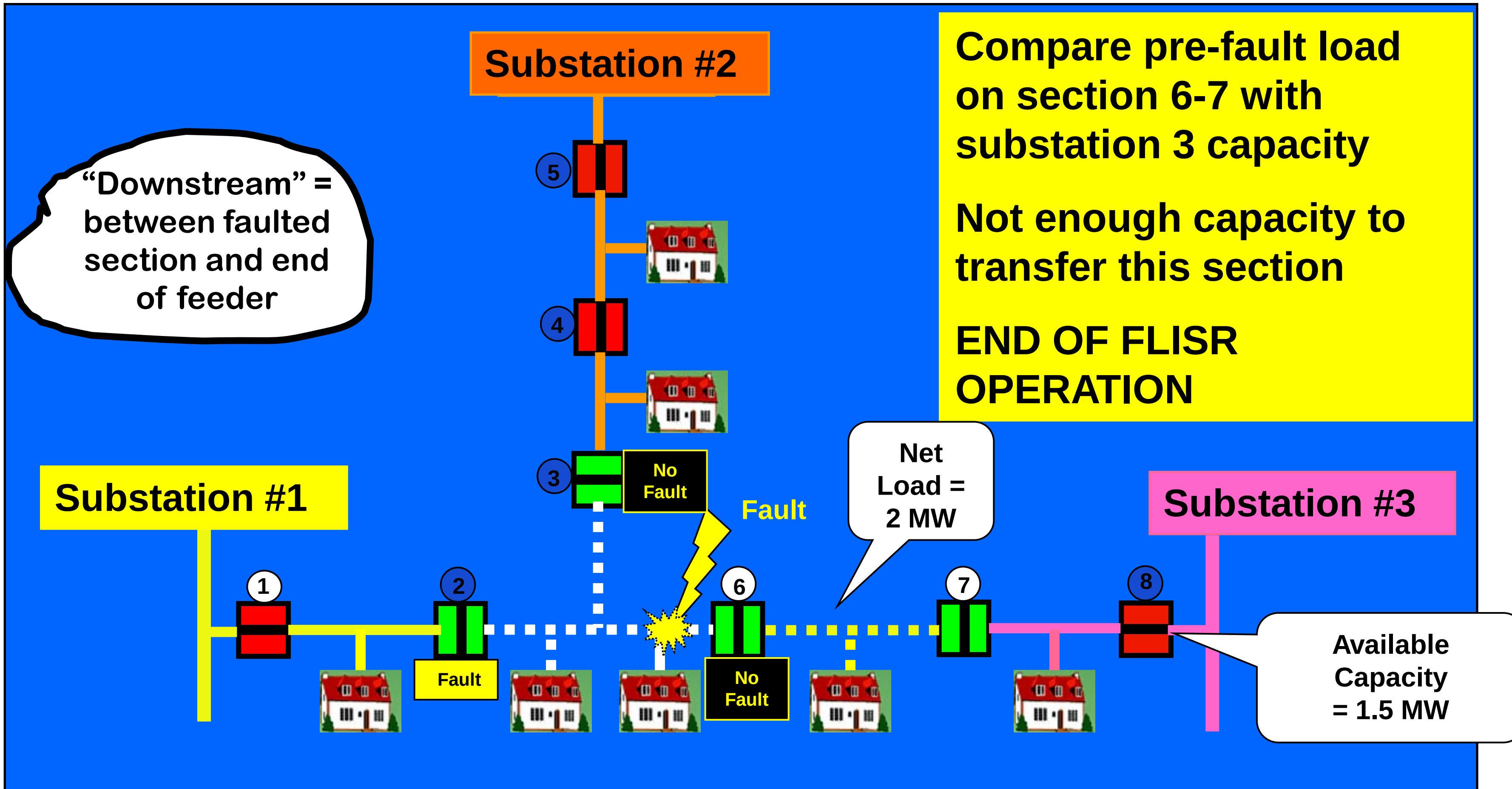
Compare pre-fault load on section 3-4 with substation 2 capacity

Enough capacity to transfer this section

FLISR Operation – Downstream Restoration



FLISR Operation – Downstream Restoration

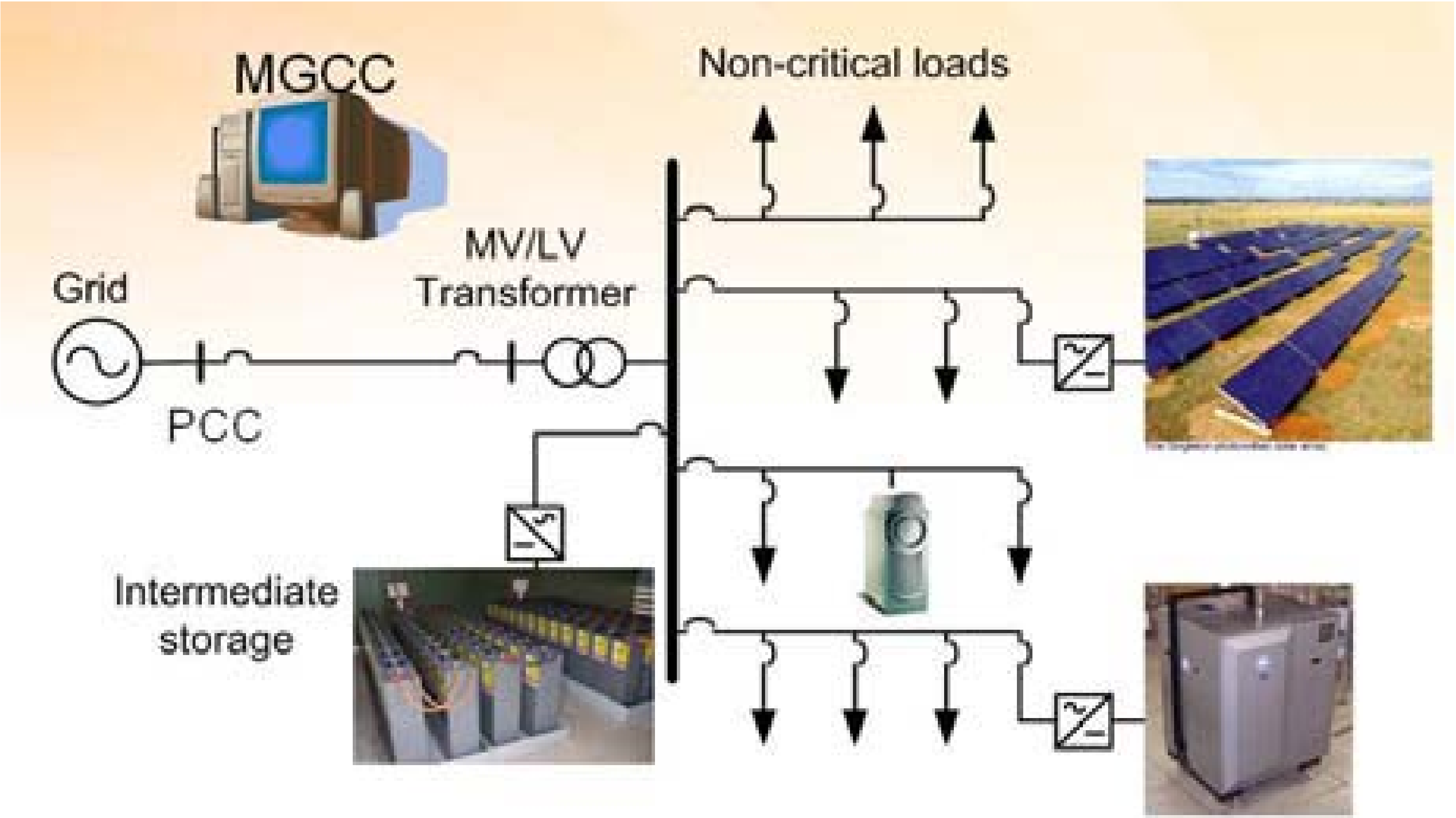


MicroGrid Paradigm

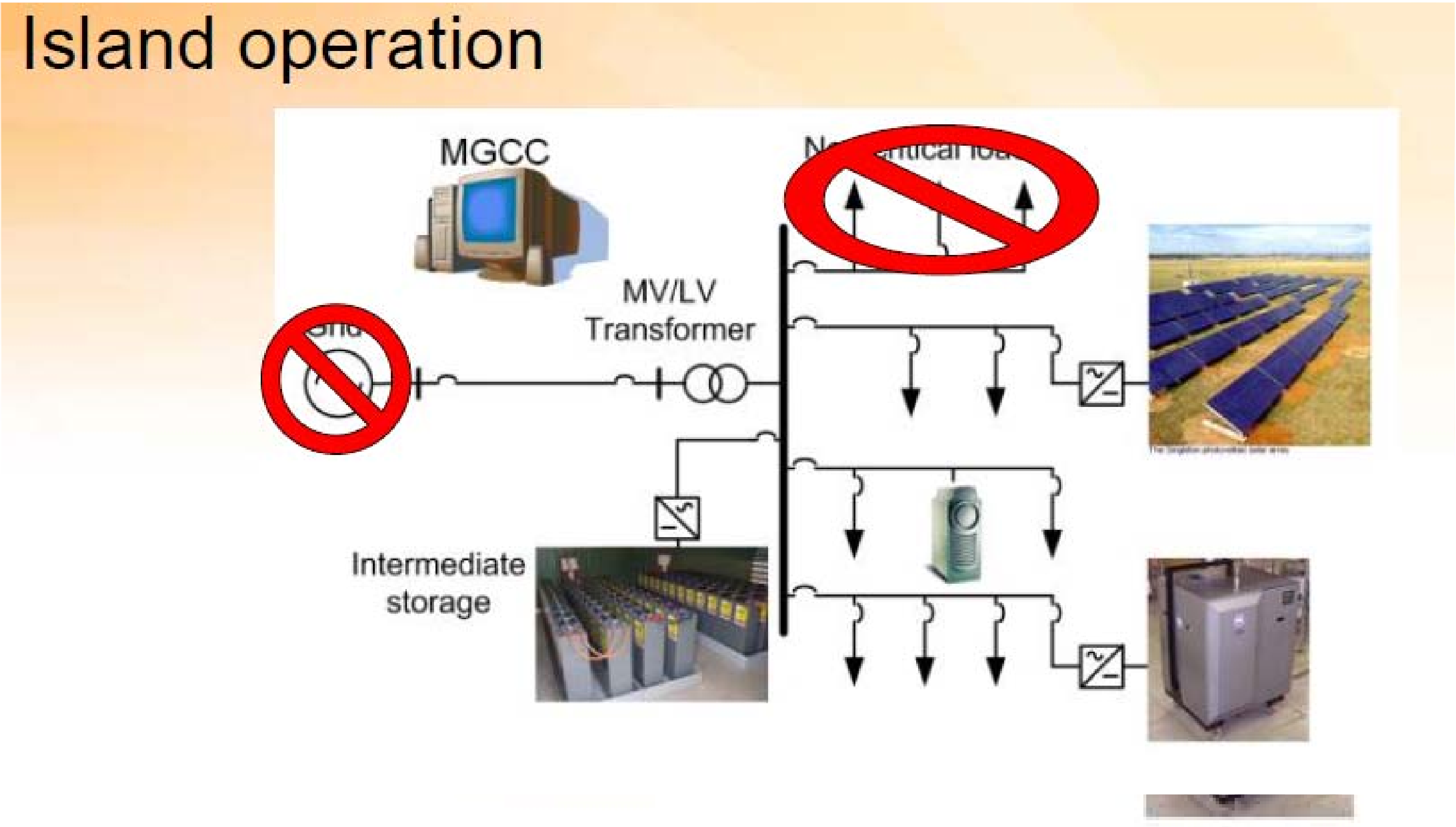
MicroGrid concept assumes a cluster of loads, micro-sources and storage operating as a single system to:

- **Presented to the grid as a single controllable unit (impacts system reliability; fits new paradigm)**
- **Meets customers needs (such as local reliability or power quality)**

Microgrids


MGCC
Non-critical loads
Grid
MV/LV
Transformer
PCC
Intermediate
storage

Microgrids


Island operation
MGCC
MV/LV
Transformer
Intermediate
storage

Community Energy Storage – A Virtual Substation Battery

Operated as a Fleet offering a Multi-MW, Multi-hour Storage

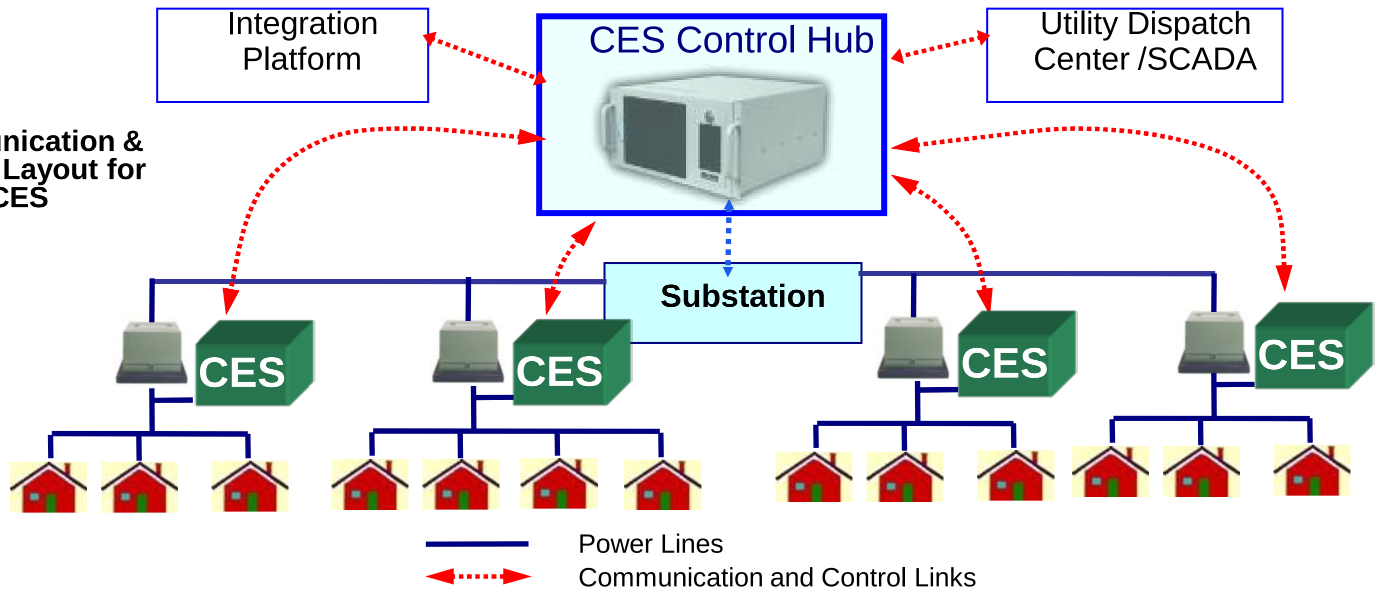
Local Benefits:

1) **Backup power**
2) **Voltage correction**
3) **Renewable Integration**

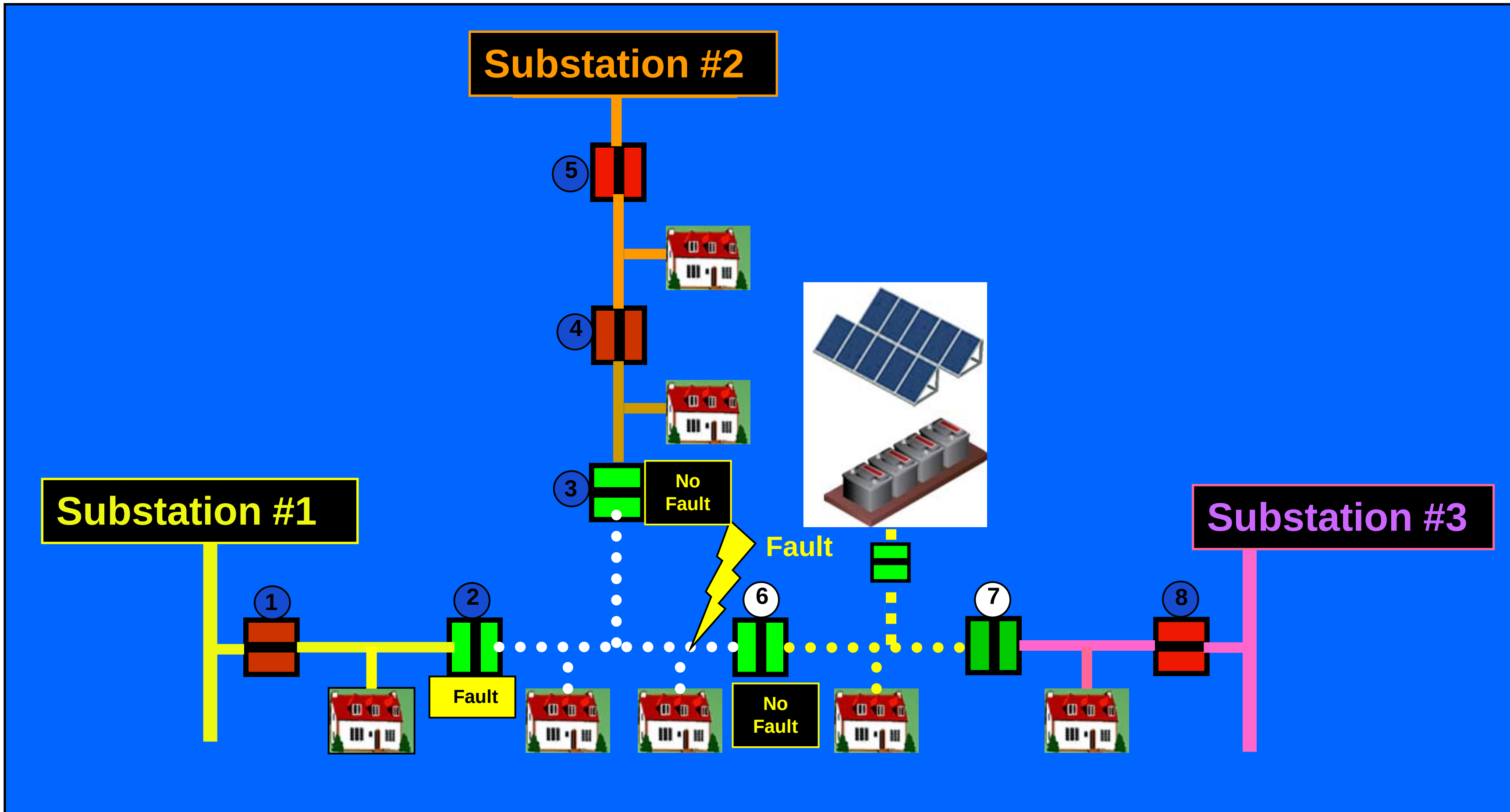
Grid Benefits:

4) **Load Leveling at substation**
5) **Power Factor Correction**
6) **Ancillary services**

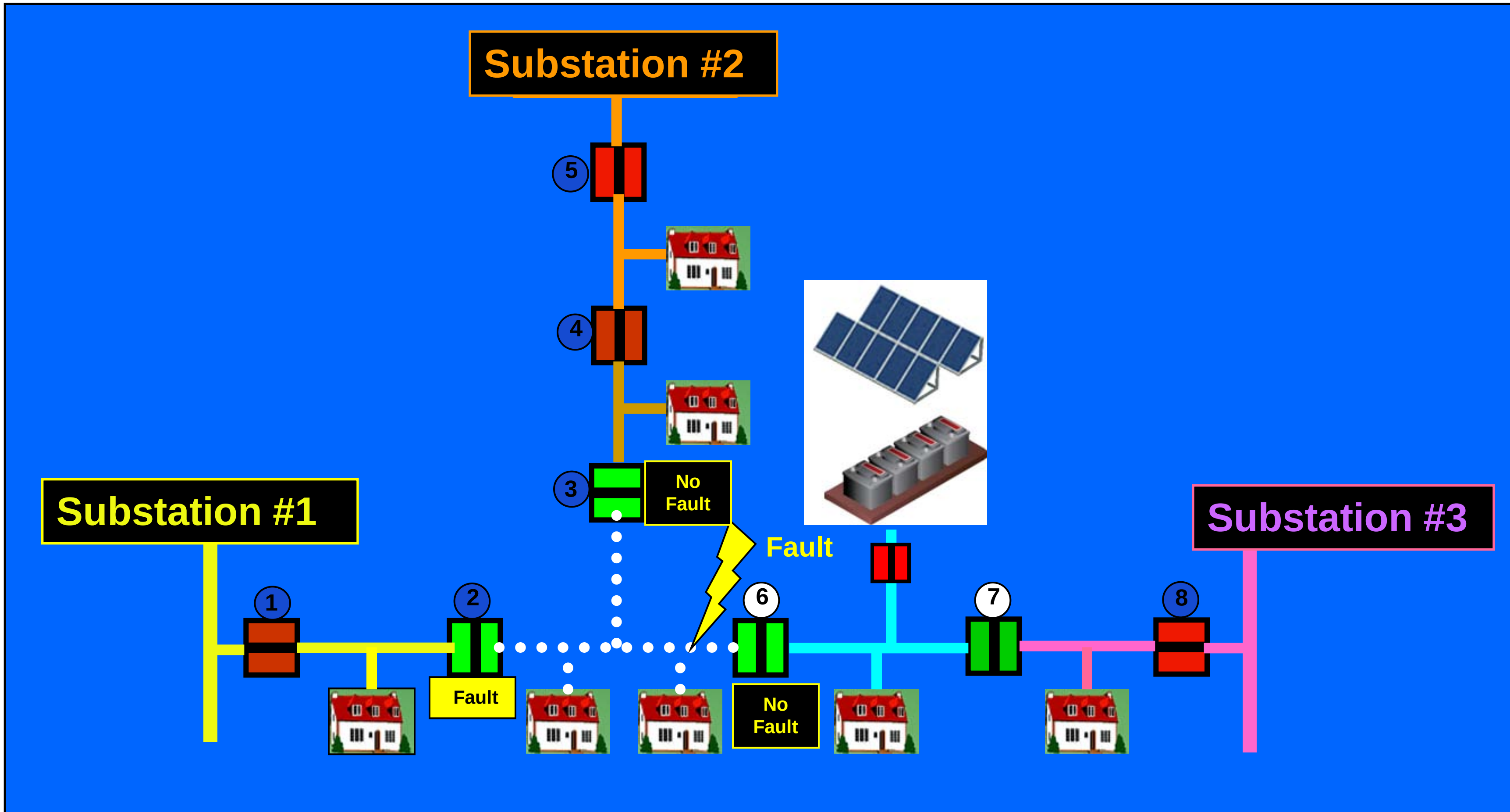
Communication & Control Layout for CES



Applying Microgrid Concept to FLISR

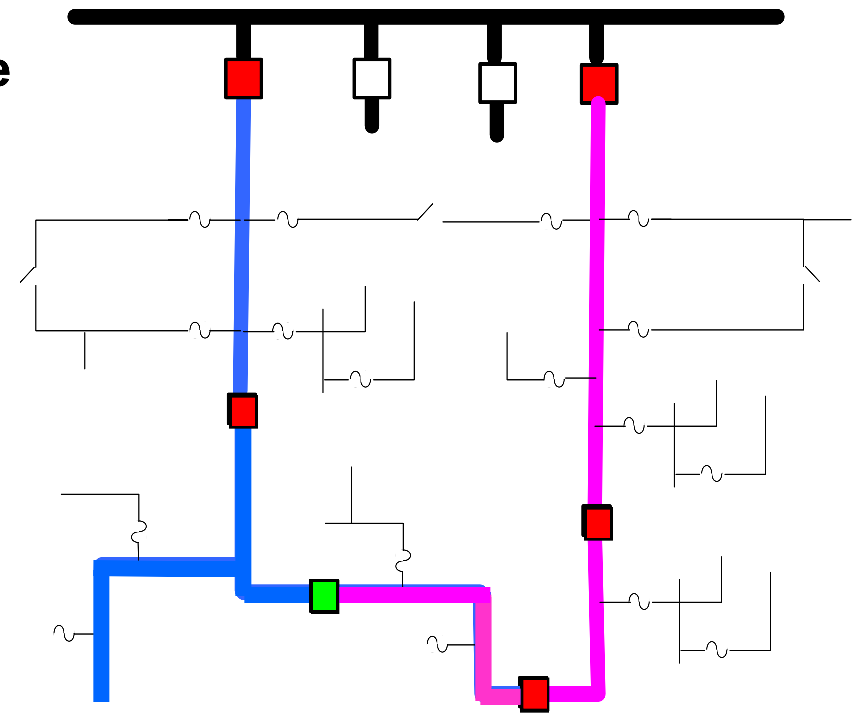


Applying Microgrid Concept to FLISR



Optimal Network Reconfiguration

- **Goal: Identify changes in feeder configuration that would improve overall distribution feeder performance and reliability**
  - **optimize topology for steady state operations…**
- **Selectable Operating Objective**
  - **Minimal power and energy losses**
  - **Maximum reliability**
  - **Best load balance**
  - **Best voltage profiles**
  - **Weighted combination of the above**



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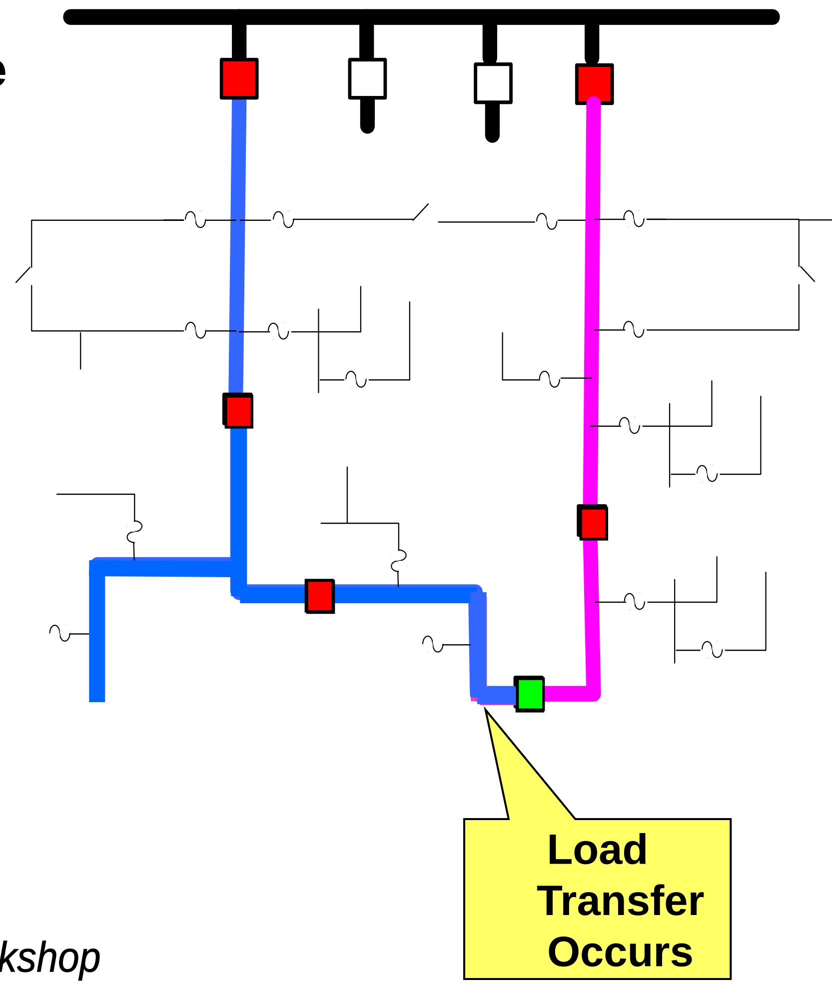
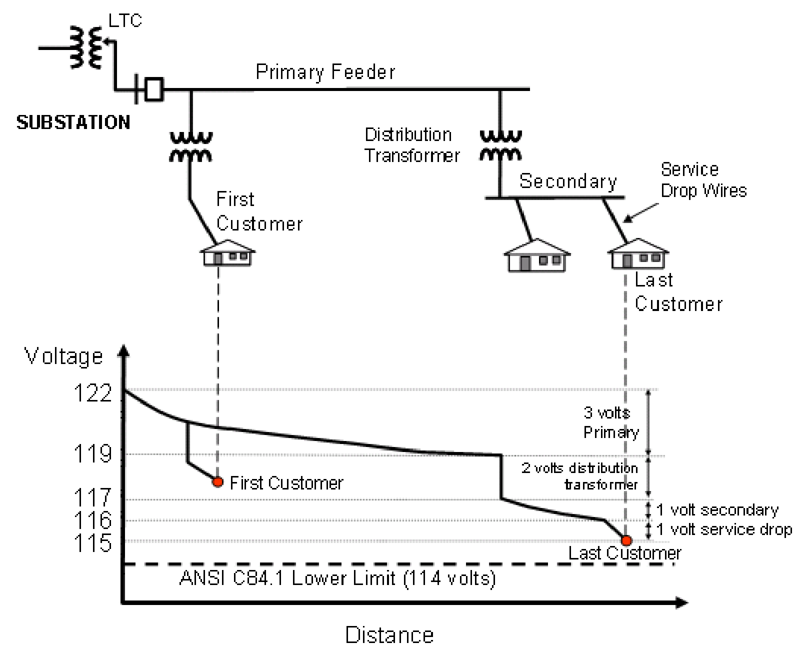


What is Volt-VAR control (VVC)?

- VVC is a fundamental operating requirement of all electric distribution systems
- Prime purpose is to maintain acceptable voltage at all points along the distribution feeder under all loading conditions

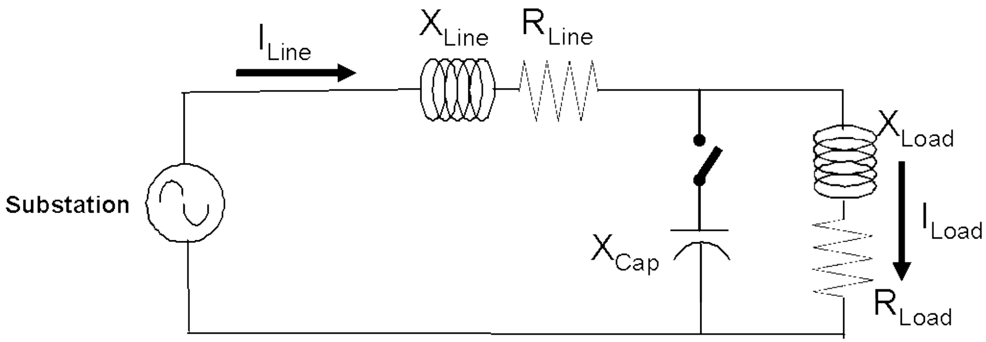


Volt-VAR Control in a Smart Grid World

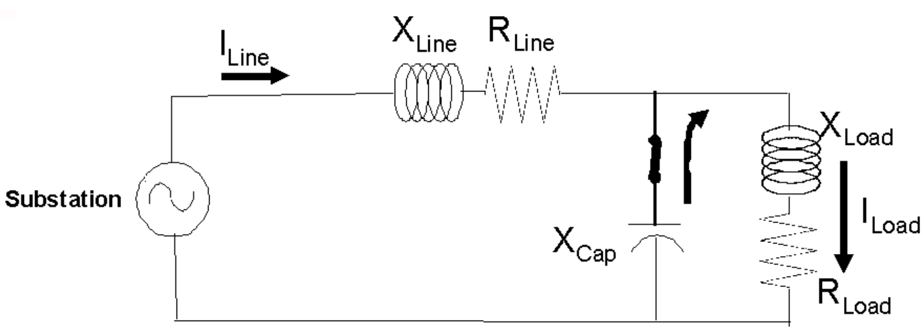
- **Expanded** objectives for Volt-VAR control include
  - **Basic req't – maintain acceptable voltage**
  - **Support major "Smart Grid" objectives:**
    - **Improve efficiency**
    - **Reduce electrical demand and/or accomplish energy conservation** through voltage reduction
    - **Promote a "self healing" grid**
    - Enable widespread deployment of Distributed generation, Renewables, Energy storage, and other distributed energy resources (dynamic volt-VAR control)

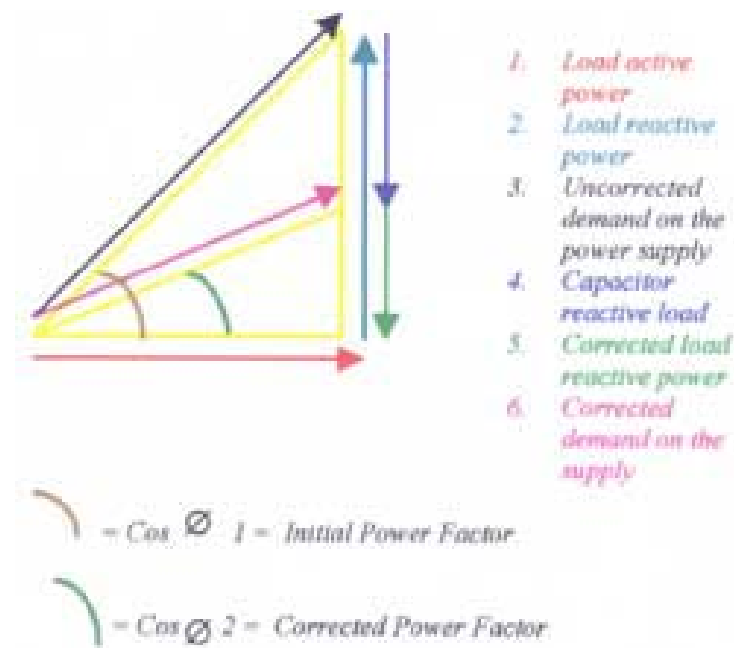



Efficiency Improvement/Loss Reduction Through Reactive Power Compensation



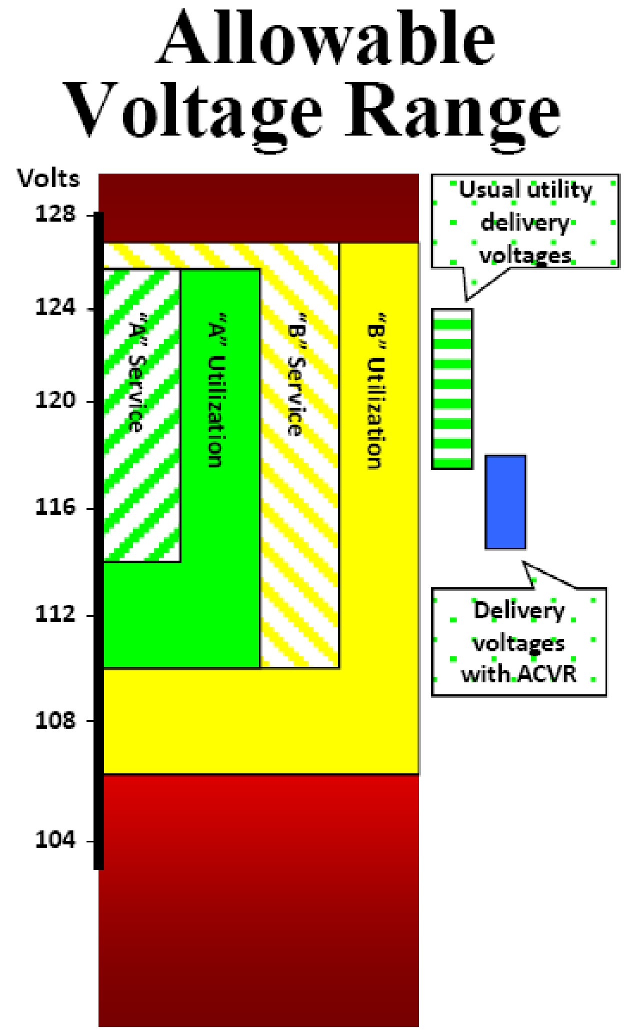
$$\text{Losses} = I_{Line}^{2} \times R_{Line}$$





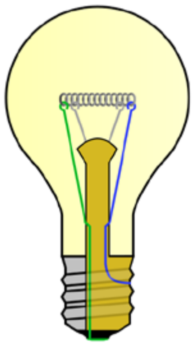
Concept of Conservation Voltage Reduction

- ANSI standards have some flexibility in the allowable delivery voltage
- Distribution utilities typically have delivery voltage in upper portion of the range
- **<u>Concept of CVR:</u> Maintain voltage delivered to the customer in the lower of the acceptable range of normal operation**



Conservation Voltage Reduction – Why Do It?

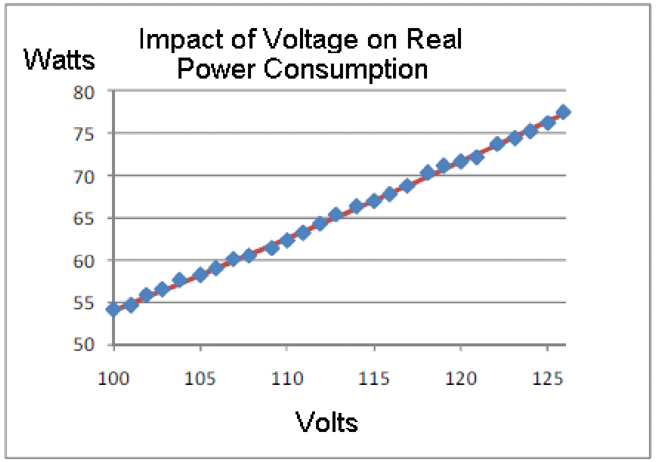
- Many electrical devices operate more efficiently (use less power) with reduced voltage



$$P = V^2 \div R$$

"Constant Impedance" Load

Incandescent Light Bulb (70W)

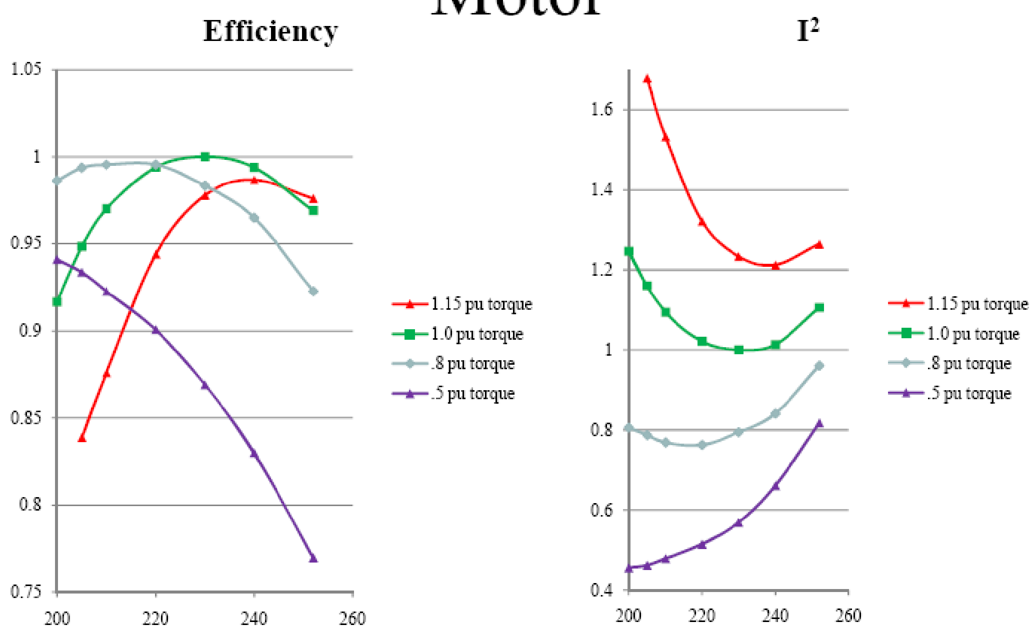


"Evaluation of Conservation Voltage Reduction (CVR) on a National Level"; PNNL; July 2010

Conservation Voltage Reduction – Why Do It?

- Many electrical devices operate more efficiently (use less power) with reduced voltage

Voltage effects on ½ Hp, 230 Vac, 1Ø Motor



M.S. Chen, R.R. Shoults and J. Fitzer, *Effects of Reduced Voltage on the Operation and Efficiency of Electric Loads, Volumes 1 & 2,* EPRI, Arlington: University of Texas, 1981, Motor Number 3

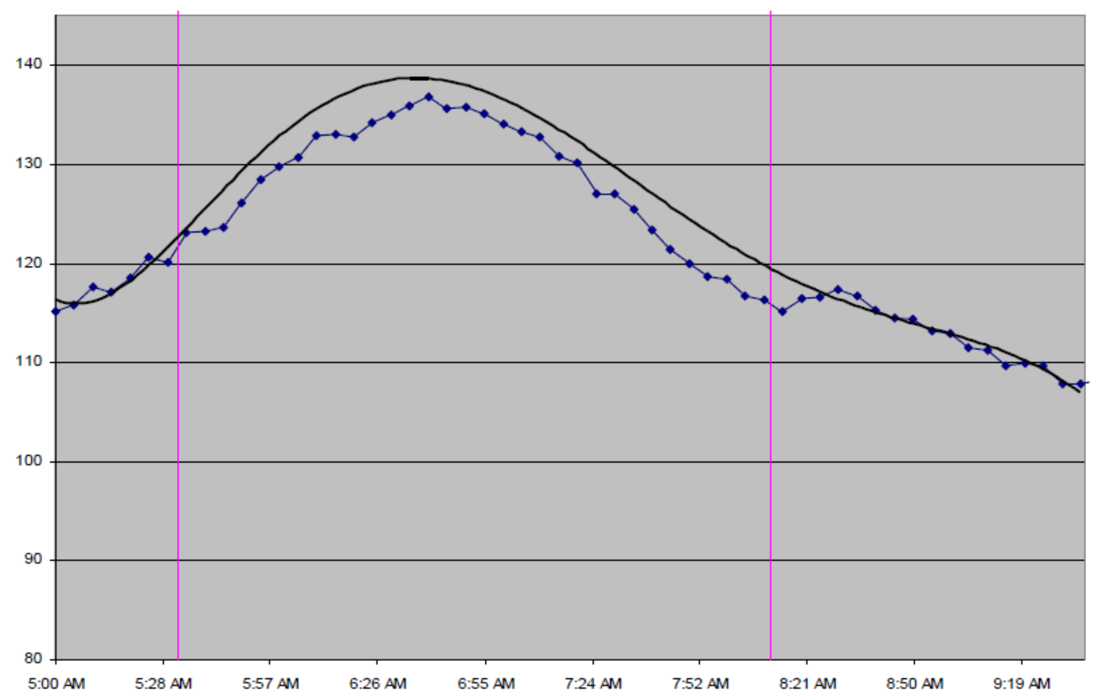
Motors are often viewed as **“constant power”** devices

Motor efficiency actually improves for small voltage reduction

CVR for Demand Reduction

Applying CVR at peak load can reduce total **demand** (kW)

Typical Winter Morning



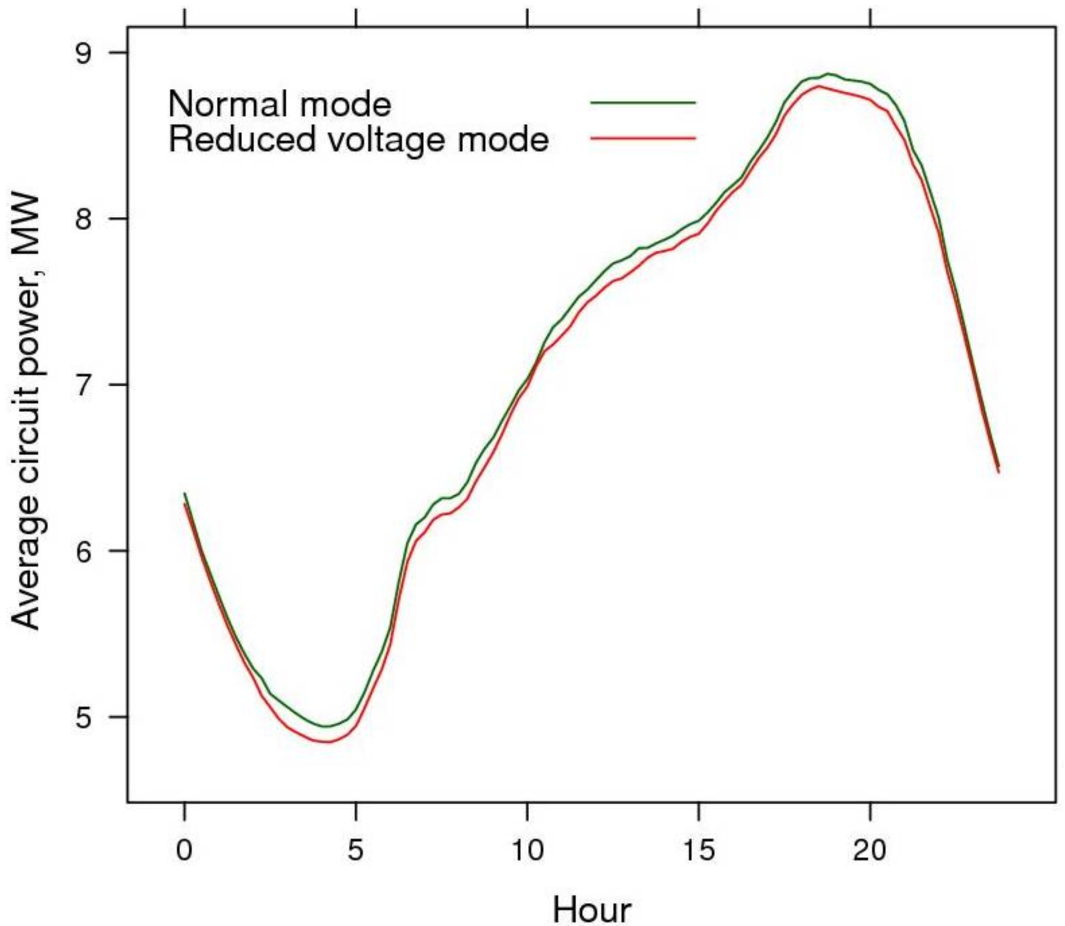
EUCI Conference
September 16-17, 2010

Peak Shaving via Voltage Reduction

PEE DEE ELECTRIC COOPERATIVE

CVR for Energy Savings

Applying CVR around-the-clock can reduce **energy consumption** (kWh)



Benefits of CVR

- Effectiveness measured by CVR factor:

CVR factor = % change in load ÷ % change in voltage

- Example:
  - If CVRf = 0.8
  - Reducing voltage from 120 to 117V (2.5%)
  - Reduces power consumed by 2.0%

Utility CVR Factors, Based on Implementations or Tests

Utility	CVR Factor[22]	Comments
California IOUs	0.75	
New York State Electric & Gas	0.6	
Central Florida Electric Cooperative	0.5 – 0.75	0.5 in the summer; 0.75 in the winter
Clay Electric Cooperative (Florida)	1.0	
Progress Energy – Florida	1.0	
Georgia Power	0.8 – 1.7	1.25
Cobb EMC (Georgia)	0.75	
Progress Energy – Carolinas	0.4	
Avista Utilities	1.09	Ongoing pilot project
Clatskanie PUD	1.4	Ongoing pilot project
Inland Power & Light	0.93	Ongoing pilot project
Snohomish PUD	0.65	
Seattle City Light	0.13	Discontinued program
Average	**0.8**	**Mean of all values, equally weighted, with mid point values used for ranges.**

Distribution Efficiency Initiative

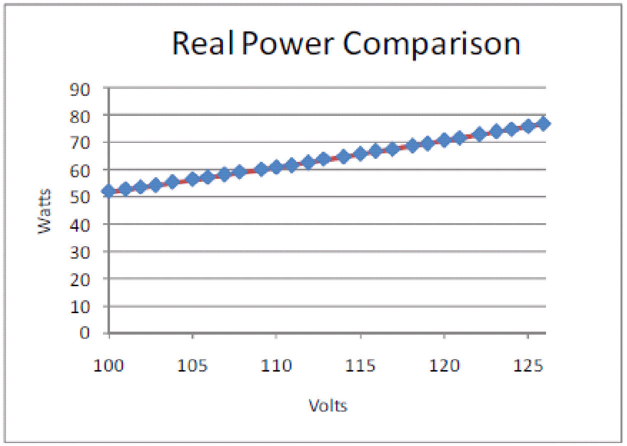
Market Progress Evaluation Report, No. 1

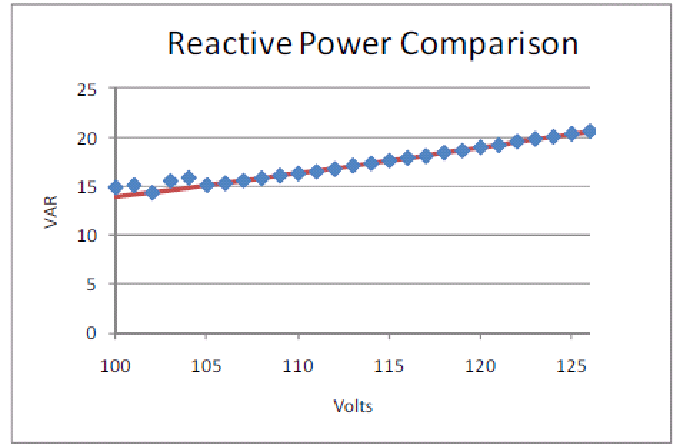
prepared by Global Energy Partners, LLC

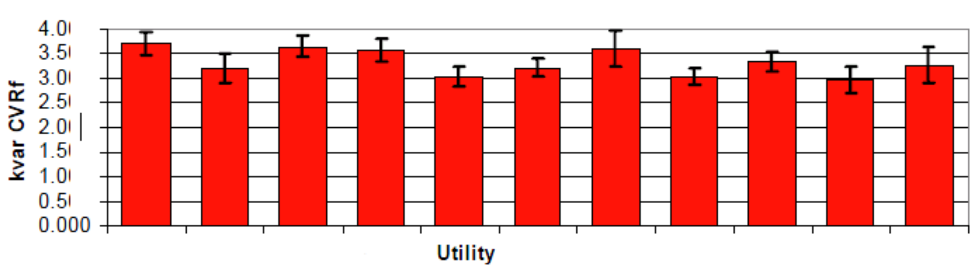
report #E05-139 May 18, 2005

CVR Also Impacts Reactive Power

Oscillating Fan







OVERALL kvar CVRf	*CVRf* 3.284

kvar CVR factor Results by Utility

Effect of CVR on kVAR is more significant than on kW

kW CVRf ≈ 0.7

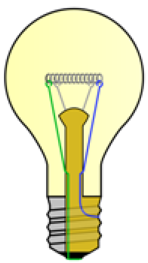
kVAR CVRf ≈ 3.0

Distribution Efficiency Initiative
Northwest Energy Efficiency Alliance

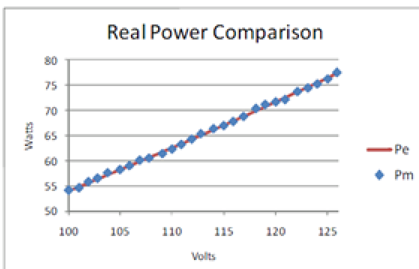
McGranaghan/Uluski –Smart Distribution Systems Workshop

Emerging Load Characteristics

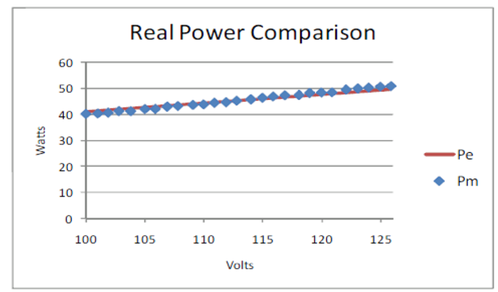
- Characteristics of some emerging load characteristics don’t favor CVR
- Need better understanding of “up and coming” appliances to determine if CVR will provide lasting effects



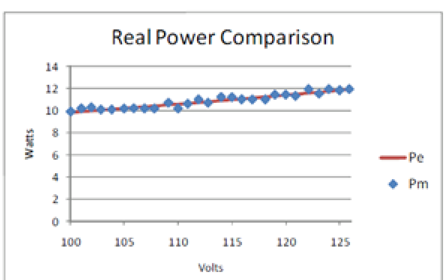
Incandescent Light Bulb (70W)



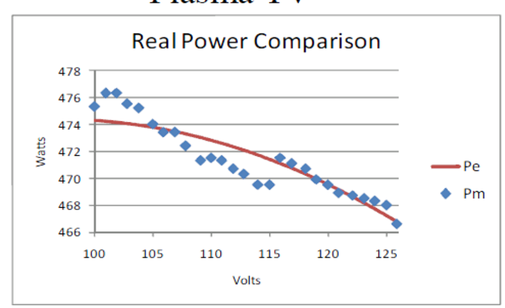
Television (Cathode Ray Tube)



Compact Fluorescent Light (CFL) 13W



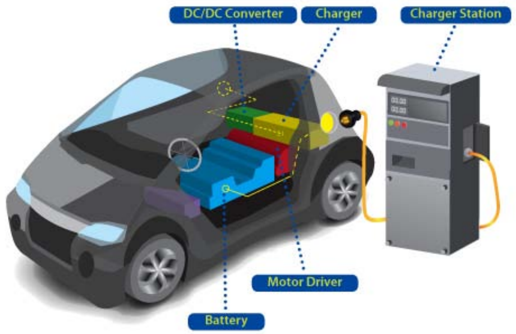
Plasma TV



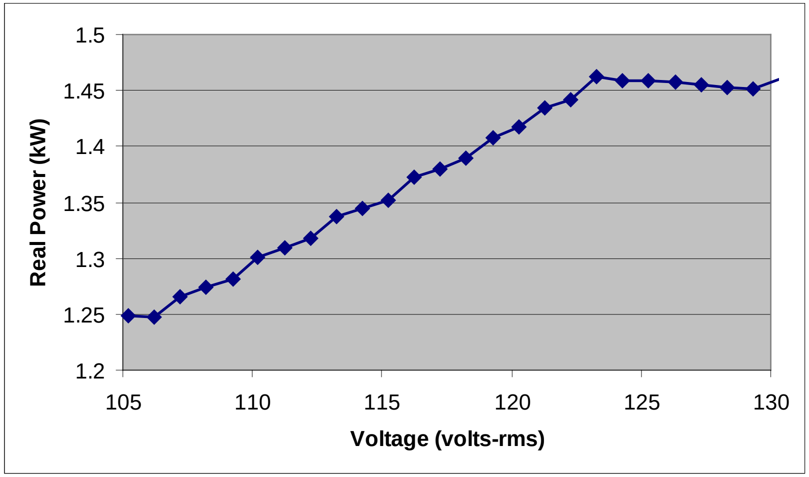
Frankfurt (Germany), 6-9 June 2011

Not All Good News About CVR Impact?

- Inverter based loads may exhibit **Constant Power** behavior
  - Voltage reduced
  - Power (= voltage x current) stays the same
  - Current flow increases
  - Electrical losses (I^2R) increase



- Some new loads have fixed current limits
  - Start off as constant power
  - As V is reduced, I increases
  - When current reaches max, revert to **Constant Current** behavior



McGranaghan/Uluski –Smart Distribution Systems Workshop

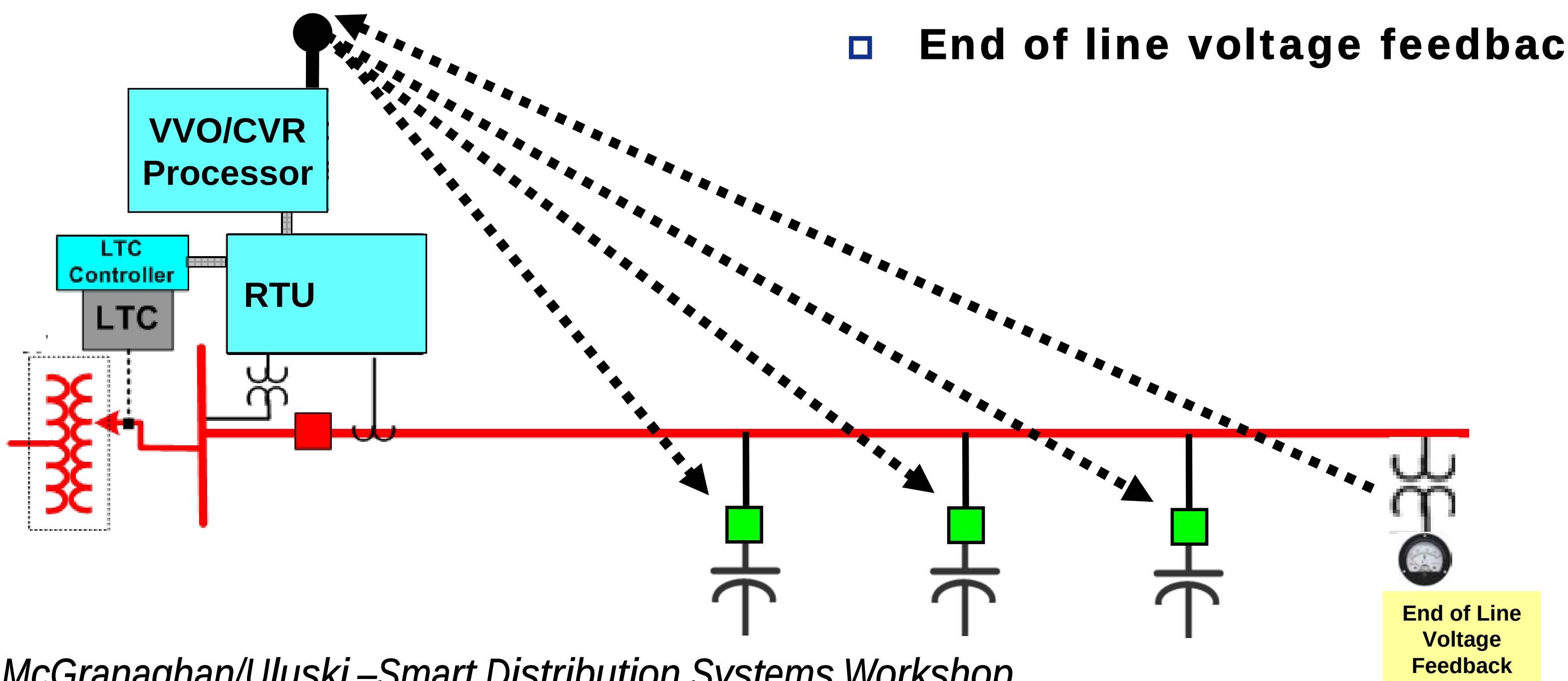
Conclusion about CVR

Need to understand the behavior of major electrical devices (including conventional and up and coming devices) when voltage is reduced

EPRI Supplemental Project ““Load Modeling for Voltage Optimization“ is exploring key issues pertaining to CVR

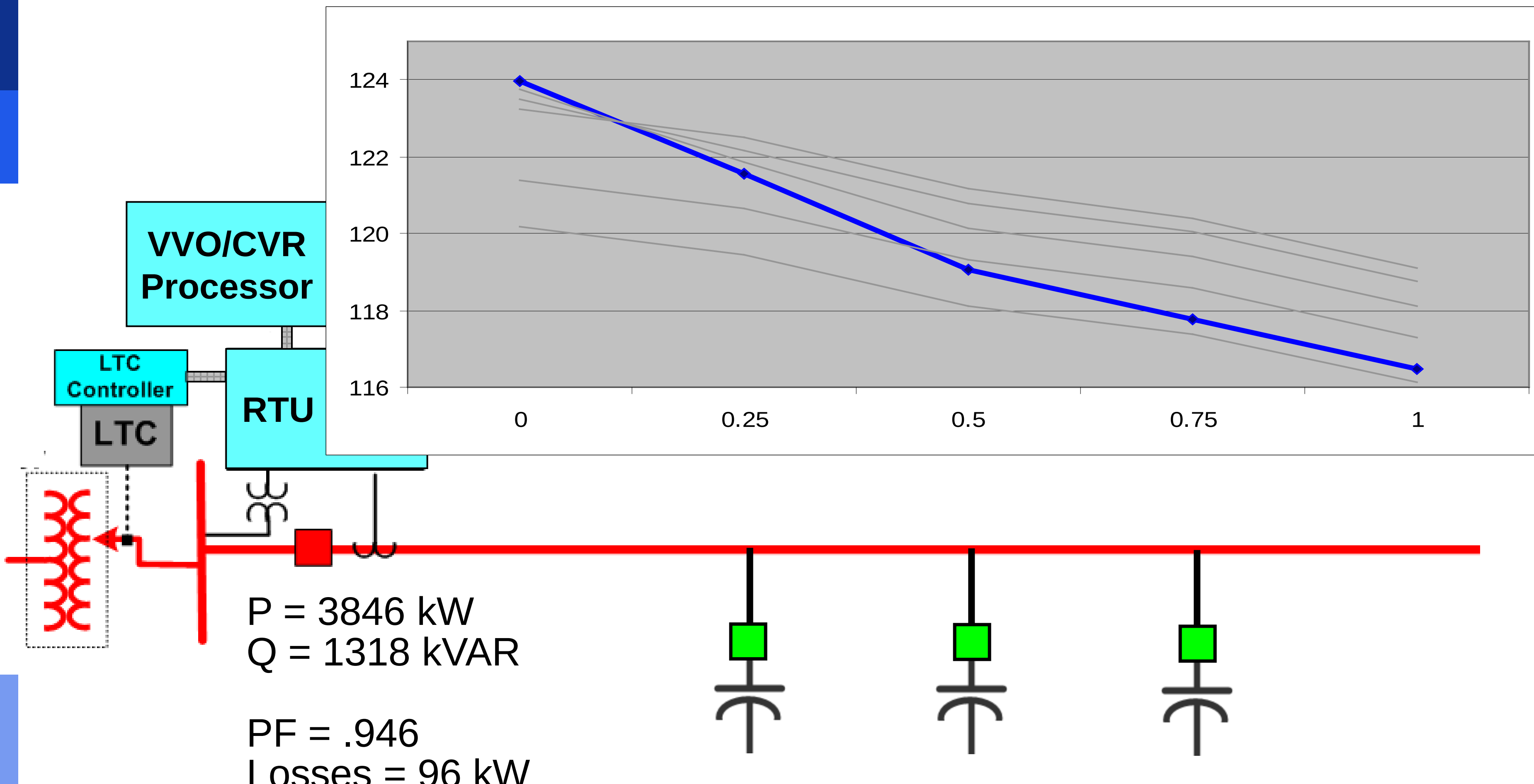
Rule Based VVC System Components

- Substation Remote Terminal Unit
- VVO / CVR processor
- Switched Cap banks & local measurement facilities
- Voltage regulators (LTCs) & local measurement facilities
- Communication facilities
- End of line voltage feedback



Part 1: VAR Control (Power Factor Correction)

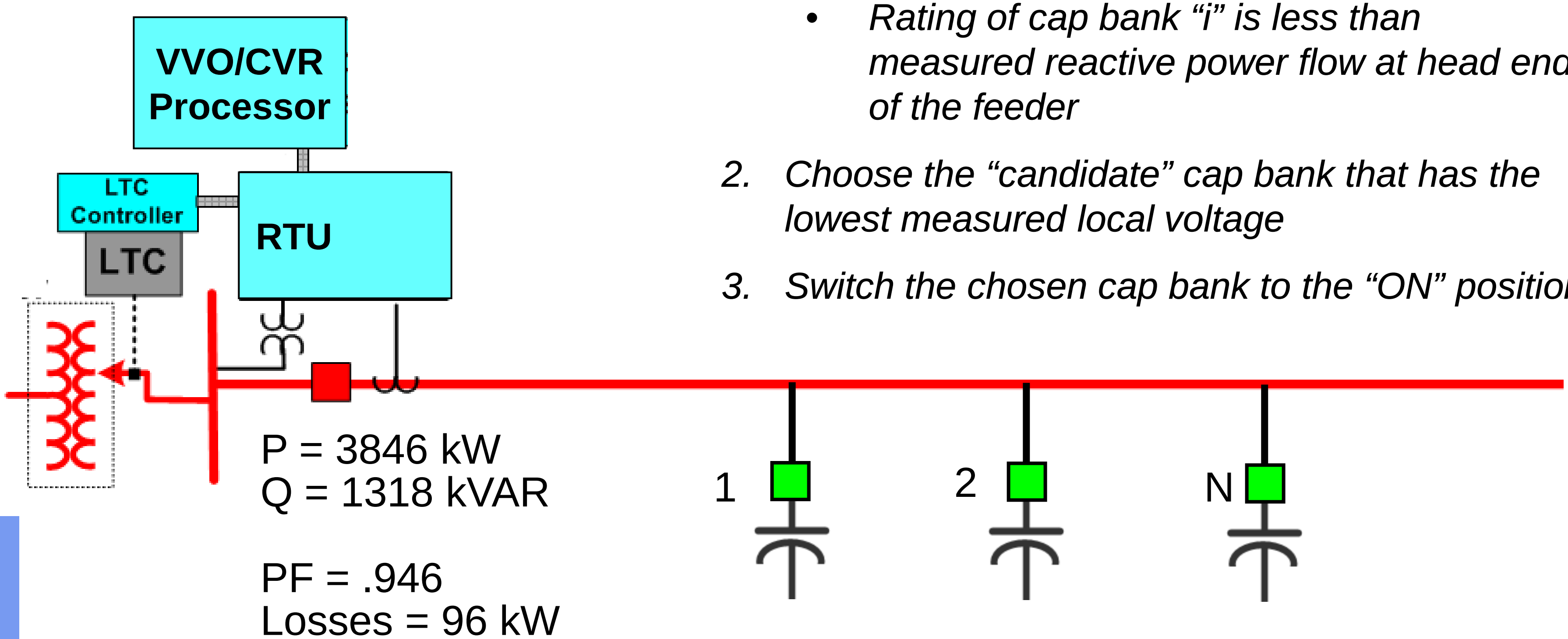
Voltage Profile

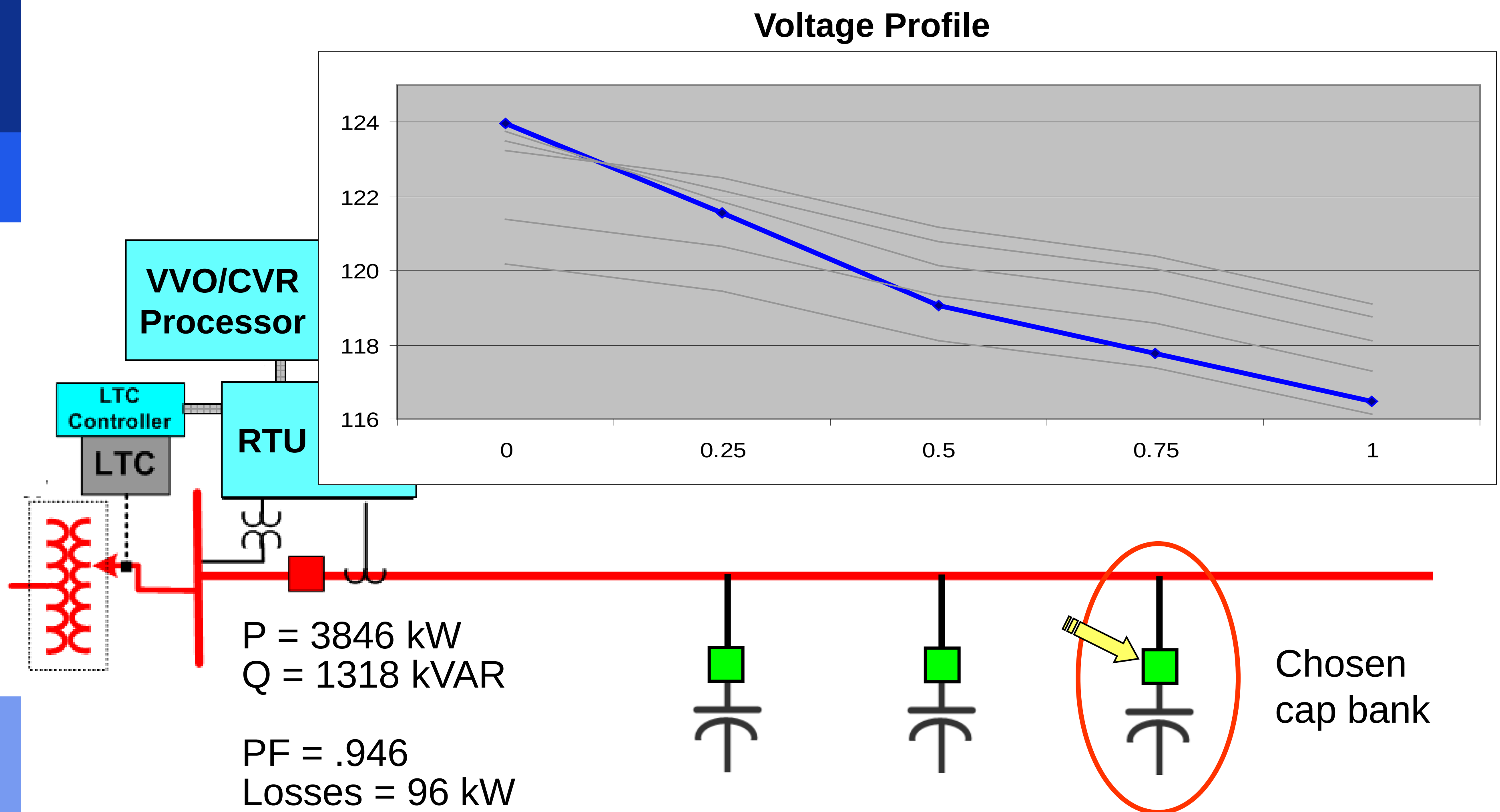


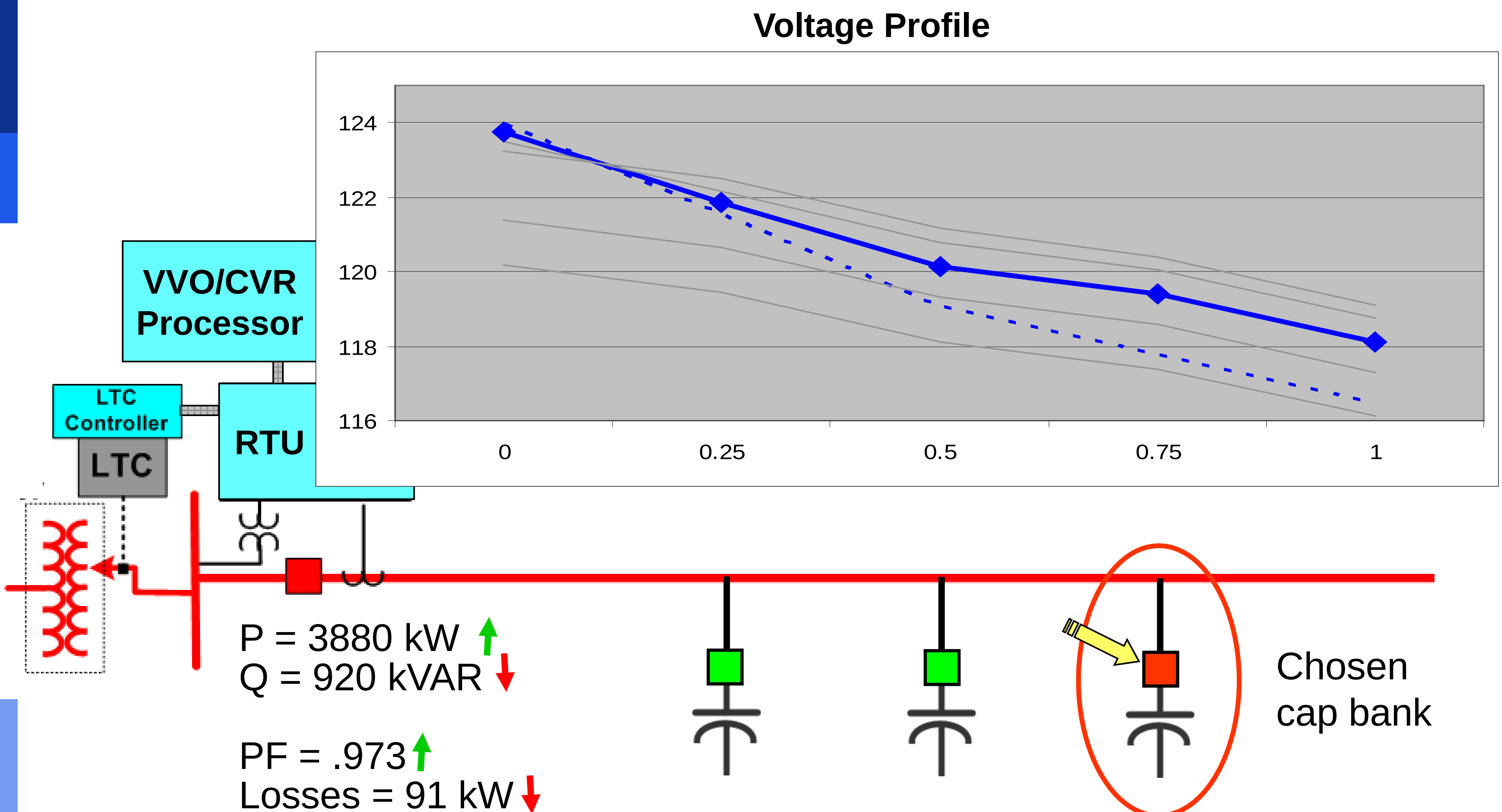
Part 1: VAR Control

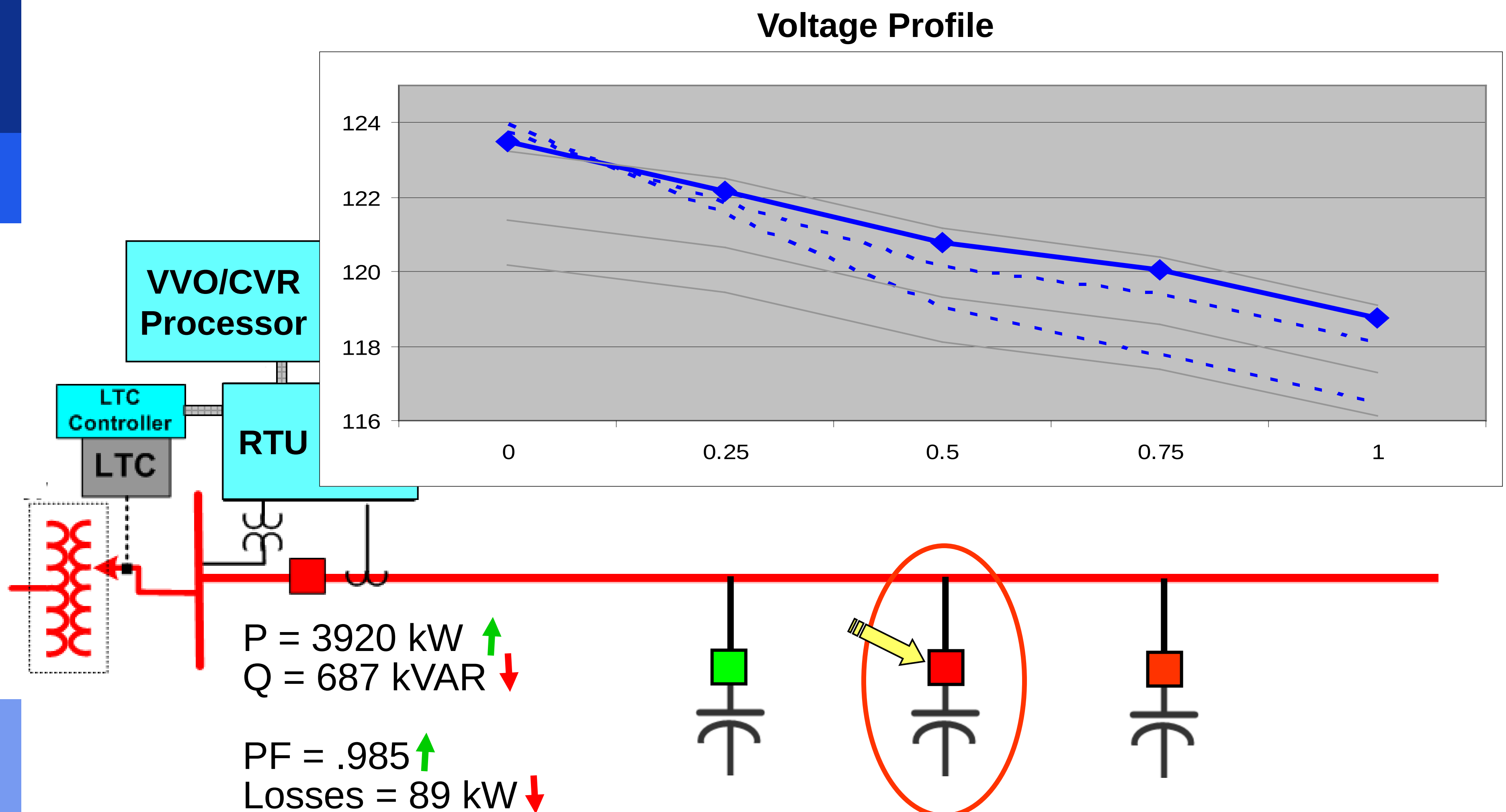
Sample Rules:

1. *Identify "candidate" cap banks for switching*
   - *Cap bank "i" is currently "off"*
   - *Rating of cap bank "i" is less than measured reactive power flow at head end of the feeder*
2. *Choose the "candidate" cap bank that has the lowest measured local voltage*
3. *Switch the chosen cap bank to the "ON" position*




Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3846 kW
Q = 1318 kVAR
PF = .946
Losses = 96 kW
Chosen cap bank


Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3880 kW
Q = 920 kVAR
PF = .973
Losses = 91 kW
Chosen cap bank



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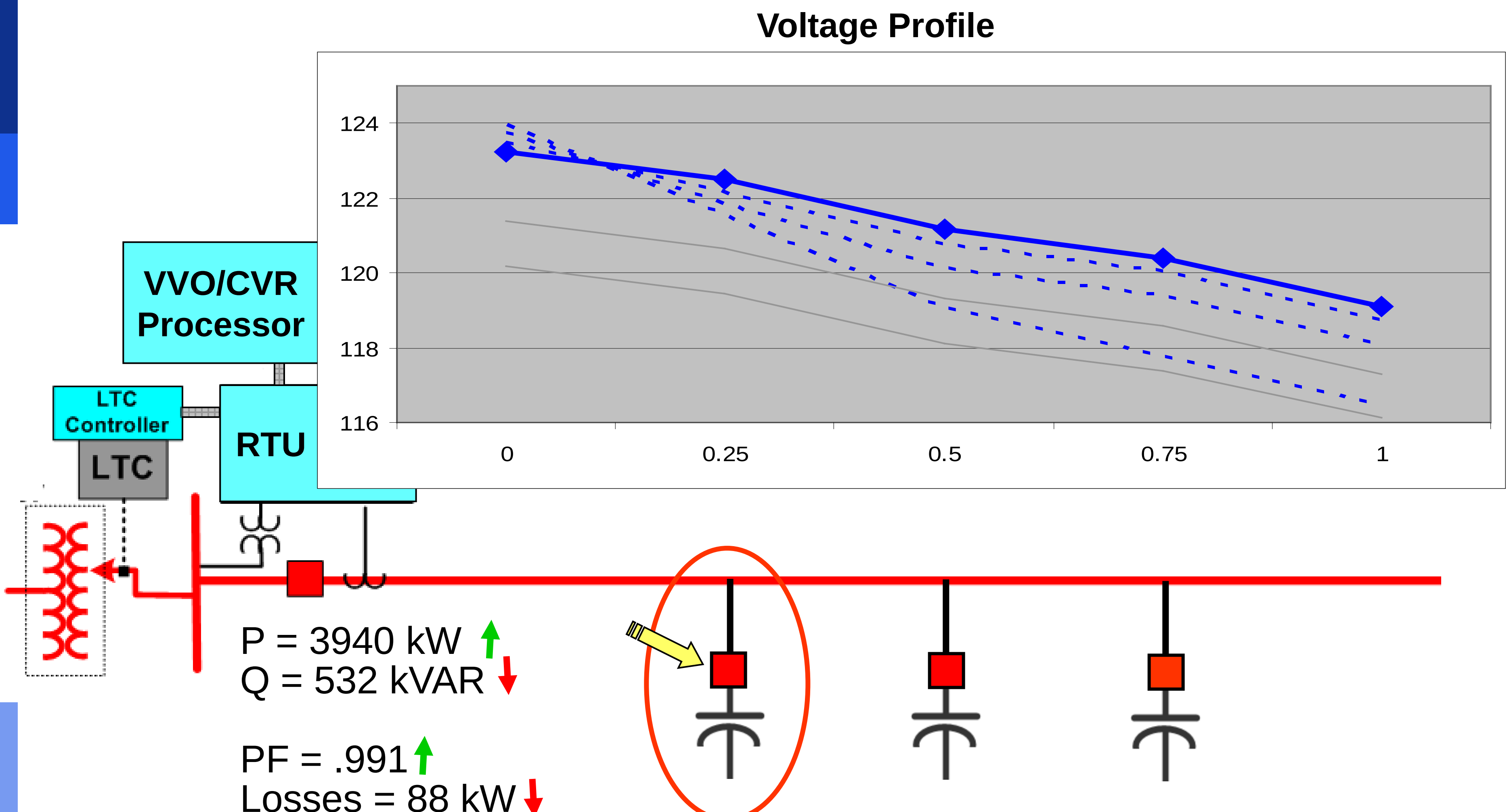
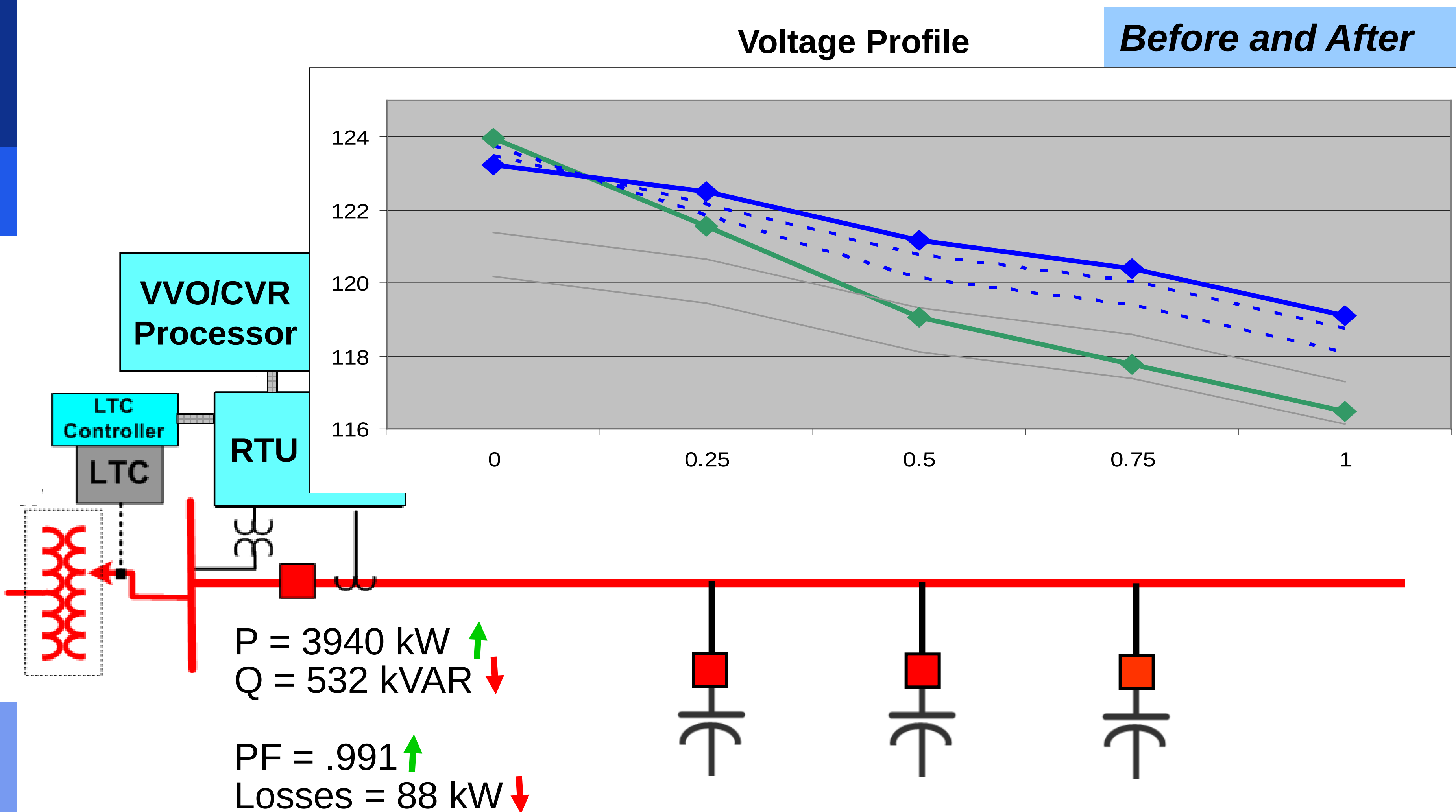
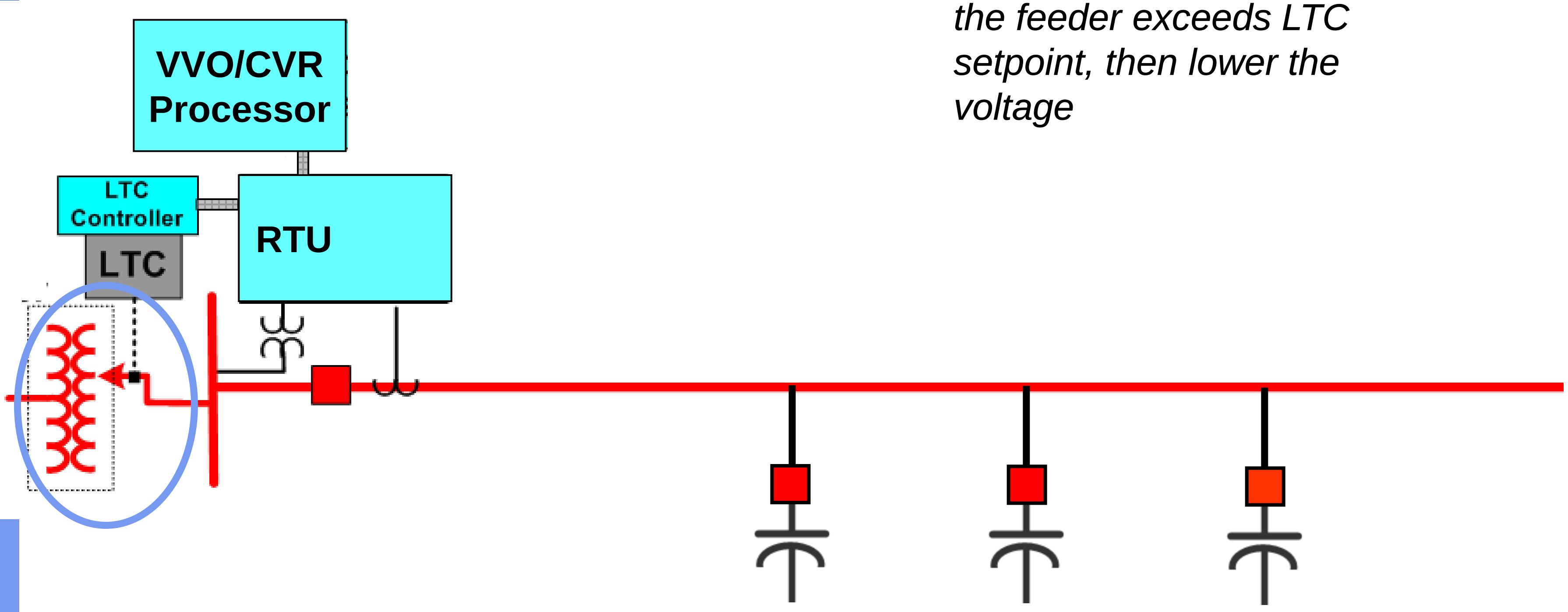

Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3940 kW
Q = 532 kVAR
PF = .991
Losses = 88 kW

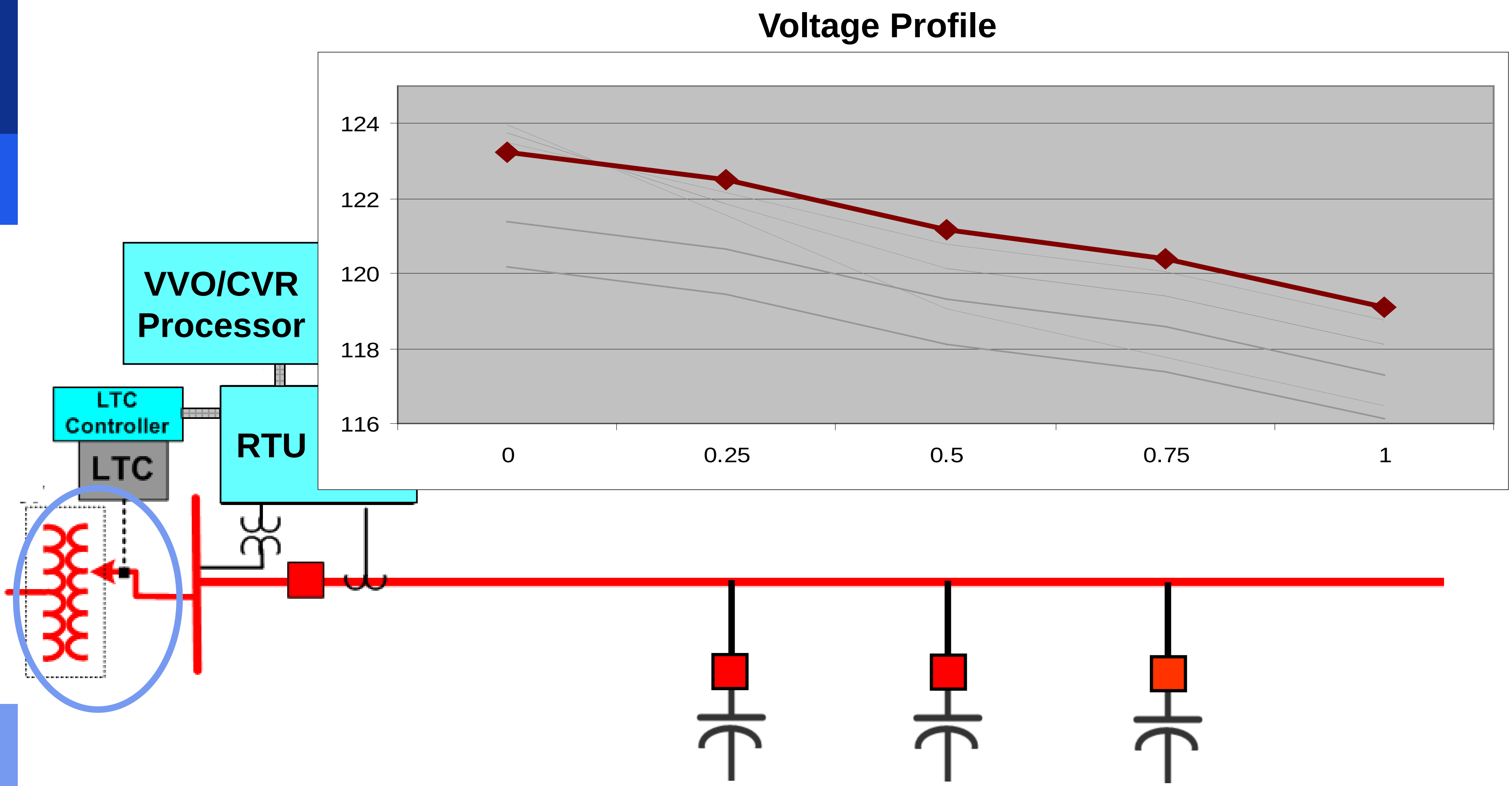

Voltage Profile
Before and After
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3940 kW
Q = 532 kVAR
PF = .991
Losses = 88 kW

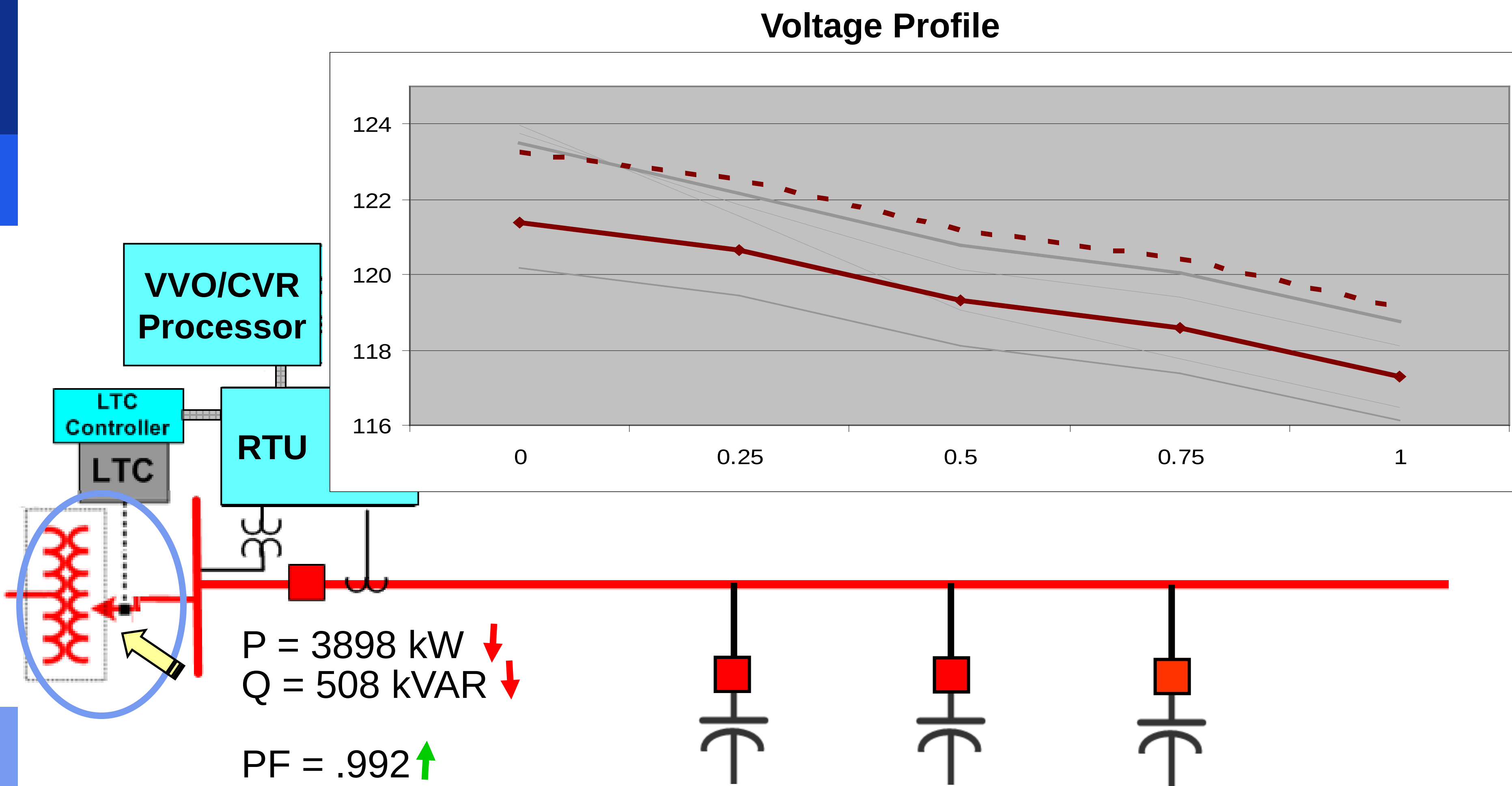
Part 2: Voltage Control (CVR)

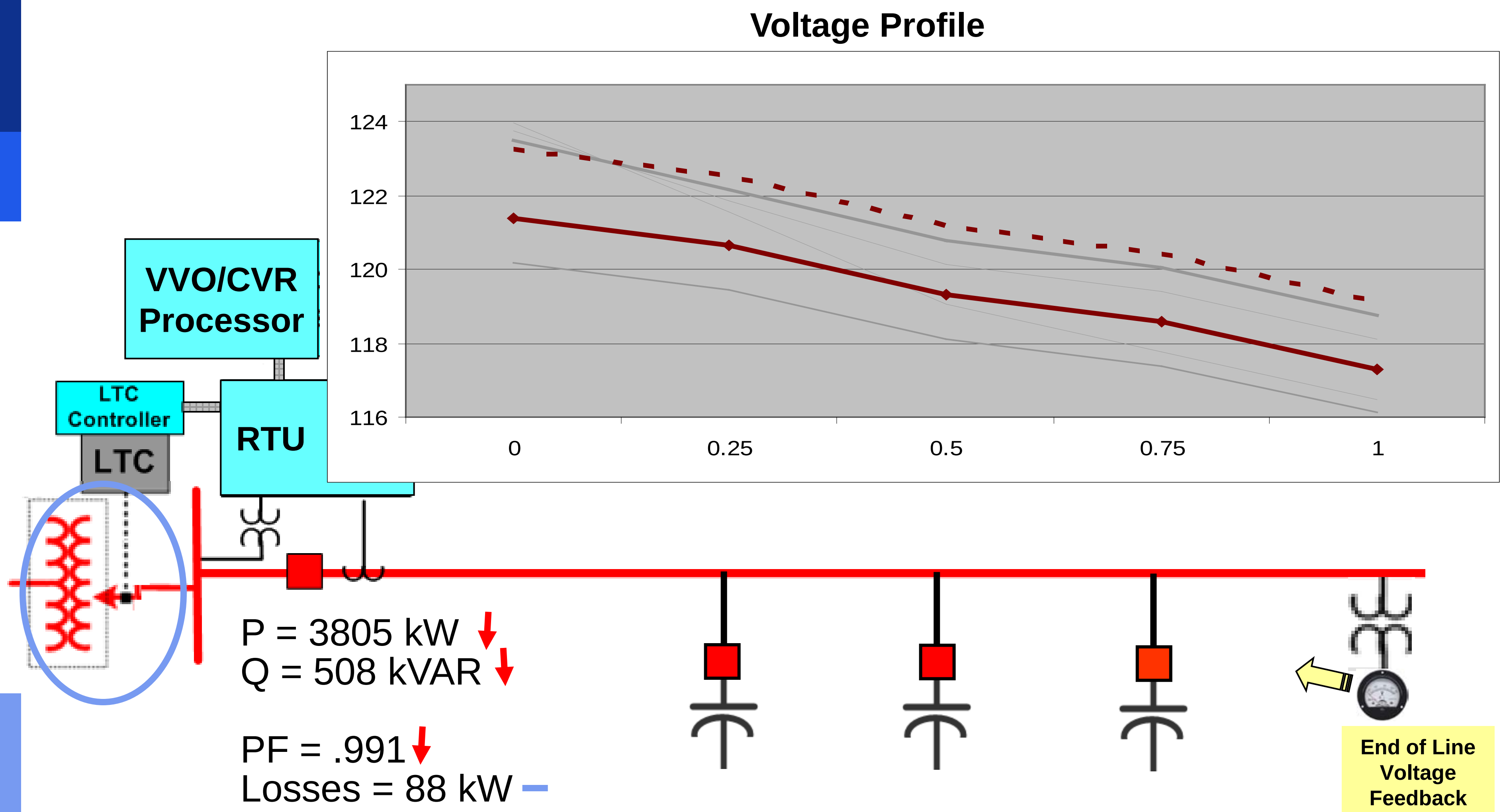


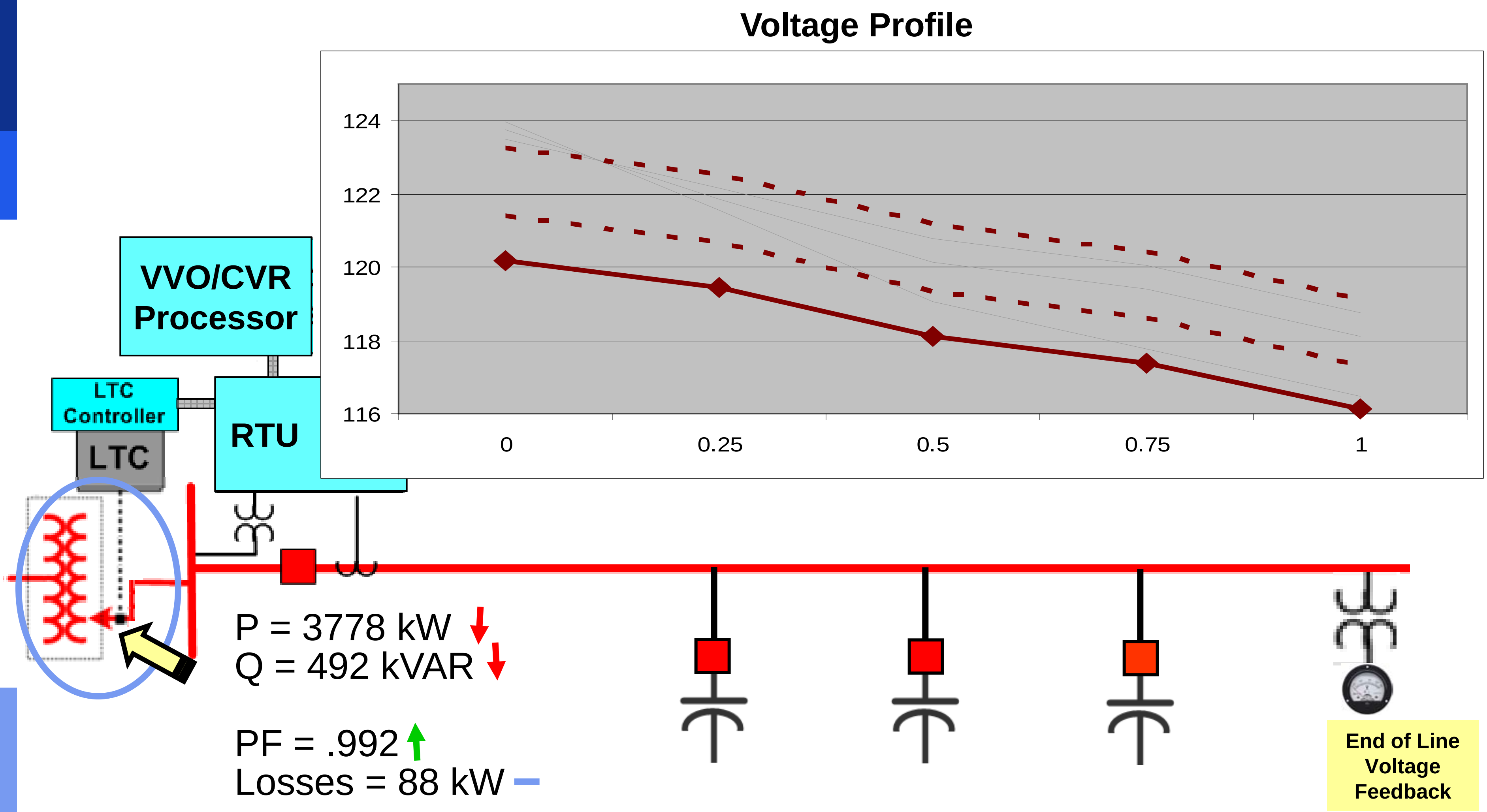
<u>Sample rule for voltage reduction:</u>

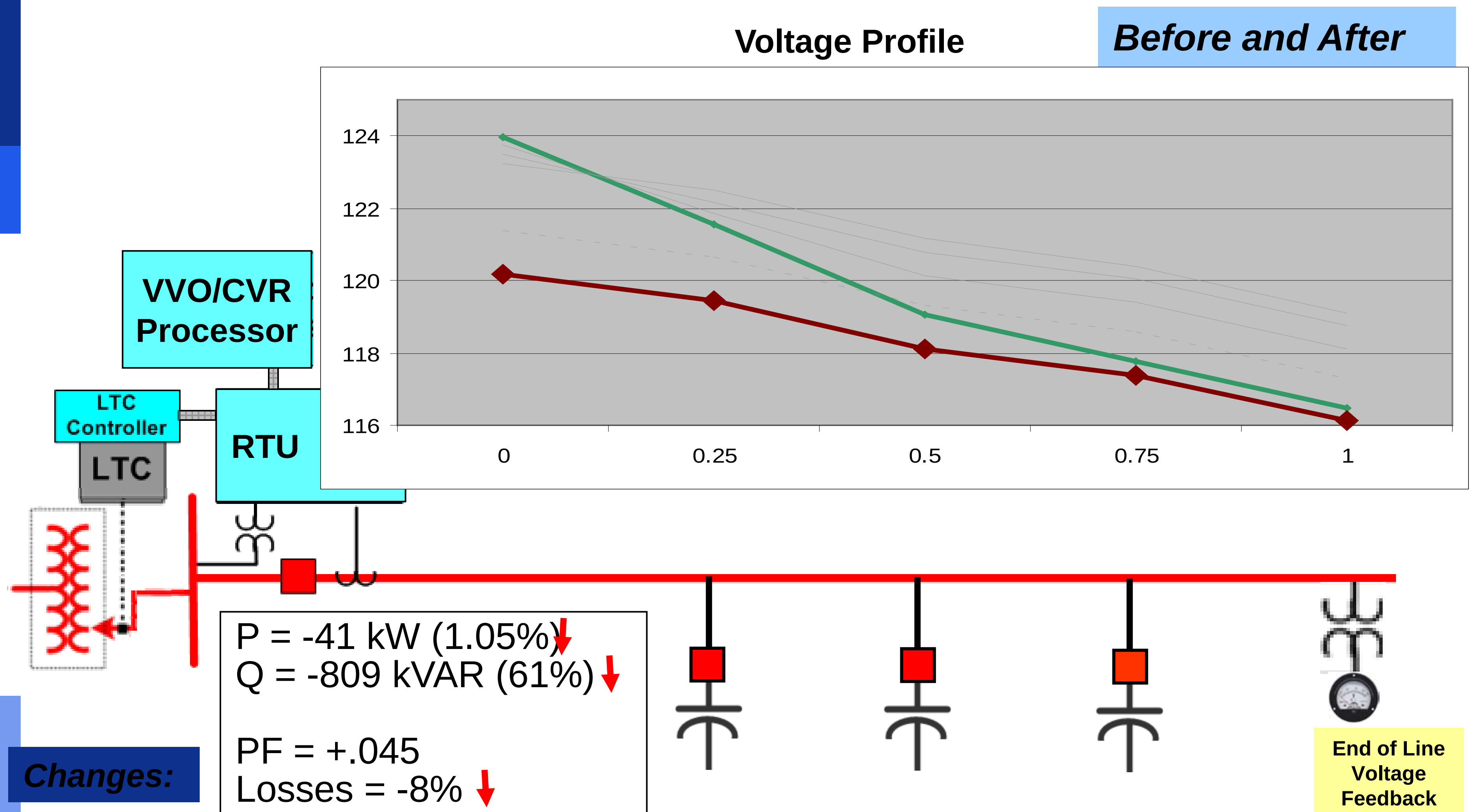
1. *If voltage at head end of the feeder exceeds LTC setpoint, then lower the voltage*


Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU


Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3898 kW
Q = 508 kVAR
PF = .992
Losses = 88 kW


Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3805 kW
Q = 508 kVAR
PF = .991
Losses = 88 kW
End of Line Voltage Feedback


Voltage Profile
124
122
120
118
116
0
0.25
0.5
0.75
1
VVO/CVR Processor
LTC Controller
LTC
RTU
P = 3778 kW
Q = 492 kVAR
PF = .992
Losses = 88 kW
End of Line Voltage Feedback



Changes:

P = -41 kW (1.05%)
Q = -809 kVAR (61%)

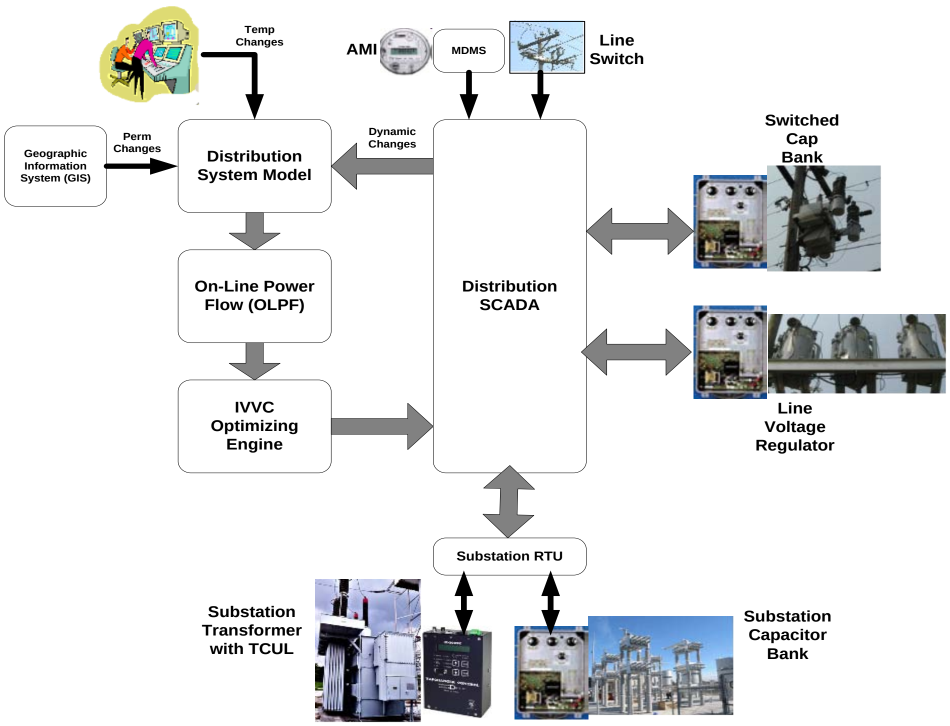
PF = +.045
Losses = -8%

DMS (Model Based) Volt-VAR Control and Optimization

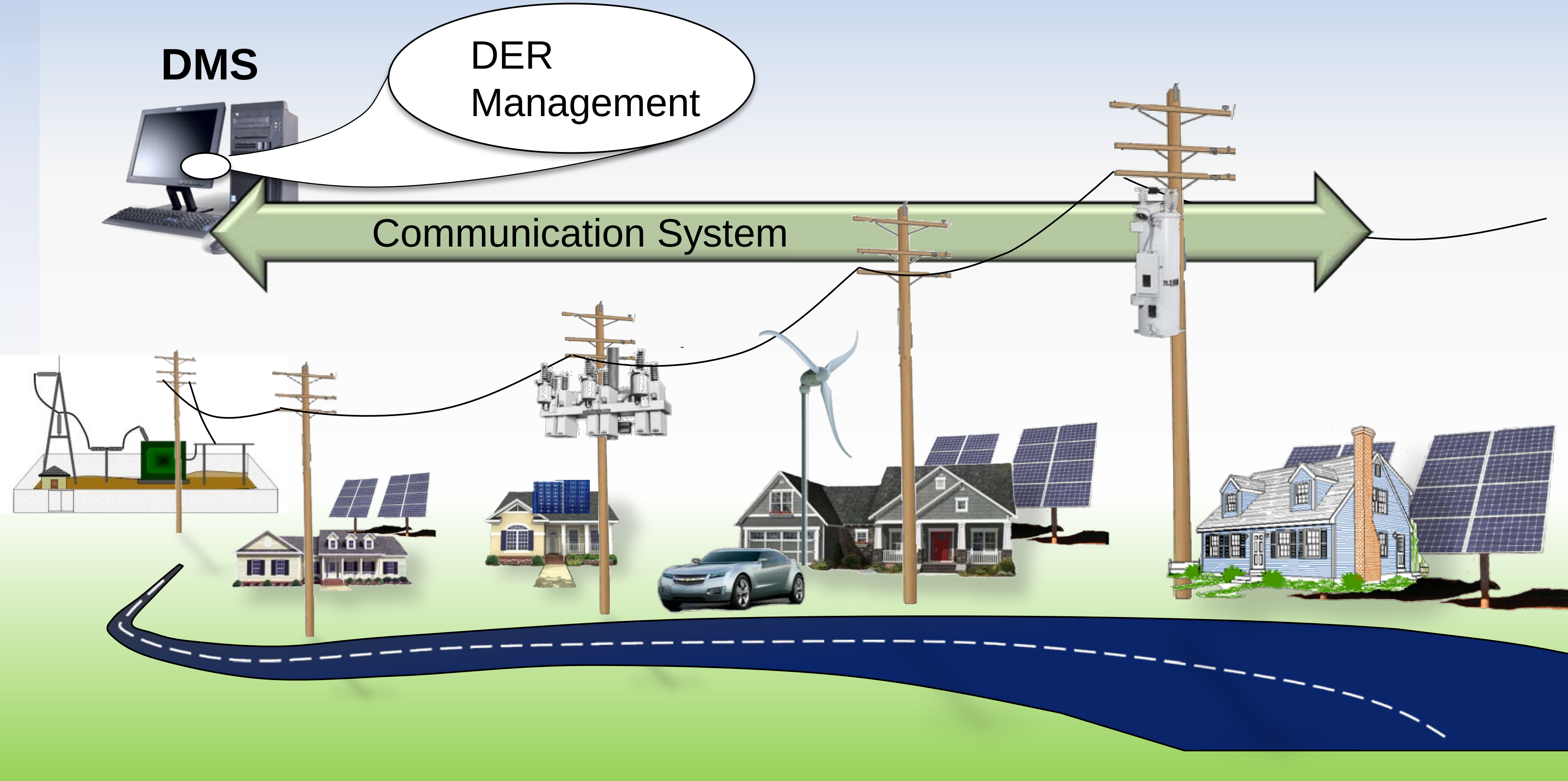
- Develops and executes a coordinated "optimal" switching plan for all voltage and VAR control devices
- DMS uses OLPF program to determine what actions to take
- Two Variations of the Model Driven Approach
  - Voltage Reduction – DMS version of Conservation Voltage Reduction
  - Volt VAR Optimization (VVO) – accomplishes one or more utility specified "objective functions

Volt-VAR Optimization

- Develops and executes a coordinated "optimal" switching plan for <u>all</u> voltage control devices to achieve utility-specified objective functions:
  - Minimize energy consumption
  - Minimize losses
  - Minimize power demand
  - Combination of the above
- Can bias the results to minimize tap changer movement
  - Reduce "wear and tear" on the physical equipment



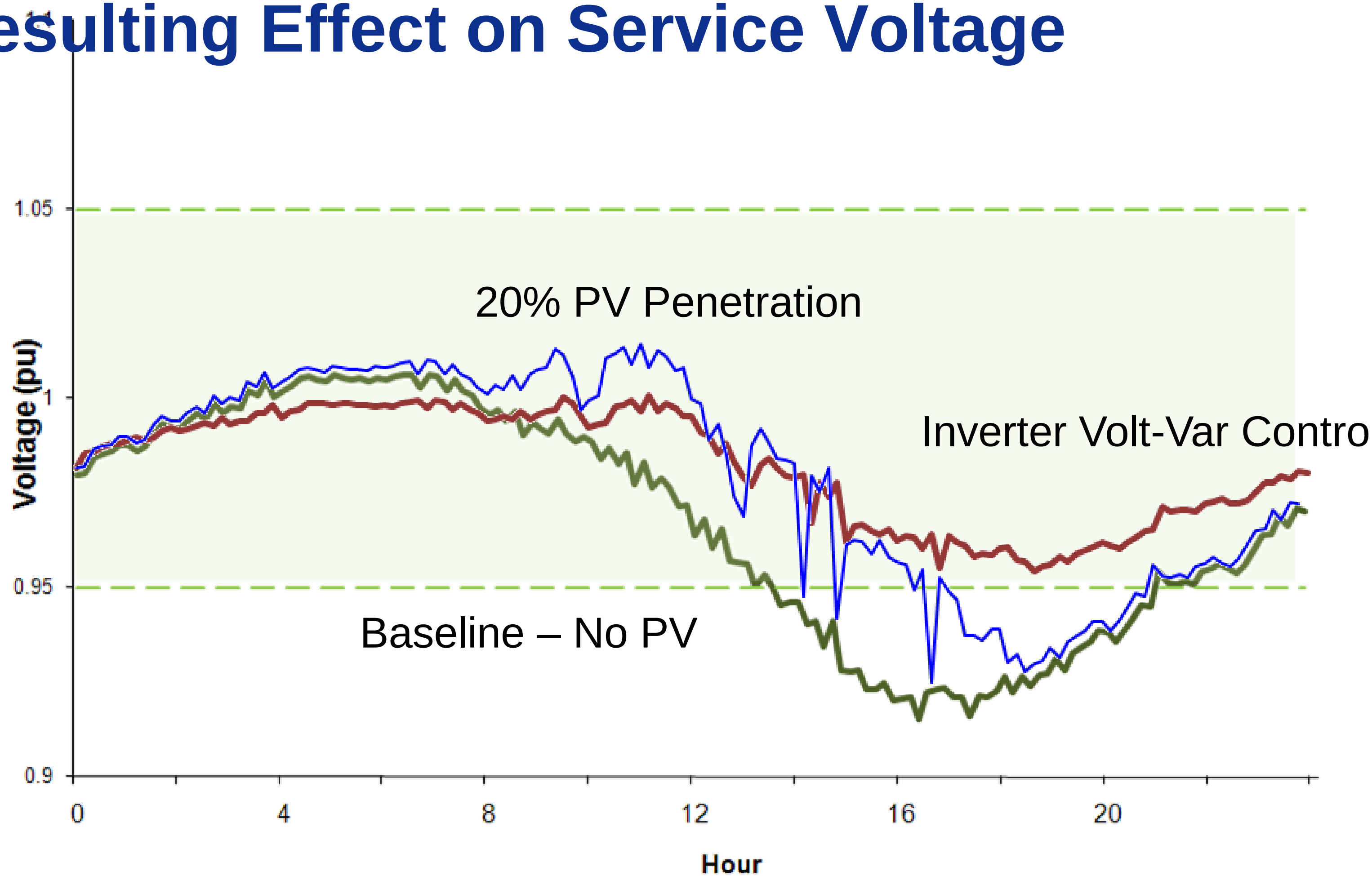
Growing Need for Dynamic Volt-Var Control



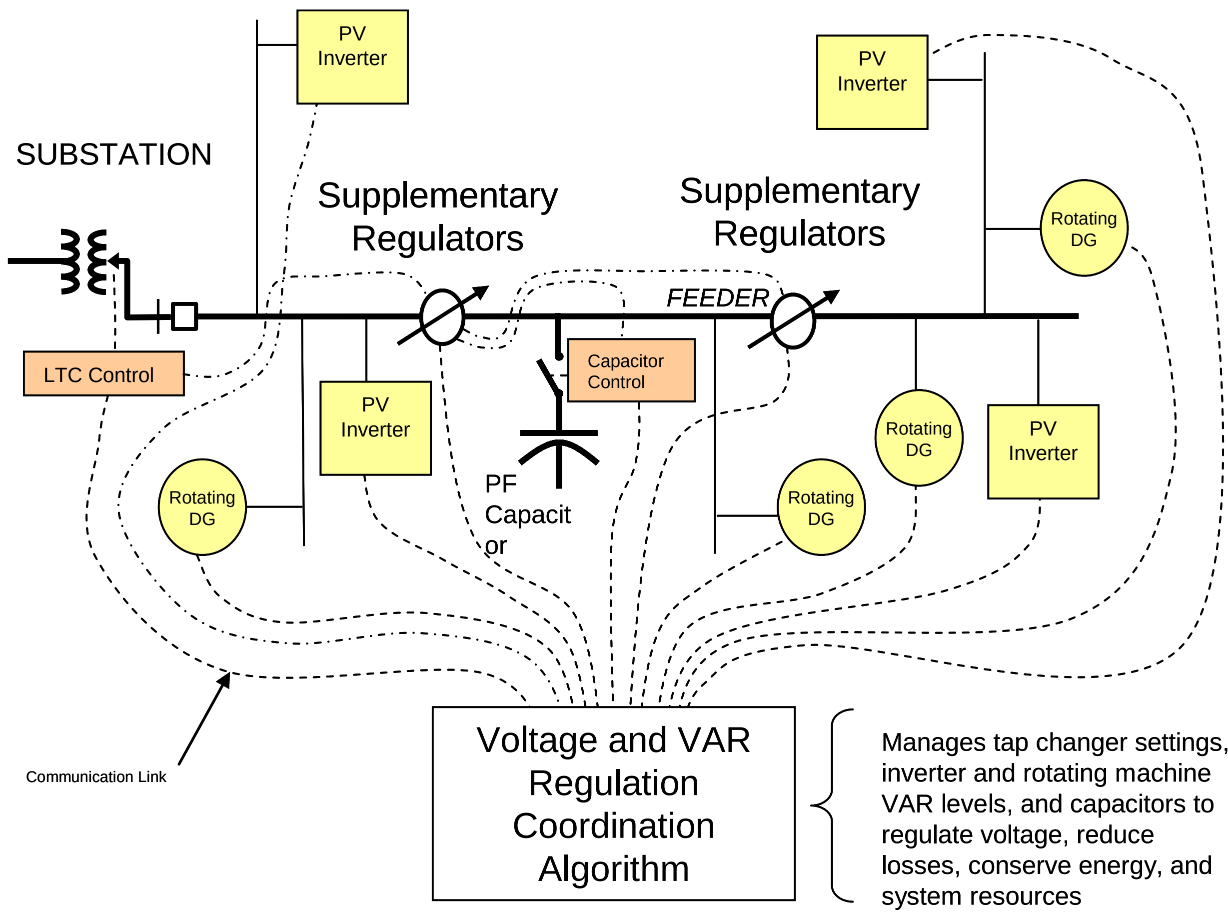
Power Inverters – What Could They Do?

- Produce Intelligent Vars – varying with voltage, temperature, and schedule
- Intelligently Employ Battery Storage – shifting to peak and controlling ramp rates
- Manage Peak Power – reducing generation when voltage is high
- Respond dynamically to variations in voltage or frequency, for system stabilization
- Provide voltage sag support – riding through events as configured
- Islanding – intentionally when desired, avoiding unintentional islanding
- Monitoring – power, energy, status, events

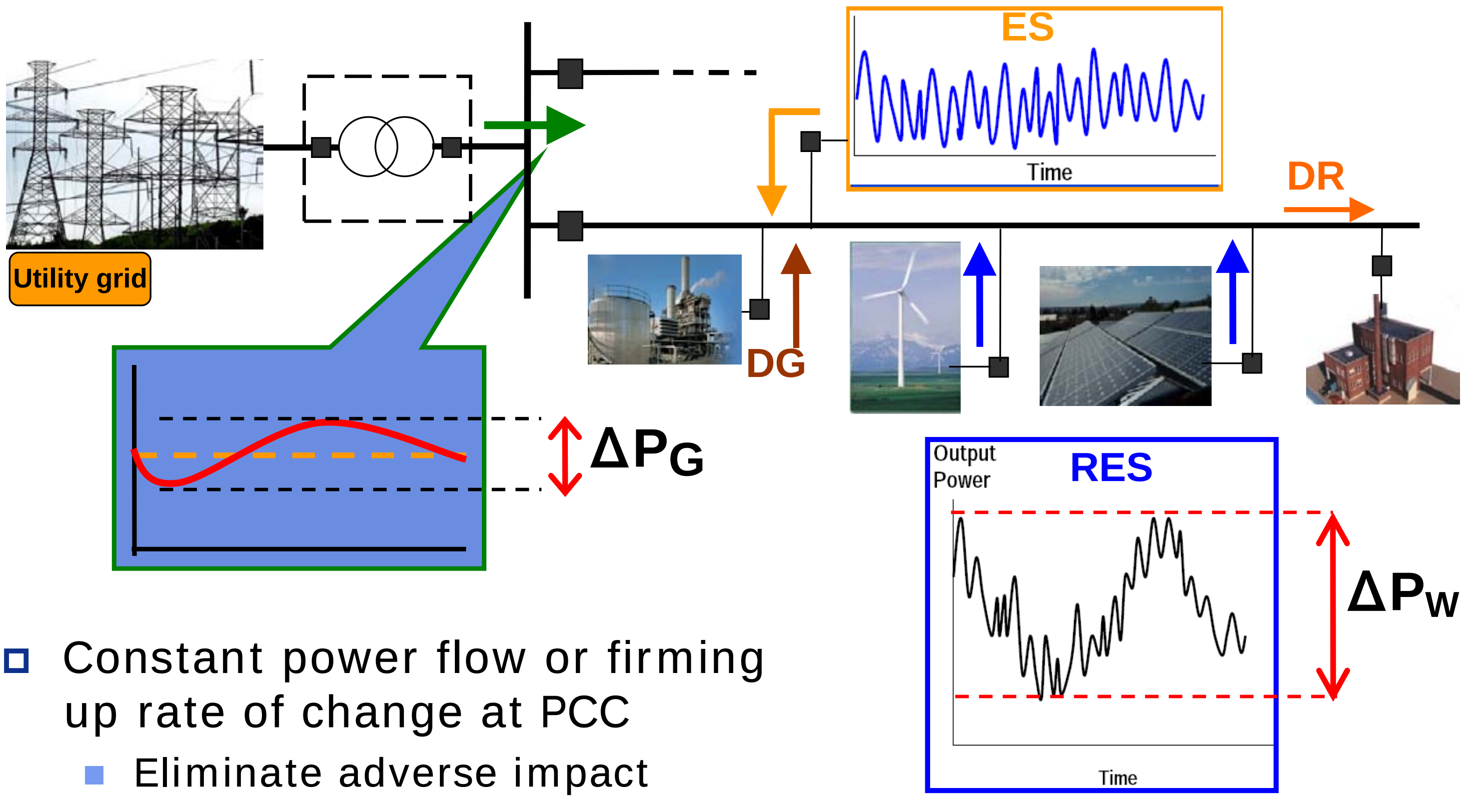
Resulting Effect on Service Voltage



Volt VAR Optimization – Next Steps



Feeder Flow and Resource Control (DG+ES)



- Constant power flow or firming up rate of change at PCC
  - Eliminate adverse impact
  - Reduce reserve capacity requirement

Together…Shaping the Future of Electricity

Frankfurt (Germany), 6-9 June 2011

Hydro-Québec Smart Grid

Christian Perreault and Georges Simard

Smart Distribution Systems
for a Low Carbon Energy Future Workshop

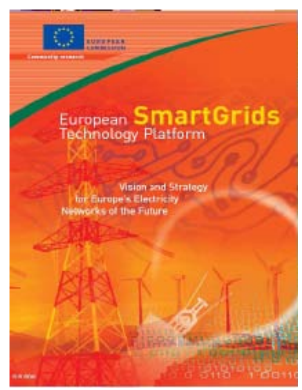
6 June 2011

Outline

- Distribution System Roadmap
  - Smart Grid Framework
  - Smart Grid Project
- Smart Grid Zone
  - Description
  - Benefits
  - Technologies
- Smart Distribution Systems and GHG
- Conclusion

2010 World Benchmark and Smart Grid Drivers

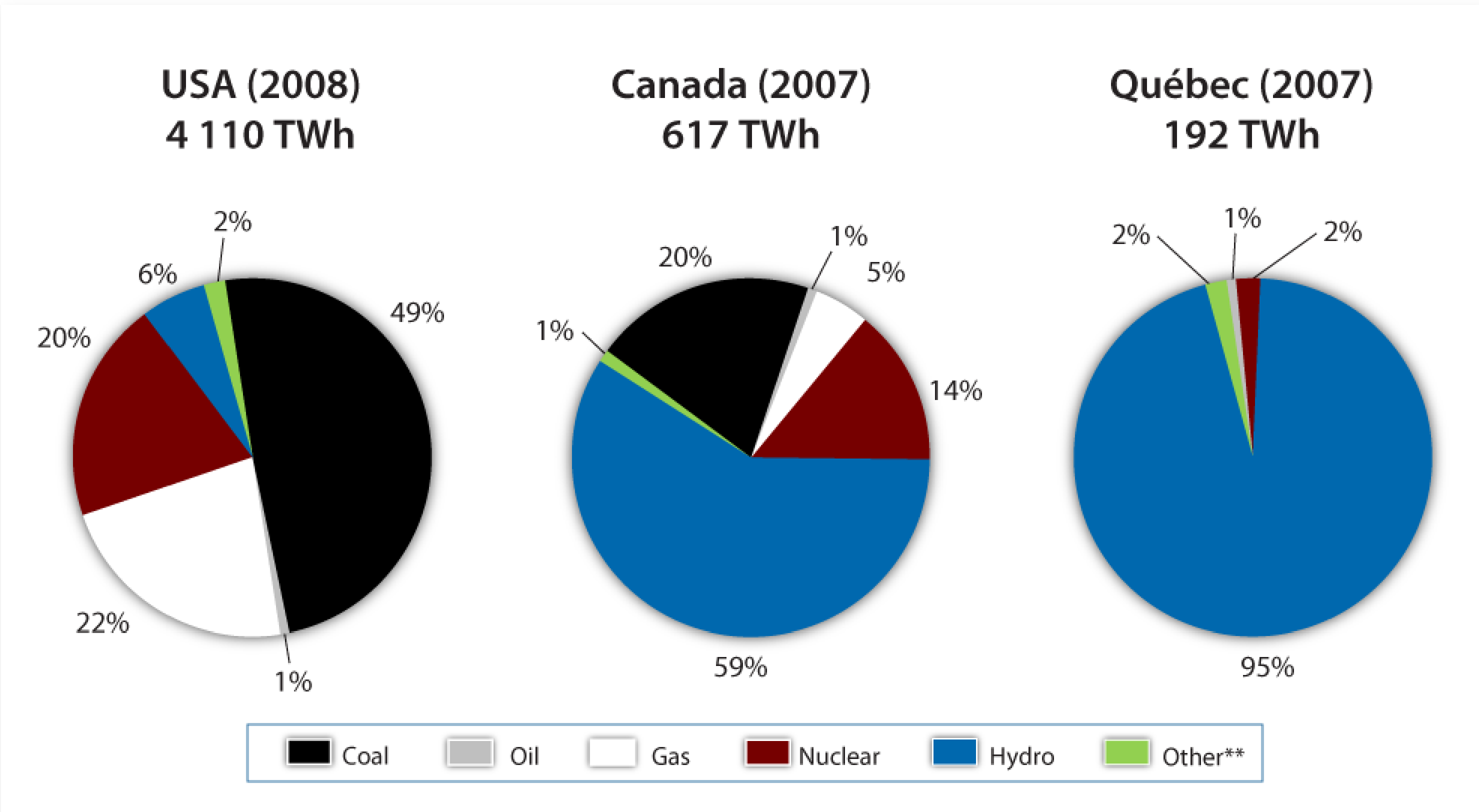
	Europe	U.S.	Canada
Availability of energy	x	x	x
Control of peak power	x	x	x
Political targets for green energy (distributed generation)	x		Ontario British Columbia



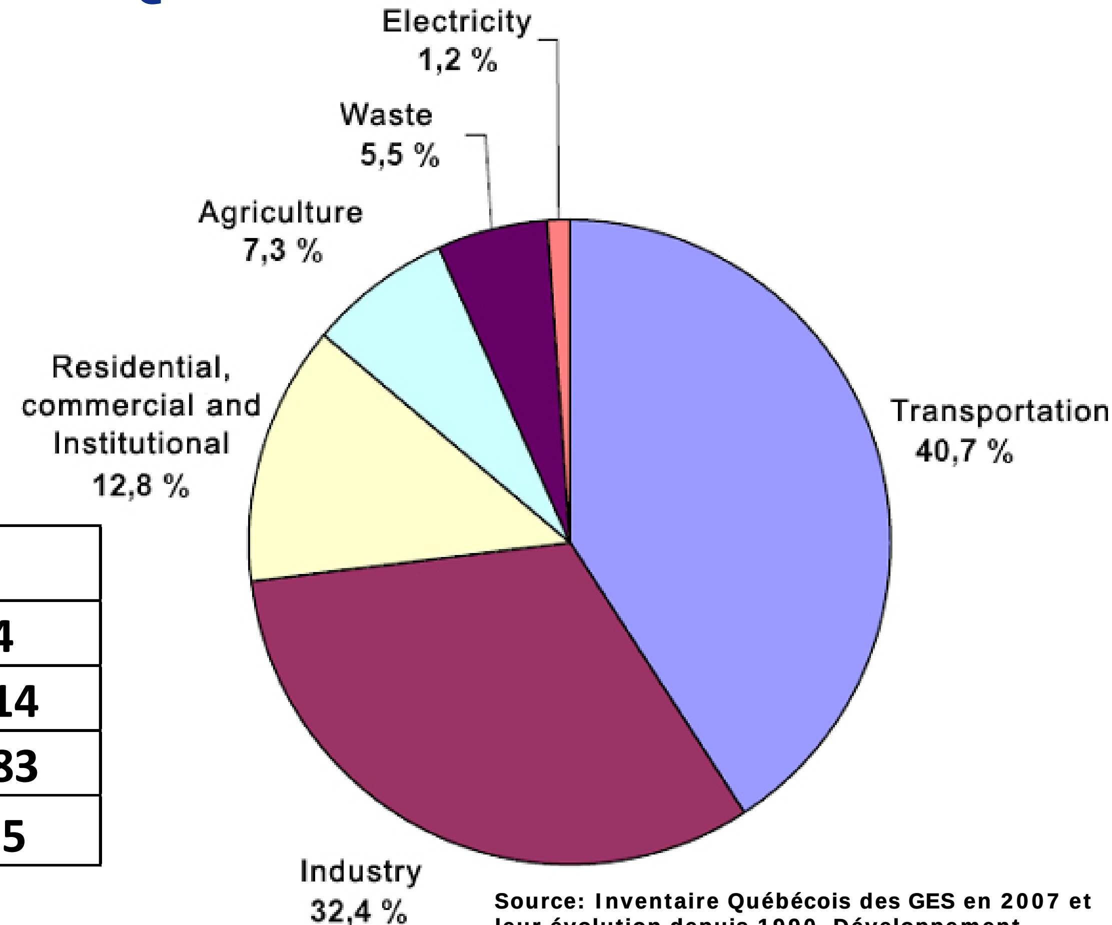
Snapshot of Hydro-Québec

- Hydro-Québec is one of the largest power generator in North America.
- Hydro-Québec is among the largest power transmission companies in North America. (>16B$ in transmission assets)
- Hydro-Québec is the largest electricity company in Canada.
- Hydro-Québec is the number one hydroelectricity producer in the world.

Comparison of Energy Options in North America



Breakdown of GHG in Québec in 2007



Emission factor (tCO_2e/GWh)	
Quebec	2,04
Ontario	161,14
Alberta	886,83
British-Columbia	15,15

Source: Rapport d'inventaire national 2008, Environnement Canada 2010.

Source: Inventaire Québécois des GES en 2007 et leur évolution depuis 1990, Développement durable, Environnement et Parcs, déc. 2009.

2010 Quebec Context

- **Energy**
  - Potential and available hydropower vs. fossil fuels
  - Relatively low cost of energy (6.88¢/kWh)
  - Robust distribution system
    - Electrically: Designed for electric heating (more than 75% of residential customers)
    - Mechanically: Certain areas strengthened following the 1998 ice storm
- **Customers**
  - High level of customer satisfaction (≈ 8/10)
  - In Québec, the peak is associated with electric heating in winter (longer period, hours/days)
- **Social context**
- **Regulatory context**

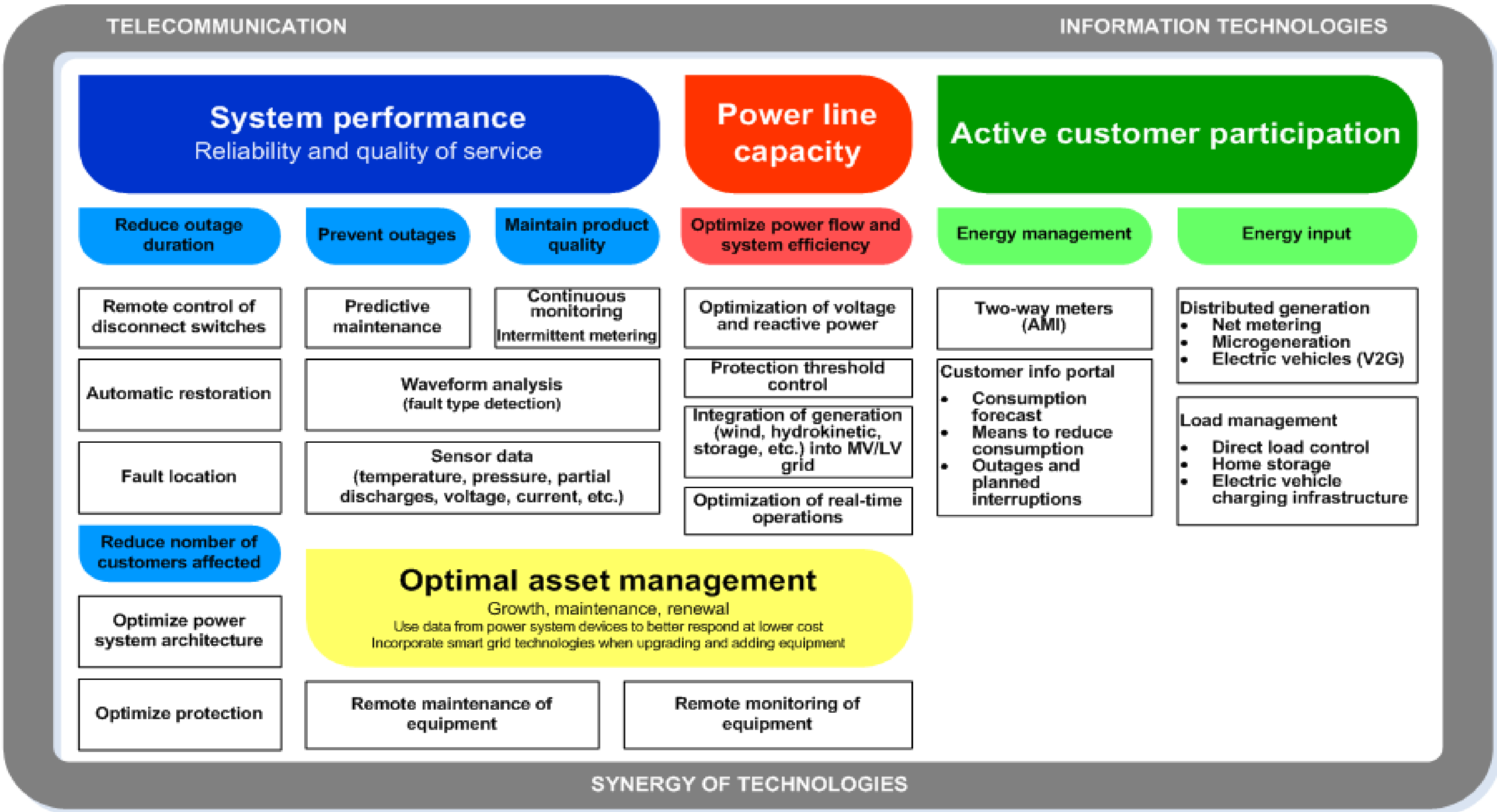
- **Priorities set out by Hydro-Québec's CEO at the World Energy Congress (September 12 to 16, 2010):**
  - Renewable energy
  - Electric mobility
  - Interactive transmission and distribution systems

CME | WEC MONTRÉAL 2010

HQD Orientations and Strategies Related to the Smart Grid

- Ensure the quality of customer services
  - **Improve overall reliability of the distribution system**
- Step up energy efficiency efforts
  - **Save 11 TWh of energy in 2015**
  - **Promote efficient, sustainable use of electricity**
- Meet electricity needs in a flexible manner
  - **Manage electricity supplies optimally**
- Further enhance the division’s performance
  - **Continue to improve efficiency**
  - **Focus on technological innovation**

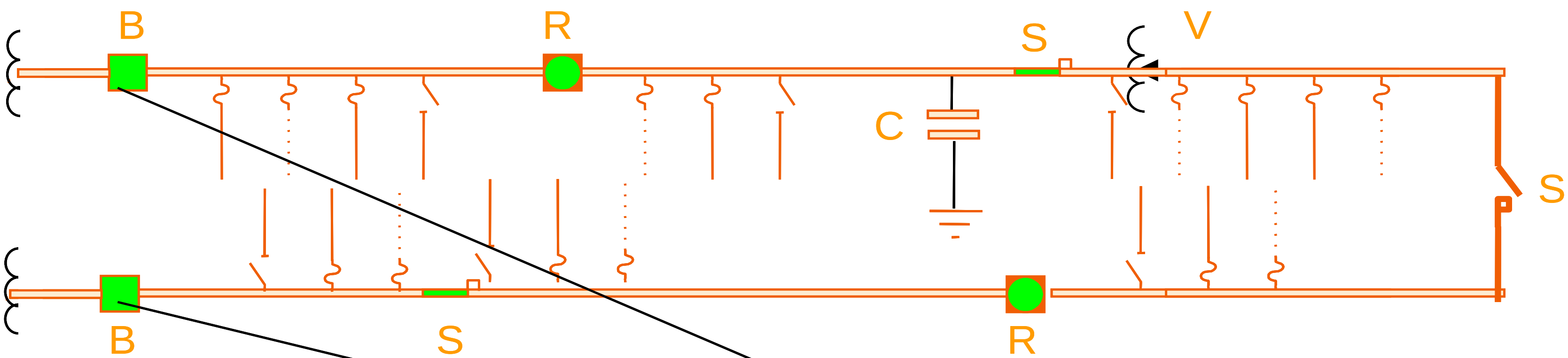
Hydro-Québec Smart Grid Framework



Distribution Smart Grid Roadmap

Hydro-Québec Smart Grid – Smart Distribution Systems Workshop

Conventional Distribution System



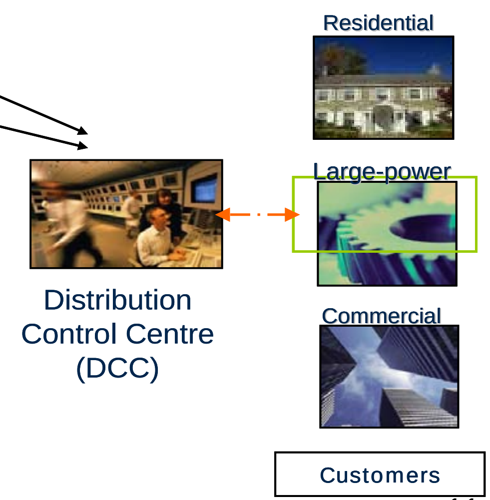
B – Breaker

R – Breaker-recloser

S – Switch

C – Capacitor

V – Voltage regulator



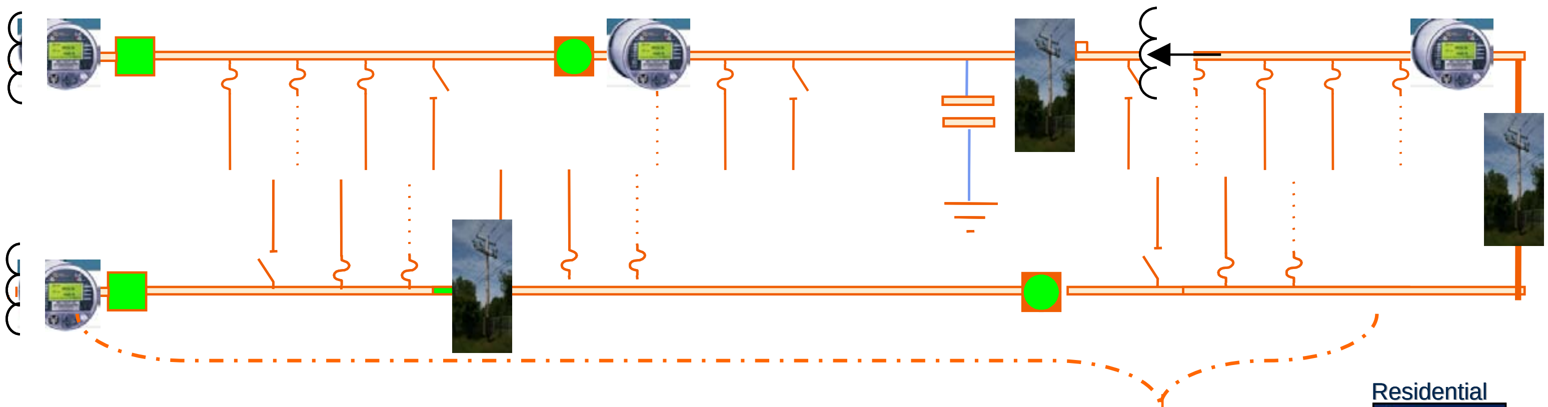
Grid performance limited by:

- Little real-time information
- High safety margins

Projects to Enhance System Performance

(Reliability and Quality of Service)

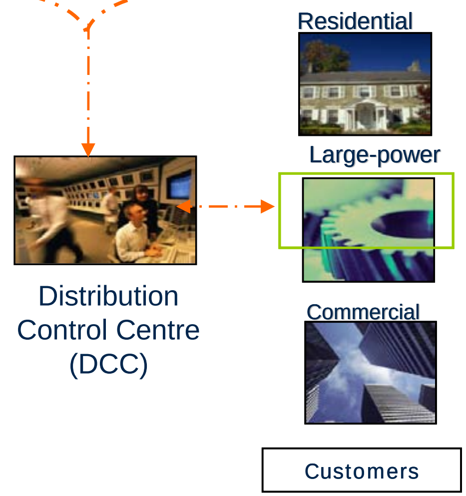
System Performance
Reliability and quality of service



Reduce outage duration
- Distribution system automation project
- Sectionalizers (advanced protection)
- Automatic restoration

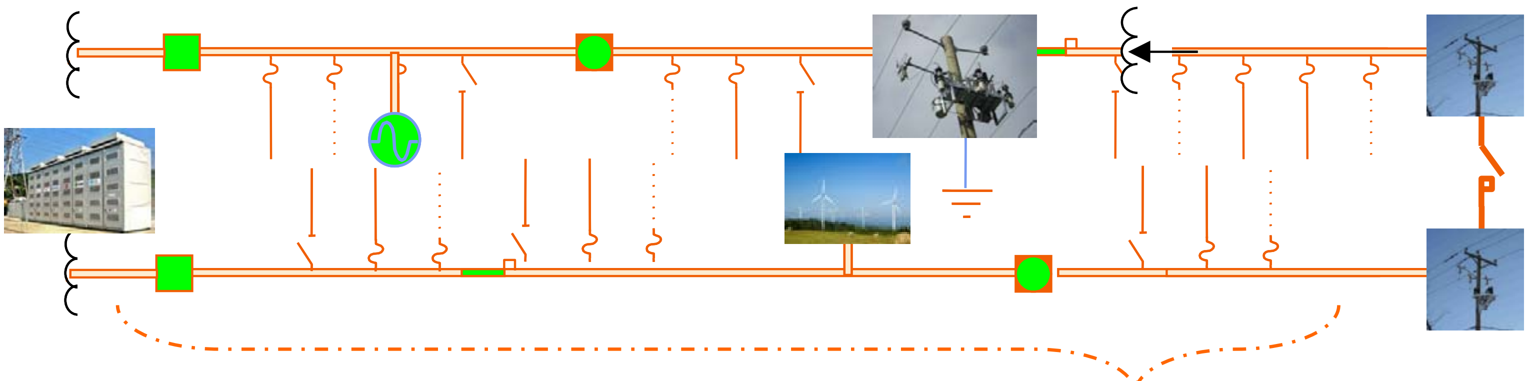
Prevent outages
- Fault location
- Waveform analysis to enhance system performance

Maintain product quality
- Voltage quality monitors
- Probes and sensors



Projects to Increase Power Line Capacity

Power Line Capacity

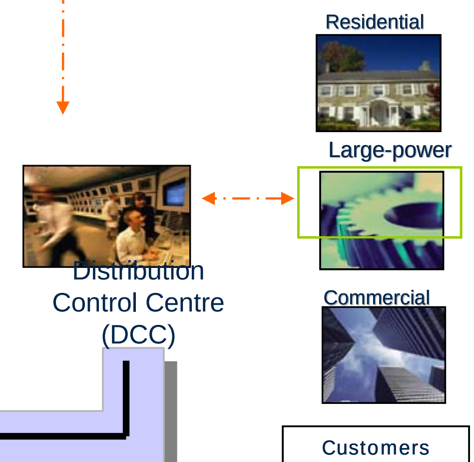


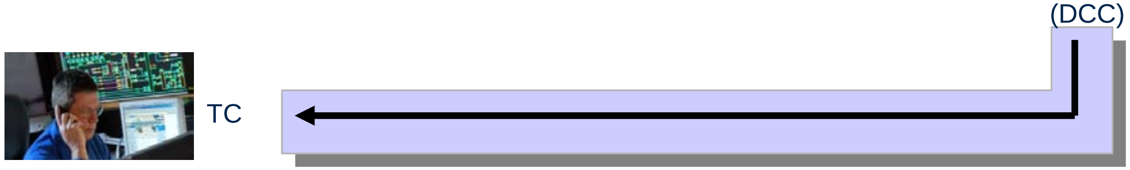
Optimize power flow and system efficiency

– Voltage regulation and reactive power control (CATVAR), including the installation of 1,000 Mvar of capacitors

Locally accessible energy

– Distributed generation
  Distribution connected to the medium-voltage grid
– Medium-voltage (MV) storage

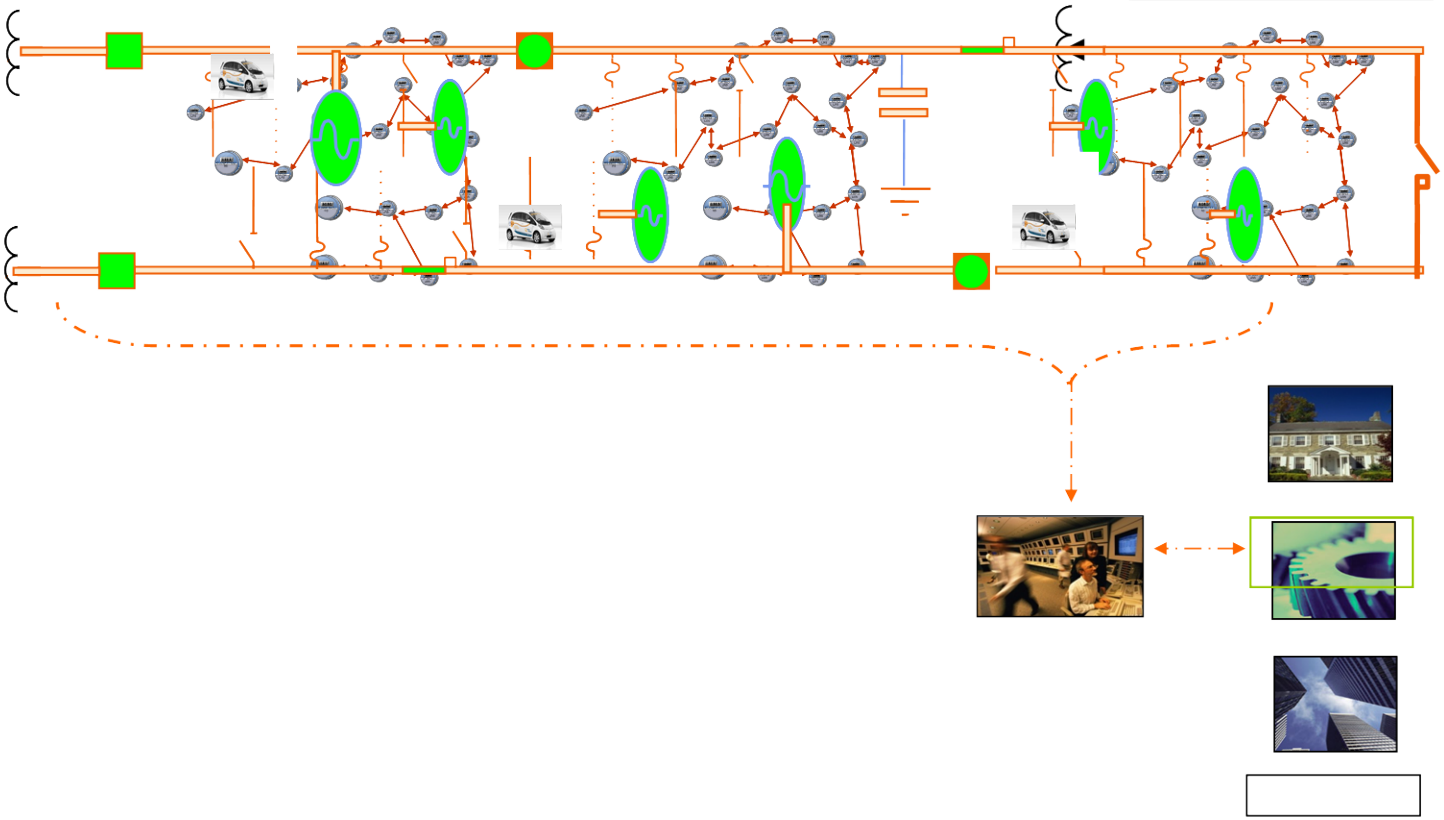




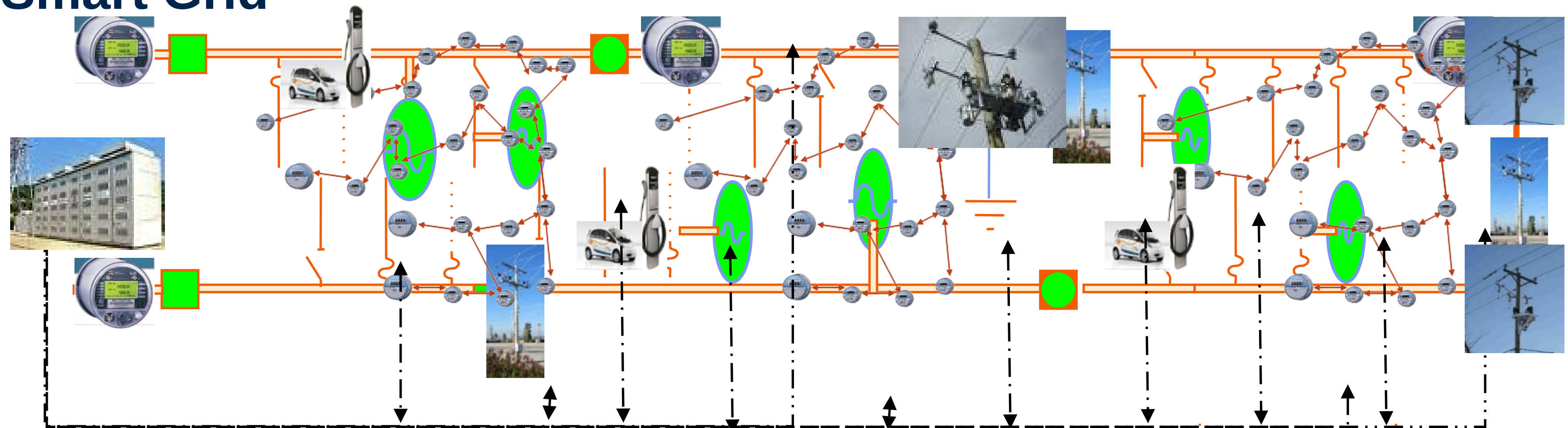
1 Hydro-Québec

Projects Involving Active Customer Participation

Active Customer Participation

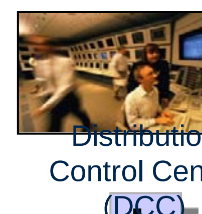


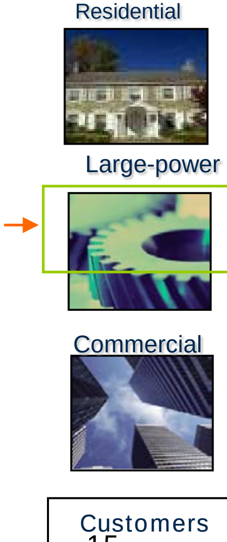
Smart Grid



Integrated architecture

Distribution system integrating sensor technologies, communications and data processing to achieve our objectives at the lowest possible cost.





TC

Hydro-Québec Smart Grid – Smart Distribution Systems Workshop

Major Challenges in Smart Grid Implementation

TELECOMMUNICATIONS

INFORMATION TECHNOLOGY

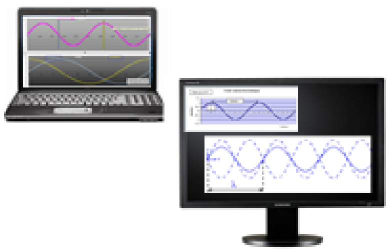
Smart grid

1. Telecommunications infrastructure
2. Information technology
3. Standardization in the field
4. Management of equipment-grid interaction

SYNERGY OF TECHNOLOGIES

Approach to Validating Technology

Testing facilities



IT Environment
- Simulators
- Offline database
- Real-time data access

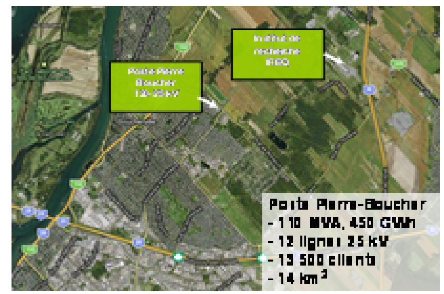
Site for concept development:
- Algorithm testing
- Power system simulation
- Leveraging of historial data
- Scenario playback
- Calculating gain
- Data quality assessment

Labs Test lines (IREQ)

Labs with metering equipment
Lines with typical grid equipment

Site for establishing proof of concept:
- Equipement testing
- Interoperability testing
- Equipment certification testing

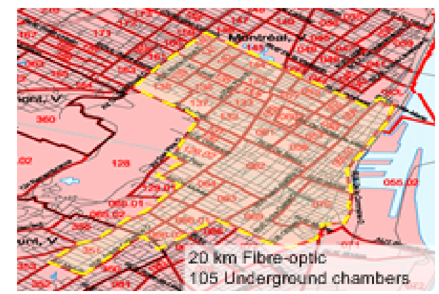
SGZ Smart grid zone (Boucherville)



Why Pierre-Boucher substation?
- Typical substation near IREQ
- Test site: BPL, CATVAR, etc.

Demonstration site for:
- Fault location
- Automatic restoration
- Advanced protection (automatic disconnect switches)
- Electric vehicle charging infrastructure
- Load control (smart meters)
- Energy storage (MV and quick-charge stations)
- Distributed generation (solar concentrator
- Wireless telecommunications (WiMax, etc.)

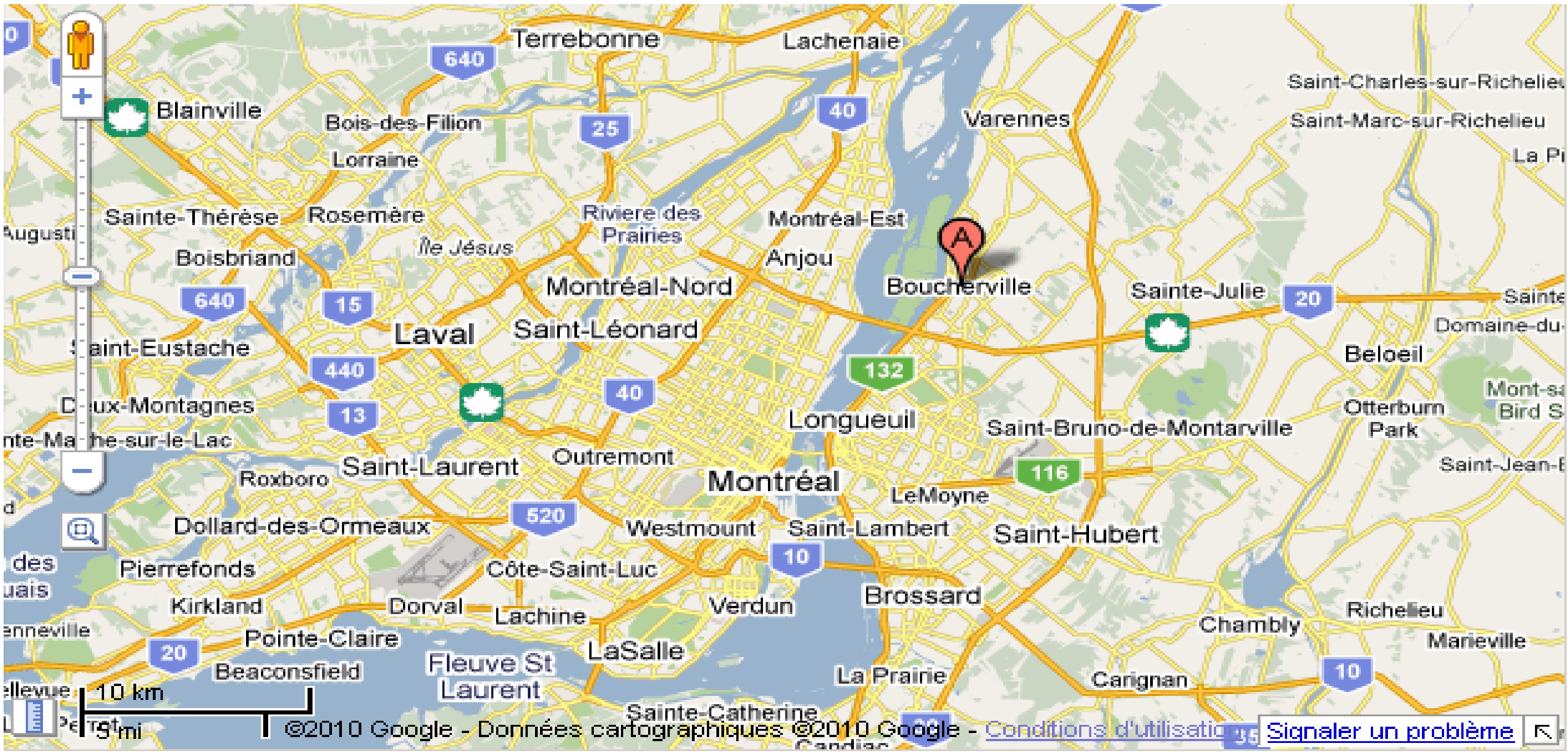
Fibre-optic network (Downtown Montréal)



Fibre-optic network
- Connecting underground chambers in the high-density economic zone

Demonstration site for:
- Remote monitoring of the grid
- Remote maintenance of equipment
- Telecommunications with intelligent underground chambers

Hydro-Québec Smart Grid Zone

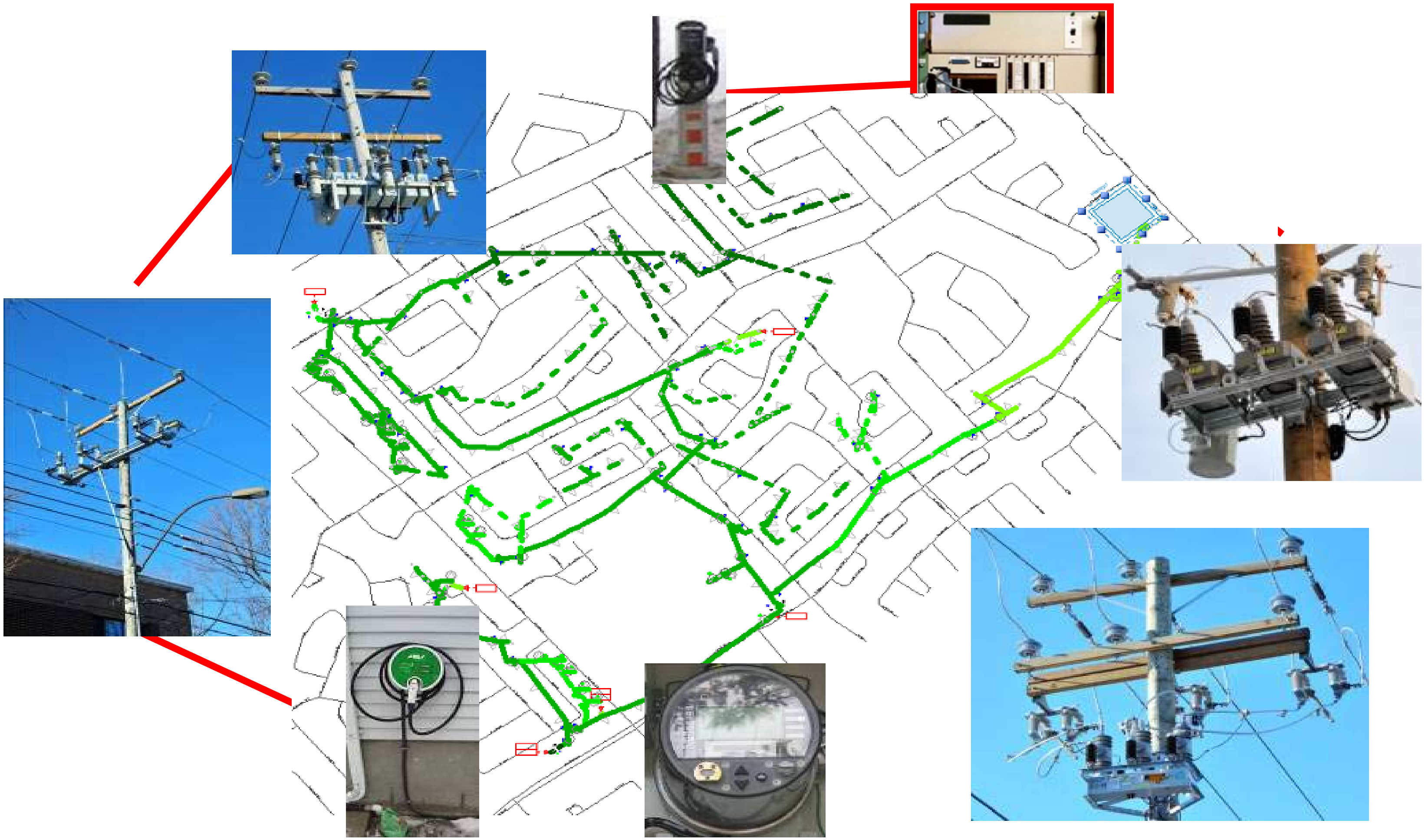


Hydro-Québec Smart Grid Zone

- **1 substation**
- **12 feeders**
  - most sections overhead
  - averaging 10 km
- **Consumption**
  - 110 MW (peak)
  - 450 GWh (annual)
- **13 500 clients, mixed load**
  - Residential
  - Commercial
  - Industrial
- **Not a preliminary test lab**

Smart Grid Zone Technologies

Smart Grid Zone Technologies



Smart Grid Zone – Future Development

- Automatic reconfiguration
- Energy Storage
  - Substation
  - Storage for plug-in terminals
- Vehicle to grid

Benefits of the Smart Grid Zone

- **Expertise**
  - Smart grid technologies
  - Monitoring, information and control, with telecom and centralized control
  - Integration with existing systems
  - Multiple Smart Grid applications operating in parallel
- **Risk management**
  - Lessons learned resulting from testing of new applications
  - Identify potential problems before large scale deployment
- **Energy Conservation**
  - Quantification of the reduction in energy consumption
- **Greenhouse gas reduction**
  - Detailed GHG reduction analysis for the Clean Energy Fund component

Smart Distribution Systems and GHG

- 4 smart rid projects that reduced GHG
  - CATVAR (Volt and Var optimization)
  - EV Charging station
  - AMI
  - Renewable Energy Integration

CATVAR (Volt and Var Optimization)

Outline :

- CATVAR is under development since 2006 in the smart zone
- Voltage monitoring stations and remote controlled capacitors banks has been installed
- VVC functions are integrated into the DMS and the system has been in operation since November 2008
- Energy saving has been confirmed (CVR = 0,4)

Objectives :

- Advanced Volt&Var Optimization (increased energy reduction)
- Var optimization with real time data exchange between Transmission and Distribution systems (increased loss reduction)
- Integration of other voltages and currents measurements (better precision leads to an increased energy reduction)

CATVAR - Deployment Between 2010 to 2015

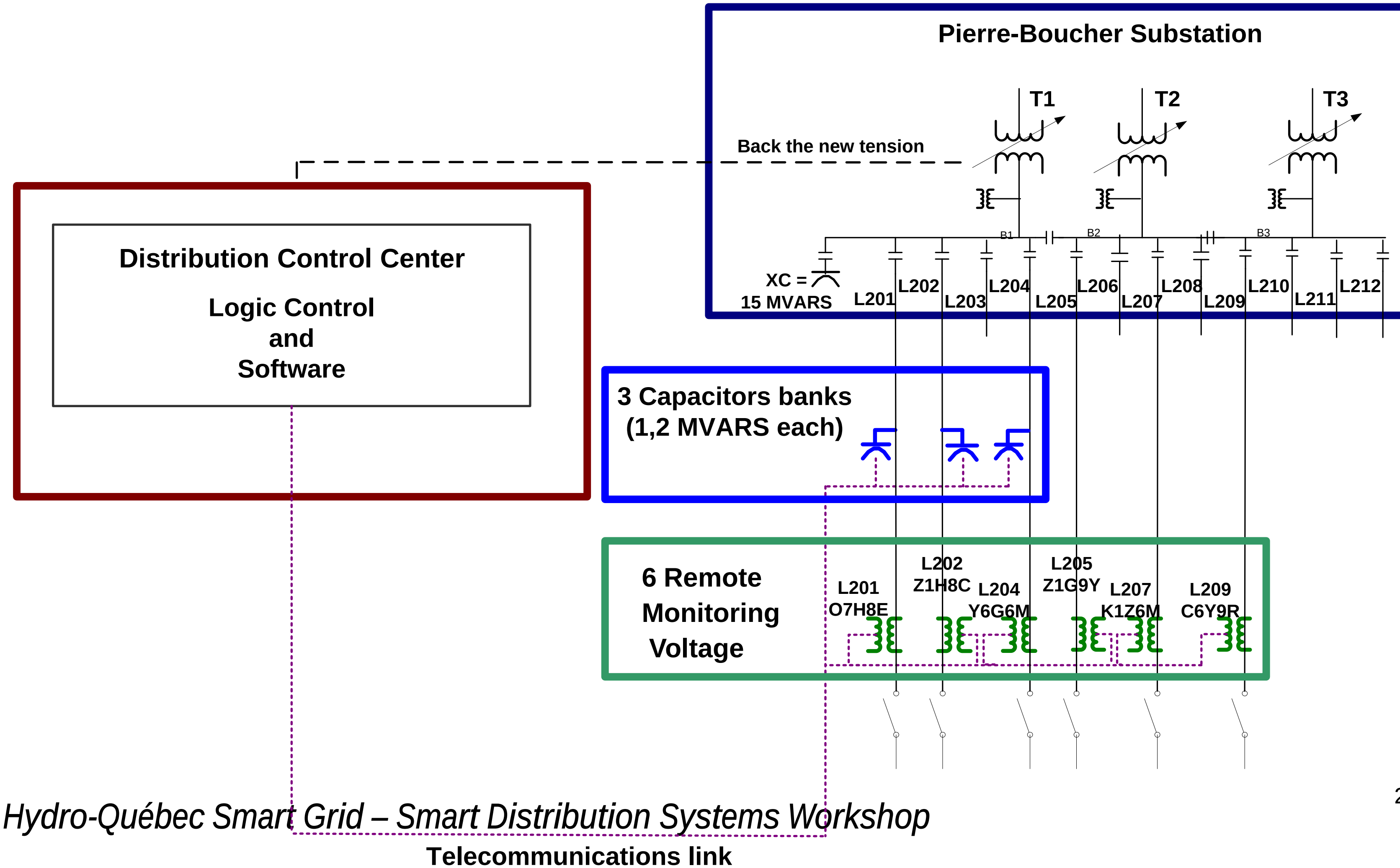
Deployment in numbers

- 130 Substations
- 2000 Medium voltage feeders
- 1000 Remote voltage monitoring stations
- 800 Remote controlled capacitors banks
- 200 M$ in investments

And the benefits will be…

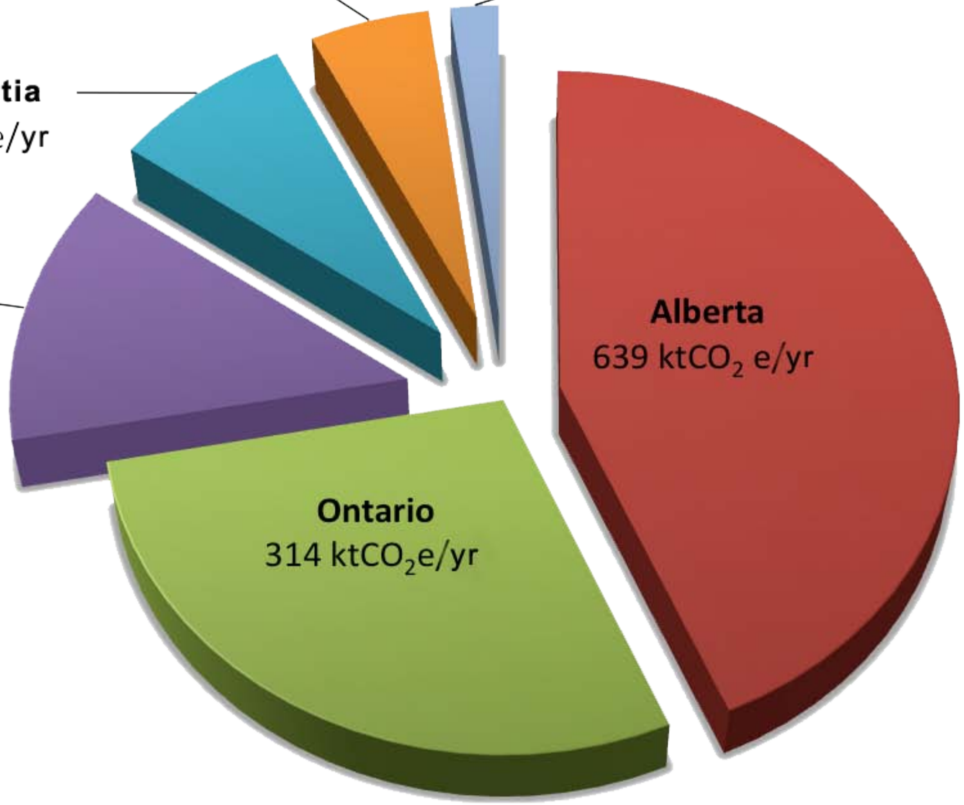
- 2.0 TWh in annual energy saving (1,7%)
- Equivalent of 1,7% reduction of CO_2 emissions

CATVAR (VVO) - Description



GHG Reduction with CATVAR

In Canada (projection)



Total Canada:

1 365 $ktCO_2e/yr$

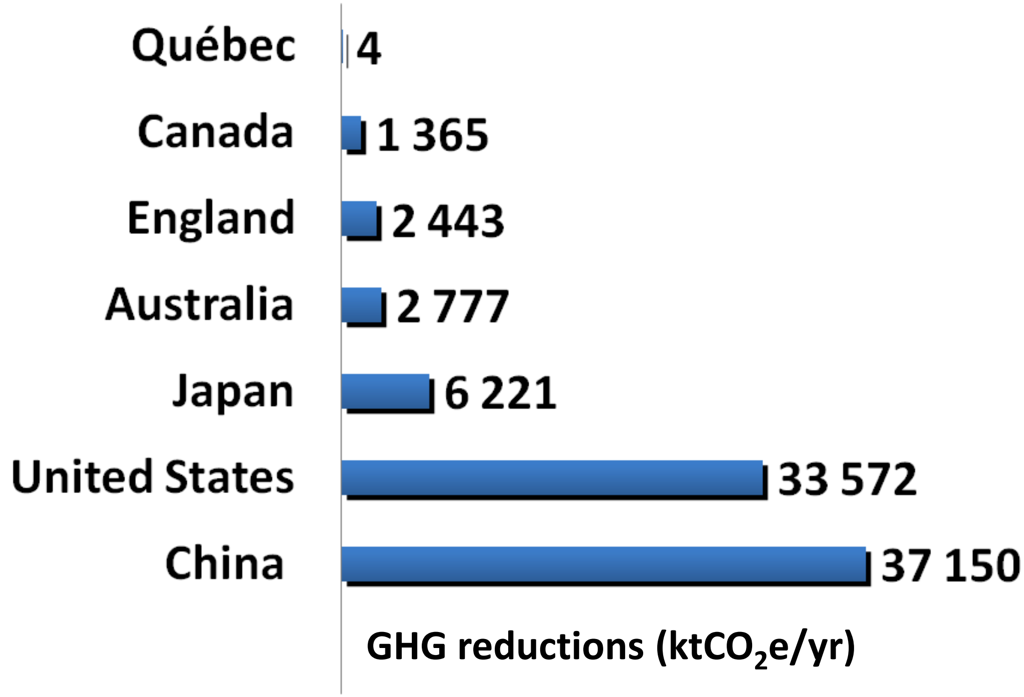
(or 400 000 cars)

Note: Based on a 3,4 tCO2e per vehicle emission ratio from the Energy Efficiency Office of Natural Resources Canada

Note: calculation based on emission factors taken from the Rapport d'inventaire national 2008 by Environment Canada, of a reduction in consumption of 1,7% applied to 2/3 of electricity consumption per province.

GHG Reduction with CATVAR

International (projection)



Breakdown of GHG reductions associated with Implementing CATVAR on an international scale

29

Electric Vehicle Charging Stations

- **Charging station infrastructure (test phase)**
  - Our goal is to master charging station technology and agree on how such stations are to be integrated into the power system.
- **Approach: Target for late 2012**
  - In the Boucherville smart grid project zone, deployment of 75 charging stations for the Mitsubishi iMiev.
  - In Communauto parking lots, installation of 50 charging stations for the Nissan Leaf.

Electric Vehicle Charging Stations Infrastructure

Public Installation
(Boucherville Town Hall)

Residential Installation

Commercial Installation

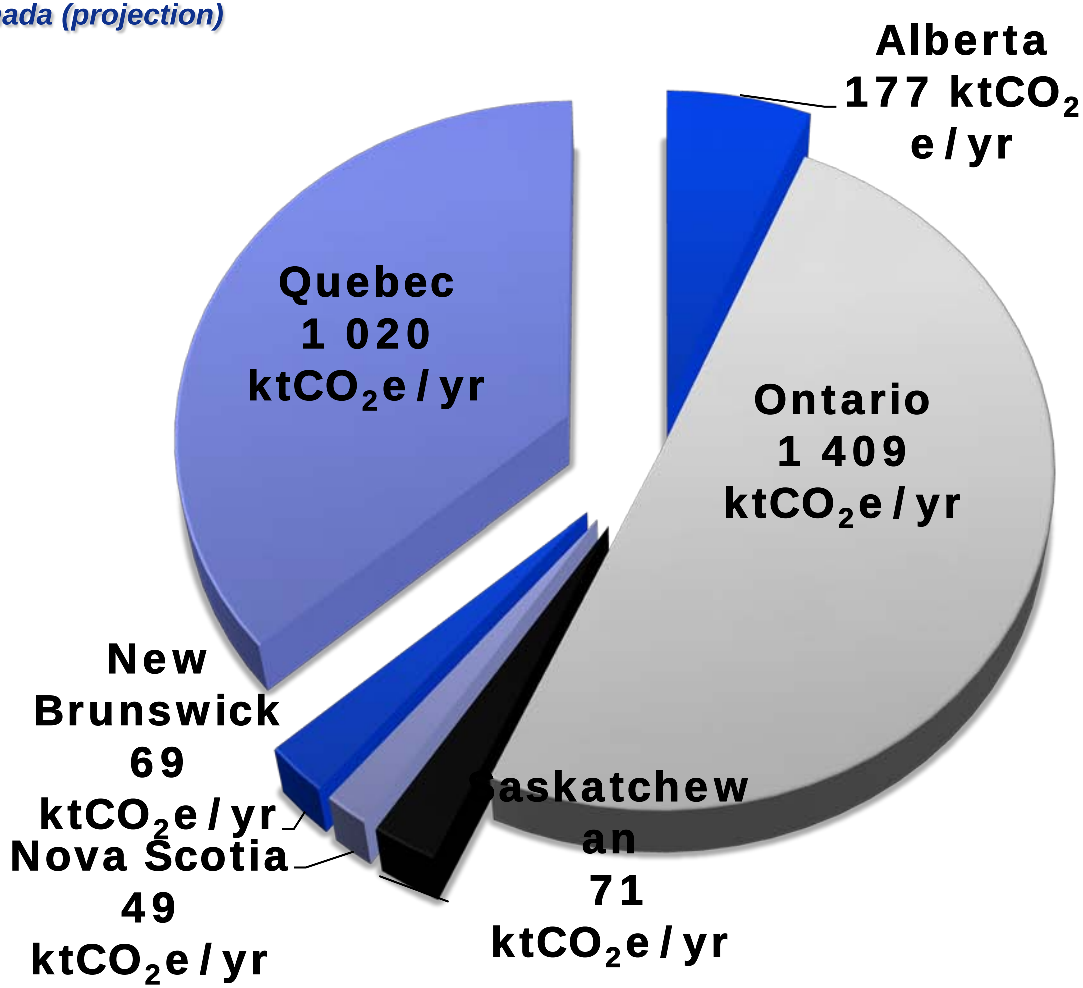
GHG Reduction with EV Charging Station

- The implantation of electric charging stations in Quebec will rise consumption by 750 GWh, but leading to an overall reduction of 1 020 ktCO_2e in GHG in 2020.

- By applying this measure to Canadian electricity enterprises, GHG emissions can be appreciably reduced in Canada and limit GHG emissions from the transportation sector.

GHG Reduction with EV charging station

In Canada (projection)



Total Canada:

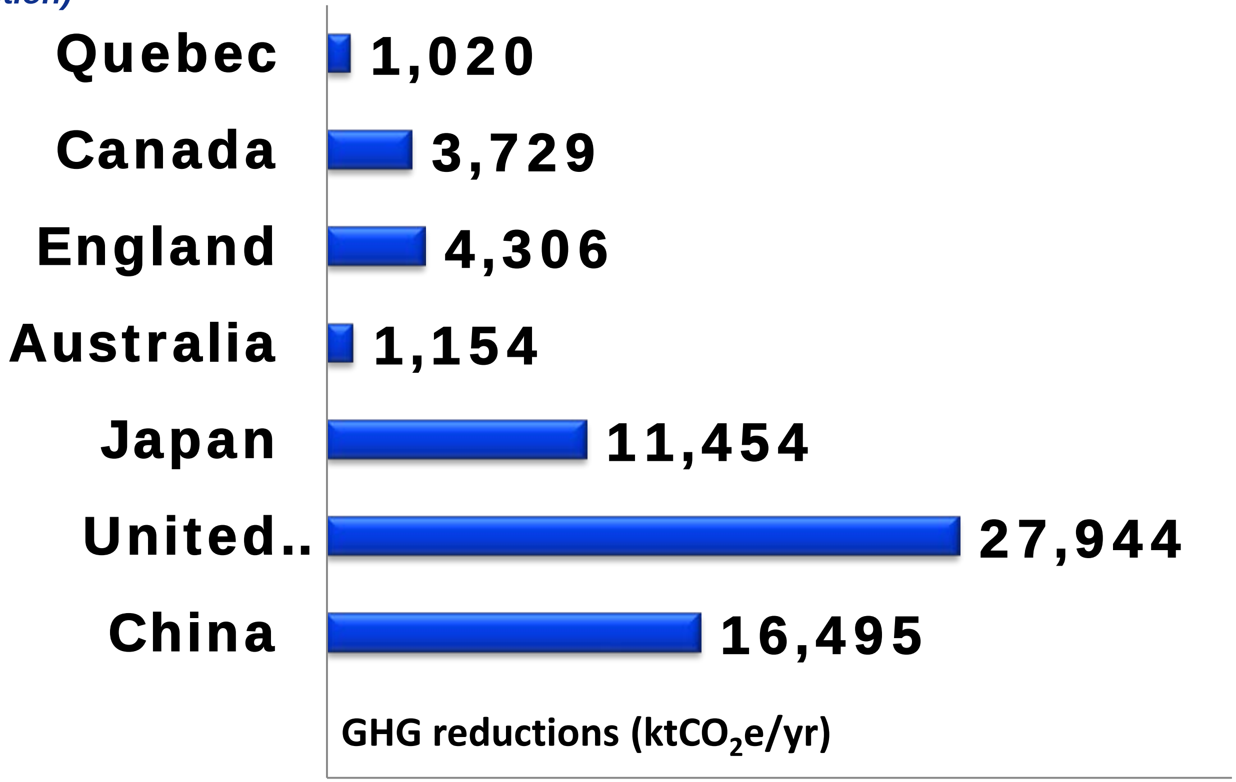
3 729 $ktCO_2e$/yr

(or 1,1 million fossil fuel cars off the road)

Note: calculation based on emission factors taken from the National inventory report 2008 by Environment Canada, of vehicule fleet from OEE Natural Resources Canada, i-Miev electric consumption and of a fleet switch of 6,8% applied per province from the Quebec Action Plan 2011-2020.

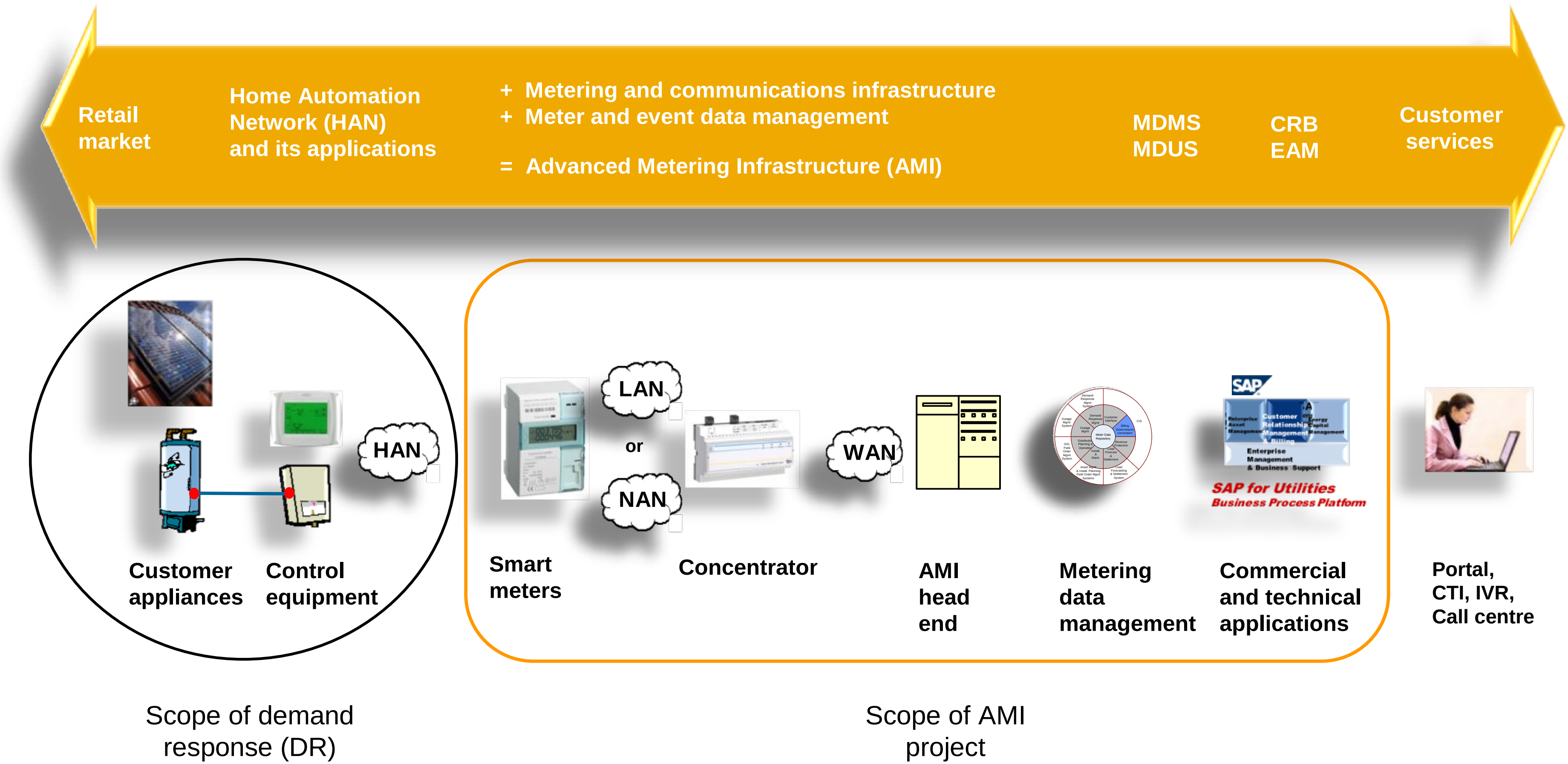
GHG Reduction with EV charging station

International (projection)



Breakdown of GHG reductions associated with Electric Vehicle Charging Stations Implementing on an international scale

AMI and Demand Response



Renewable Energy Integration

- **Smart Grid for DG integration**
- **Monitoring: smart meter for profiling and forecasting of renewable energy production**
- **Protection: smart grid based protection strategies**
- **Control: eventually integrate DG into DMS for participation in Smart Grid applications**

Example of PV concentrator

Source : http://www.electron-economy.org/article-13200027.html

Energy Gain

Measures	Energy Gain	Sources
I - CATVAR	1,7 %	Hydro-Québec. Measured data from CATVAR pilot test
II – EV charging stations	- 0,65 % [1]	Hydro-Québec. 6,8% of EV on total fleet
III – AMI	3 %	U.S. Department of Energy, 2010. *The Smart Grid : An estimation of the energy and CO2 benefits*
IV – Renewable Energy (Solar)	5 %	U.S. Department of Energy 2010. *The Smart Grid : An estimation of the energy and CO2 benefits*

[1] Based on a target of 6,8% of electric vehicle on total fleet . For Québec, 300 000 fleet of i-Miev in 2020, the energy consumption is evaluated at 750 GWh on a total 116 000 GWh distributed : 0,65 %

GHG Methodologies Selection

I - CATVAR : *World Resource Institute, «Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects»*

II - Electric vehicle charging stations : CDM AMS-III.C. « Emission reductions by electric and hybrid vehicles »

III - AMI : CDM AMS- II.E. « Energy efficiency and fuel switching measures for buildings »

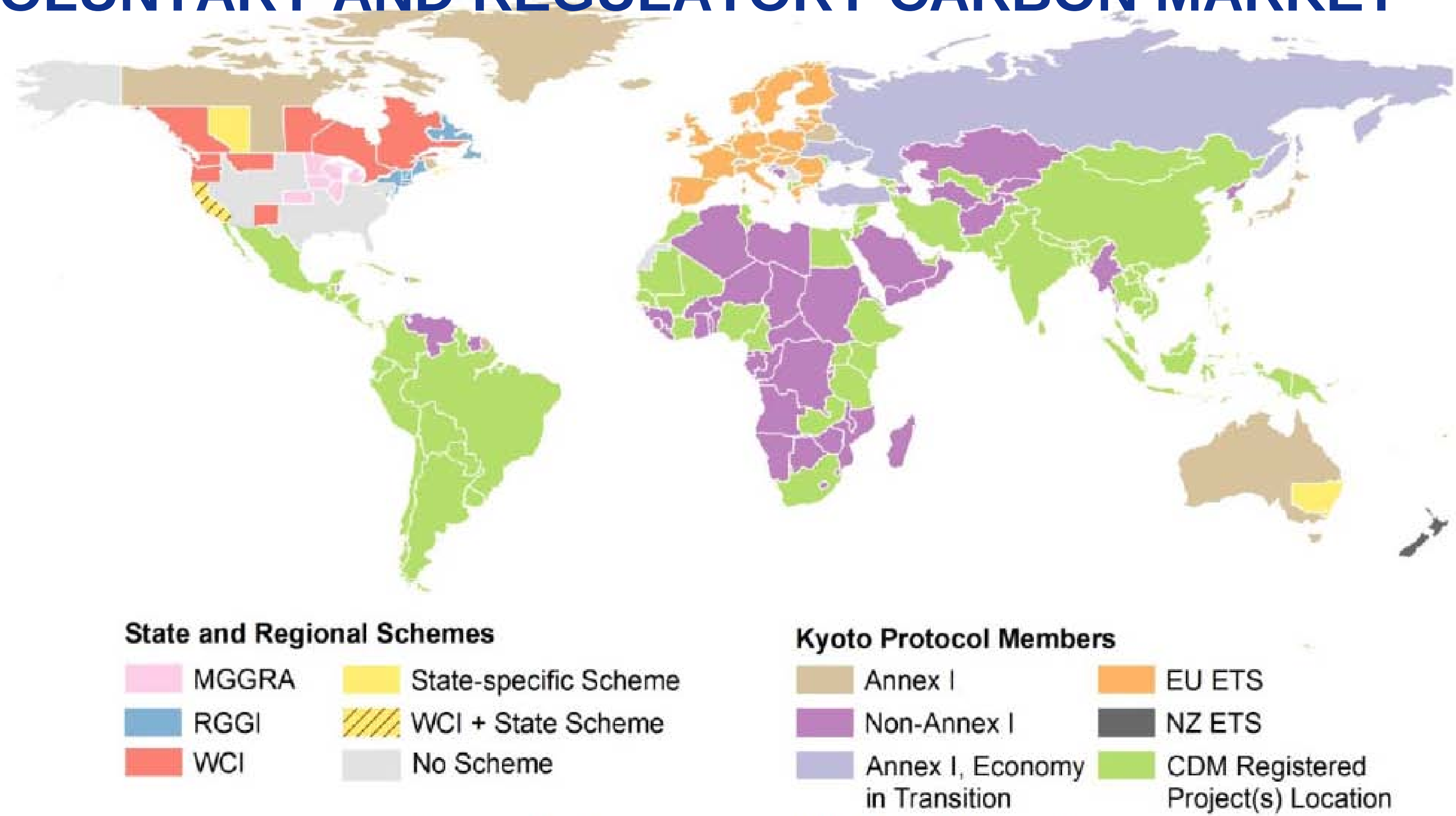
IV – Renewable Energy : CDM AMS- I.F. « Renewable electricity generation for captive use and mini-grid »

Conclusions

- Smart Zone applications are selected to meet Hydro-Québec's business objectives:
  - Distribution System Performance (Reliability and Power Quality)
  - Power Line Capacity and system efficiency
  - Active Customer Participation
  - Asset management optimization
- Smart grid Zone benefits and expectations
  - Validation of technologies
  - Integration of multiple smart grid applications
  - Evaluation of IT and Telecom infrastructure
  - Quantification of benefits related to business drivers
- Smart Grid projects can reduced significantly GHG
- Standard GHG measuring methods are being developed and Hydro-Québec is using them to evaluate the GHG benefits

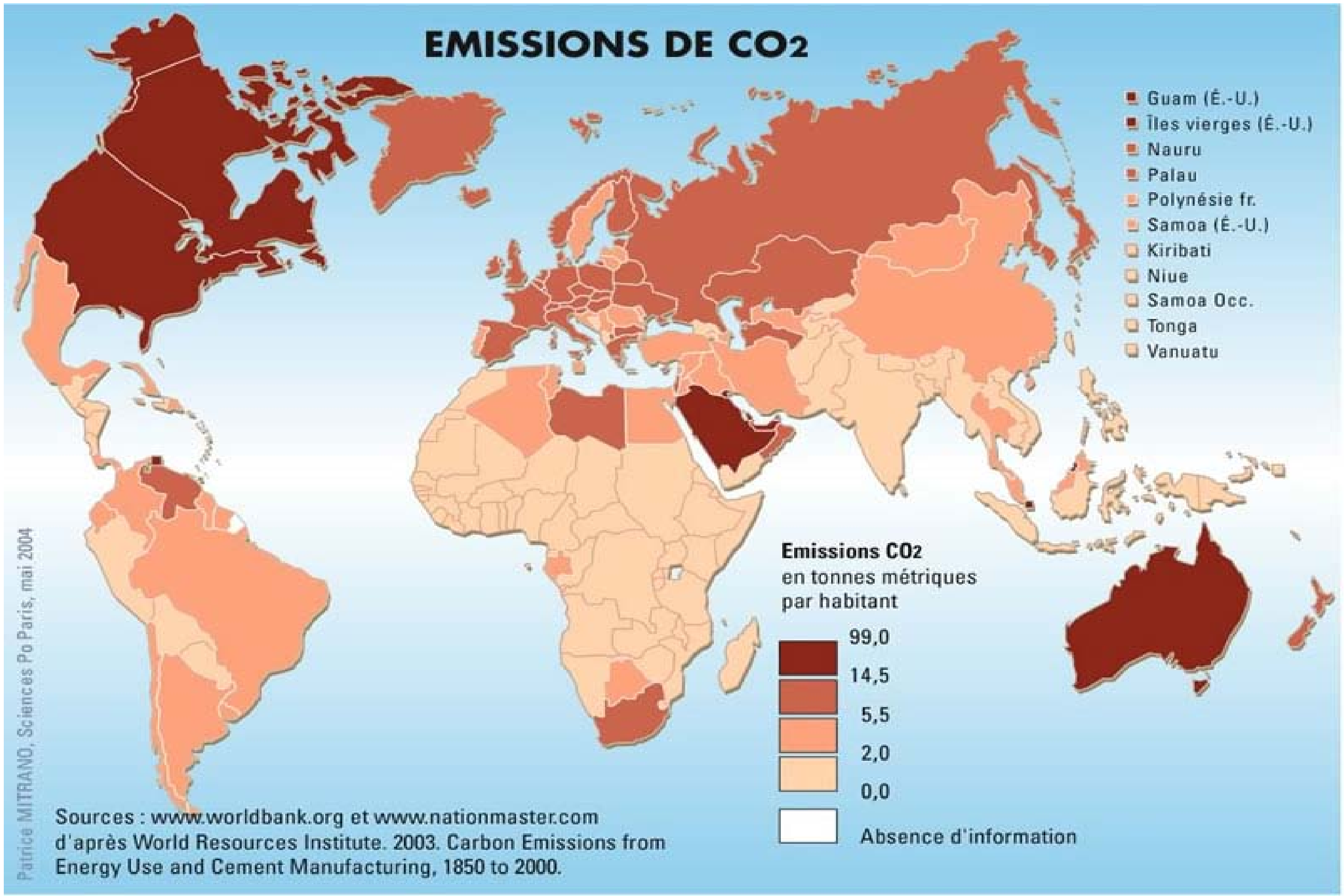
Annex 1
GHG AND CARBON MARKET

VOLUNTARY AND REGULATORY CARBON MARKET

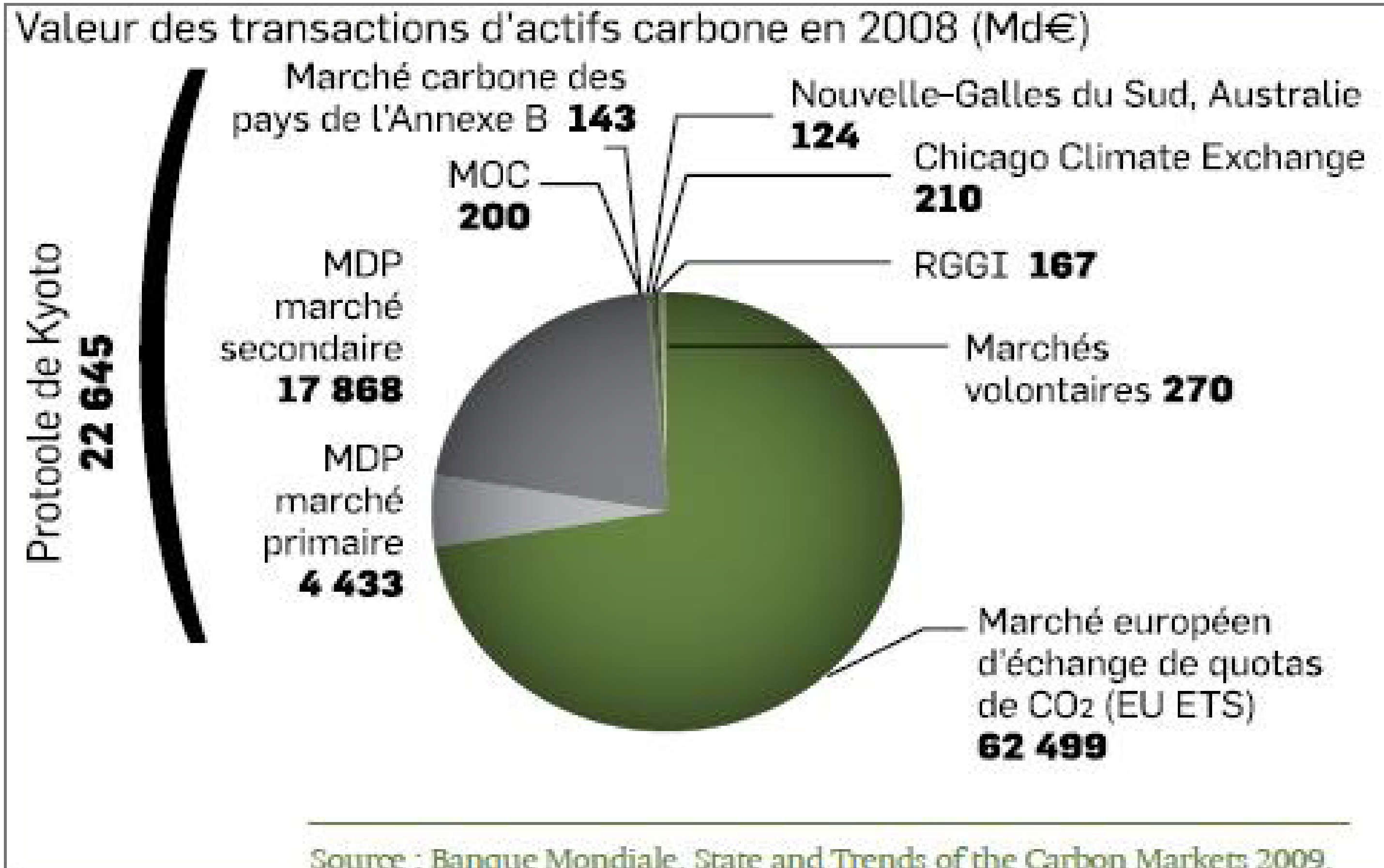


Source: UNFCCC, WCI, RGGI websites; created by Molly Peters-Stanley for Ecosystem Marketplace and Bloomberg New Energy Finance, 2010

International GHG emissions



Transactions volumes



QUEBEC AND CANADA GHG REGULATION

Québec: Bill 42 (WCI)

- ≥ 10 000 t CO_2e = GHG declaration/year application: 2011
- ≥ 25 000 t CO_2e = GHG compensation/year application: 2012

- Penalty : 3 allowances (3 tCO_2e) per exceeding tCO_2e over
- quotas if not compensate during the compliance period
- 3 compliance period (2012 to 2020)

QUEBEC AND CANADA GHG REGULATION

Québec: Bill 42 (WCI)

- Offsets can be generated by three types of industries under the WCI GHG threshold and exchanged to big emitters : Forestry, Agriculture and Waste management

Canada: CEPA[1], article 71, paragraph 46

- ≥ 50 000 t CO_2e = GHG declaration
- Cap and Trade program - Standby

[1] Canadian Environmental Protection Act

GHG QUANTIFICATION

ISO 14064-2:2006 Guidelines

GHG emissions reductions project

$EmissionReduction_{Total} = Emissions_{Baseline} - \mathrm{Emissions}_{\mathrm{Project}}$

GHG Quantification Methodologies

- Clean Development Mechanism (CDM)
- *World Resource Institute, «Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects»*

For more details on the methodologies, see Annex

Annex 2
GHG Methodologies

GHG methodologies selection

I - CATVAR : *World Resource Institute, «Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects»*

II - Electric vehicle charging stations : CDM AMS-III.C. « Emission reductions by electric and hybrid vehicles »

III - AMI : CDM AMS- II.E. « Energy efficiency and fuel switching measures for buildings »

IV – Renewable Energy : CDM AMS- I.F. « Renewable electricity generation for captive use and mini-grid »

CATVAR (VVO)

$$RE_y = FE_{CO2,y} * GEN_{project}$$

$FE_{CO2,y}$ for Quebec — Emission factor for electricity generation , 2,04 tCO_2e/GWh (Environnement Canada, 2010)

$GEN_{proj,t}$ — Total energy economy by CATAVAR (GWh) for the project period (t);

$$GEN_{project} = \frac{S_t}{1 - L}$$

S_t — Energy economy (GWh) for the project period (t);

L — Fraction of energy lost by the transportation grid : 5,2%

Electric Vehicle Charging Stations

$$RE_y = E_{baseline} - E_{project}$$

$$E_{Baseline} = D_{km} * C_{Vehicule} * FE_{Fuel}$$

D_{km} km per electric vehicle of the project

$C_{Vehicule}$ Fuel consumption per km for fuel vehicle switched by an electric vehicle; litres/km

FE_{Fuel} GHG emission factor for fuel consumption; tCO_2e/liter

$$E_{Project} = Q_{Electricity} * FE_{Electrcity} * (1 + TDL)$$

$Q_{Electricity}$ Electricity consumption for the electric vehicle of the project; GWh

$FE_{Electricity}$ Emission factor for electricity generation , 2.04 tCO_2e/GWh for Quebec (Environnement Canada, 2010)

TDL Fraction of energy lost by the transportation grid : 5.2%

AMI

$$RE_y = (Q_{SRElectricity} - Q_{PElectricity}) * FE_{CO2,y} * (1 + TDL)$$

RE_y	Emission reduction of the project (t CO_2e);
$Q_{SRElectricity}$ AMI	Electricity consumption without the implementation of (GWh);
$Q_{PElectricity}$	Electricity consumption with the implementation of AMI (GWh);
$FE_{CO2,y}$	Emission factor for electricity generation , 2,04 tCO_2e/GWh for Quebec (Environnement Canada, 2010)
TDL	Fraction of energy lost by the transportation grid : 5,2%

Renewable Energy

$$RE_y = BE_y - PE_y$$

$$BE_y = EG_{BL,y} * FE_{CO2,y} * (1 + TDL)$$

BE_y	Baseline GHG emissions (t CO_2e);
$EG_{BL,y}$	Net electricity displaced by the project (GWh);
$FE_{CO2,y}$	Emission factor for electricity generation , 2.04 tCO_2e/GWh for Quebec (Environnement Canada, 2010)
TDL	Fraction of energy lost by the transportation grid : 5.2%
PE_y	Project GHG emissions, 0 tCO_2e for renewable energy; CDM methodology.

smarter grid solutions

Active Distribution Network Concepts

Dr Bob Currie & Prof Graham Ault

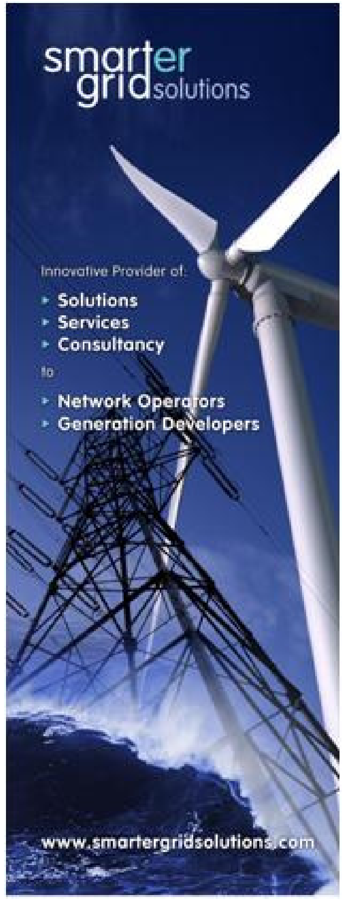
CIRED 2011, Frankfurt

Contents

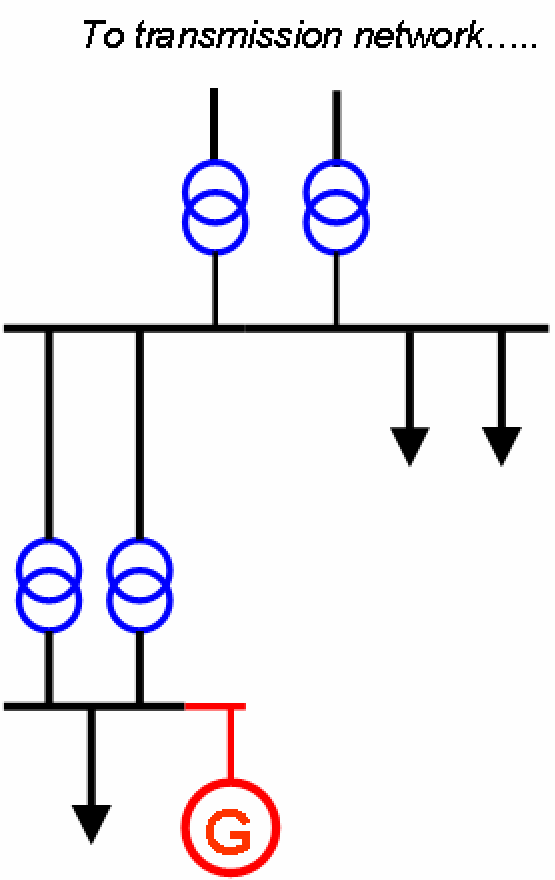
- Introduction to Active Network Management (ANM)
- Opportunities Provided by ANM
- Challenges to ANM deployment
- Simple ANM Example
- Case Studies:
  - The Orkney Project
  - Shetland Project
  - Low Carbon London
  - Further reading
- Conclusions

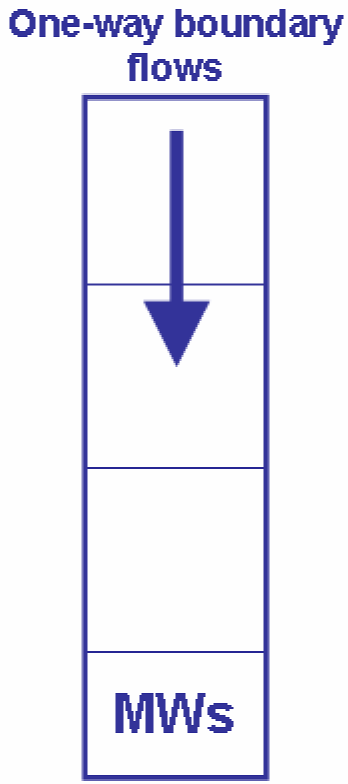
Smarter Grid Solutions Ltd

- 20 staff plus supplementary resources
- Provide Active Network Management Solutions and Consultancy Services
- Based in Glasgow, opened London office in 2011
- Working with transmission and distribution network operators in the UK and mainland Europe
- “Best New Business” and “Best Renewable Innovation” awards at the Scottish Green Energy Awards, 2009
- www.smartergridsolutions.com



Introduction to ANM

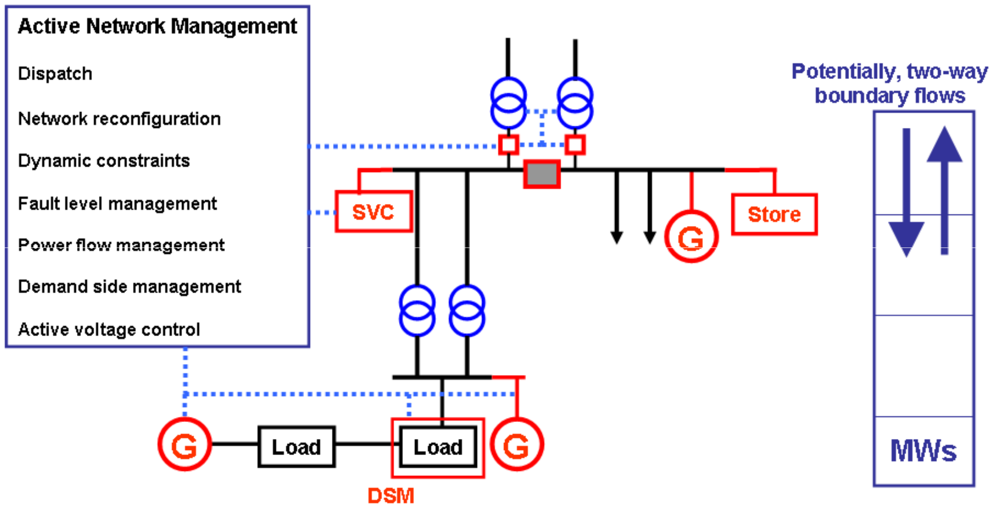




Source: Ofgem

Introduction to ANM

- No generally accepted definition
- Most in agreement as to characteristics of an active network…..
  - *DG, renewables, monitoring, comms and control, preventive and corrective actions, flexible, adaptable, autonomous? Intelligent?*
- Aspects of ANM in many international programmes
- CIGRE working Group C6.11



Source: Ofgem

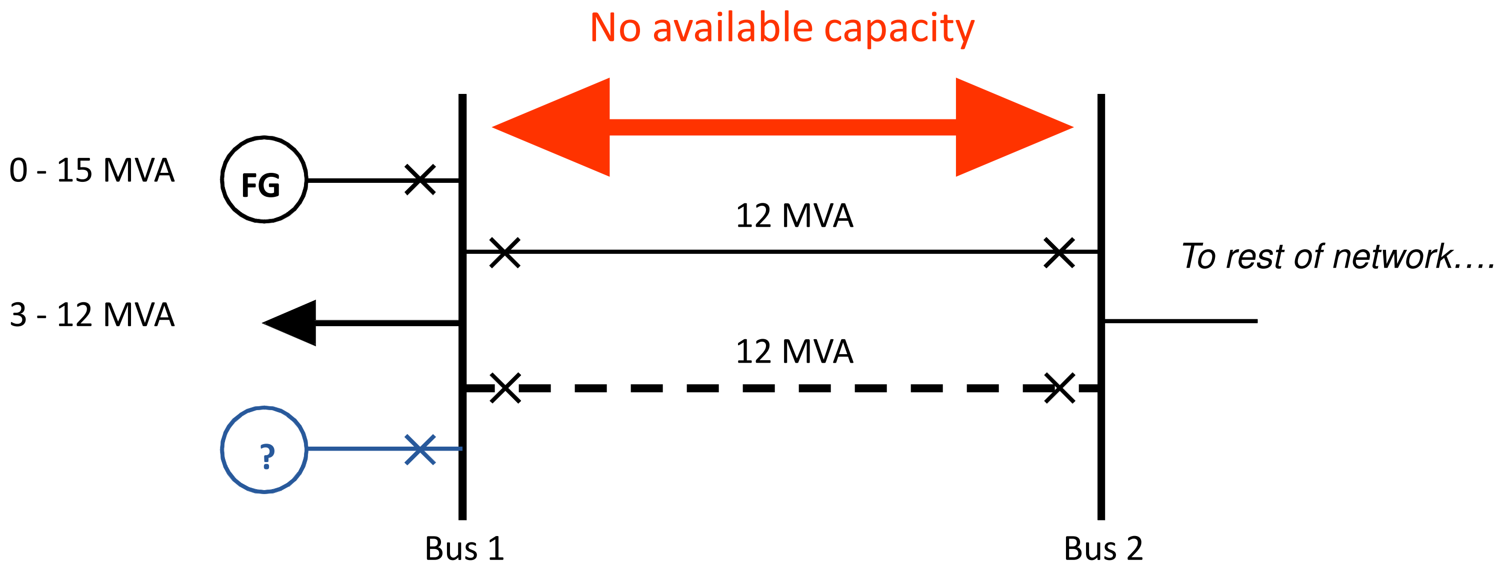
Opportunities Provided by ANM

- Connect more to existing networks previously considered full
  - Demand and generator connections
  - Interruptible connections
- Increase utilization of assets
- Avoid/Defer network reinforcements
- Incremental developments
- Quicker and cheaper grid connections
- Flexibility in network operation
- Improved network performance

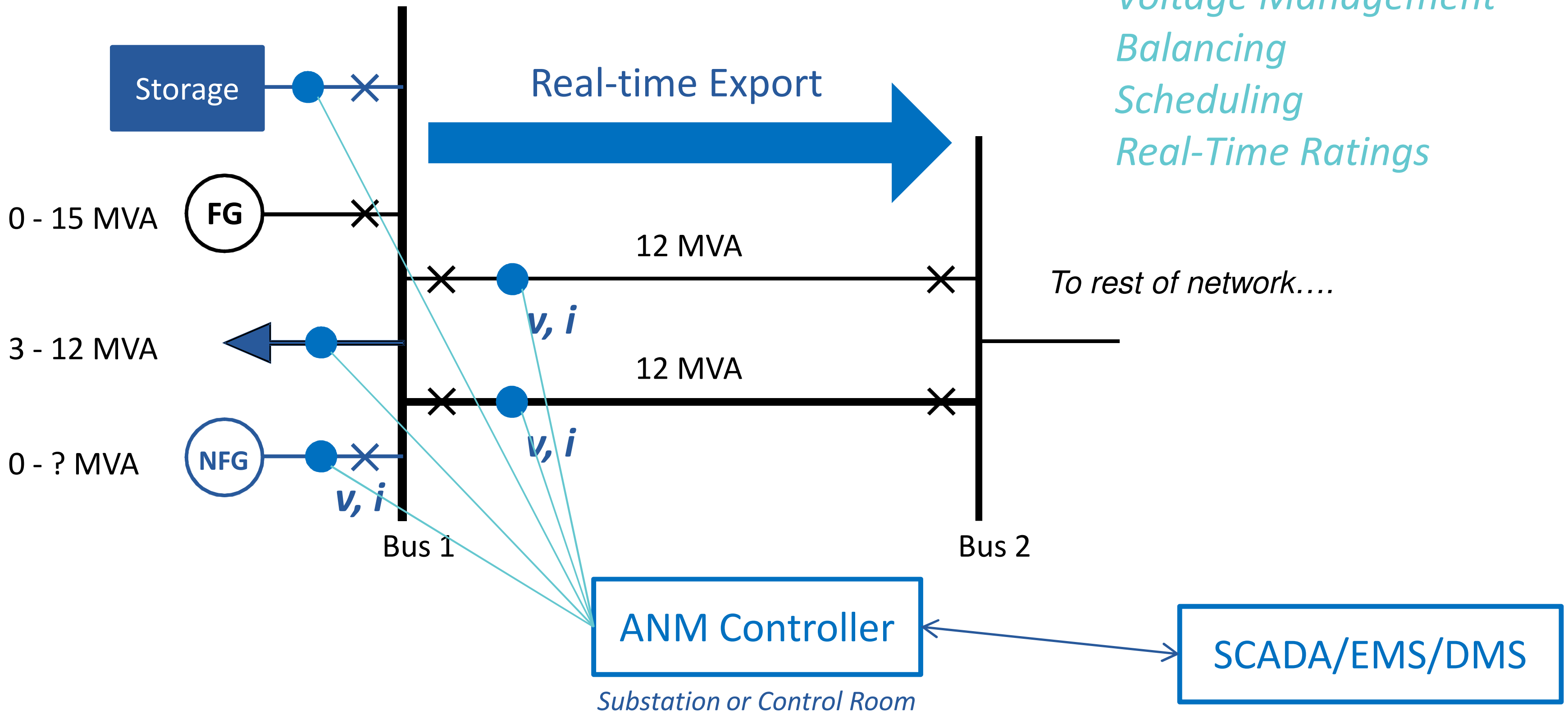
Challenges to ANM Deployment

- Commercial rules and constraint management
- Network Operator resources
- Standards (ANM solutions, Security and Quality of Supply, etc)
- Communications
- New interruptible contracts
- Planning tools and satisfying customer concerns
  - Including investors in new generation projects
- Cost-benefit analysis
- Triggers for reinforcement
- Lack of proven solutions and techniques

ANM Generator Example



ANM Generator Example



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ANM Functions:

Power Flow Management
Voltage Management
Balancing
Scheduling
Real-Time Ratings

Generation Curtailment

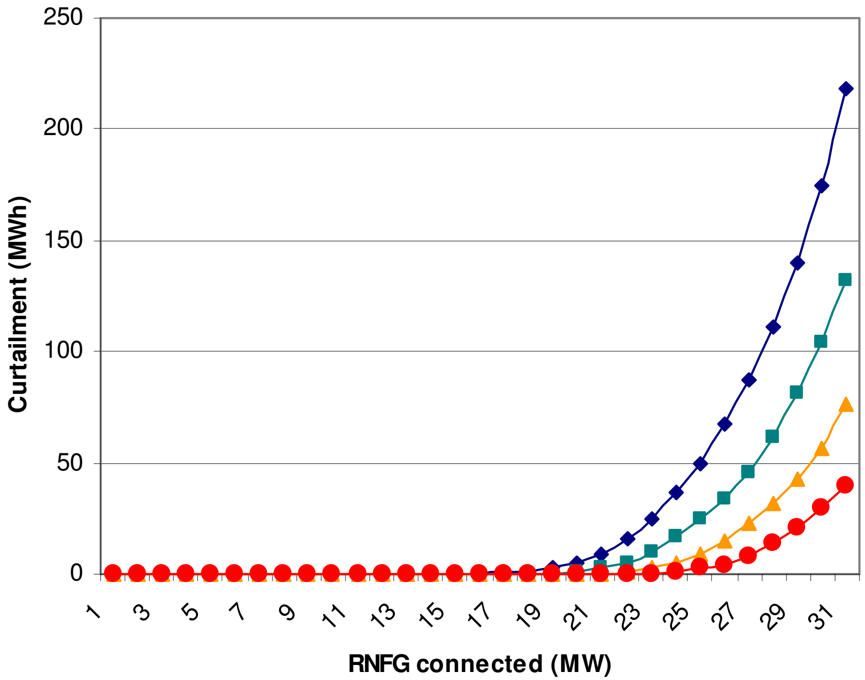
Example of curtailment studies results:

• Wind farm connection

• Curtailment is energy (MWh) lost due to ANM regulating wind farm output to meet network constraints

• Curtailment increases exponentially with wind farm capacity

• Each line represents a different level of access in terms of MVA network capacity that can be accessed



High-Level Constraint Management

Identify Generators

Offline (studies, scenarios)

Online (cost/technical best)

Constraints

What? Where?

Offline / Real-time

Forecasting

Principles of Access

LIFO, shared, cheapest, largest, smallest, etc.

Commercial Input

Regulation, rules, law, license obligations, connection agreements

ANM Scheme

Preventive limits

Corrective limits

Real-time constraints

Comms monitoring

ANM Algorithms

Operating concerns

Issue Constraint Signals

To one or more generators

Monitor generator compliance

Monitor effectiveness of constraints

Resolve Payments

Constraints, services

Assessing Constrained Connections

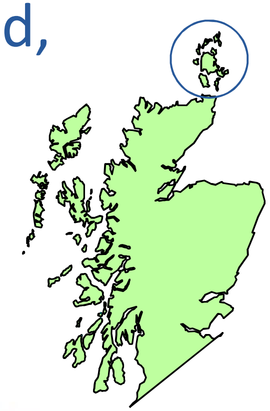
- How can interruptible connections be considered?
  - Multiple generators? Individual generators?
  - Multiple demand response providers? Or single providers?
  - What are the utility business drivers?
  - What can practically be achieved?
  - Principles of Access to employ?
- Use load flow simulation tools?
- Consider other technologies? (e.g. storage)
- Consider alternative solutions? (e.g. conventional reinforcement)
- Probabilistic or time-series based on historic profile data?
- Provide results of simulations to potential customers?
- Perform studies periodically to ensure best decisions are being taken and best information shared?

Distributed or Centralised ANM?

- Depends on site specific or utility specific factors
- Centralised approach:
  - Is all about communications
  - Is appropriate where measurement and communication requirements/capabilities make it sensible
  - Integrate with SCADA but not be dependent on the SCADA platform
- Substation based approach:
  - Leave existing systems to perform existing functions
  - Integrate to permit appropriate level of oversight and control, without burdening the control room personnel
  - ANM represented as a virtual RTU
  - In-house management of visualisation if desired
  - Investment can be limited to problem areas
  - Flexibility – quick install and quick decommission
- Decision depends on communications, measurements and utility preference
- Both approaches require new commercial arrangements with users of the network - interruptible contracts

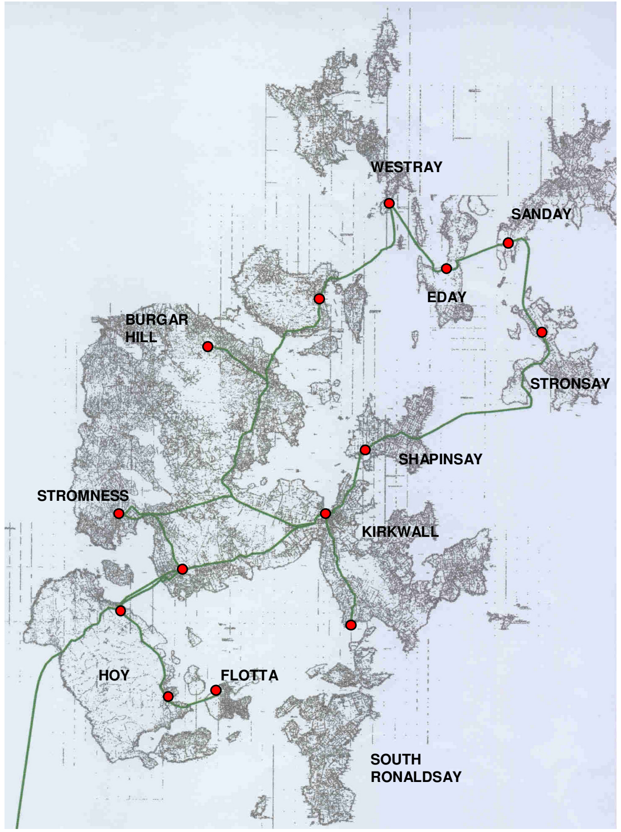
The Orkney Isles

- Overcoming grid congestion using ANM technology
- Connecting <20 MW new renewable generation capacity to 33 kV grid previously considered to be full
- Operational since November 2009
- Distributed, real-time control system
- All analysis, consultancy, control system design and build, support and warranty provided by SGS
- Cost around £500k, estimated savings £30million
- DLR and RTR installed Feb 2011
- Platform for further smart grid developments



The Orkney Isles

- Solution deployed by SGS and SSE
- SSE Planners and Control Room involved from beginning
- NEW connections only
- Multiple generators and constraints
- Real time ANM
- Nested control zones
- Existing connections unaffected
- Last In First Out (LIFO) approach
- Alternative to reinforcement

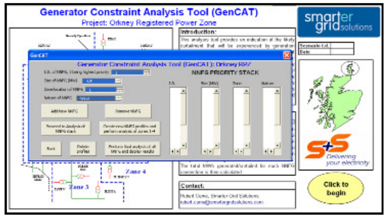


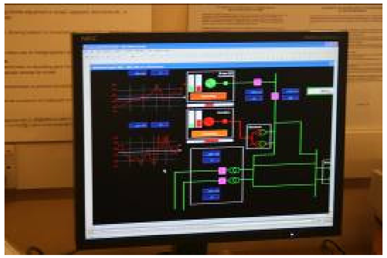
Assessing Connections to Orkney

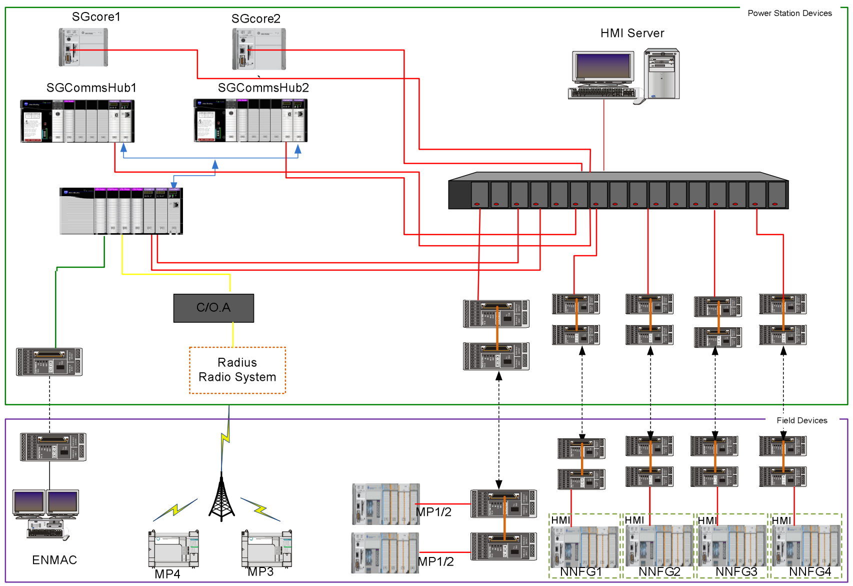
- 'Last In First Off' Principles of Access
- Generator Curtailment Analysis Tool – GenCAT
- Historic ½ hourly profiles OR probabilistic
- Simple spreadsheet based analysis or making use of load flow simulation, e.g. PSSE
- LIFO allows connection priority (perceived rights) to be maintained
- Results of curtailment modeling provided to generators to allow each developer to consider economics of connection

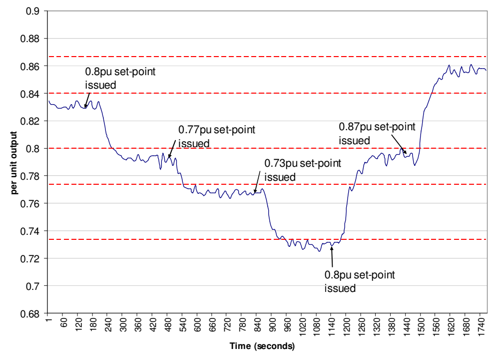
ANM Deployment on Orkney

- 10 MW of new renewable generators connected (18 MW by end of 2011)
- Over 5,000 tonnes of CO_2 saved to date

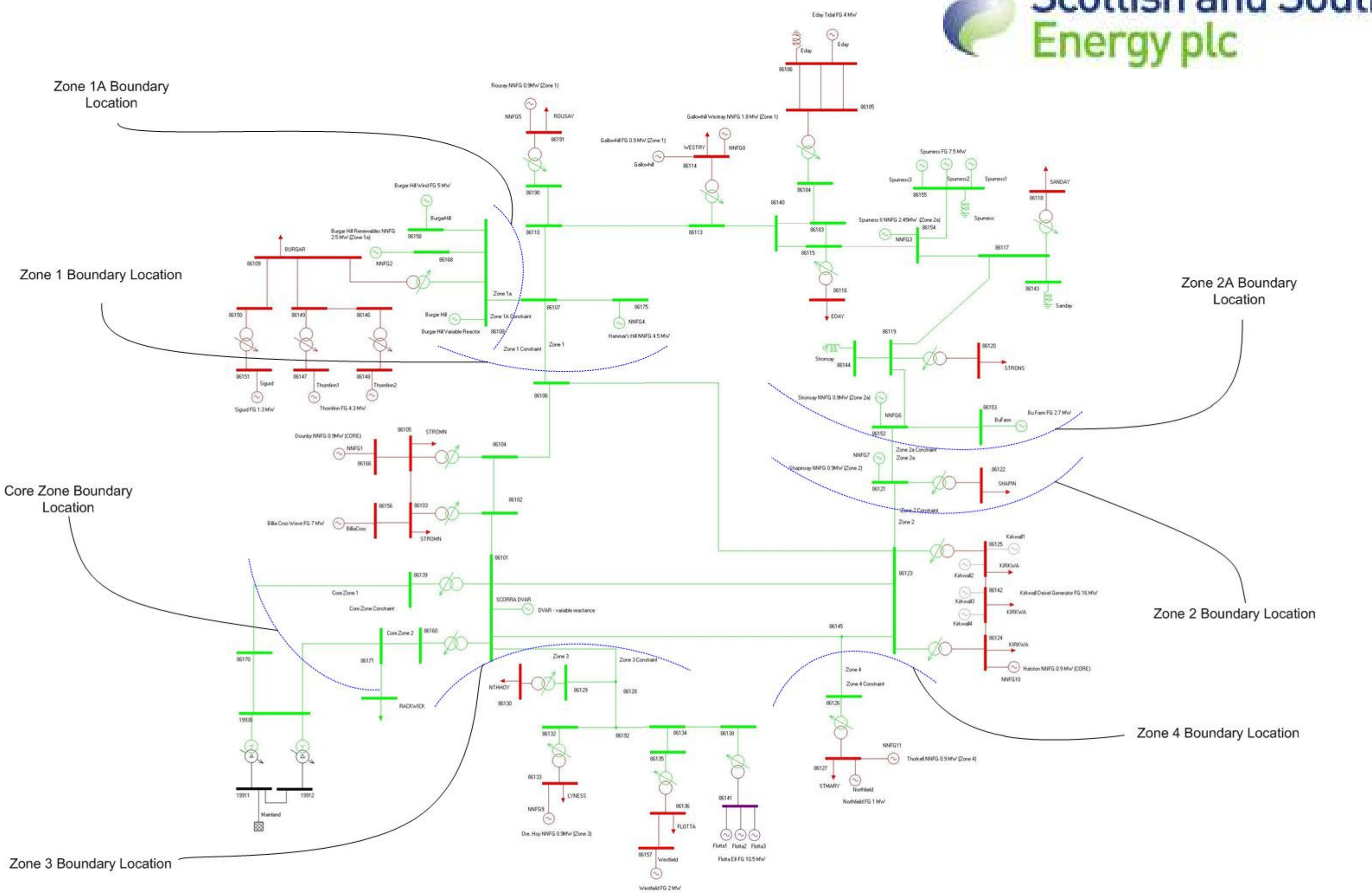








Orkney Capacity Constraints

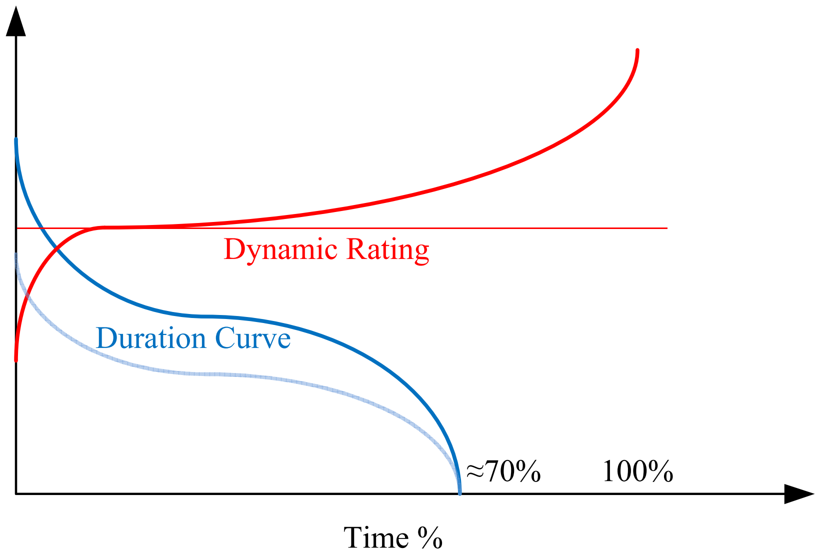


Going Further on Orkney in 2011 and beyond

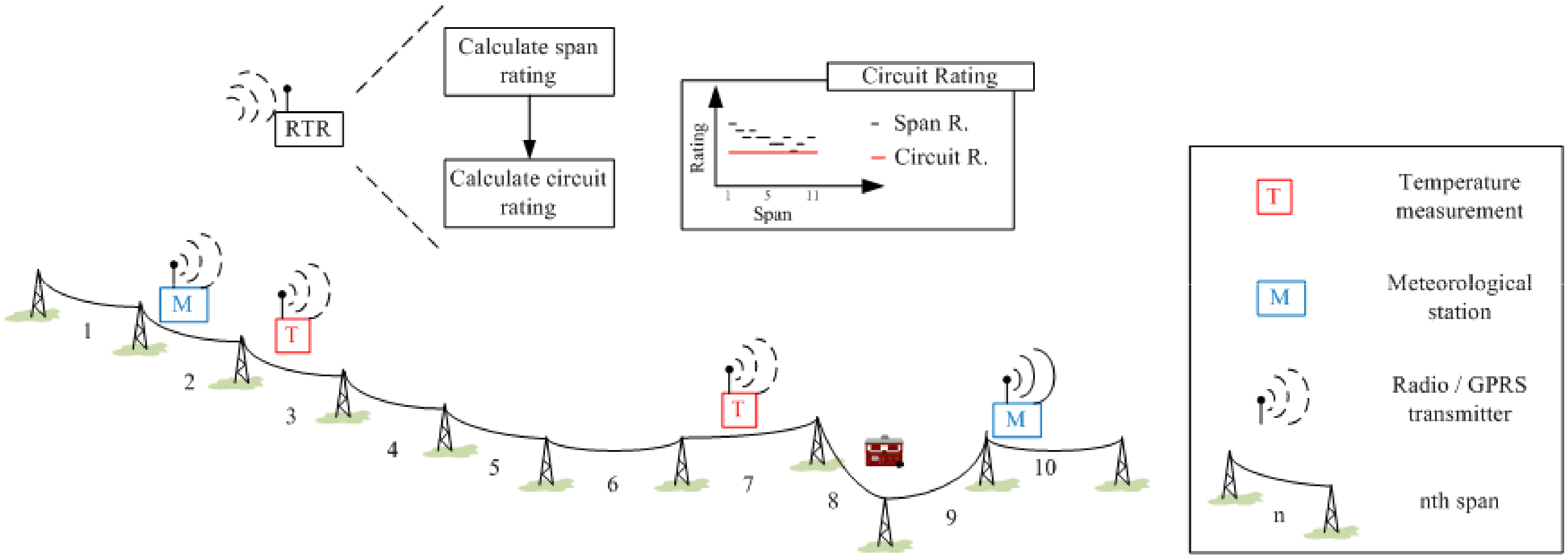
- Deployment of:
  - Further renewable generator connections
  - Dynamic Line ratings
  - Real-time ratings
  - Algorithms implemented in Real-Time Java
- Assessments underway for:
  - State estimation
  - Voltage management
  - Energy Storage
  - Integrating distribution automation with ANM

Dynamic Line Ratings Deployed on Orkney in Q1 2011

- Increased utilisation of overhead circuits
- Increased line ratings coinciding with high wind generation output



Real Time Ratings Deployed on Orkney in Q1 2011



DLR: Conductor temperature measurements - *precise but expensive*

RTR: Meteorological parameter measurements - *less accurate but more cost effective*

Lessons Learned from Orkney

- Start simple and build
- Lots of simple things can become very complicated
- A lot can be done with existing technologies
- Network planning and operation need to be brought closer together
- Network operators need to know what “goes on” inside boxes
- Network planners need to understand long-term implications and evolution
- Commercial arrangements are complex
- Support and warranty are crucial
- Timescales vary (impacts on nature of solution)
- Generator developers are good at understanding and accommodating risk
- ANM service providers need to identify and demonstrate value

Client Feedback

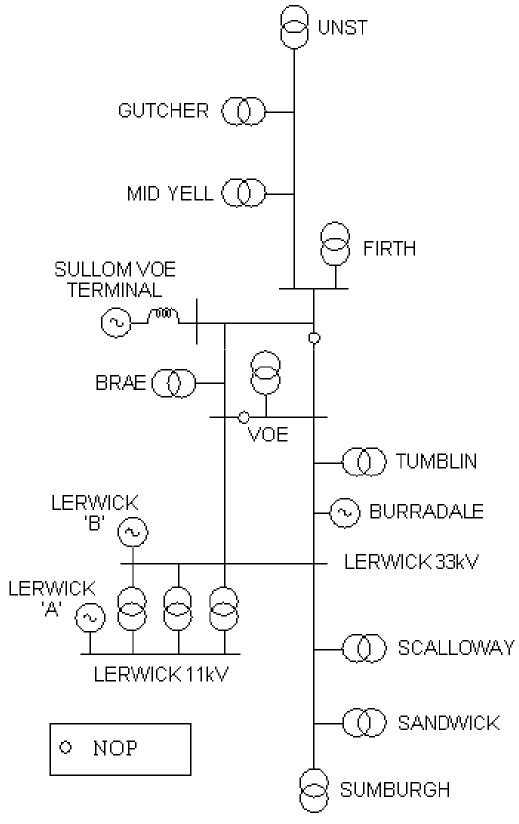
Colin Hood, Chief Operating Officer at SSE:

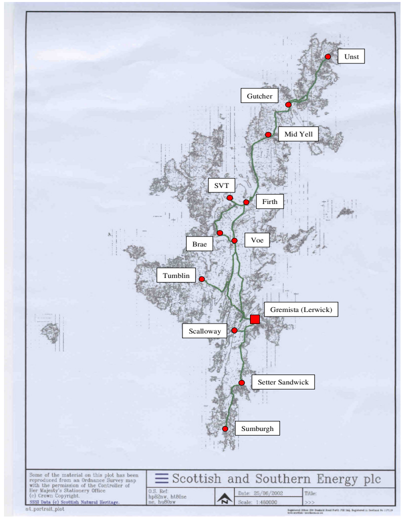
“Smart Grid technology has the potential to significantly improve the efficiency of the electricity distribution and transmission network in the UK. This deployment provides a blueprint for how Smart Grids can be used to connect high penetrations of renewable generation in a cost effective way and resolve grid congestion as a result.

“The connection of similar levels of renewable generation on Orkney by the conventional means of network reinforcement would have cost around £30 million. The total cost of developing and delivering this innovative solution has been substantially less than this and taken far less time.”

Shetland Smart Grid

- £45million pound project
- Islanded network
- Demand of 14 - 48 MW
- Existing generation portfolio
  - Gas
  - Diesel (owned and operated by SSE)
  - Wind
- Planning for replacement power station
  - What should it look like?
  - How small can it be?
  - How will it be used?
- System stability preventing the connection of further renewable generators





Shetland Smart Grid

Coordinated Smart Grid Deployment Activities 2011-2012:

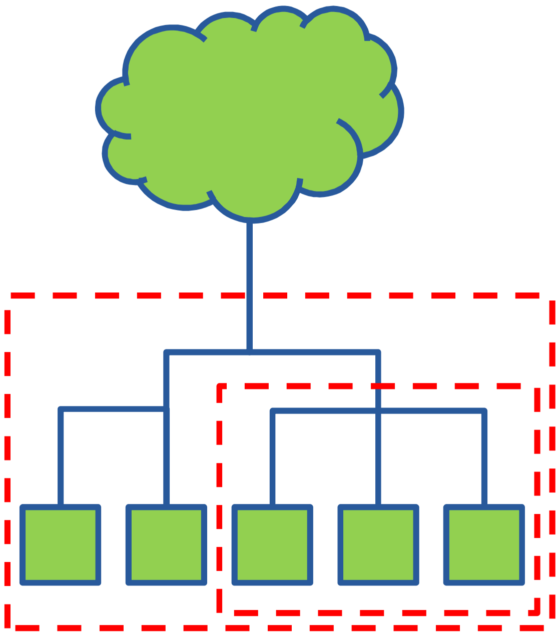
- Heat Storage (Shetland Heat and Power – SHEAP)
  - District heating scheme
  - New 4 MW frequency responsive boiler (130 MWh of thermal storage)
  - Analogue control via droop curve
- Electrical Storage
  - 1 MW NaS battery being deployed mid 2011
- Demand Side Management
  - DSM in 1000 homes (Approx. 10% of all homes on Shetland)
  - Frequency responsive demand: Analogue droop control via droop curves
  - Electrical heating loads – space and water heating
- New Renewable Generators
  - Multiple small wind turbines
  - Large wind farm
- ANM scheme at the heart of future system operation
  - Provide automatic control of multiple resources
  - Scheduling, stability, power flow and voltage constraints

Shetland Smart Grid

Scottish and Southern Energy plc

smarter grid solutions

The Shetland Smart Grid will operate at a number of coordinated levels:



SYSTEM LEVEL

REQUIREMENTS & CONSTRAINTS

e.g. system balancing, frequency stability

LOCAL NETWORK

REQUIREMENTS & CONSTRAINTS

e.g. power flow, voltage

END USER

REQUIREMENTS & CONSTRAINTS

e.g. comfort levels, energy transfer

Shetland Smart Grid

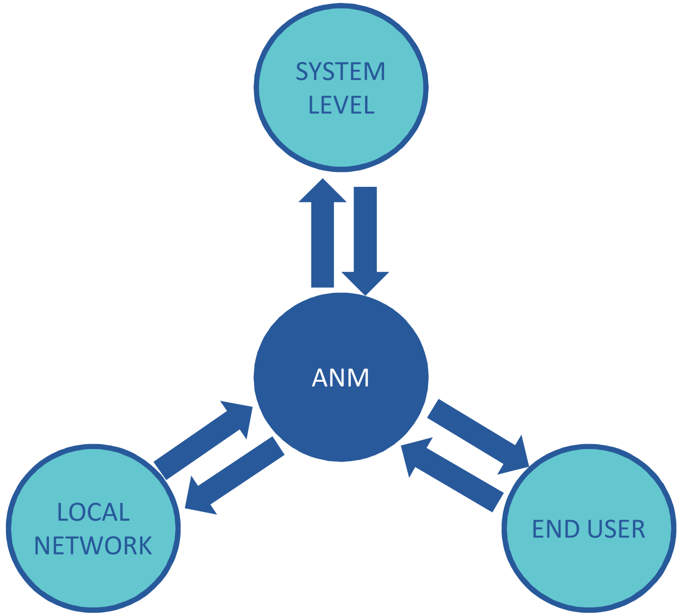
Scottish and Southern Energy plc

smarter grid solutions

- ANM at the heart of performing network management functions and ensuring needs of customers are incorporated into design and operation
- Interdependent requirements and constraints resolved by the ANM scheme by exploiting flexibility, controllability and backup options

For example

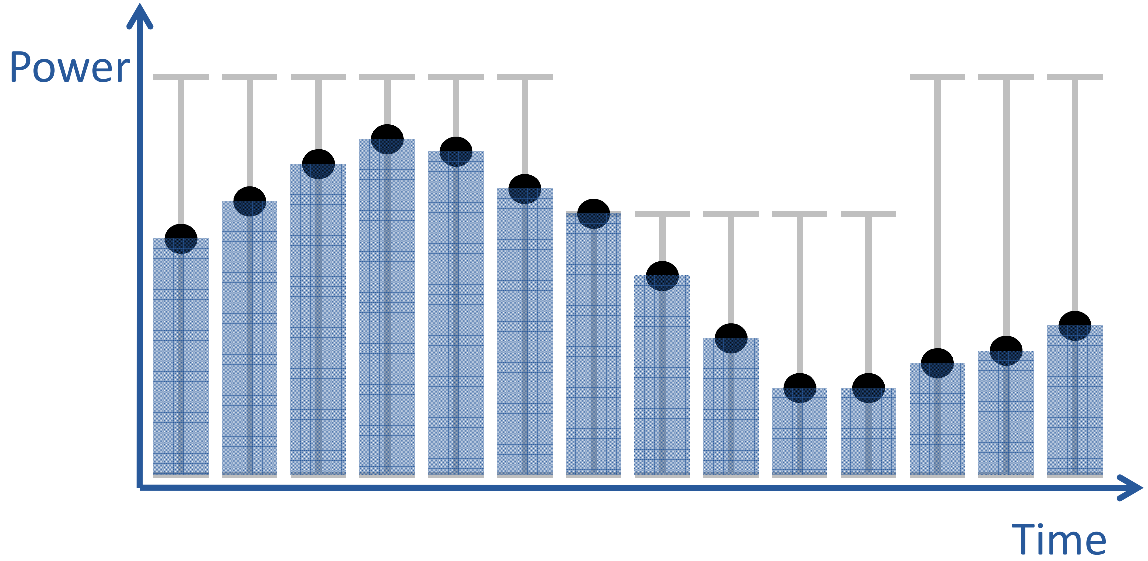
- Thermal energy storage in end user devices
- Variable frequency response characteristics
- Activation of alternative supplies when necessary



Shetland Smart Grid

Scottish and Southern Energy plc

smarter grid solutions



Power setpoint defined in day ahead schedules or updated in real time

Energy transfer over the period satisfies user's requirements or contract

Device range limited according to prevailing constraints (system and local)

Low Carbon London

A smarter electricity network to manage the demands of a low carbon economy and deliver reliable, 'decarbonised' and affordable electricity to customers

Low Carbon London

- £24million award from Regulator (competitive bidding)
- SGS consultancy support to scope and prepare bid for funding
- SGS providing ANM solutions to deliver learning on:
  - Overcoming network constraints that prevent the connection and operation of DG in a heavily loaded urban network using ANM
  - Deploying ANM to reduce network loading where constraints are being driven by rising demand
- ANM will be regulating DG units and possibly EVs.
- 5 ANM Deployments, <50 DG units and <25 network constraints in total

Low Carbon London Partners

smarter grid solutions

UK Power Networks

SIEMENS

logica

nationalgrid

Imperial College London

Transport for London

MAYOR OF LONDON

Thames Gateway Institute for Sustainability

smarter grid solutions

EDF ENERGY

ENERNOC

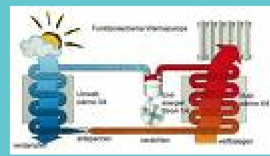
flexitricity

Low Carbon London

…maximise opportunities for low carbon, distributed and micro-generated electricity

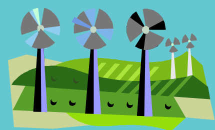


…respond to new demands on the electricity network from a low carbon economy

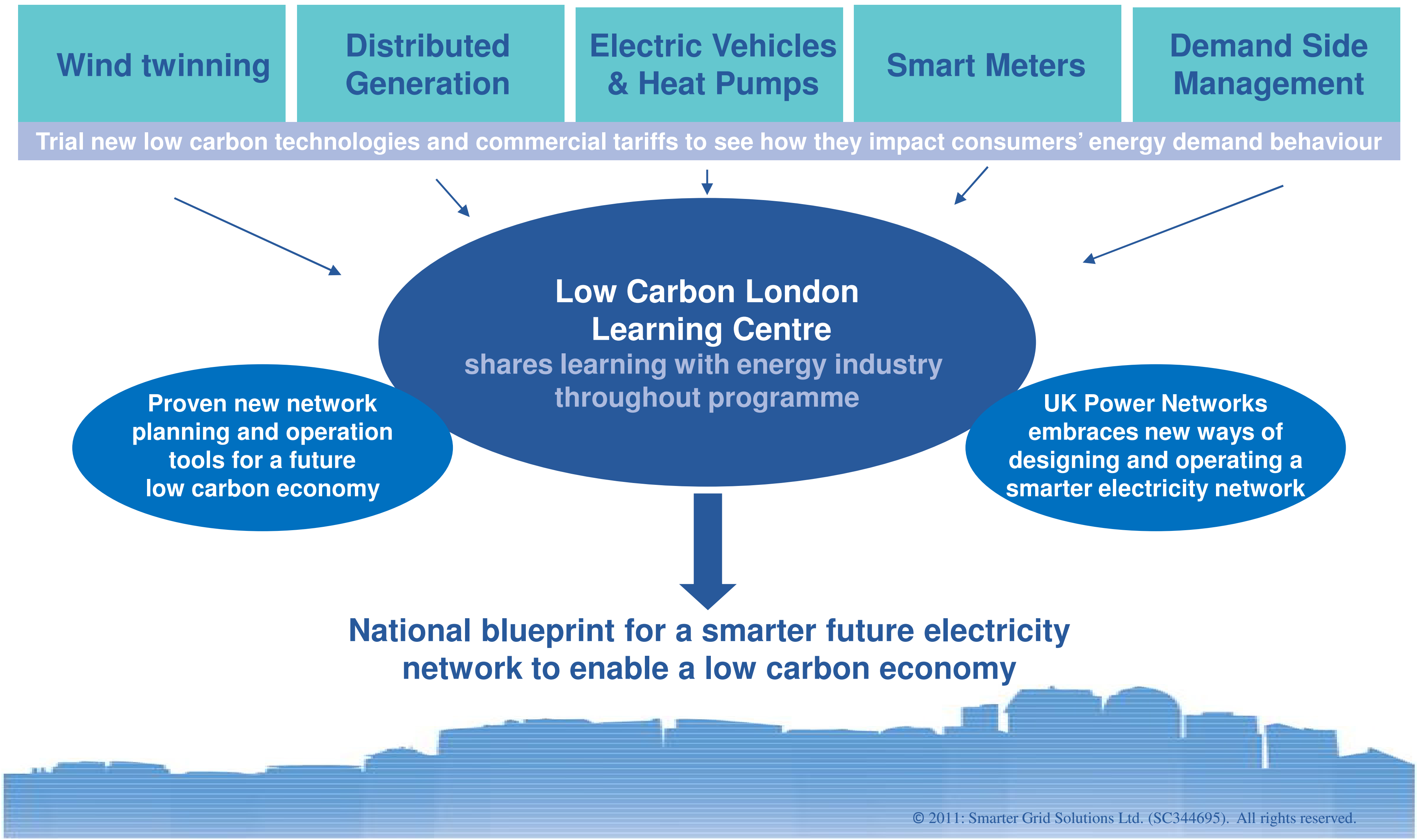



…work with communities and businesses to help them manage demand


…match local energy demand with national low carbon energy demand



Low Carbon London



Low Carbon London – Electric Vehicles

UK Power Networks

smarter grid solutions

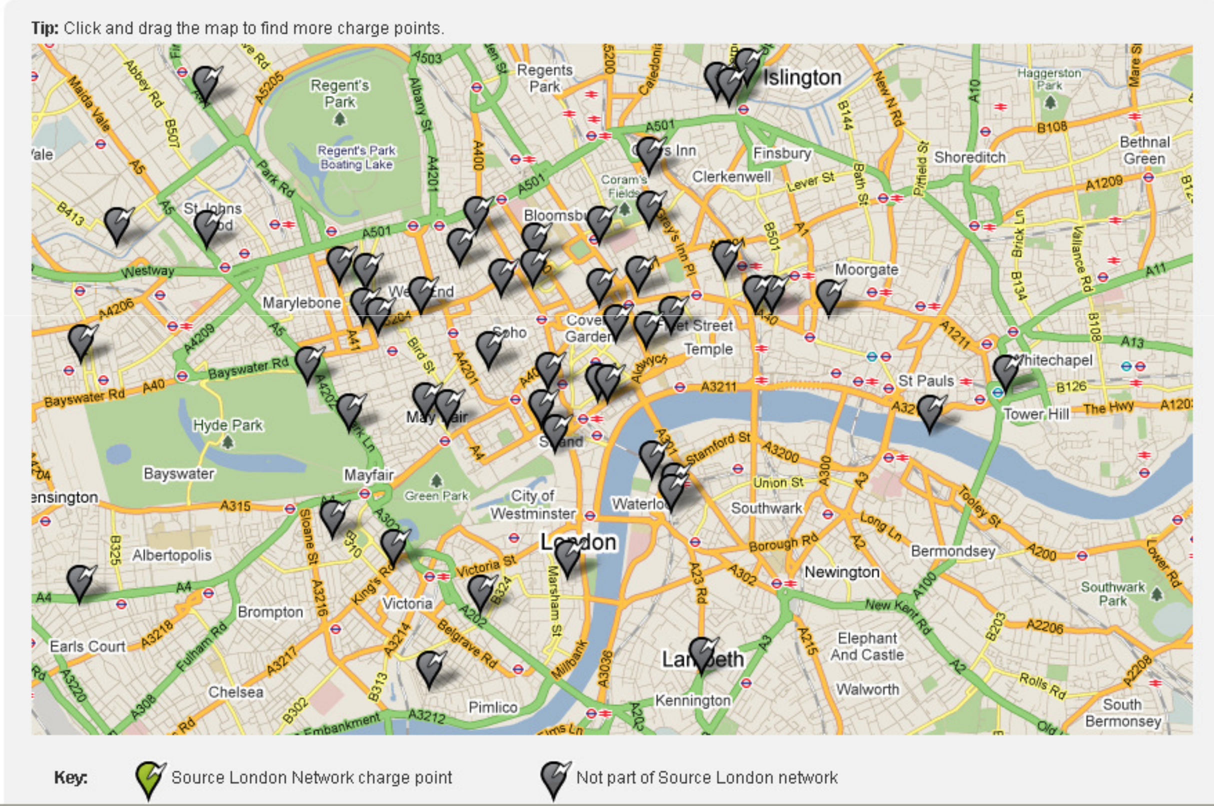
Phased installation of **1,300** public charge points.

Residential streets

and

Off-street locations:
- supermarkets
- public car parks
- shopping and leisure centres

source LONDON



Low Carbon London – Smart Meters

Challenge:

Government wants a smart meter rollout to all UK homes and most SMEs by 2020

UK Power Networks' response:

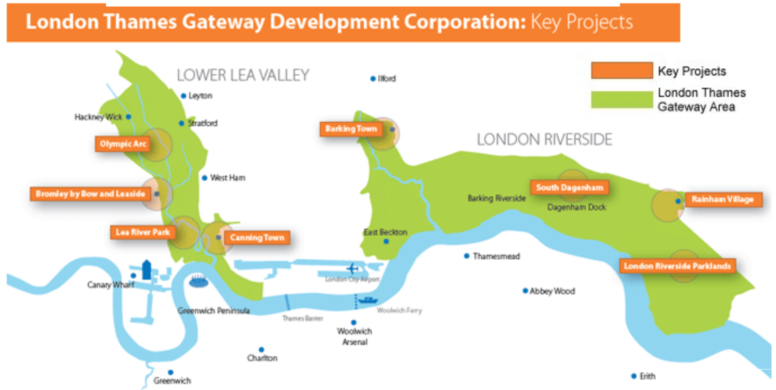
Install smart meters in 5,000 homes across London's 10 Low Carbon Zones and the Green Enterprise District to understand how smart meters can impact customers' energy demand.

Use smart meter data to inform smarter network operating techniques

The learning:

How smart meters can encourage energy efficiency and improve how we manage the electricity network

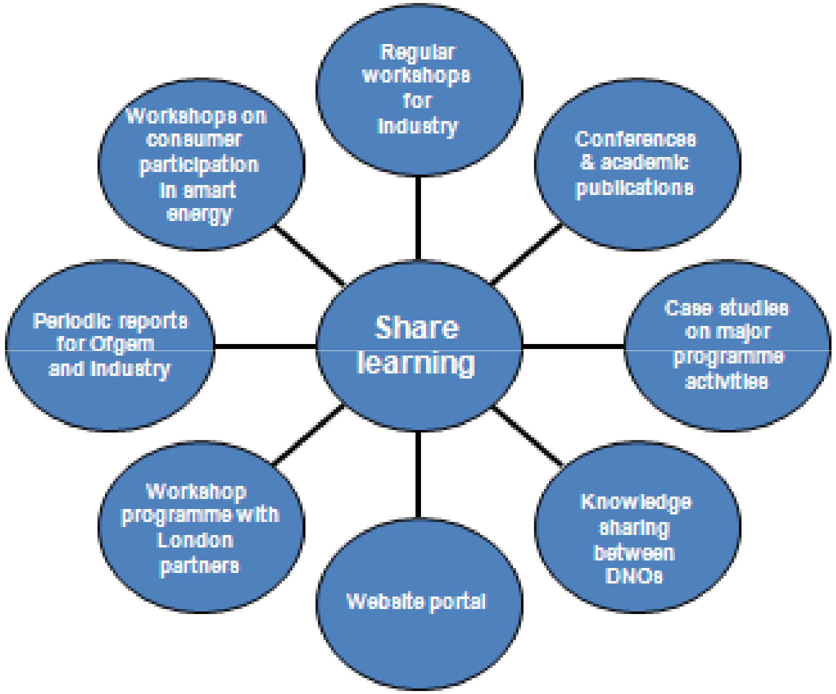
Green Enterprise District



10 Low Carbon Zones

Low Carbon London – Learning Lab

Imperial College London



Further Reading

- CIGRE C6.11 Report on Active Distribution Networks
  - Introduction to ANM
  - Focus on deployment
  - International review
  - Case studies
  - Provides state of the art
- The ANM Register: http://cimphony.org/anm
  - Independent Reporting by University of Strathclyde
  - International review (annual updates since 2007)
  - Links/reports/contacts
- Search online for "Low Carbon Network Fund"

Summary

- ANM emerging as an economic and technical solution to connect distributed resources
- Applicable to generator and demand connections
- Can incorporate new technologies, e.g. storage and DLR
- 18 months operational experience on Orkney of first multiple generator, multiple constraint ANM scheme
- Other major projects underway in the UK
- Other deployments imminent, further development work ongoing
- CIGRE Working Group as a reference point for industry
- ANM is one important part of the overall Smart Grid vision

Frankfurt (Germany), 6-9 June 2011

Deployment of an advanced Distribution Management System in the french network

Sébastien GRENARD
EDF R&D (France)

Smart Distribution Systems for a Low Carbon Energy Future Workshop

6 June 2011

Contents

- Overview of the network control structure in France
- Existing FDIR functions
- Future DMS functions
- Roadmap of implementation

Why new automation functions are needed for distribution networks ?

Distribution grids are facing new constraints

- Integration of Renewable Energy & Distributed Resources on the networks
- Necessary improvement of grid performance (flexibility, QoS, hosting capacity, costs)
- Ageing assets

Smarter Functions are needed :

- ✓ **Automatic Fault Detection Isolation and Recovery (FDIR)**
- ✓ **Full integration of distributed resources in DMS**

Network control Structure in France

RTE (TSO)

400kV — 1 NCC (National Control Centre)

225kV & HV networks — 8 RCCs (Regional Control Centres)

ERDF (DSO)

MV networks (10, 15 & 20 kV) — 30 DCCs (Distribution Control Centres) Each serving >1 M Customers

eRDF
ÉLECTRICITÉ RÉSEAU DISTRIBUTION FRANCE

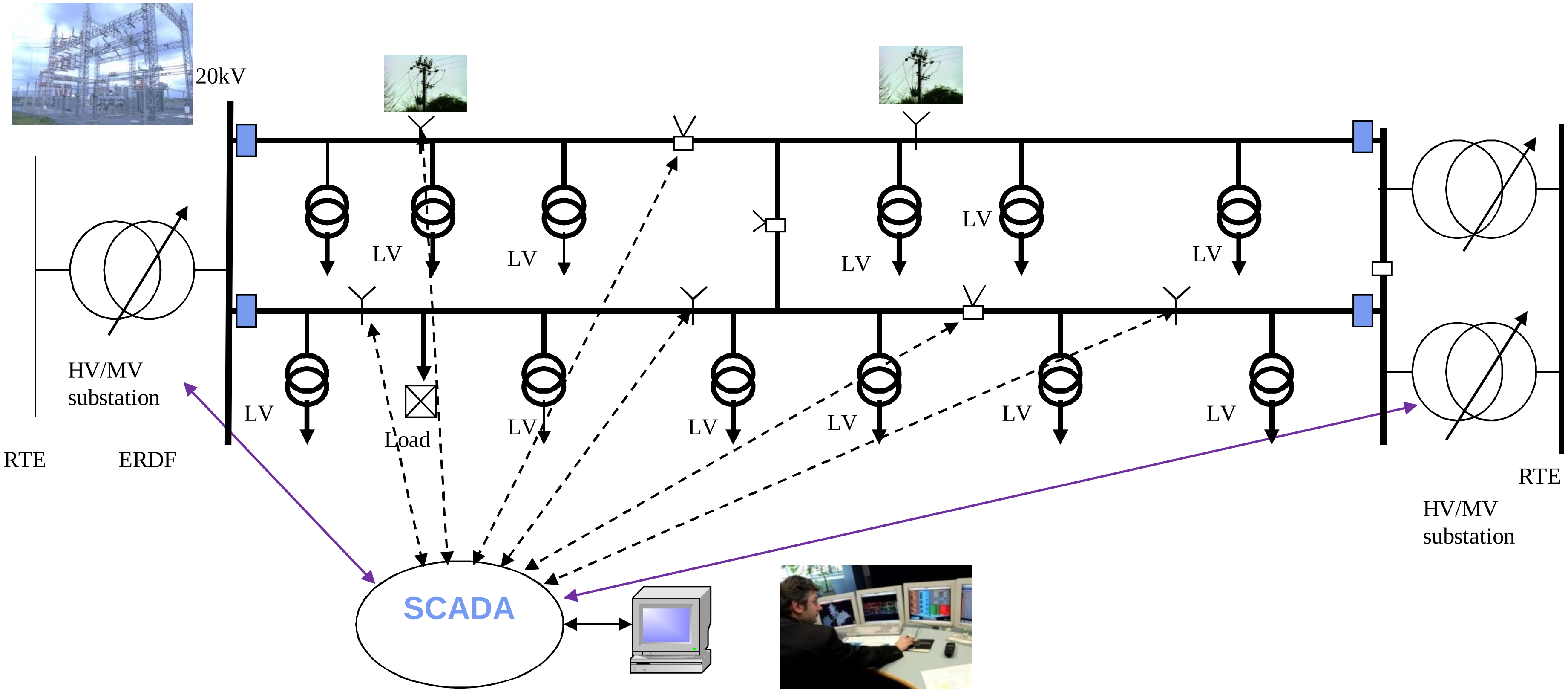
2200 delivery point substations connected to the transmission grid

MV network:

- 596 200 km, overhead : 62 %, underground : 38 %
- 100 000 connection points (P_s > 250 kVA)
- 727 000 MV / LV substations

Automatic Fault Detection, Isolation and Recovery (FDIR): functions implemented in ERDF control centers

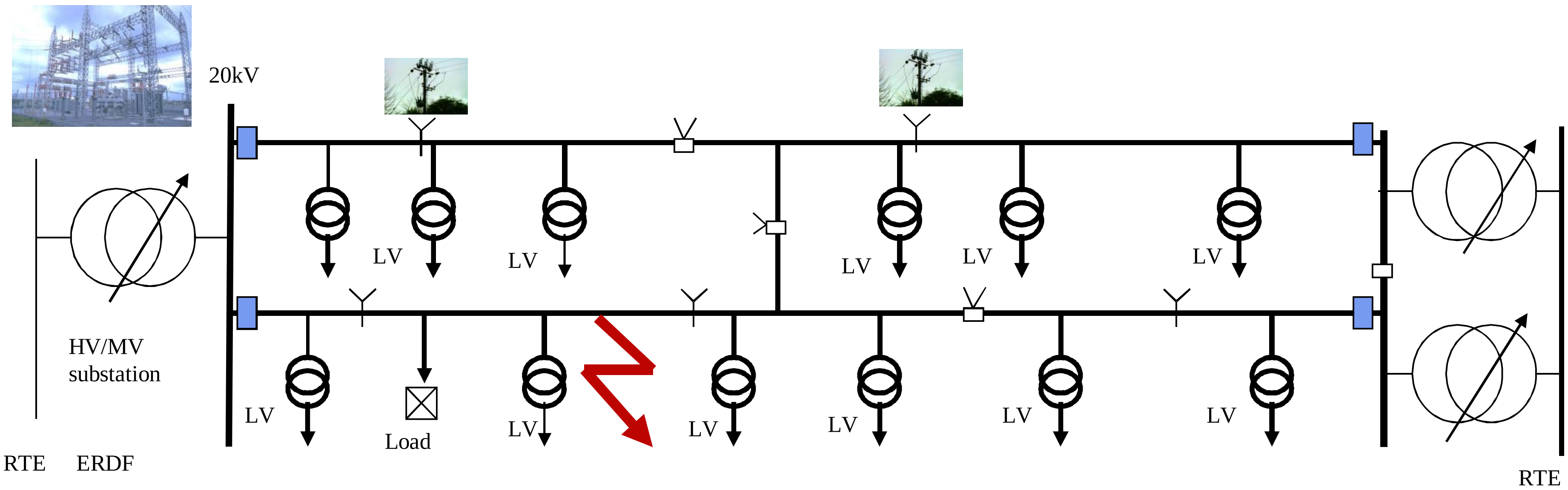
Existing MV network control systems

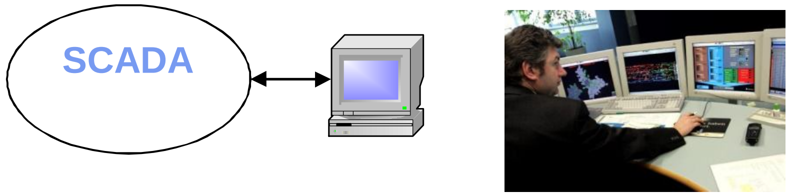


ERDF control center tools:

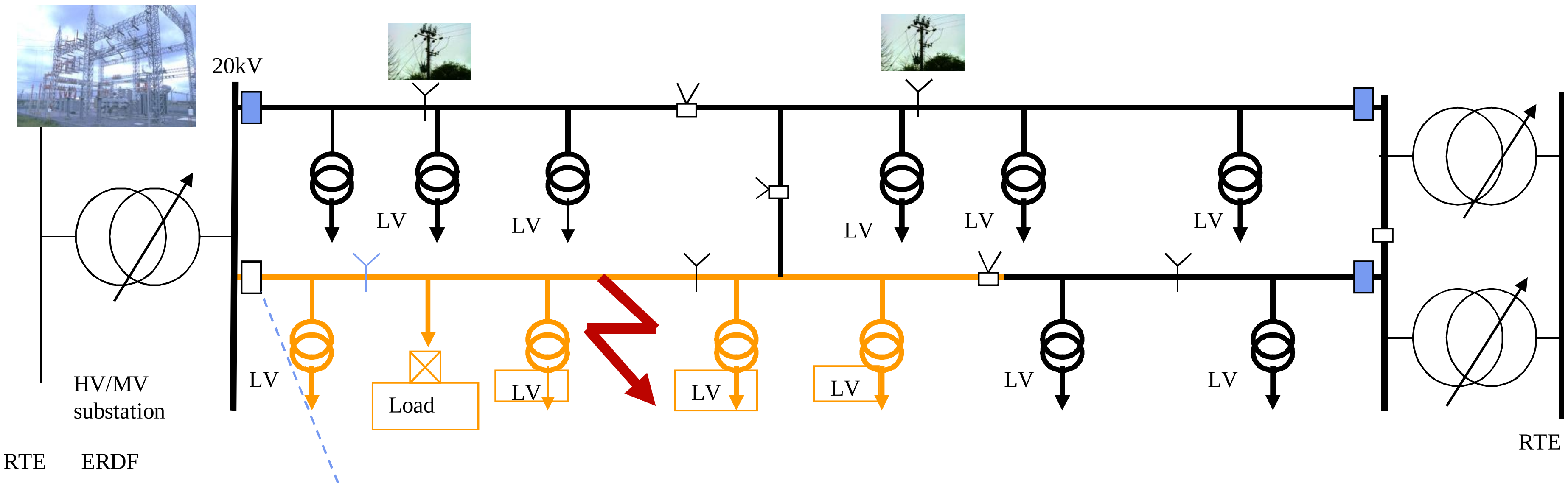
- **In House developed** (by EDF R&D & ERDF) to fully benefit from the internal "network operation" expertise
- **Deeply interfaced with ERDF "proprietary" SCADA system**

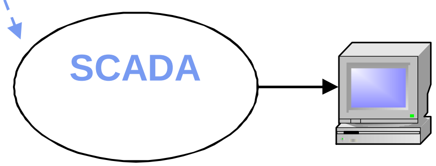
Illustration of the existing FDIR functions

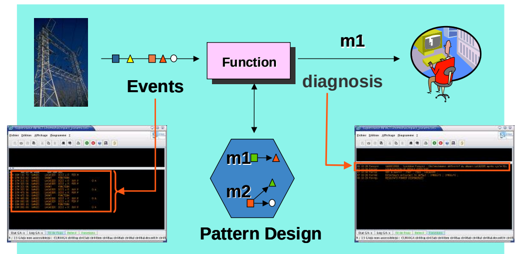




Fault diagnosis after fault occurrence

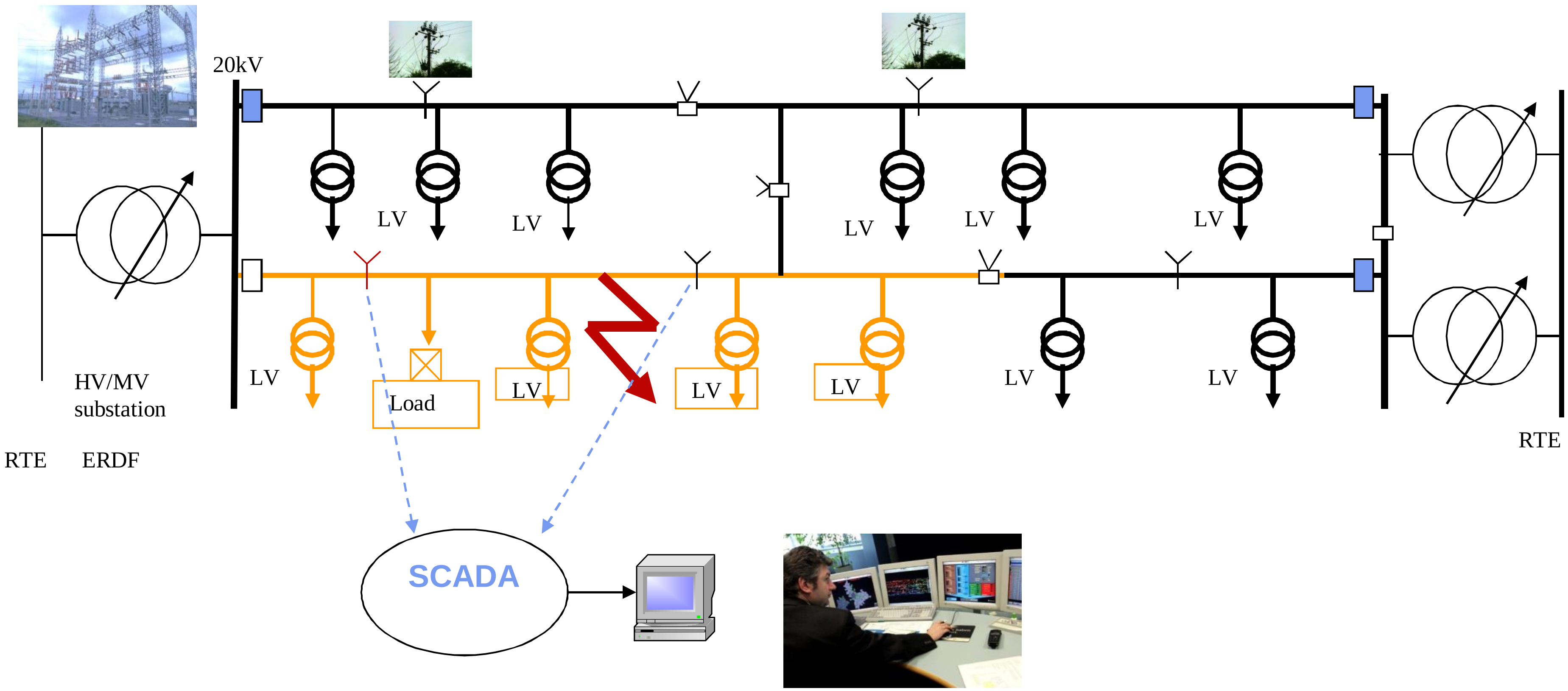






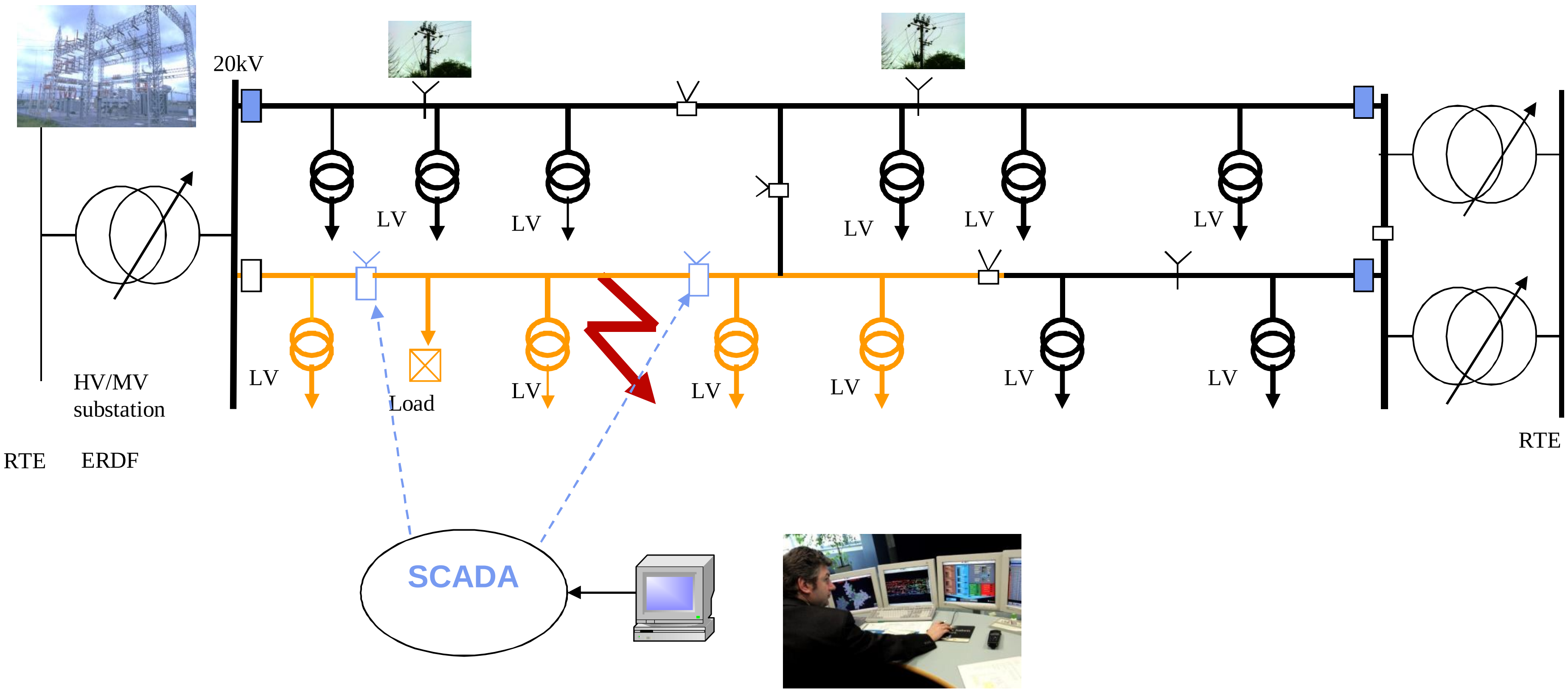
Occurrence of a fault in the MV network: fault diagnosis with FONSYNT

Fault location and isolation in the network



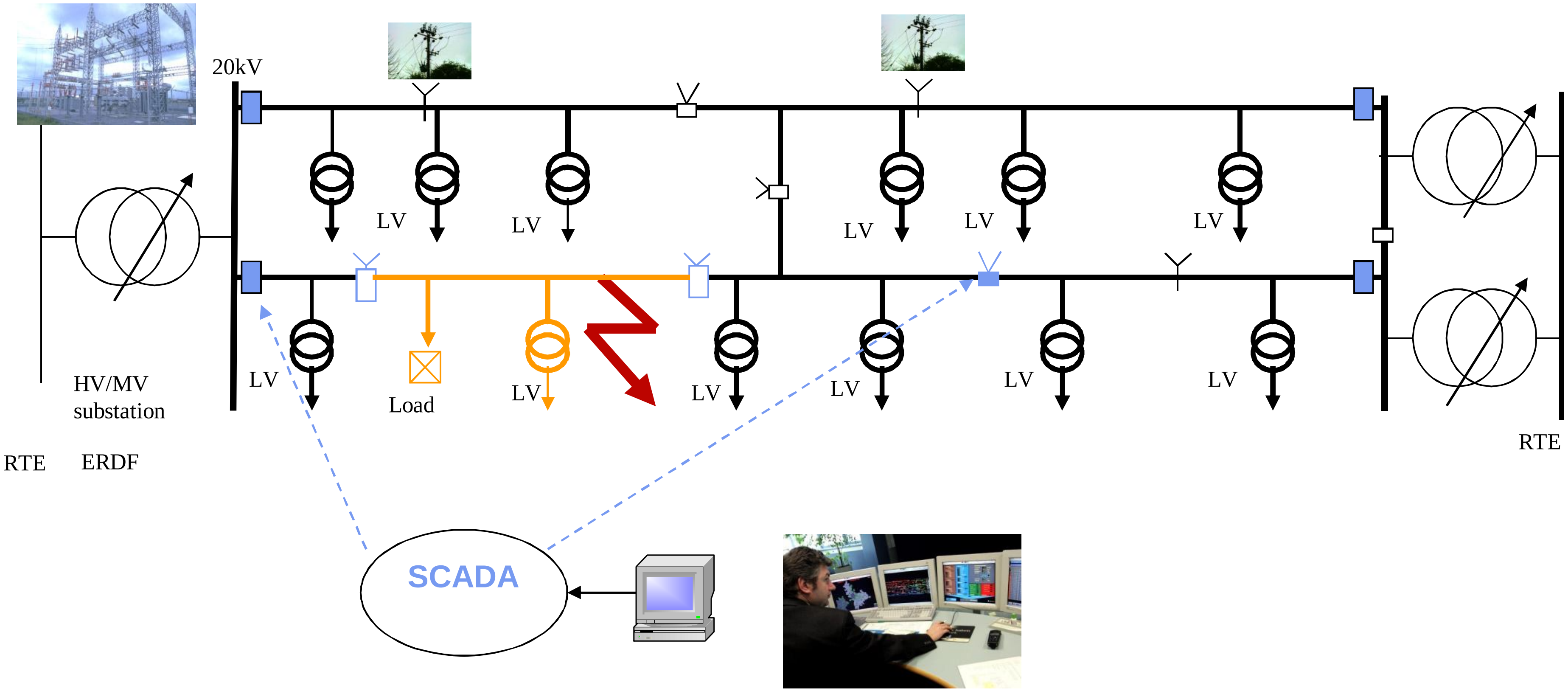
MV protection operation + Information from Fault Passage Indicators (FPIs)→ Fault location and isolation by FONLOC

Fault location and isolation in the network



MV protection operation + Information from Fault Passage Indicators (FPIs)→ Fault location and isolation by FONLOC

Power restoration through network reconfiguration



MV network reconfiguration → Power restoration with FONREP

First Results of the FDIR implementation

ERDF ÉLECTRICITÉ RÉSEAU DISTRIBUTION FRANCE

Efficiency - performance (FDIR deployed in 80% of ERDF' Control Centres)

- 90% of the MV Feeders faults are presently managed automatically
- ➘ of average mean time for restoration : from 3 min (without FDIR) down to 1min30s with FDIR

Security:

- No dangerous situation encountered until now

Acceptability:

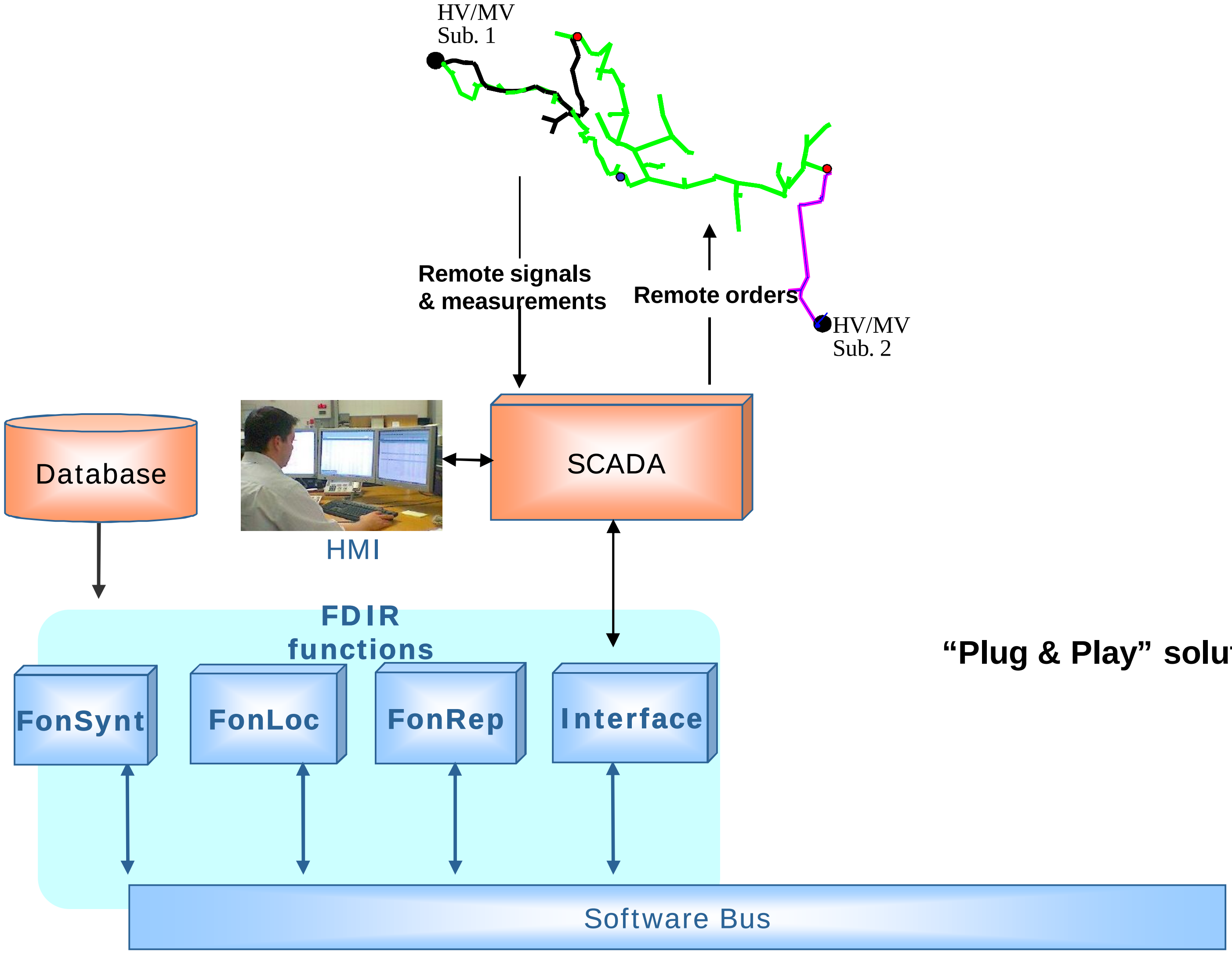
- Well accepted by control center operators

Other outcomes:

- Improvement of telecontrol maintenance due to : Standardisation of Control Wiring, SCADA configuration & related practices
- Focus on the necessary maintenance of FPIs
- Better quality of network description data
- Improved sustainability due to the choice of an open architecture

Early Communication on the project and feeding motivation of end-users is key !

Architecture of the control system



"Plug & Play" solution via SoftBus

Future DMS functions

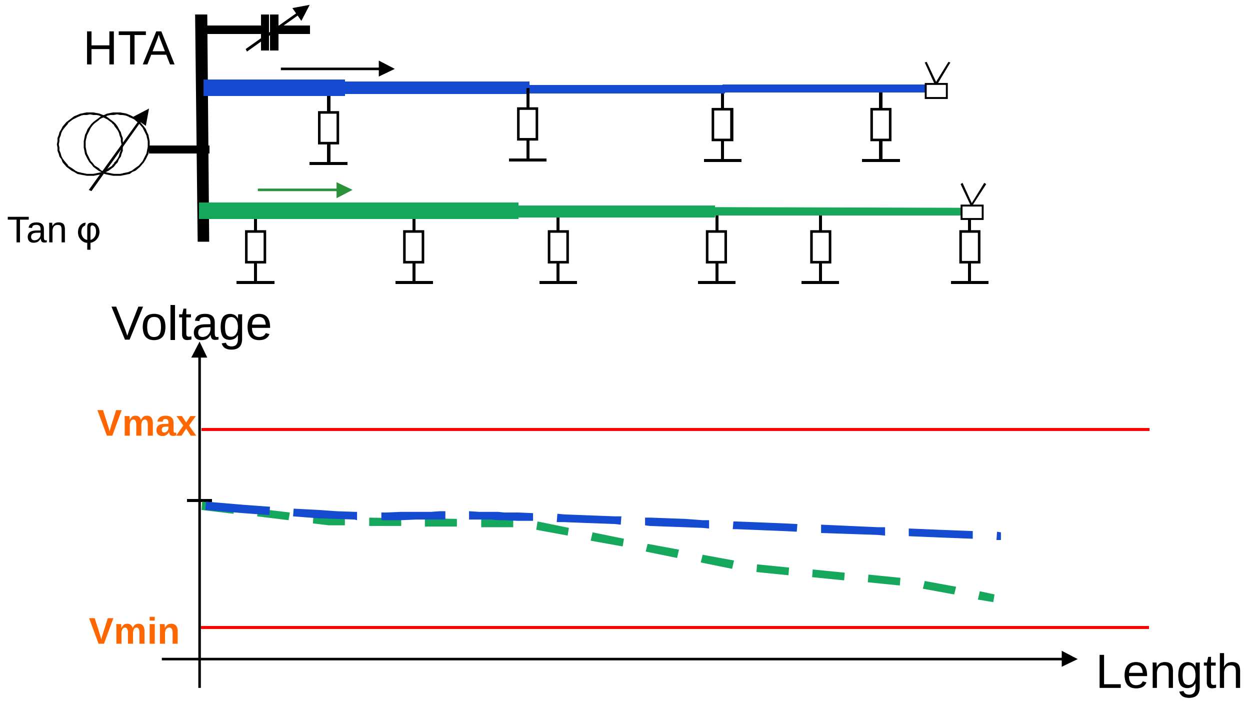
1/ Full integration of distributed resources in DMS

2/ Methodology for the choice of functions

3/ Roadmap

Impact of DG on the MV network

- New constraints and opportunities:
  - Development of DG in the french network (300MW of wind generation in 2005; more than 5GW today, mainly connected to the MV network). The network was not planned for bi-directional flows



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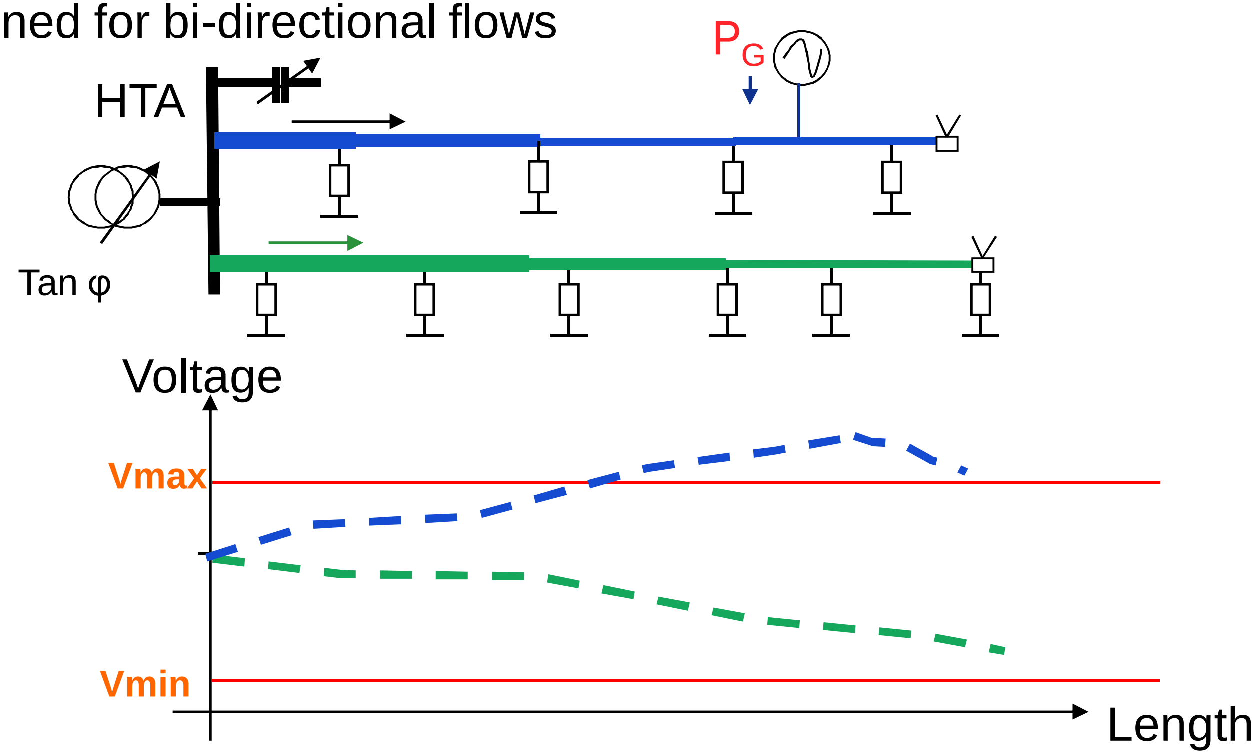
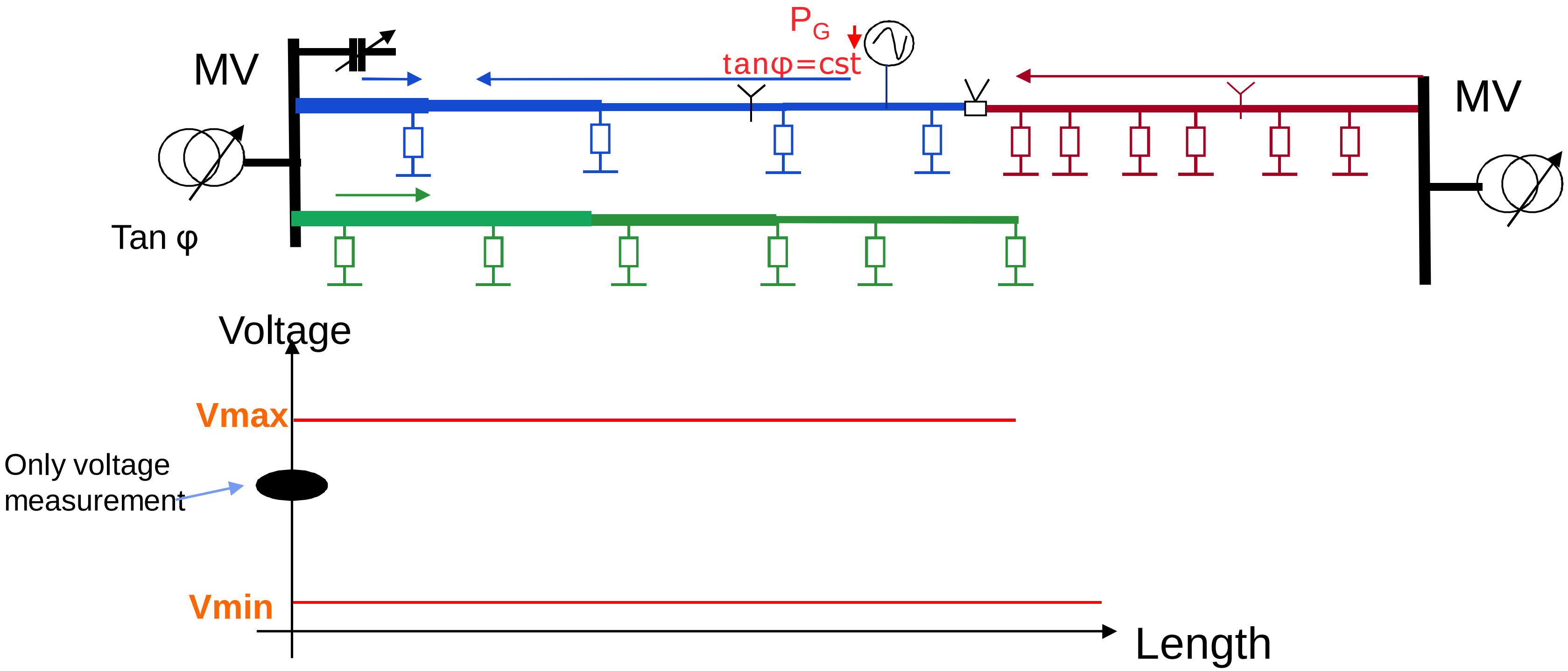
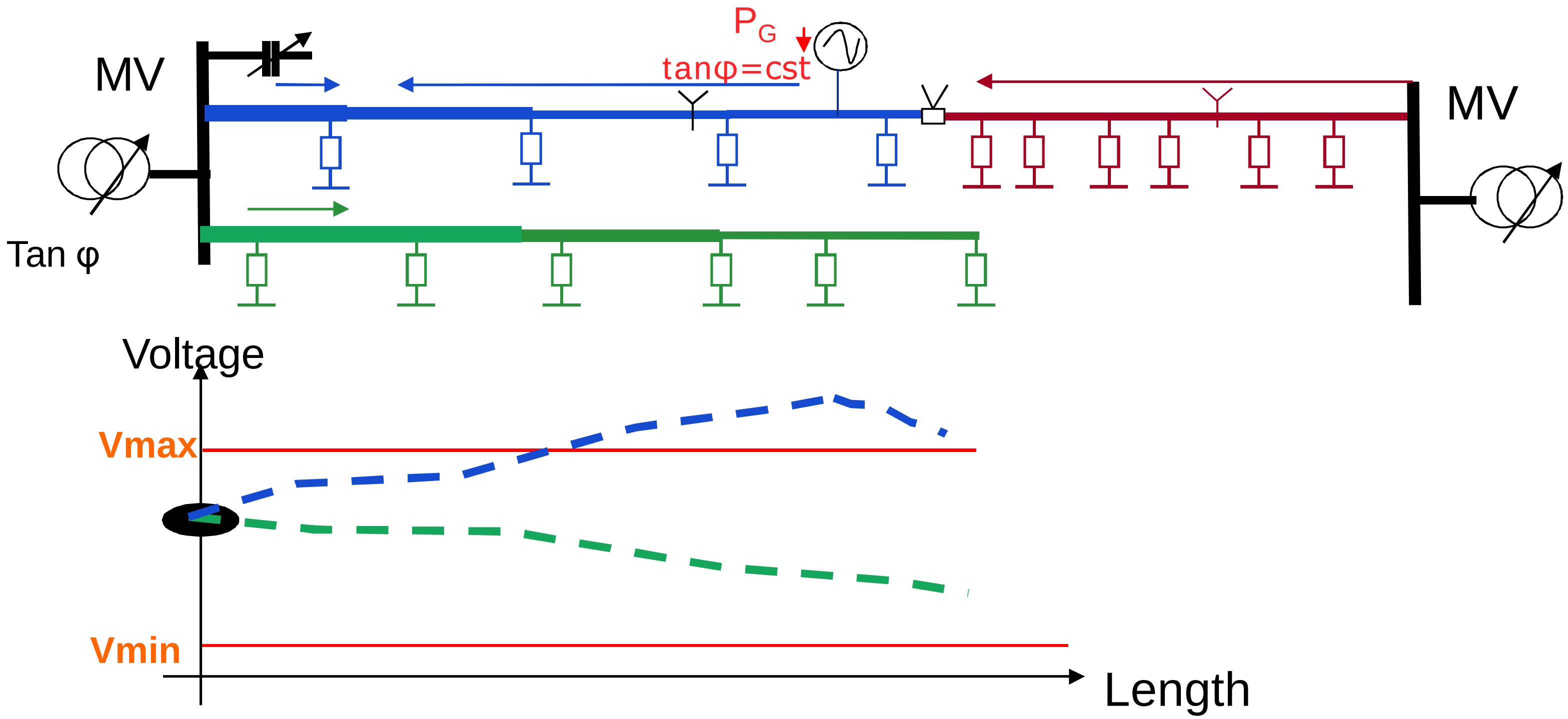


  - Looking for improvement of grid performance (losses, CMLs)
  - In the longer term: Use of Smart meters (Linky/ERDF)

Active MV network: new automation functions

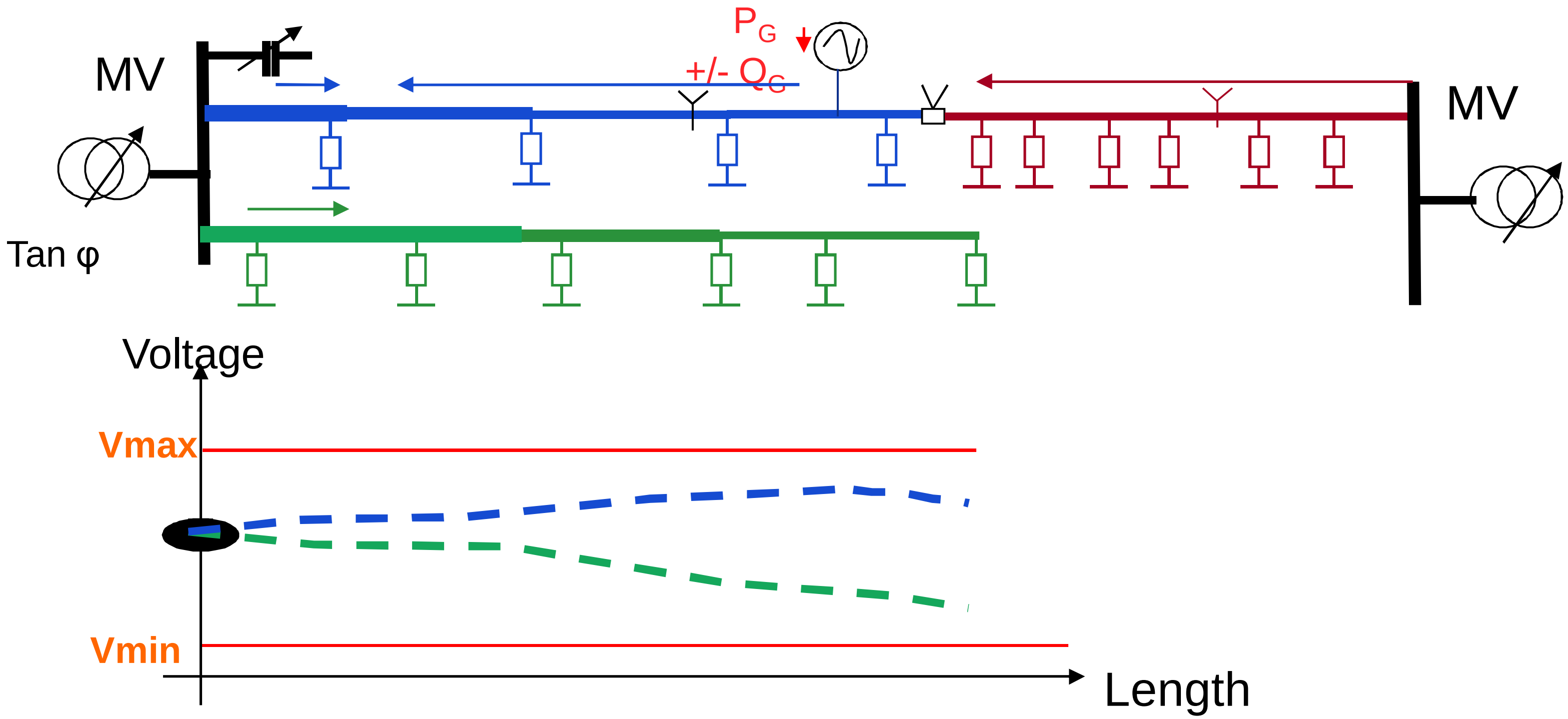


Active MV network: new automation functions



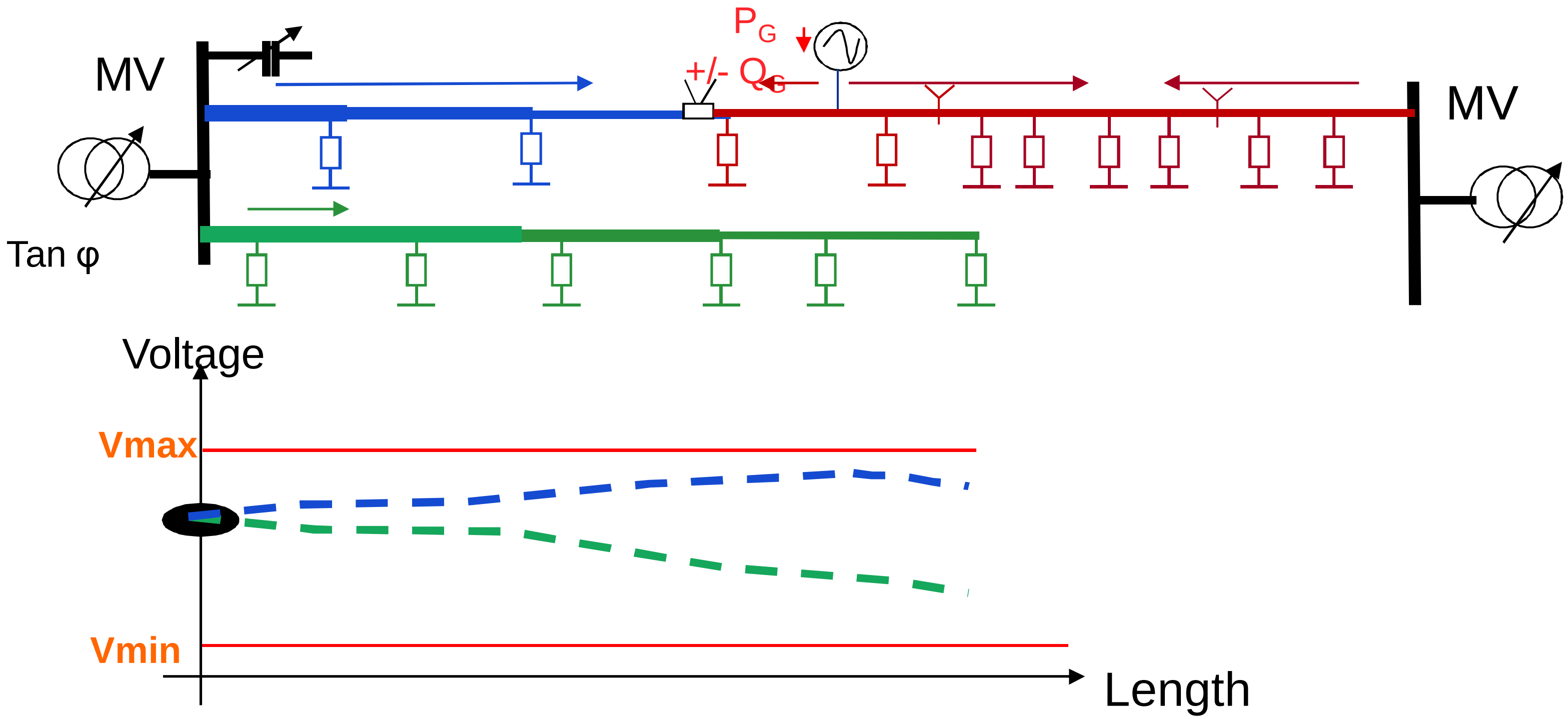
1) Improve MV network observability → State Estimation

Active MV network: new automation functions



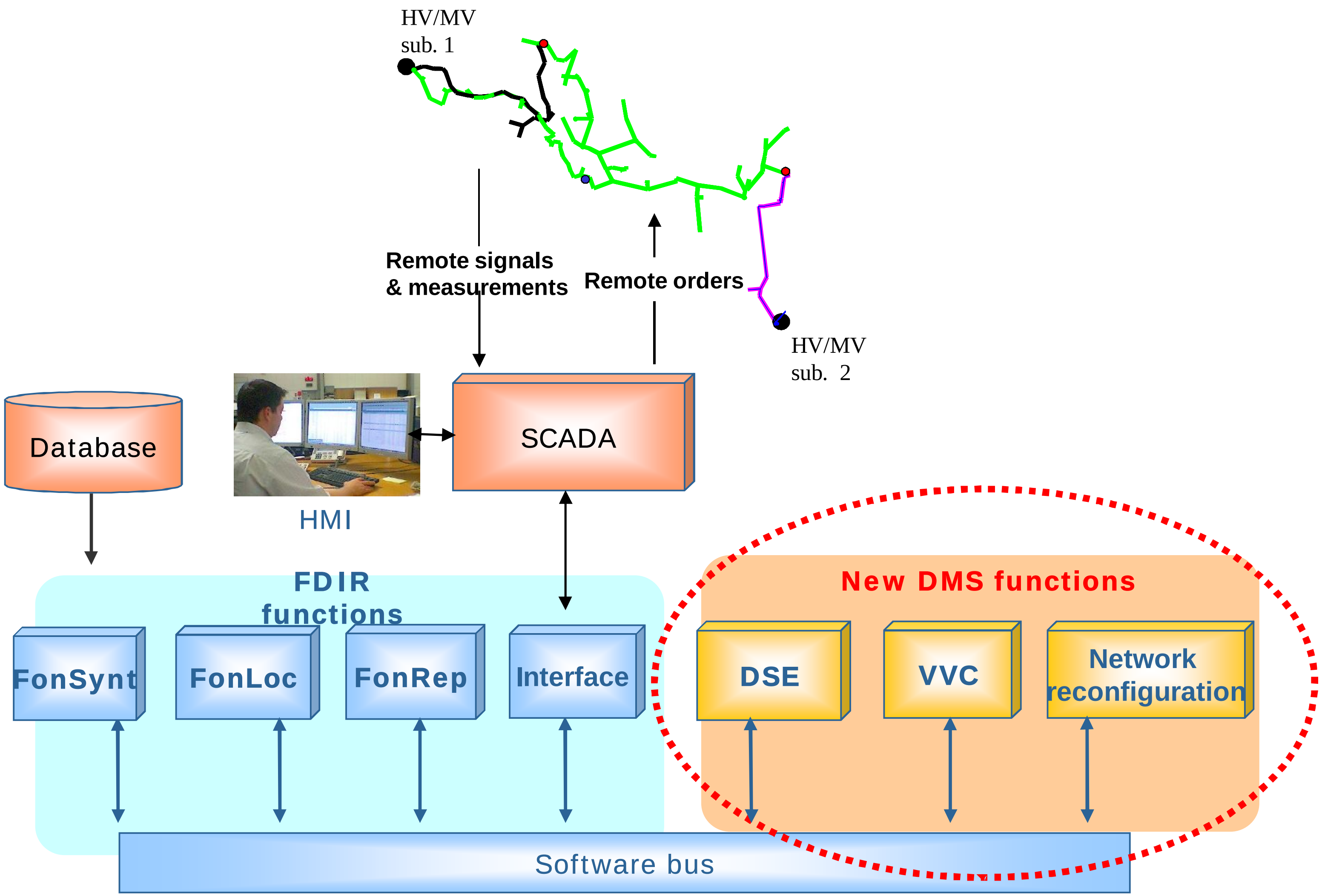
1) Improve MV network observability → State Estimation
2) Voltage regulation function → VVC (Volt Var Control) function

Active MV network: new automation functions



1) Improve MV network observability → State Estimation
2) Voltage regulation function → VVC (Volt Var Control) function
3) Network reconfiguration in steady state for losses and flows optimisation

Control center tools with new functions



Methodology for the choice of new DMS functions

1) Development of algorithms (with Matlab)

- Case studies
- Fine tuning of the algorithm

2) Interactions with existing functions and automation systems

3) Cost benefit analysis

- Define the value of the functions for which type of network/configuration
- **Go or no Go**

Distribution network simulator required

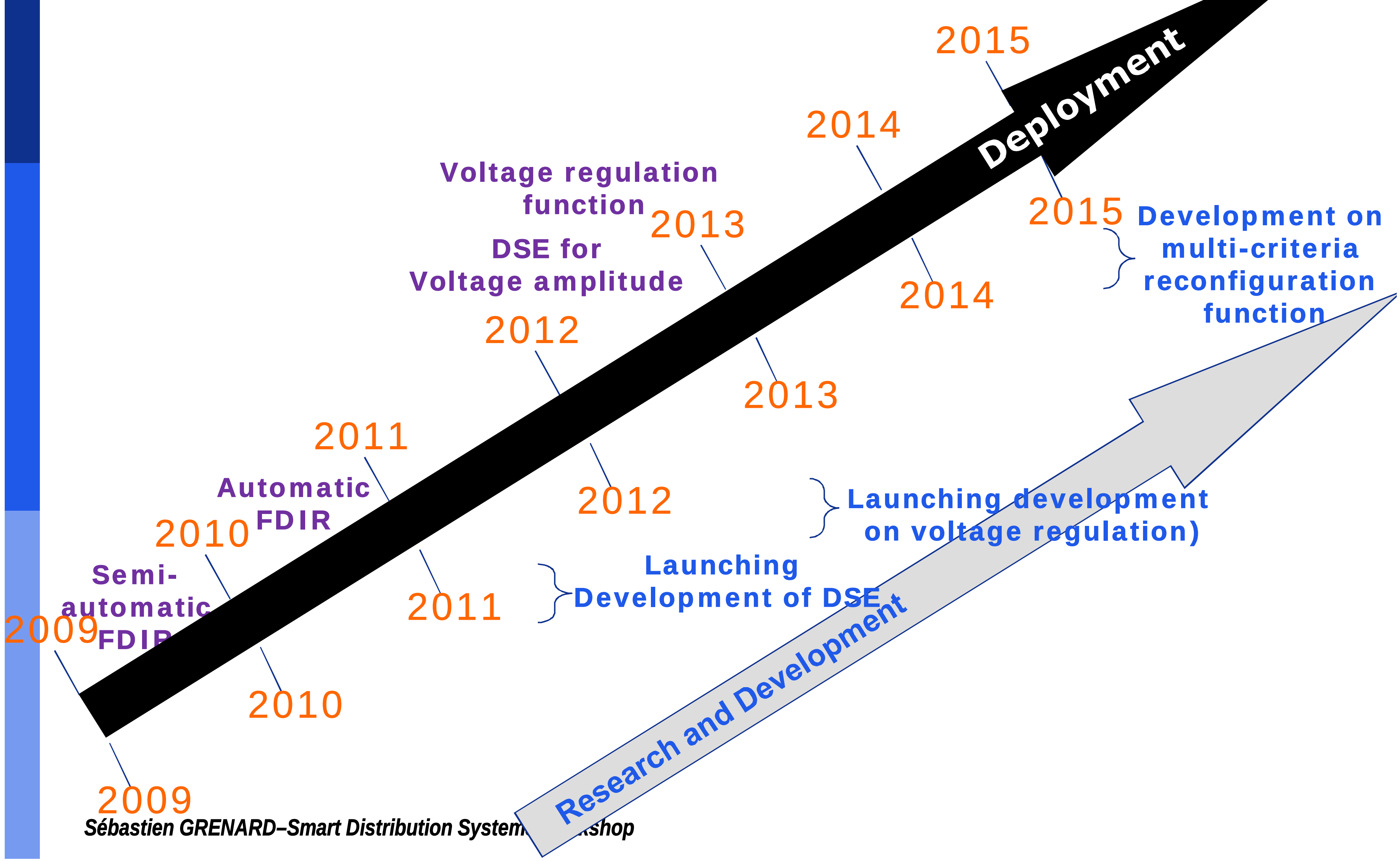
4) Integration with planning policies

5) Function implementation

- Coding the function for use in real-time
- Integration in the real time control tool

6) Field experiment

Outlook to create an active network !

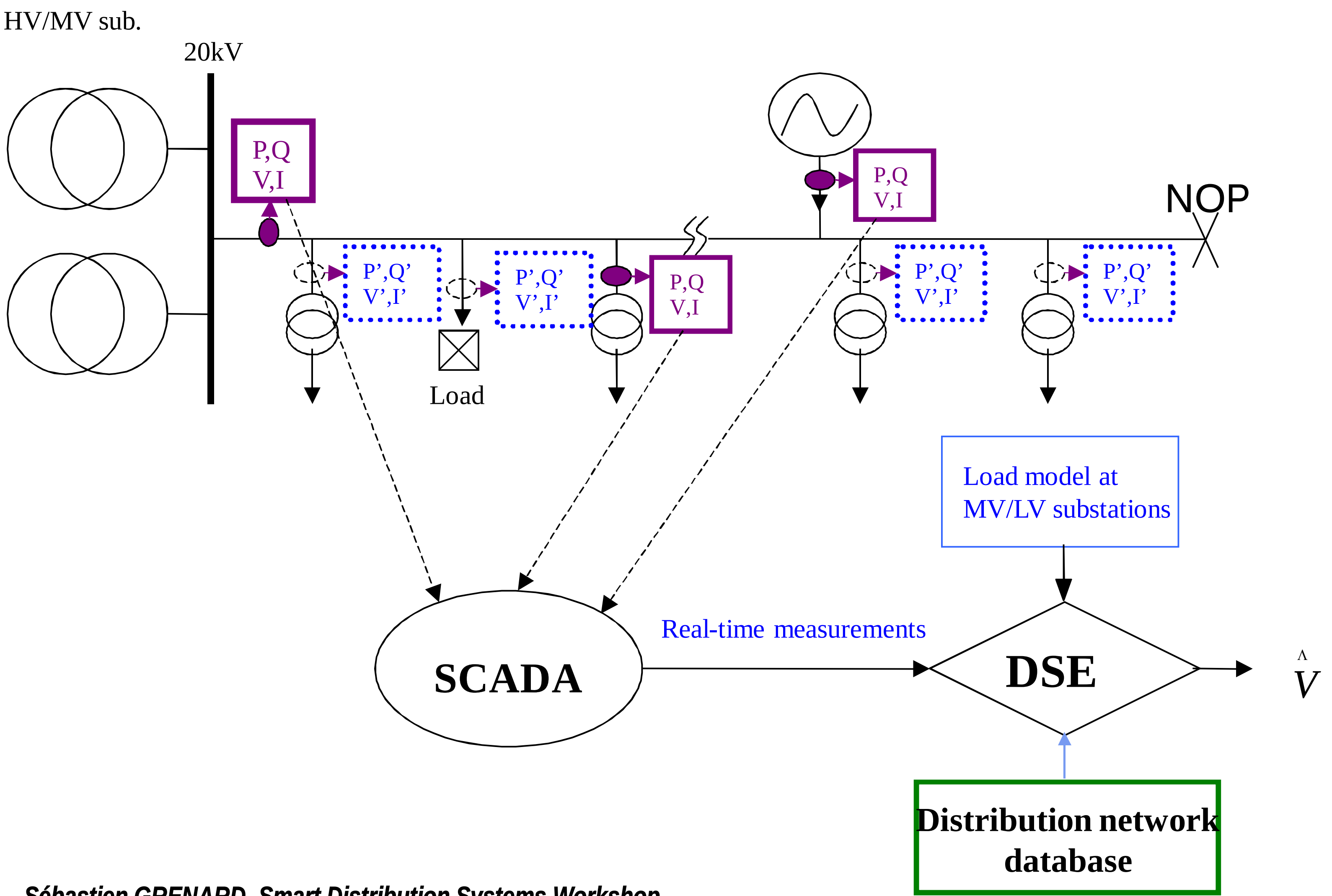


Frankfurt (Germany), 6-9 June 2011

Sébastien GRENARD
EDF R&D (France)
sebastien.grenard@edf.fr

Thank you !

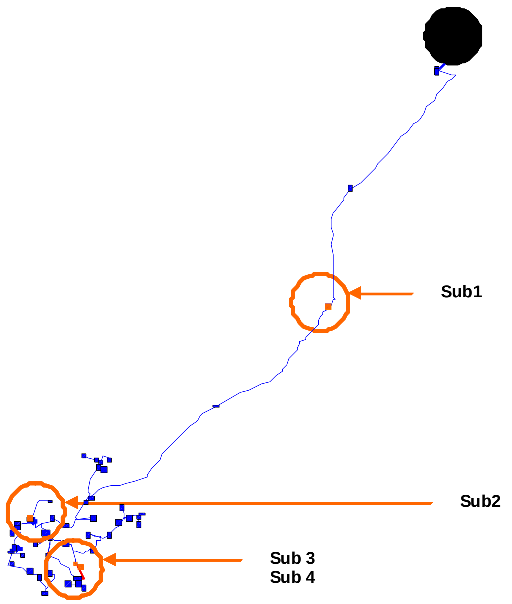
Illustration of the DSE function

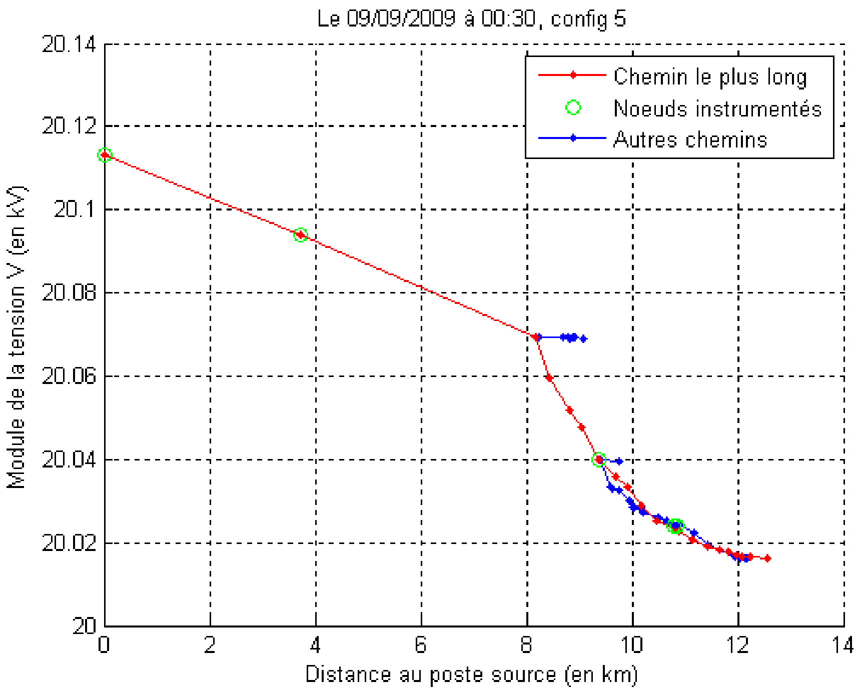


Distribution State Estimation: First off-line field experiment (paper 209)

- Off-line experiment on two MV feeders in the French Network (ERDF)
- Sensors installed in several secondary substations

P,Q, V sensors at the HV/MV substations and 7 sensors in MV/LV substations

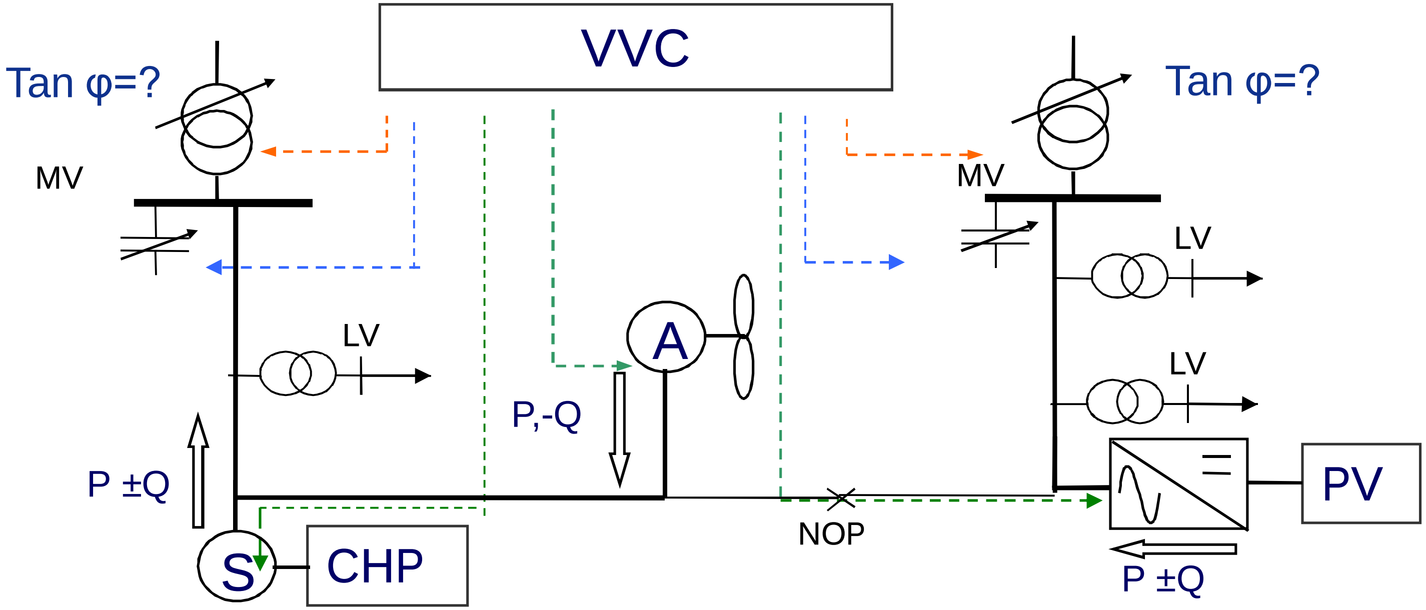




Voltage and reactive power optimal solutions

Objectives of Volt VAR Control optimal solutions :

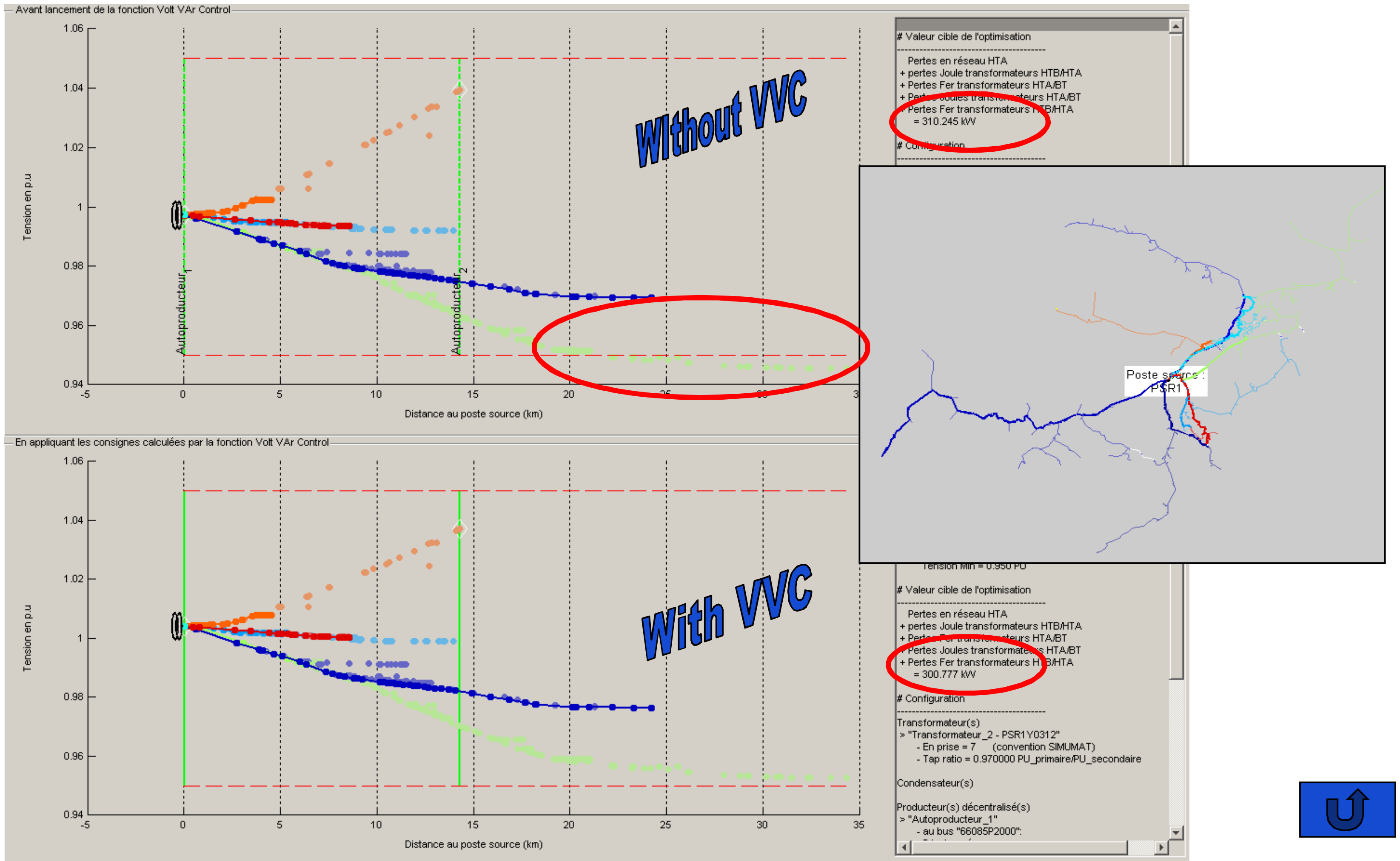
- Maintain voltages within contractual limits
- Optimise other network parameters (losses, power factor at the HV/MV substation, etc…)



First experiment scheduled with ERDF:

- Change the voltage setting value at the MV busbar

Illustration of the VVC results (in Matlab)



Optimal reconfiguration of network

- Objective : optimal reconfiguration to minimize losses, CMLs, number of switching orders. Takes into account DG

Topology

Acceptable U,I

Meshed or not

DG

Closed loop currents (HV ->MV-> HV)

Objective Fonction

Losses minimization

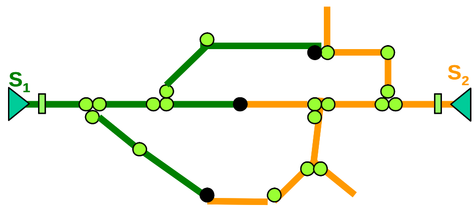
Openning and closure of breaker minimization

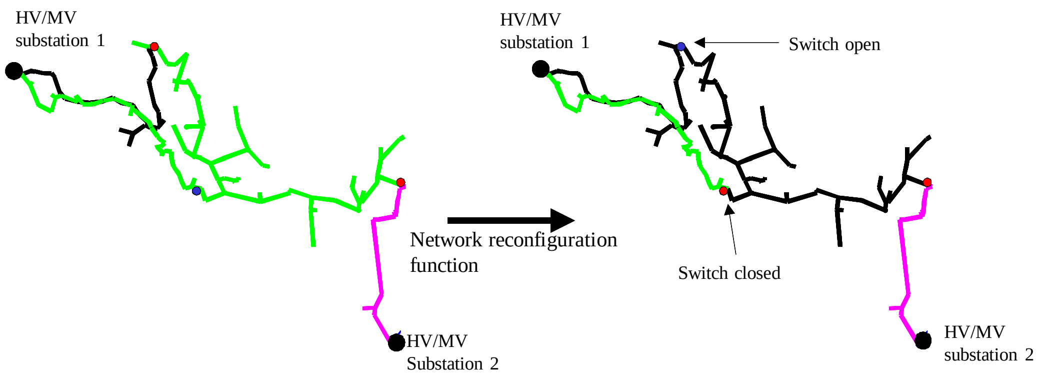
Best voltage profile

Minimization of CMLs

etc.

Optimization methods





Initial network configuration — Optimal network configuration

Frankfurt (Germany), 6-9 June 2011

Integration of Distributed Renewables and Electric Vehicle Charging in Ireland

Andrew Keane

Electricity Research Centre

University College Dublin

Smart Distribution Systems for a Low Carbon Energy Future Workshop

6 June 2011

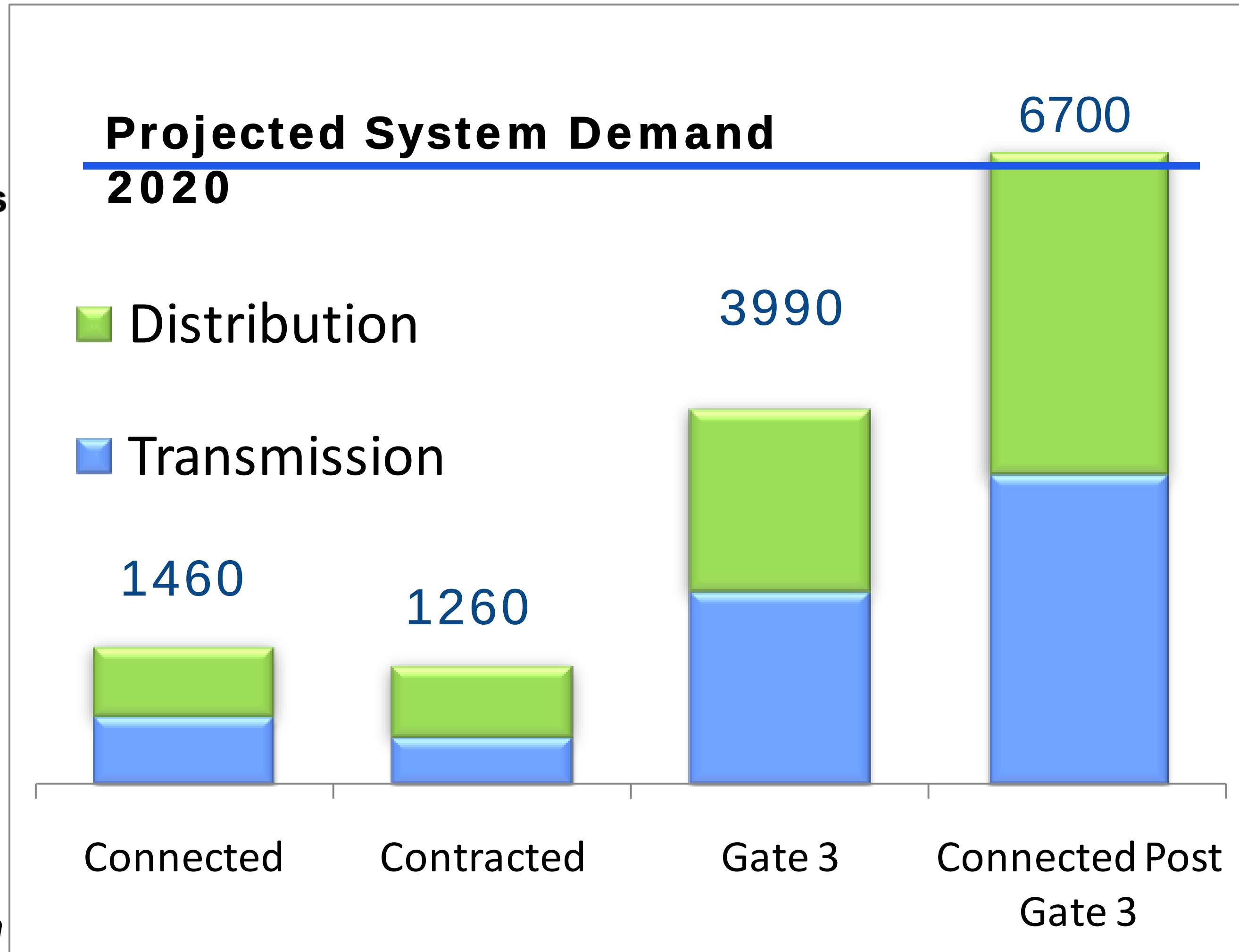
Demonstration Programme Overview

- Wind farm control demonstration
  - Voltage/Var control
- Electric vehicle trials
  - Network impact
  - Charging and usage data
- ESB Networks (Irish DSO), EPRI and UCD

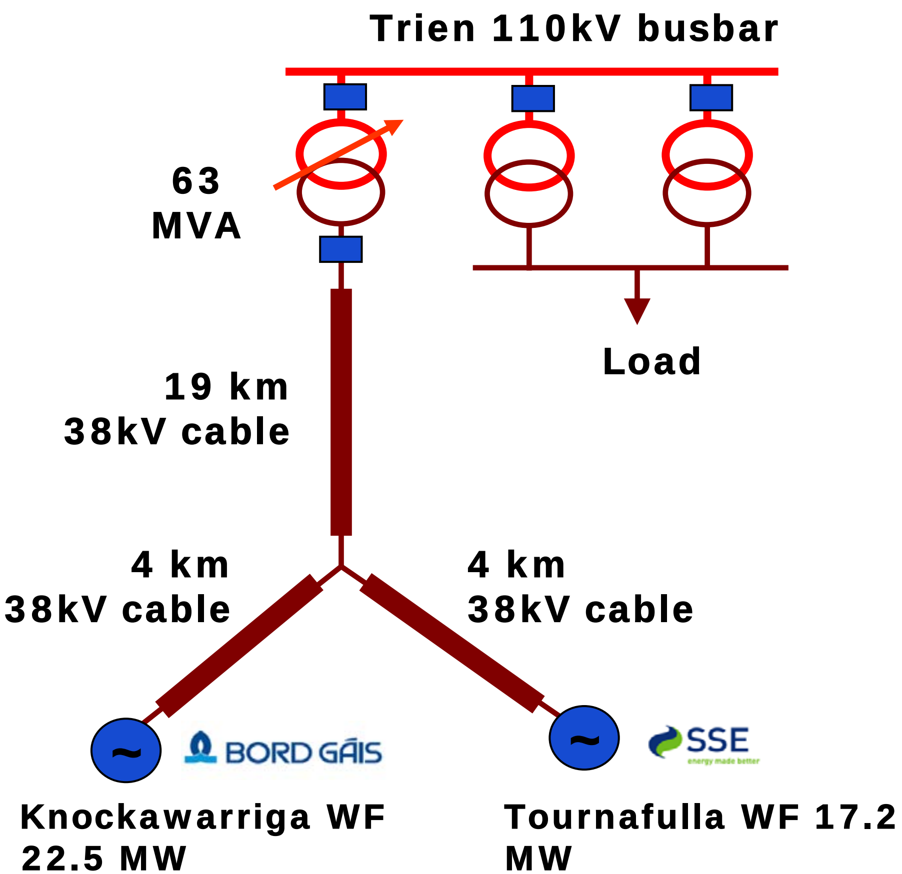
ESB Networks Wind Demonstration Project

- Exploration of Voltage / Var control on Distribution connected wind farms
- Use of voltage regulators to limit voltage rise
- Single transformer cluster stations for wind farms
- Can we maintain distribution system within limits and aid system security?

Ireland Wind Connections (MW)

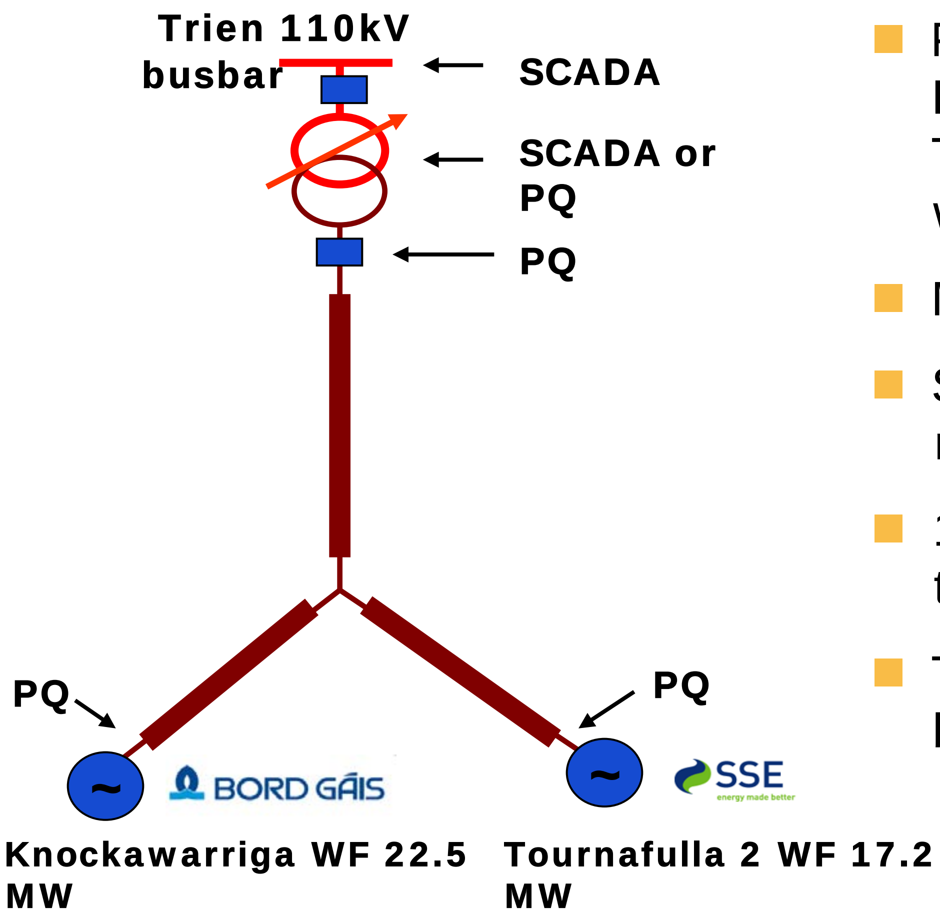


Project site and approach



1. Measure baseline data
2. Determine V control parameters
3. Switch Knockawarriga into const. voltage mode
4. Switch Tournafulla 2 into const. voltage mode
5. Switch both wind farms into const. voltage mode

Set-up of measuring equipment



- PQ meters set up at Knockawarriga, Tournafulla and Trien at 38 kV with 30 sec interval
- Measuring inter alia P, Q, V_{ll}, I
- Some problems being fixed at the moment (gaps in data)
- 110 kV voltage in Trien available through SCADA system
- Tap changer pos. to be picked up by PQ meter in Trien

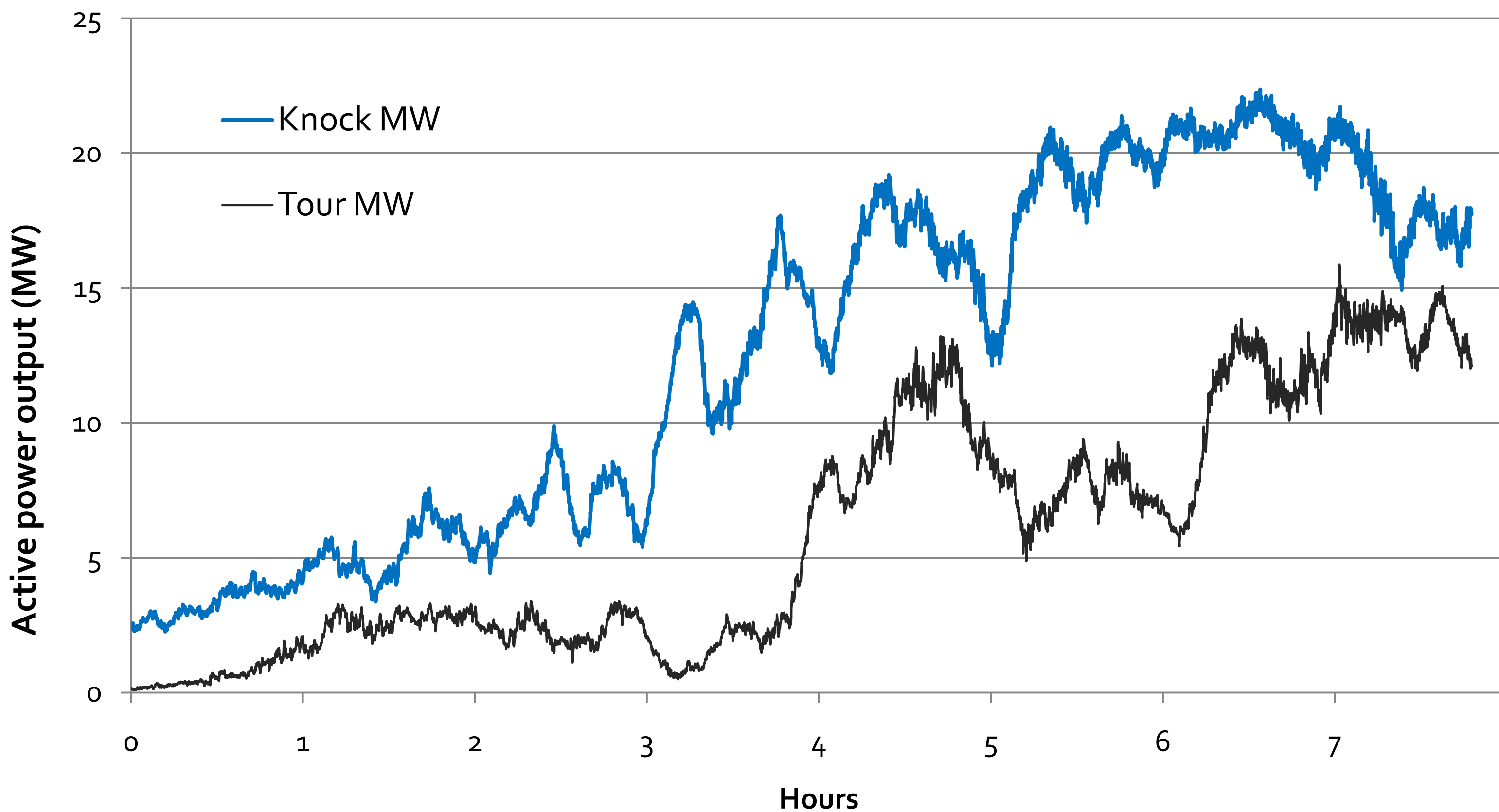
Simulation Study Methodology

- Transmission network represented by impedance to remote source at Trien 110 kV
- Every combination of wind farm outputs
- 1 MW steps

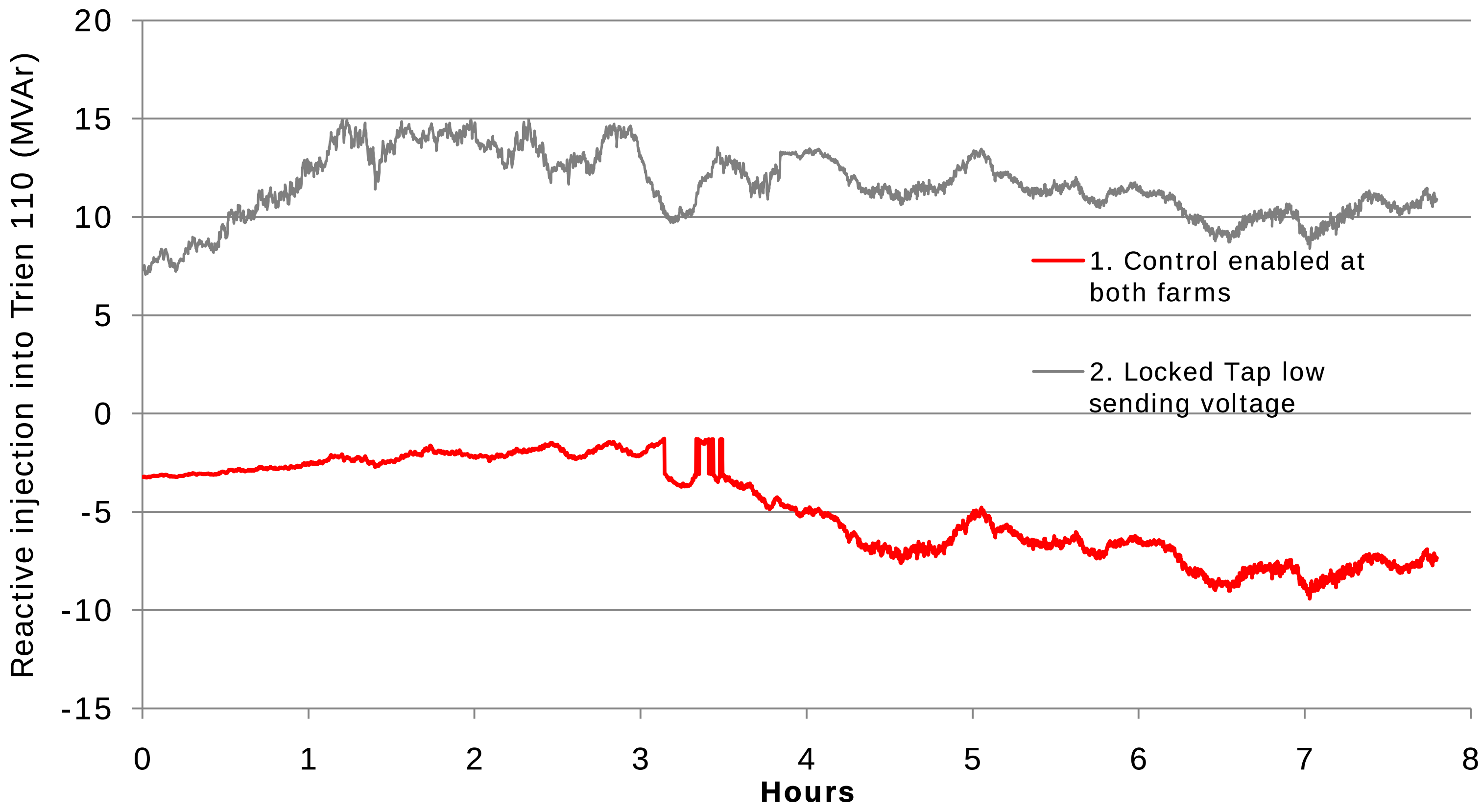
Study Cases

- Multiple voltage control scenarios modelled
- Variables: control at each farm and tap changer
  1. Both farms regulating voltage to 41.6 kV
  2. Tap locked to low sending voltage, both wind farms regulating voltage to 42.2 kV

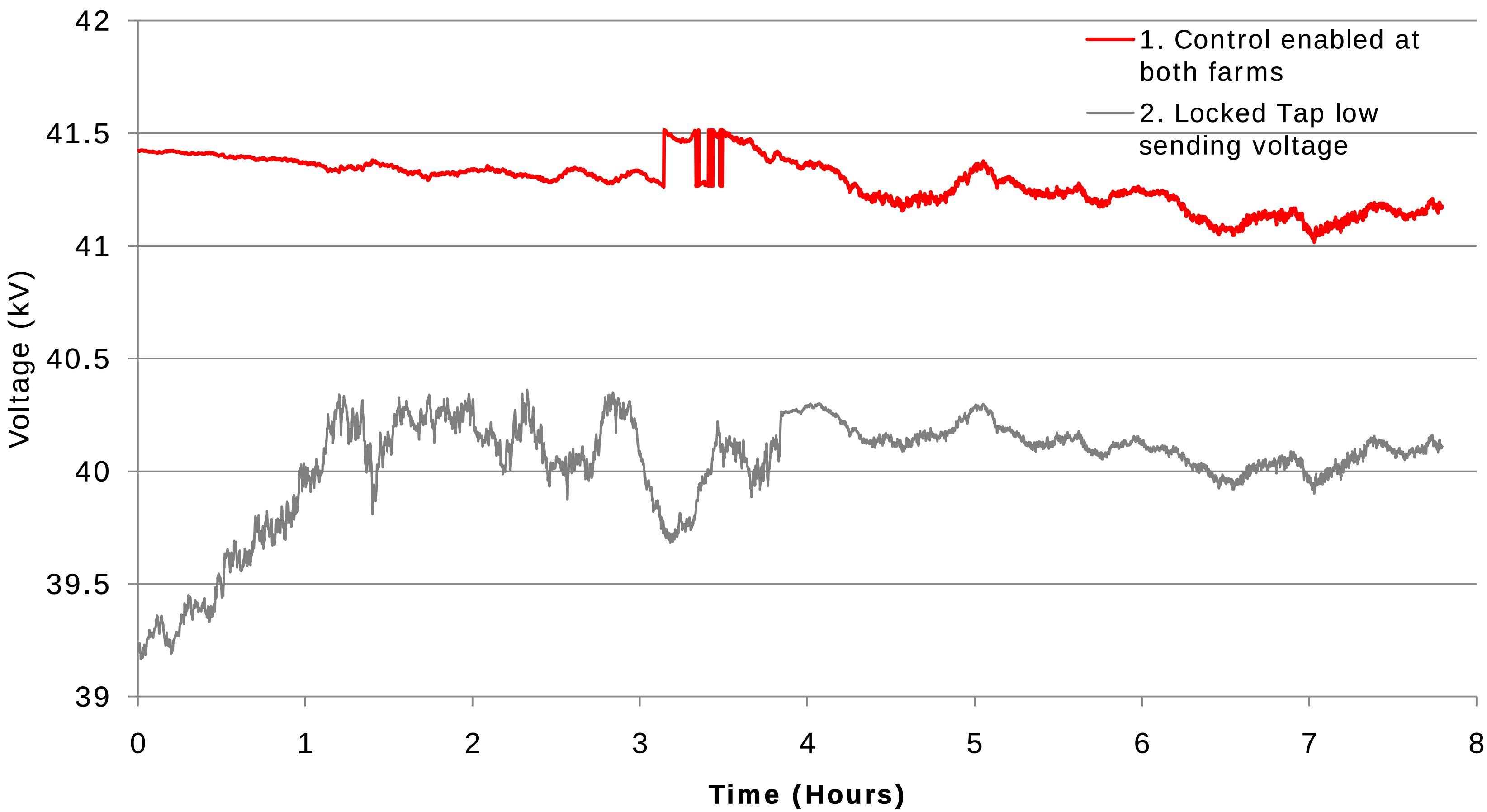
Time Series Analysis



Time Series Analysis



Time Series Analysis



Summary

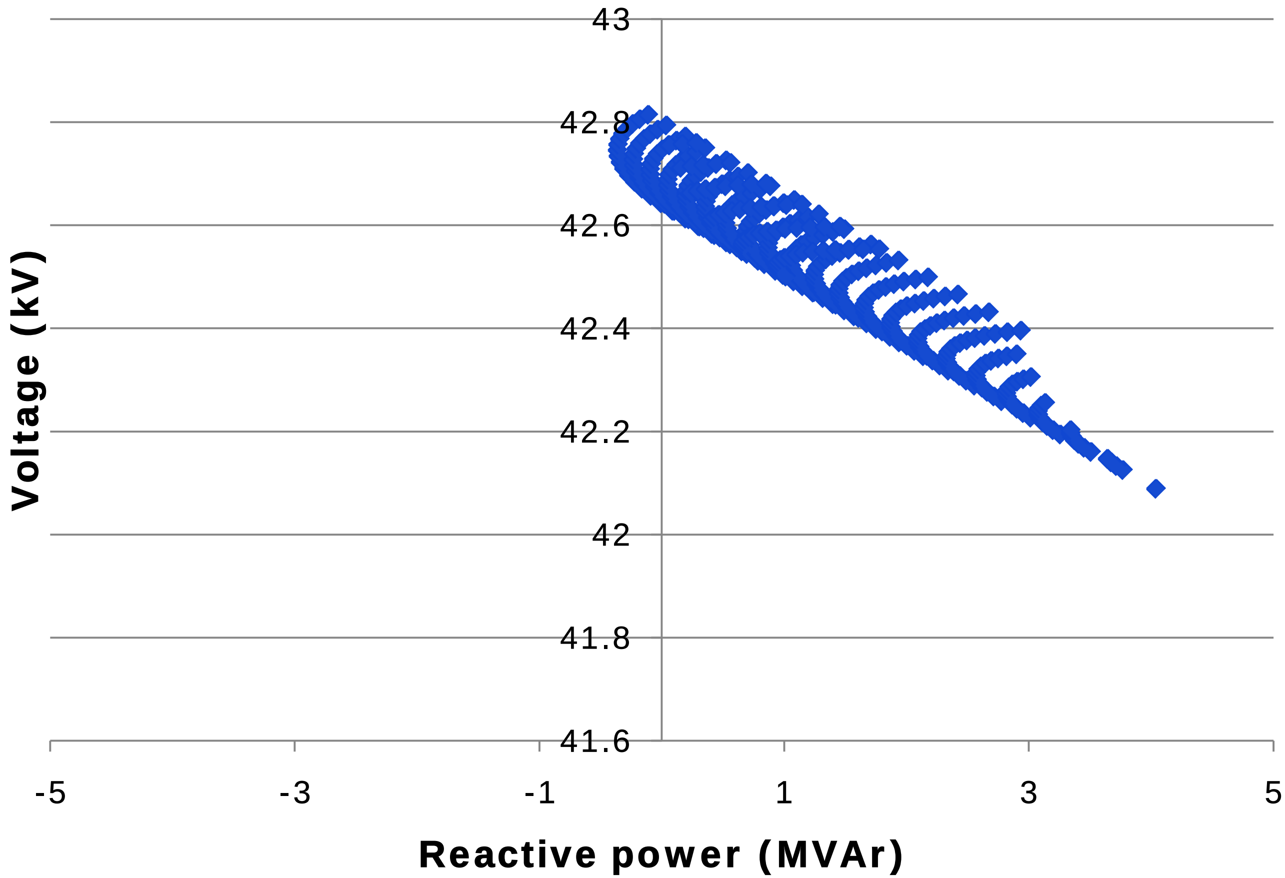
- When tap changer not locked, voltage did not vary enough to cause tap change
  - Control devolved to the wind farms, which keeps the voltage profile relatively flat

- Selection of sending voltage and enabling voltage control can free up voltage headroom to allow export of reactive power to transmission system

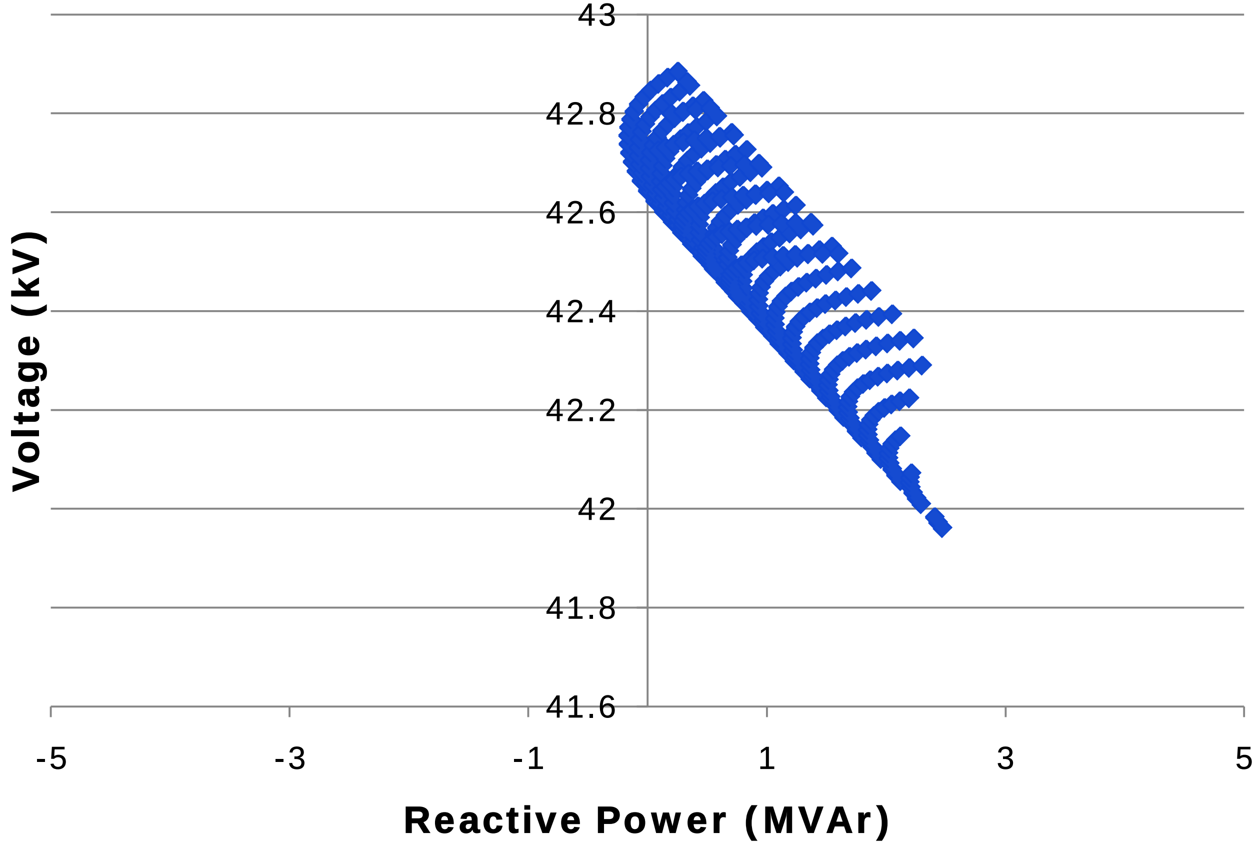
Droop Settings

- Choice of droop determines acceptable range of voltages
- 0% common for simulation but not practical for real systems
- Important for coordination of multiple controllers

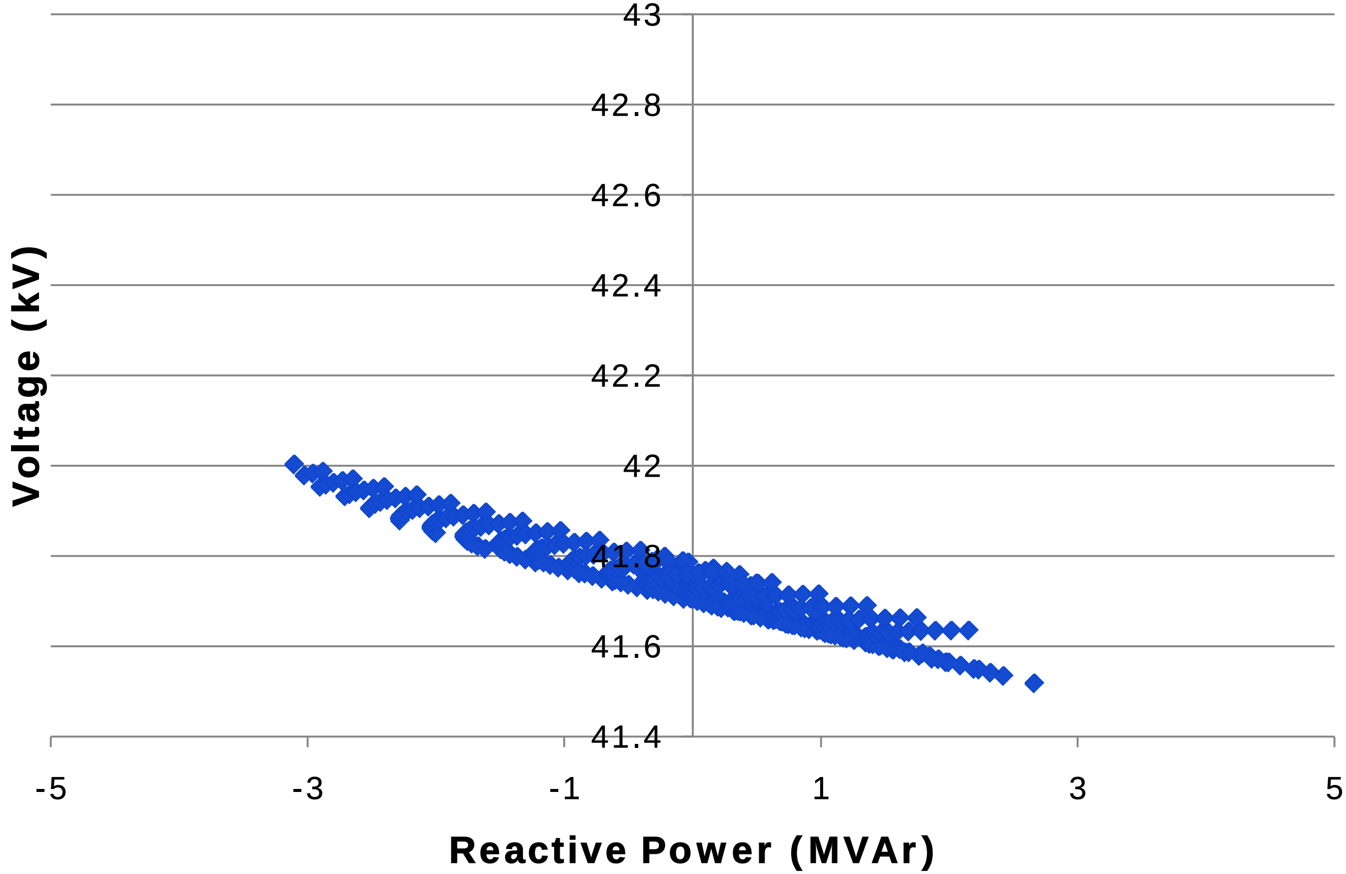
42.6 kV, 2% Droop



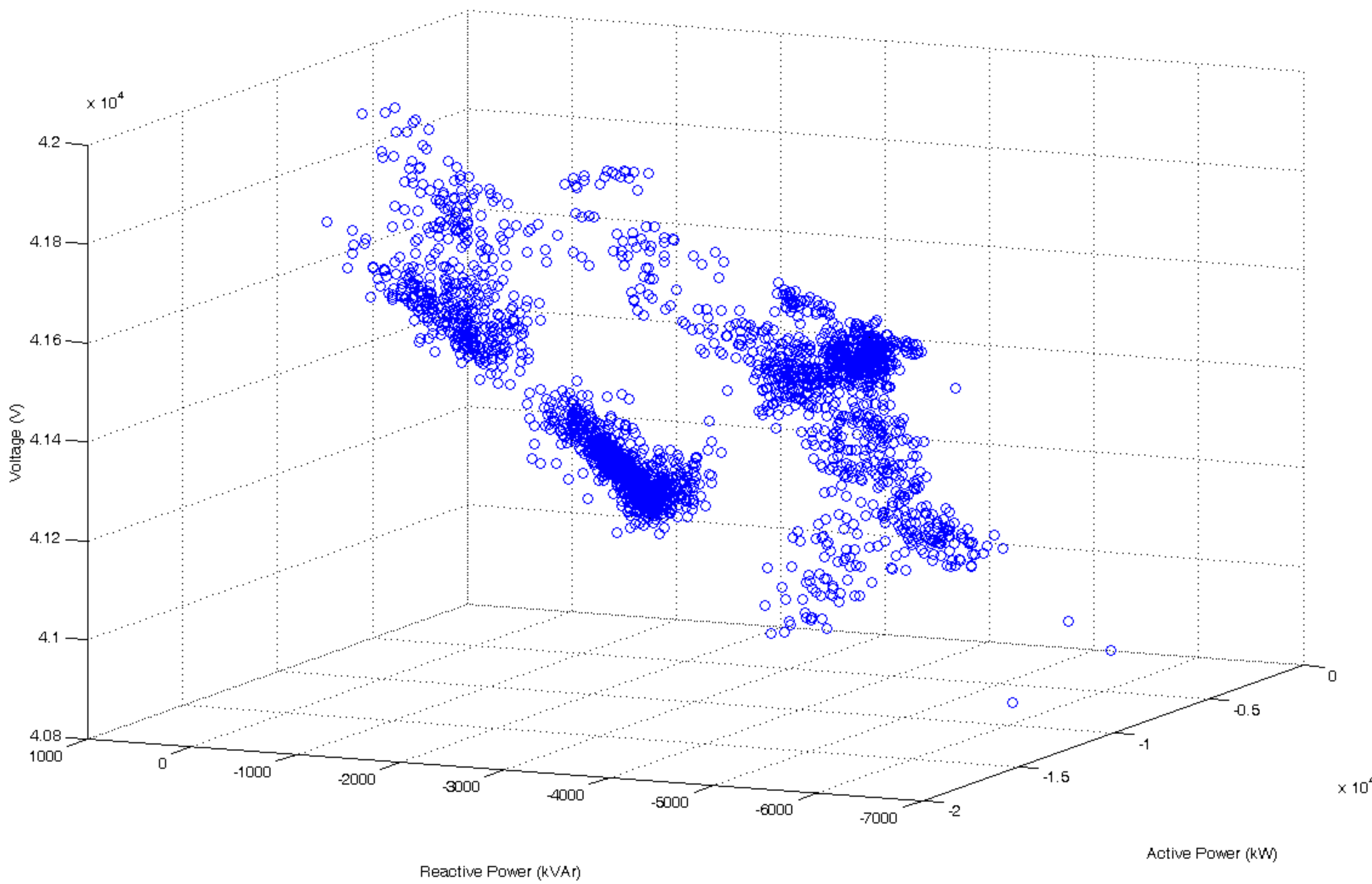
42.6 kV, 4% Droop



41.7 kV, 1% Droop



Initial Trial Results – Knockawarriga 4% Droop, 42.4 kV



Summary

- Aim to reconcile the requirements of distribution system with those of transmission system
- Can control voltage locally
  - Can we also export reactive power to transmission system effectively?
- Dynamic response requirements?

Future Plans

- Can we establish a standard framework for DG wind to control voltage locally and support system?
  - Coordinated Control
  - Droop sensitivity
  - Tap changer interaction
  - Transmission voltage changes

Electric Vehicle Trials

ESB ecars Programme

- Government targets 2020:
  - 10% of all vehicles electric
  - 10% of all road energy transport

  will be renewable
- Early supply of electric cars
  - MOU signed with Renault-Nissan, Mitsubishi, PSA
- Government incentives
  - €5000 grant
  - Zero VRT
  - Lowest road tax band
  - Accelerated Capital Allowance
  - Government taskforce

Nationwide infrastructure by end 2011

1,500 Public Charge Points

- Dublin & County 500
- Cork 135
- Limerick 45
- Galway 45
- Waterford 45

At least one charging point for every town < 1500 population

30+ DC Fast Chargers

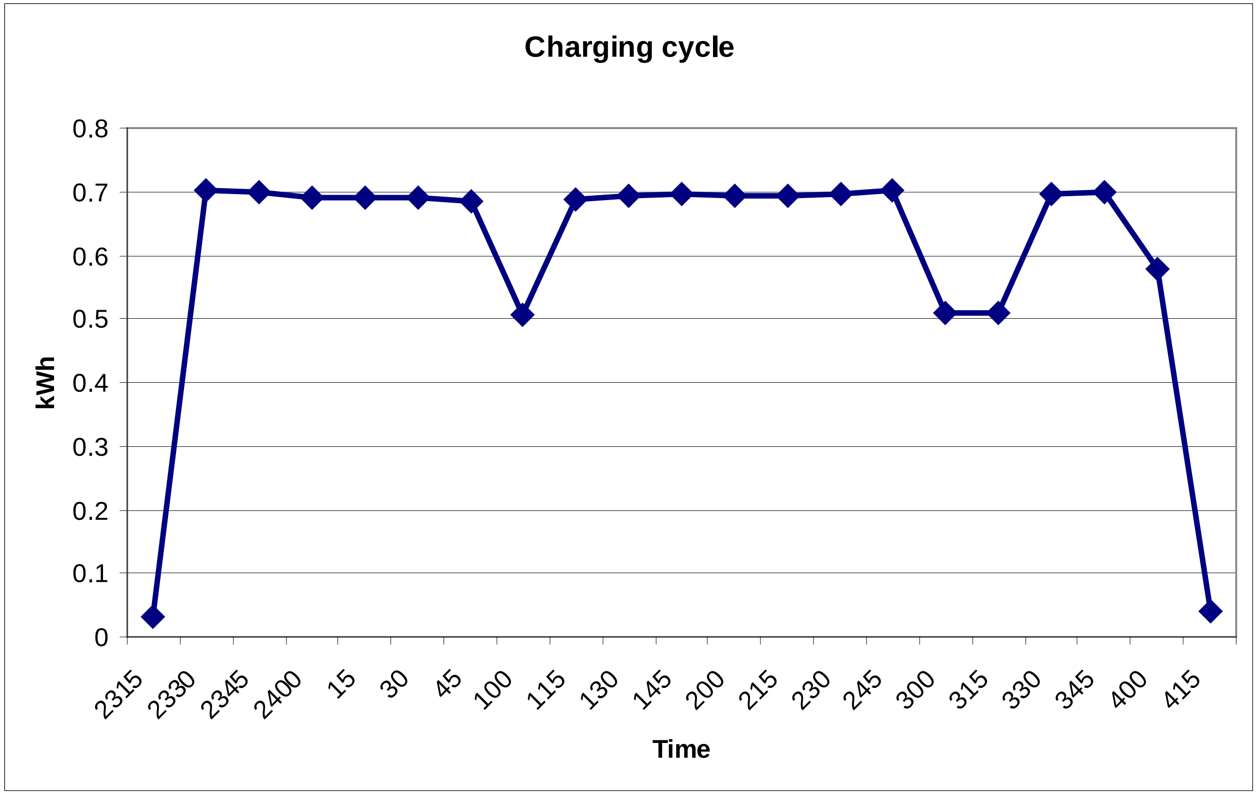
2,000 Home Chargers

Test Network - Roebuck Downs, Dublin

- Suitable for trial:
  - Outdoor accessible meter box
  - Primarily owner occupier
  - Drive way for dedicated parking

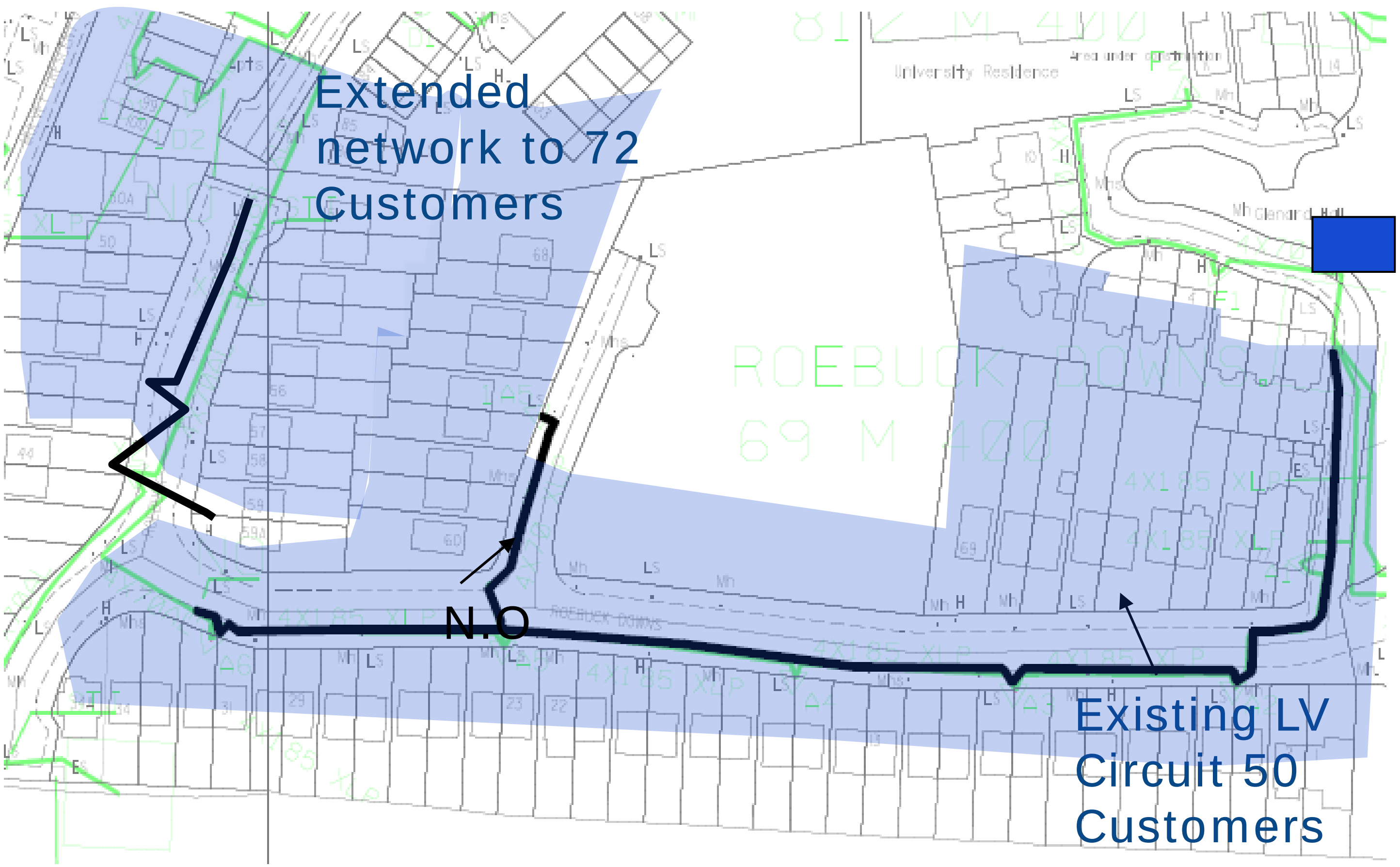
Home Charge Point

Smart Meter Data

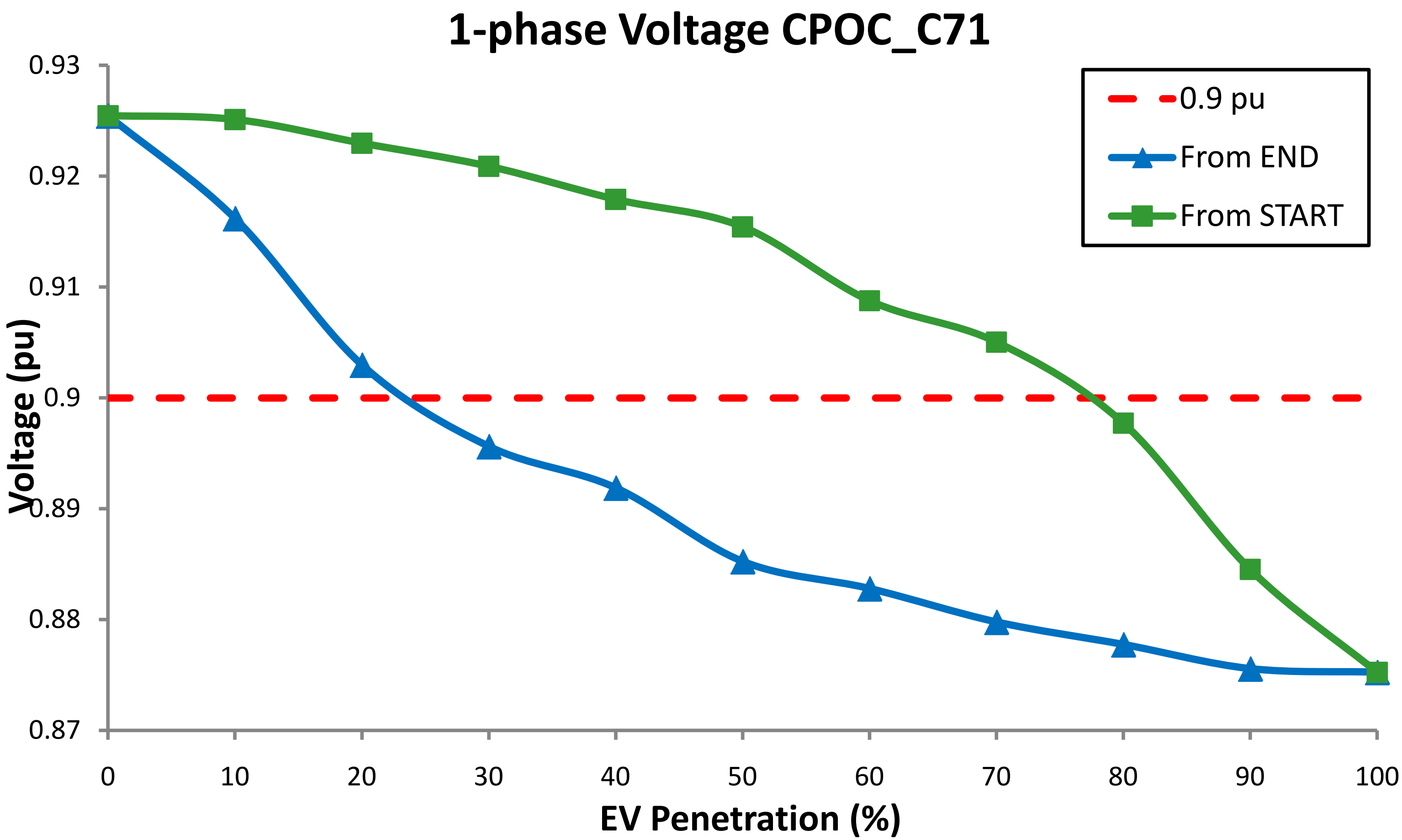


- Trial participant plugging in
- 12.6 kWh energy
- Notching needs investigation

Network Reconfiguration



Worst Case Scenario



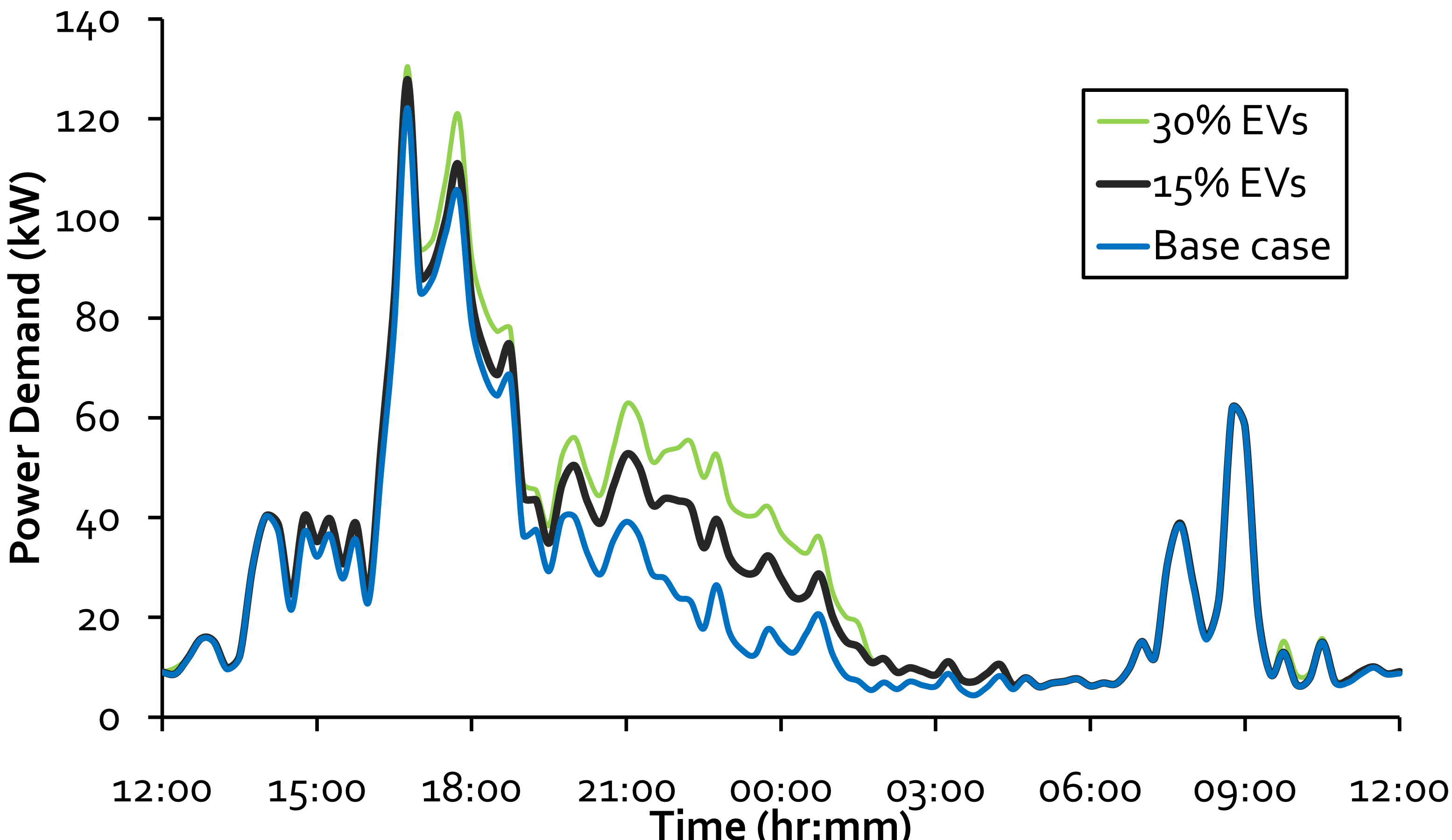
Time series analysis

- Limited data presents challenges for a definitive time series analysis
  - Annual kWh demand from each customer
  - Phase each customer connected to
  - Local demand time series
  - 3 Standard residential load profiles

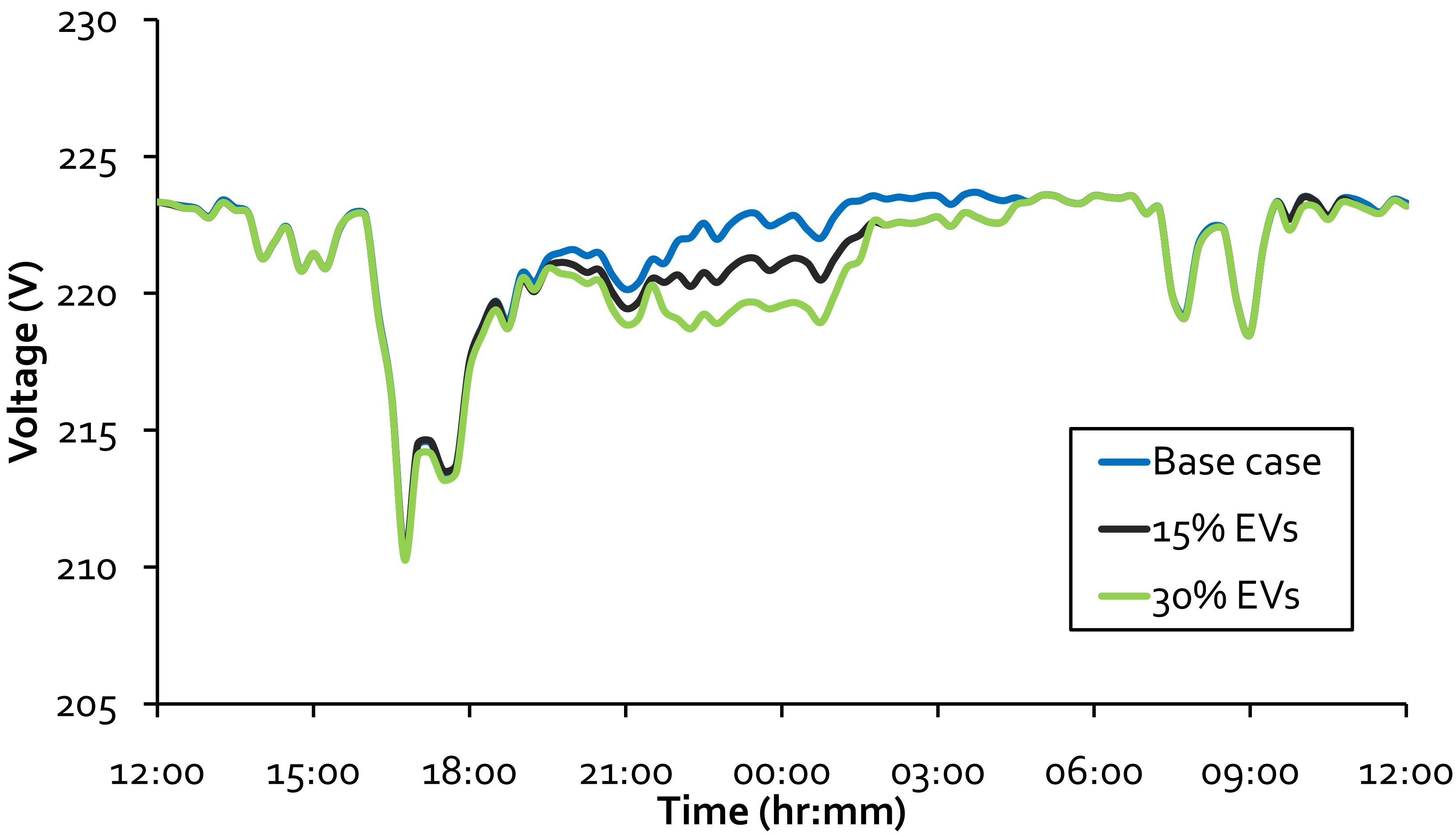
Time series analysis

- Three Cases
  - Base (0 vehicles), 15% (11 vehicles), 30% EVs (22 vehicles)
  - Randomly allocated across feeder
  - 25 single week charge profiles provided by ESB Ecars
  - High demand day in January
  - Energy Summary for 24 hour period:
    - Base Case: 628.34 kWh
    - 15% Case: 735.027 kWh
    - 30% Case: 807.922 kWh

Time series analysis



Time series analysis



Harmonic Analysis

- 5 minute averaged harmonic data
- Two charging periods examined
- No breach of harmonic content limits

Charge Periods	THD		Harmonic: 2		Harmonic: 3		Harmonic: 4		Harmonic: 5	
	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max
Time Breached	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mean	0.9318	1.0163	0.0535	0.1491	1.1117	1.2282	0.0221	0.0837	1.6767	1.7941
Max	1.0786	1.2003	0.1848	0.3682	1.3989	1.5902	0.1502	0.4131	2.3005	2.4727
Min	0.7518	0.8224	0.0000	0.0725	0.7158	0.8232	0.0000	0.0361	1.2634	1.3400

Electric Vehicles Summary

- Valuable network and consumer data gathered
- Network impacts do not appear too severe
- Modelling challenges remain
  - Residential demand
  - Charging patterns
  - Further data required
- Scope for optimisation

Acknowledgements

- UCD – Paul Cuffe, Paul Smith, Peter Richardson
- ESB Networks – Tony Hearne, Teresa Fallon, Ellen Diskin
- EPRI – Jason Taylor

Frankfurt (Germany), 6-9 June 2011

Electric Vehicle Impact Modelling

Andrew Keane', Alison O'Connell', Peter Richardson' and Jason Taylor*

University College Dublin' and EPRI*

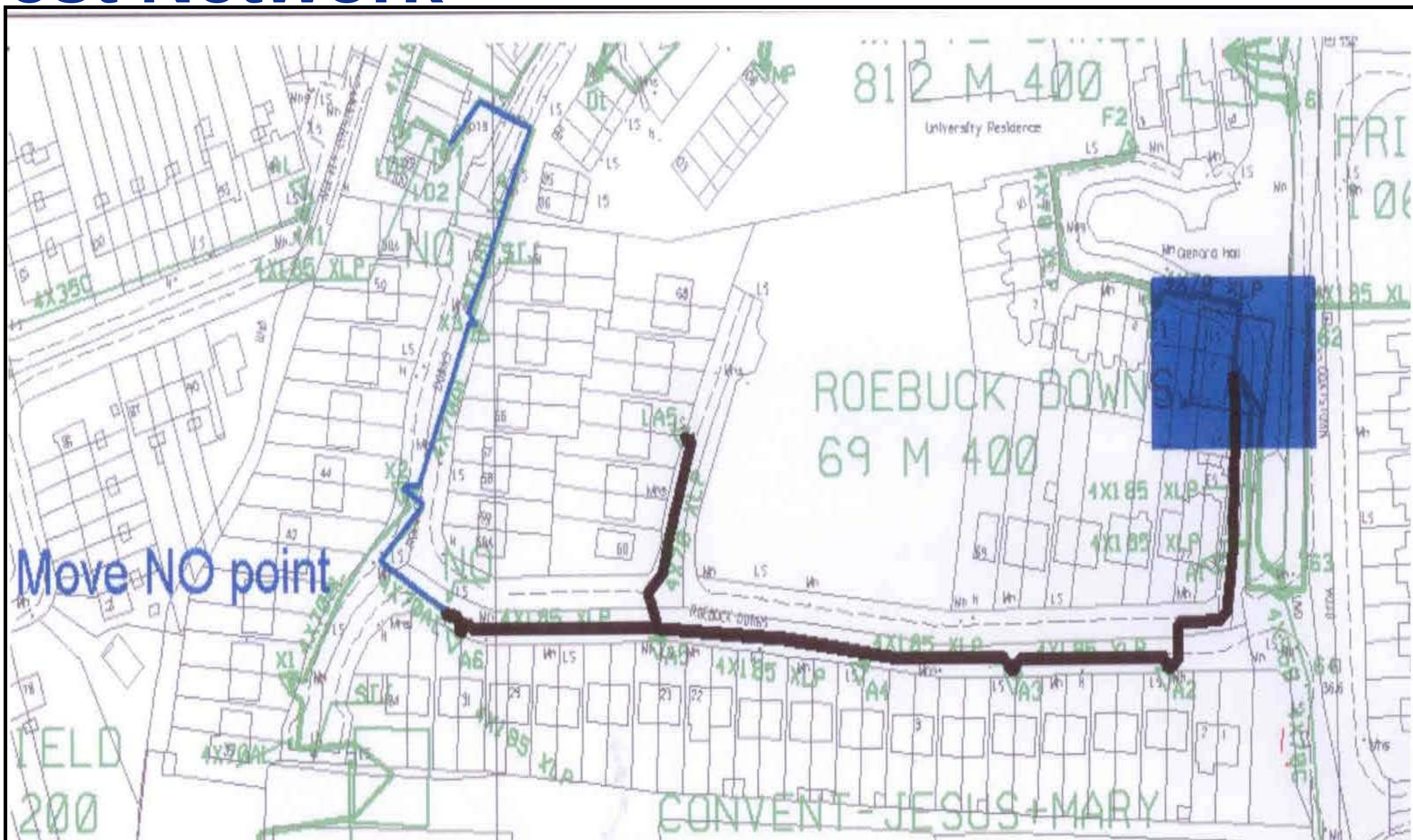
June 2011

Overview

- Traditional impact modelling
- Stochastic EV modelling
- Combined power flow and optimisation

- New modelling challenges due to uncertainty and optimisation requirements

Test Network



Roebuck Downs

- **Substation:** Roebuck Downs (400 kVA, 10 kV/0.4 kV)
- **Outlet:** 1 (Roebuck Downs)
- **No. of Houses:** 54 (+20)
- **PF Houses:** 0.95
- **PF EVs:** 1.0
- **EV Charge Rate:** 2.8 kW
- **Load Type Houses:** 40/60 Power/Impedance
- **Load Type EVs:** Constant Power
- **Sending Voltage:** 0.97 pu

Snapshot Analysis

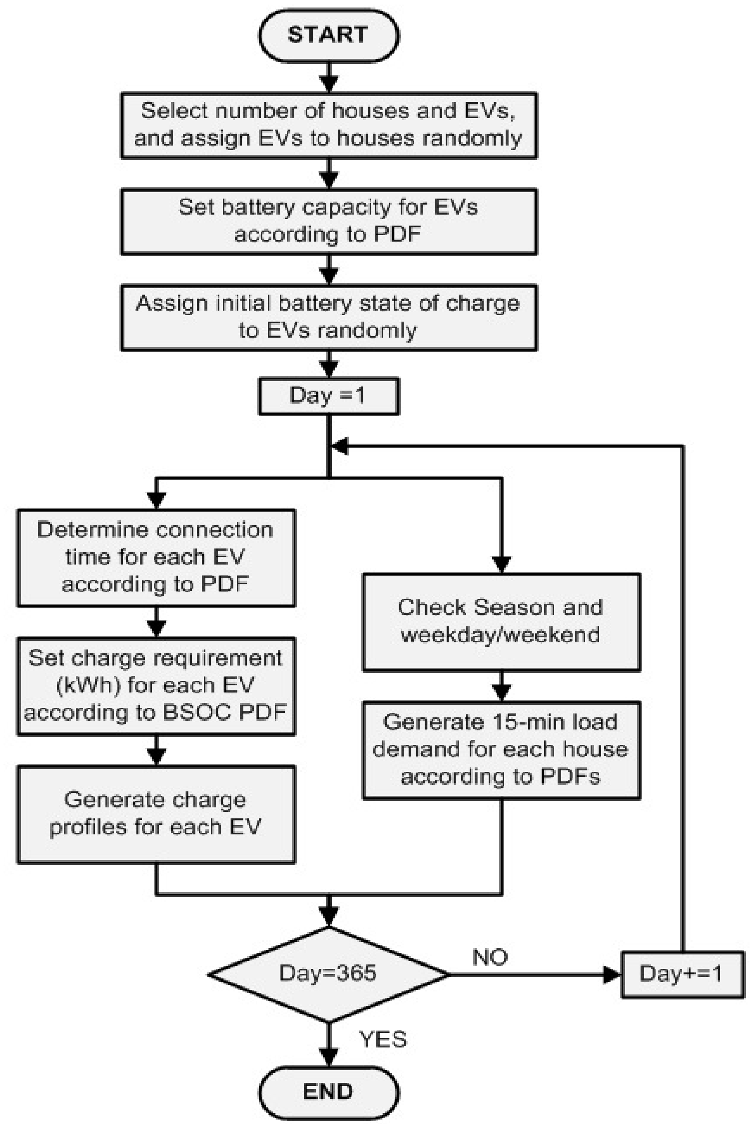
- Results presented earlier
- Assess worst case operating point
- Still a valuable method of assessment
- Possible to reveal more with a more detailed simulation

Time series analysis

- Limited data presents challenges for a definitive time series analysis
- What we have:
  - Annual kWh demand from each customer
  - Phase each customer connected to
  - Roebuck downs demand time series
  - 3 Standard residential load profiles
- What we don't have:
  - Individual demand time series for all 74 customers
  - Enough vehicle data (yet)
  - Typical battery state of charge

Stochastic Analysis

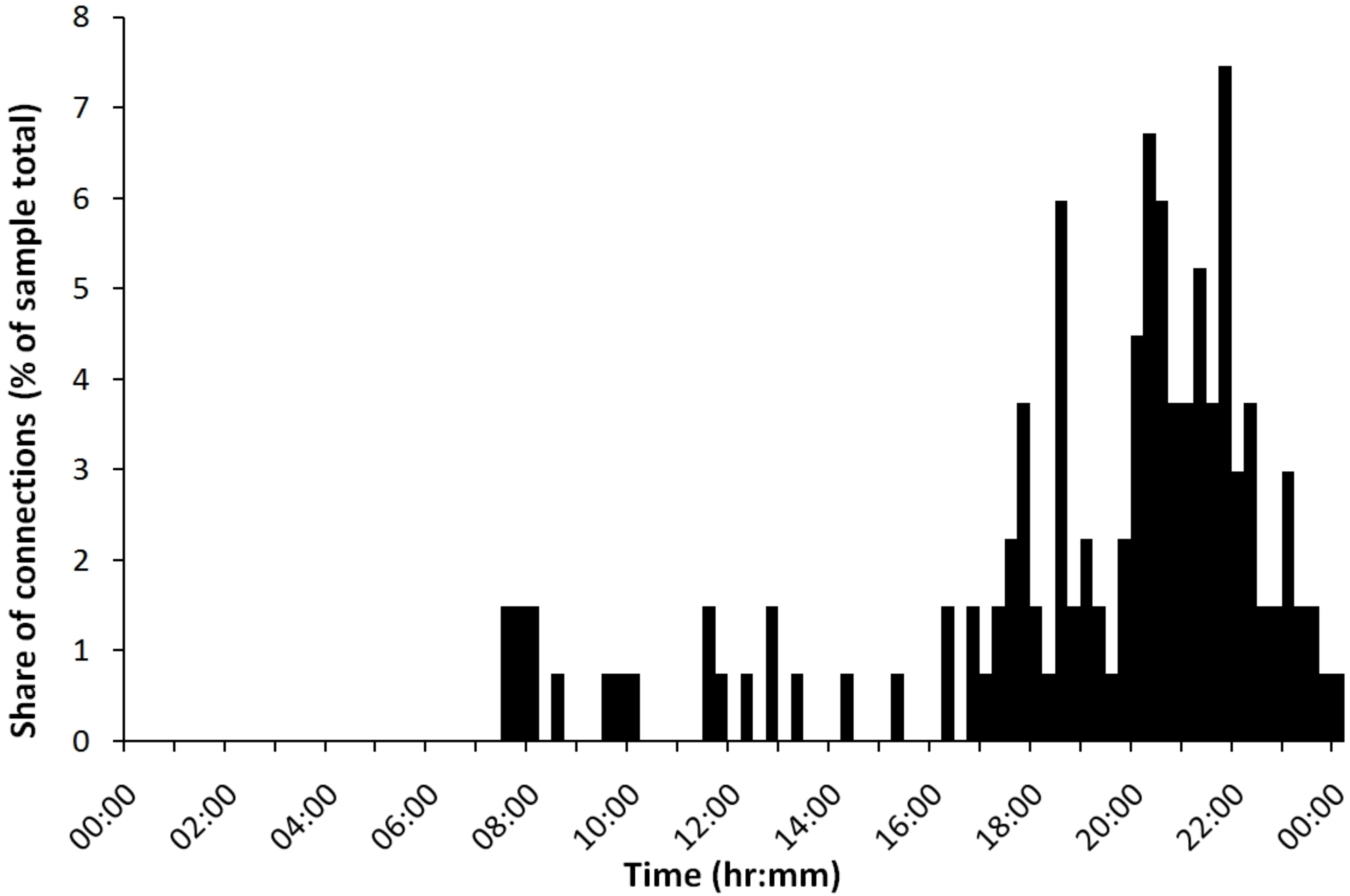
- Location of EVs
- Type of EV
- Residential demand
- Availability of EV
- Battery state of charge



Model Interfaces and structure

1. Model uncertainty with PDFs
2. Create input data from PDFs
3. Export to power flow software
4. Solve circuit
5. Post processing of results

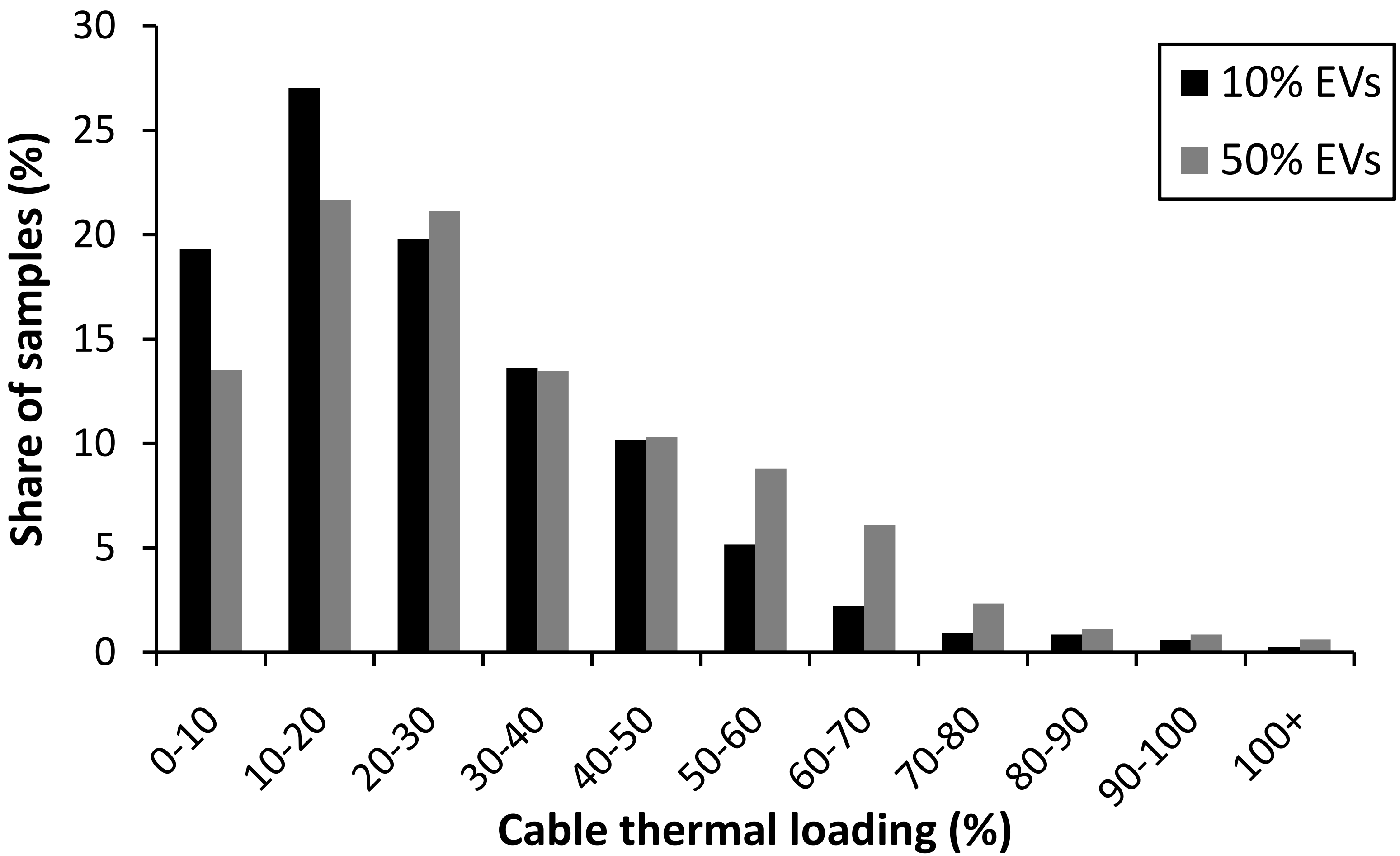
EV Connection Times



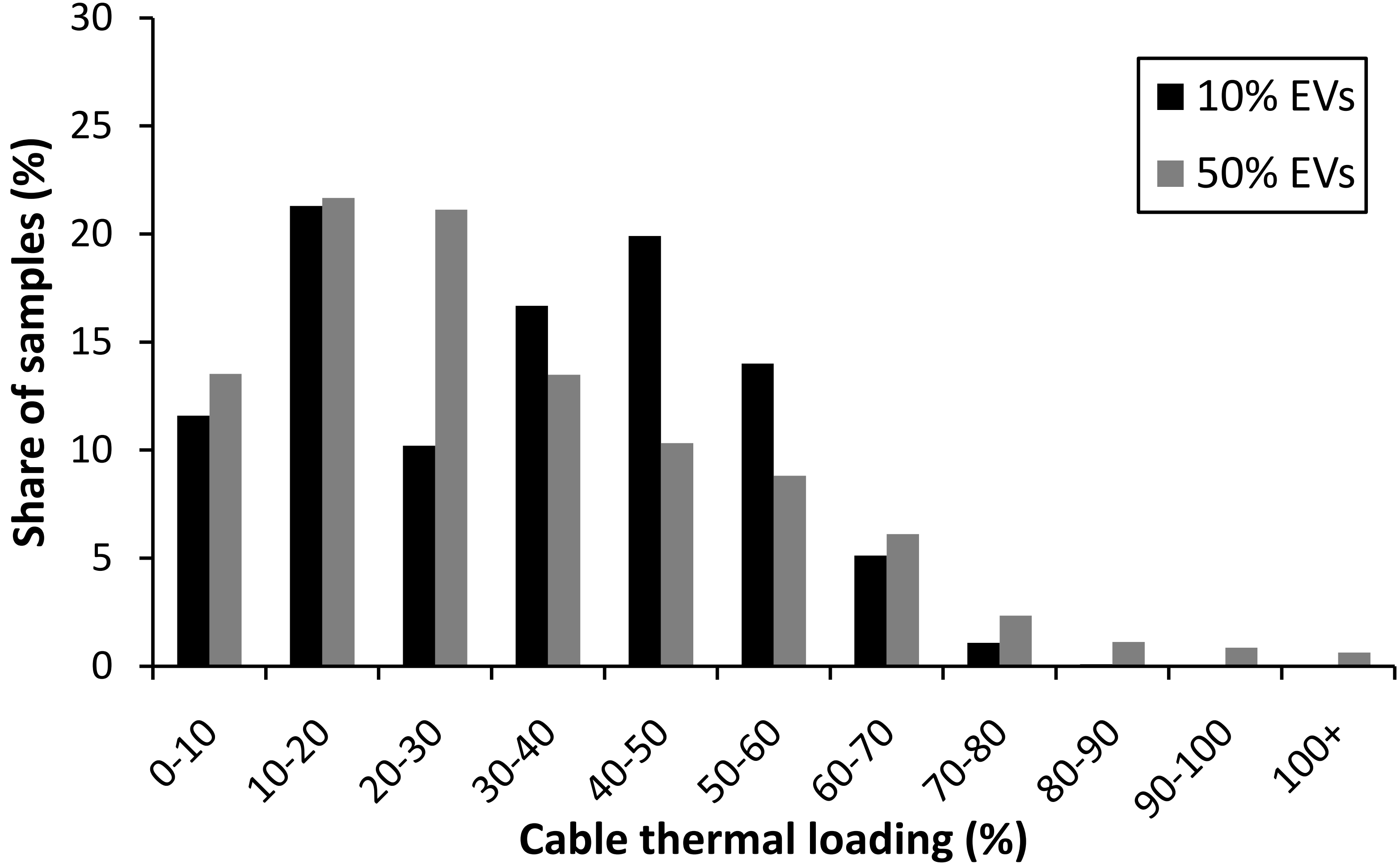
Simulation Results

- Proceed with automated time series power flow
- Analyse multiple scenarios
- Question of calculation time and what is of interest

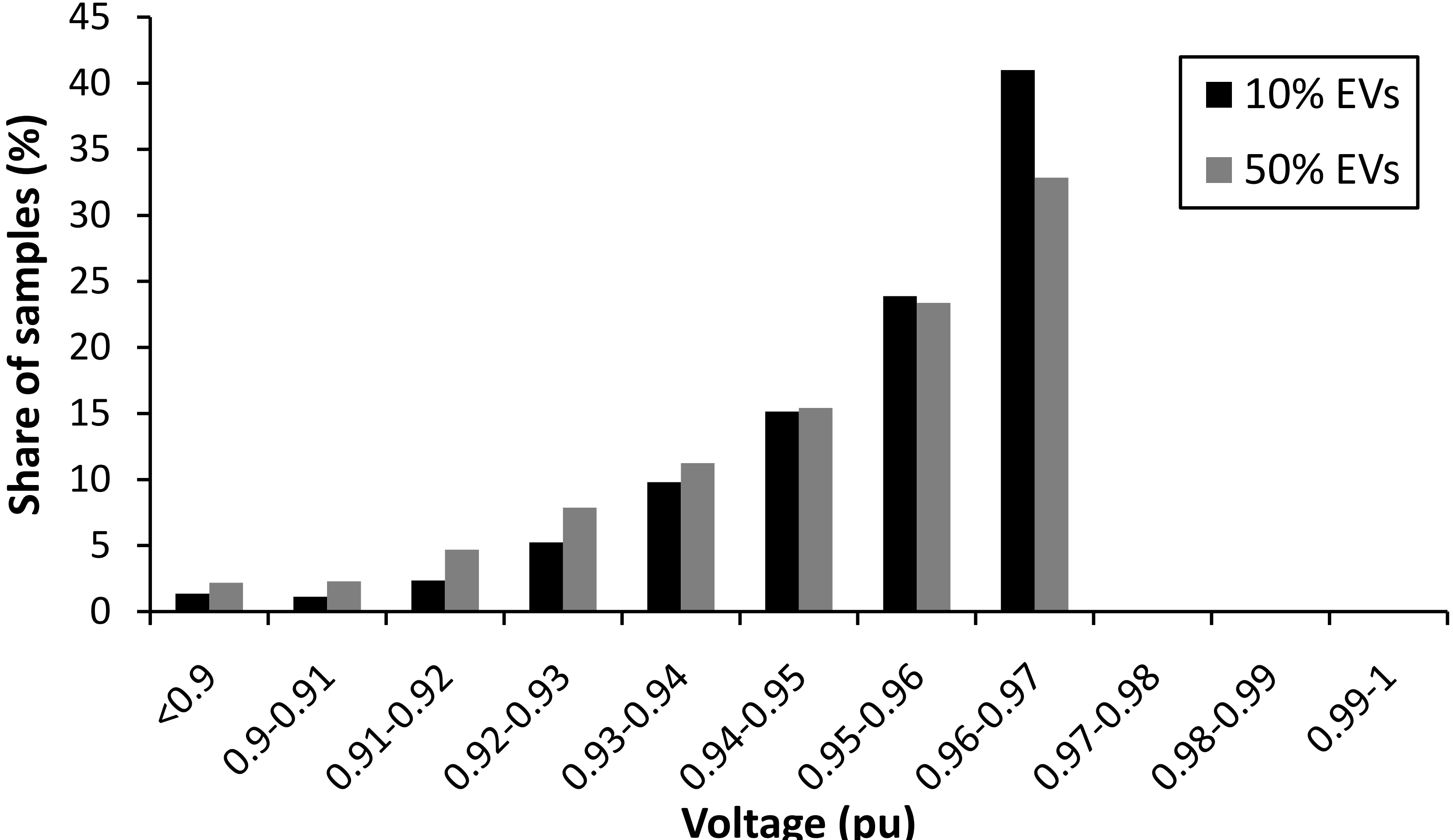
Summer


30
25
20
15
10
5
0
Share of samples (%)
10% EVs
50% EVs
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100+
Cable thermal loading (%)

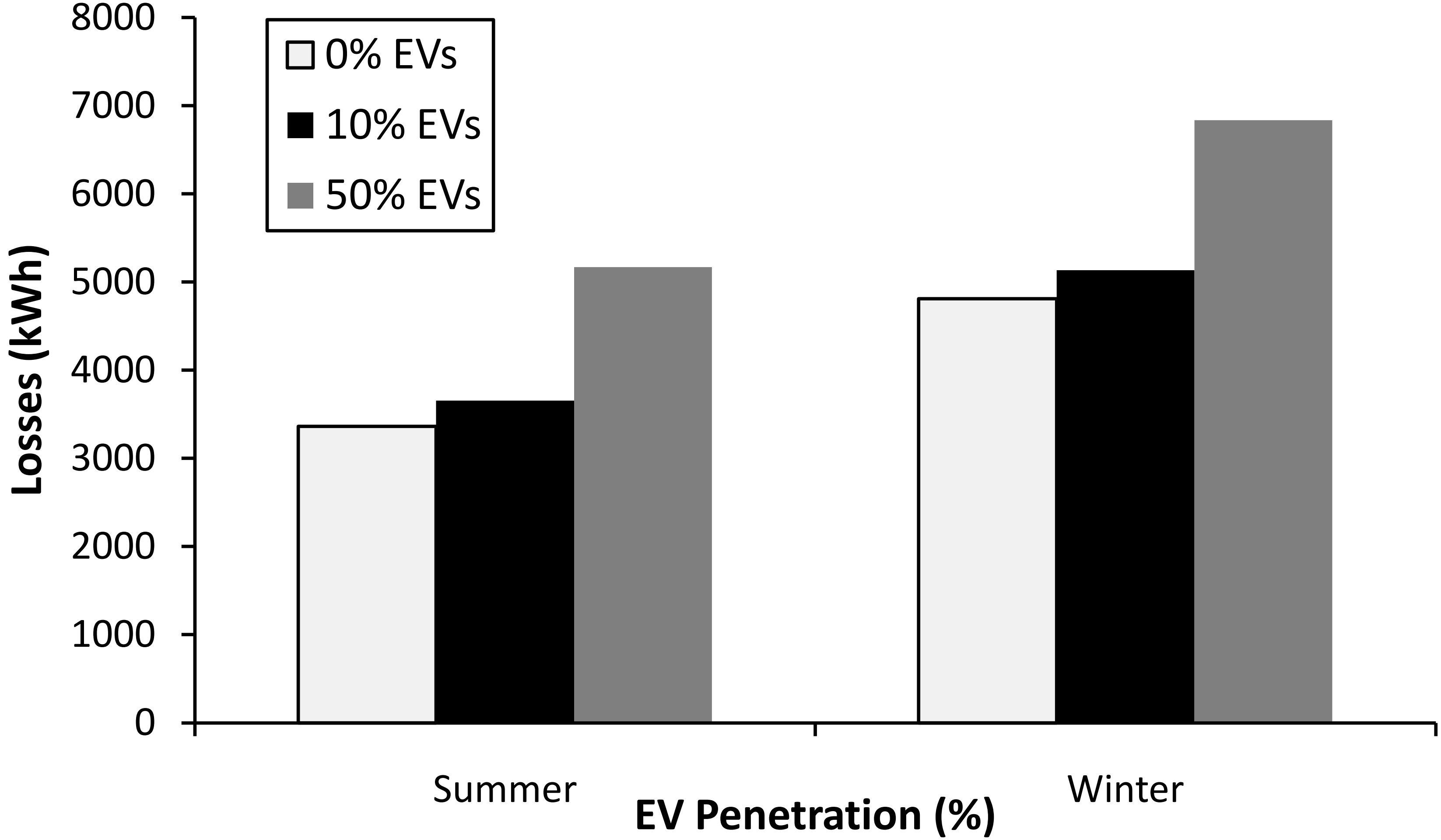
Winter


30
25
20
15
10
5
0
Share of samples (%)
10% EVs
50% EVs
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
100+
Cable thermal loading (%)

CPOC Voltages Summer



Losses


8000
7000
6000
5000
4000
3000
2000
1000
0
Losses (kWh)
0% EVs
10% EVs
50% EVs
Summer
Winter
EV Penetration (%)

Optimisation

- Scope for integrated power flow and optimisation
- Optimal power flow
- Linear programming
- Multi-objective
- ....

Sample Application

- Optimise scheduling of vehicle charging
- Objective:
  - Minimise Cost
- Variable:
  - Charge Rate
- Subject to:
  - Vehicle availability
  - Battery capacity

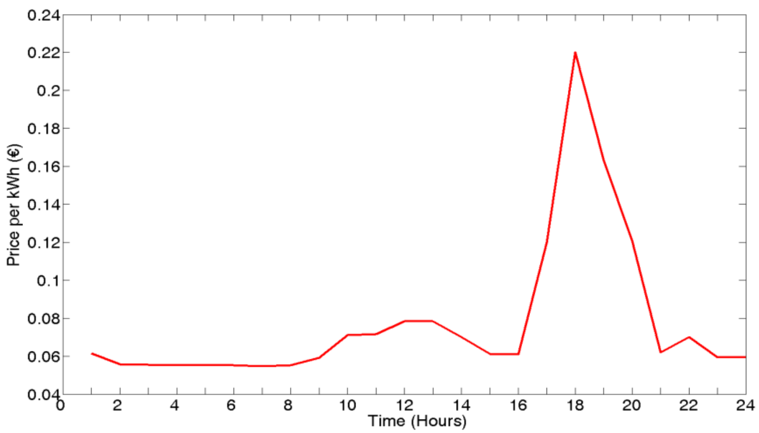
Sample Application

- Formulate and run initial optimisation in Matlab
- Export optimised charge profiles for 24 hours to OpenDSS
- Solve circuit and check network constraints

Sample Application

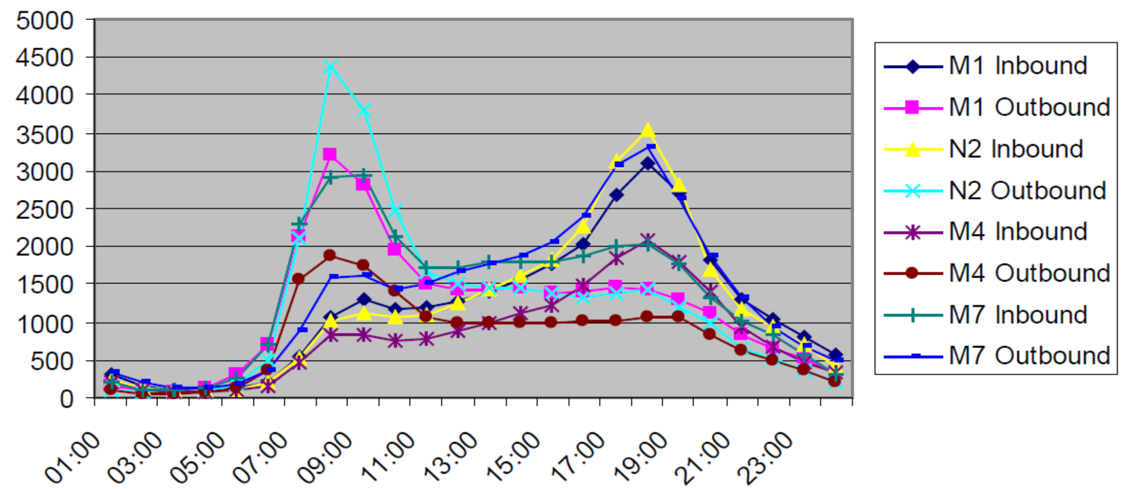
- If a limit is breached
  - Update optimisation formulation
  - Adjust appropriate constraint
  - Repeat until solution reached which satisfies network constraints while minimising cost to consumer

Parameters

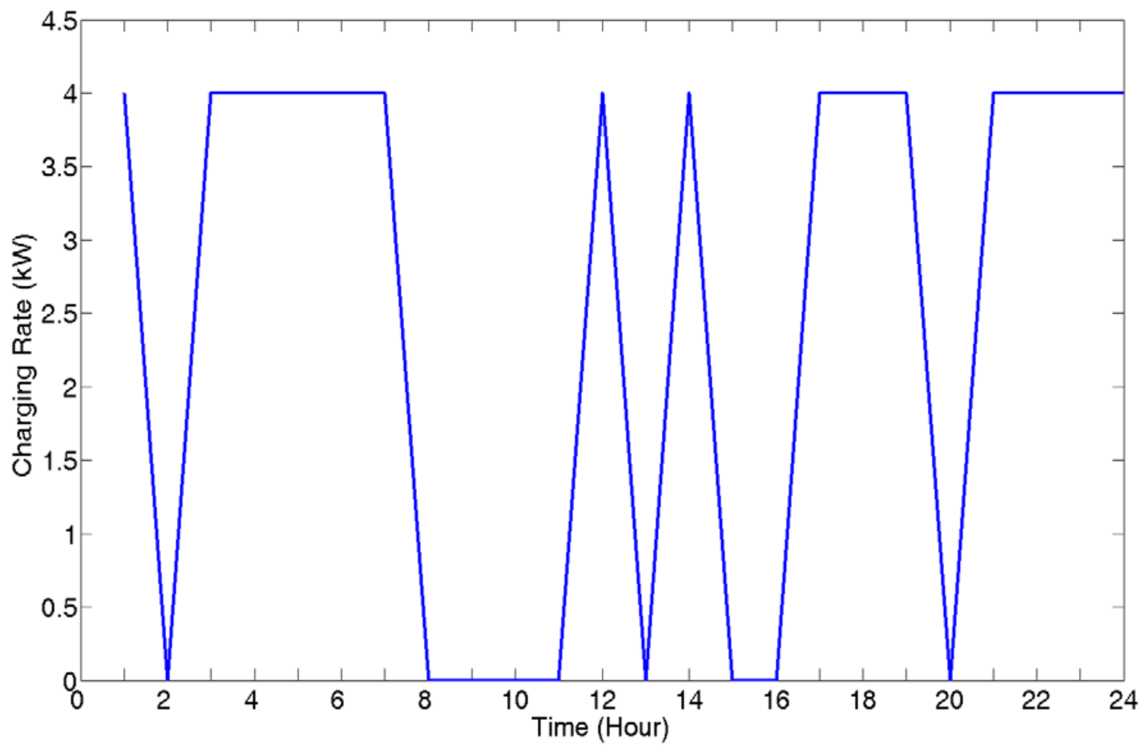


Market Price

Vehicle Usage



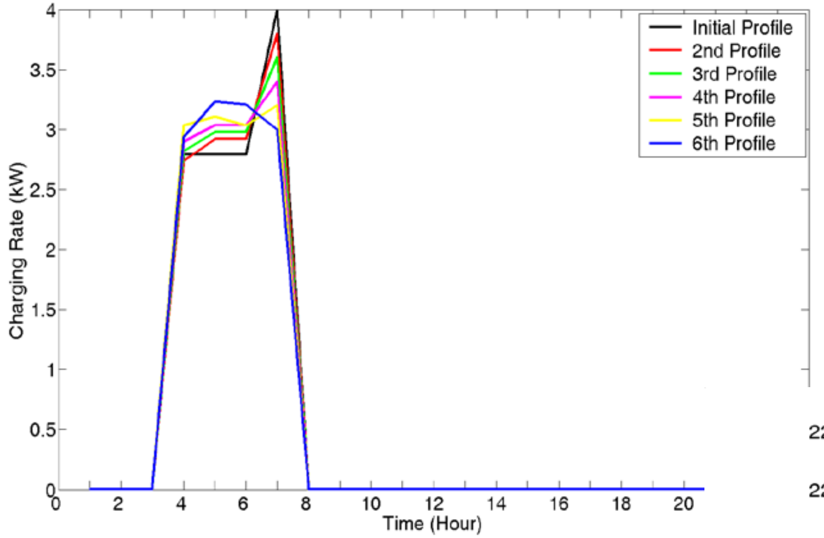
Resulting availability profile for a sample vehicle



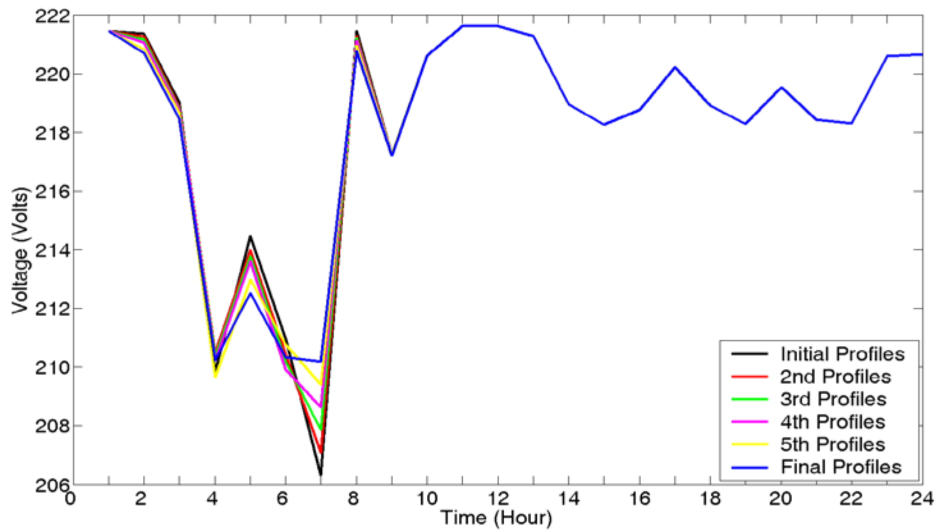
Input Data

- EV locations and characteristics
- Optimised charge profile for each vehicle
- Residential demand

Outputs



Charge Rate



Node Voltage

Summary

- This is a just a sample application!

- Flexibility in terms of stochastic modelling
- Handle larger volumes of data
- Speed of power flow calculation
- A lot of potential for assessing a wide range of smart distribution challenges

Summary Challenges

- Two broad categories of model required:
- Impact analysis
  - Limited worries regarding data volumes, time of calculation
- Real solutions
  - What data available?
  - Cost of implementation
  - Contingencies

Frankfurt (Germany), 6-9 June 2011

Model Requirements for Smart Distribution

Roger C. Dugan
Sr. Technical Executive
EPRI US

Smart Distribution Systems for a Low Carbon Energy Future Workshop

6 June 2011

What is the Smart Grid?

- "Smart Grid" means different things to different people
  - **Communications and control**
    - Not typically represented in distribution system analysis
  - **Distributed resources**
    - Generation, storage, demand response, microgrids
    - Some of these issues have been addressed
  - **Monitoring (AMI, etc.)**
  - **Intelligent protection**
  - **Energy efficiency**

What Kind of Analysis Tools are Needed?

- If everything is monitored, do we even need planning tools?
- What can be done if more is known about the system?
- What different approaches to DSA tools?

What Kind of Analysis Tools are Needed?

- Expected:
  - **Convergence of distribution monitoring and Distribution State Estimation (DSE) into DMS**

State of the Art

- Most DSA for US can perform 3-phase analysis
  - Some more than three phases (e.g. OpenDSS)
- Most tools were originally designed for static power flow
  - A few can perform power flows over time
- Tools and techniques designed for uniprocessors
  - Satisfactory for the time being – future ??
- Many (most?) exploit radial nature of feeders
  - For simulation efficiencies
  - Increased call for meshed network solution

State of the Art, cont'd

- Frequency-domain tools are preferred for DSA
  - Time-domain tools do exist but used infrequently
- Dynamics analysis (electromechanical transients) is uncommon for DSA
- Planning and operational tools (DMS) are often separate
- Secondary (LV) has been ignored (changing!)
- Loads modeled by time-invariant ZIP models
- Harmonics analysis is optional, if available

Needs Envisioned by EPRI

- Sequential time simulation
- Meshed network solution capability
- Better modeling of Smart Grid controllers
- Advanced load and generation modeling
- High phase order modeling (>3 phases)
  - Stray voltage (NEV), crowded ROWs, etc.
- Integrated harmonics
  - NEV requires 1st and 3rd
- User-defined (scriptable) behavior
- Dynamics for DG evaluations

EPRI's Vision

- Distribution planning and distribution management systems (DMS) with access to real time loading and control data will converge into a unified set of analysis tools.
- **Real-time analysis and planning analysis will merge into common tools.**
- Distribution system analysis tools will continue to play an important role, although they might appear in a much different form than today.

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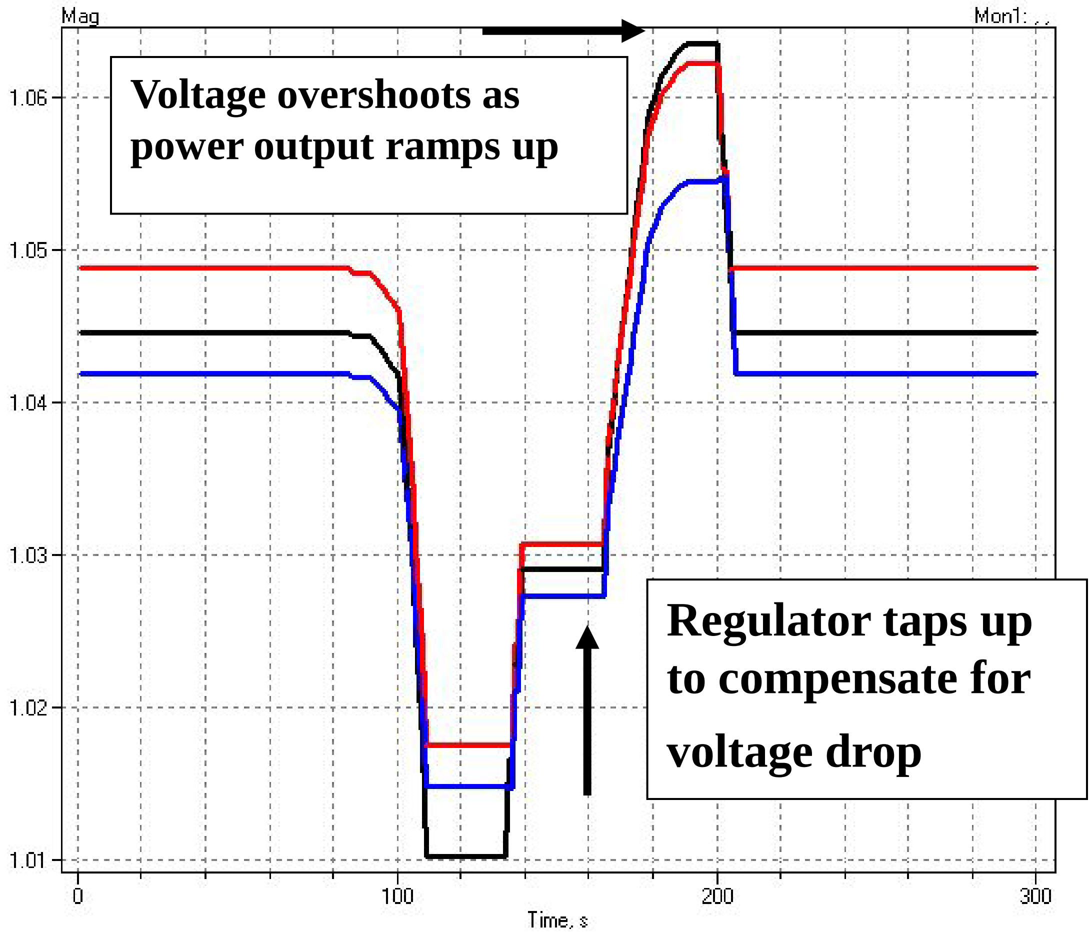
Tackling Smart Grid Issues

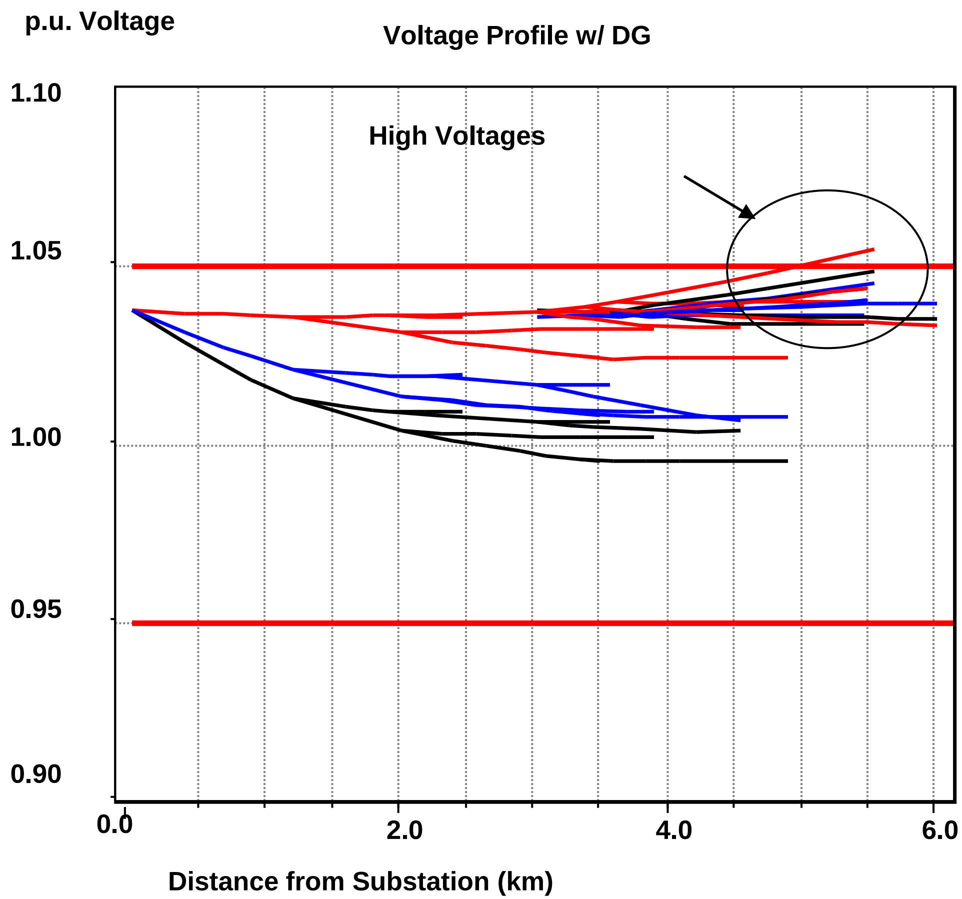
Modeling for Distributed Generation

- Voltage rise and regulation,
- Voltage fluctuations,
- Protective relaying and control functions,
- Impact on short-circuit analysis,
- Impact on fault location and clearing practices,
- Interconnection transformer,
- Transformer configuration,
- Harmonics,
- Response to system imbalances
  - e.g. open-conductor faults due to failing splices.

Example of an Expected DG Problem



Root of Problem



Distribution Systems designed for voltage DROP, not voltage RISE.

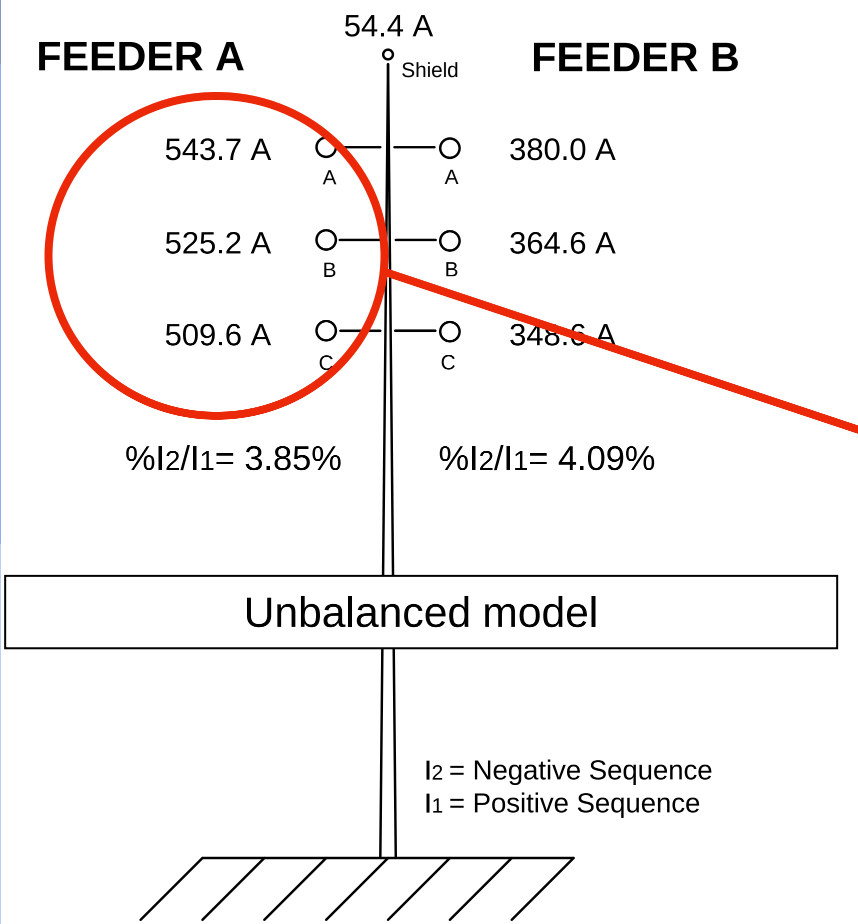
Time Sequential Simulation

- Electric vehicle charging (minutes, hours)
- Solar and wind generation (seconds)
- Dispatchable generation (minutes to hours)
- Storage simulations (minutes to hours)
- Energy efficiency (hours)
- Distribution state estimation (seconds, minutes)
- End use load models (minutes to hours)
- End use thermal models (minutes to hours)

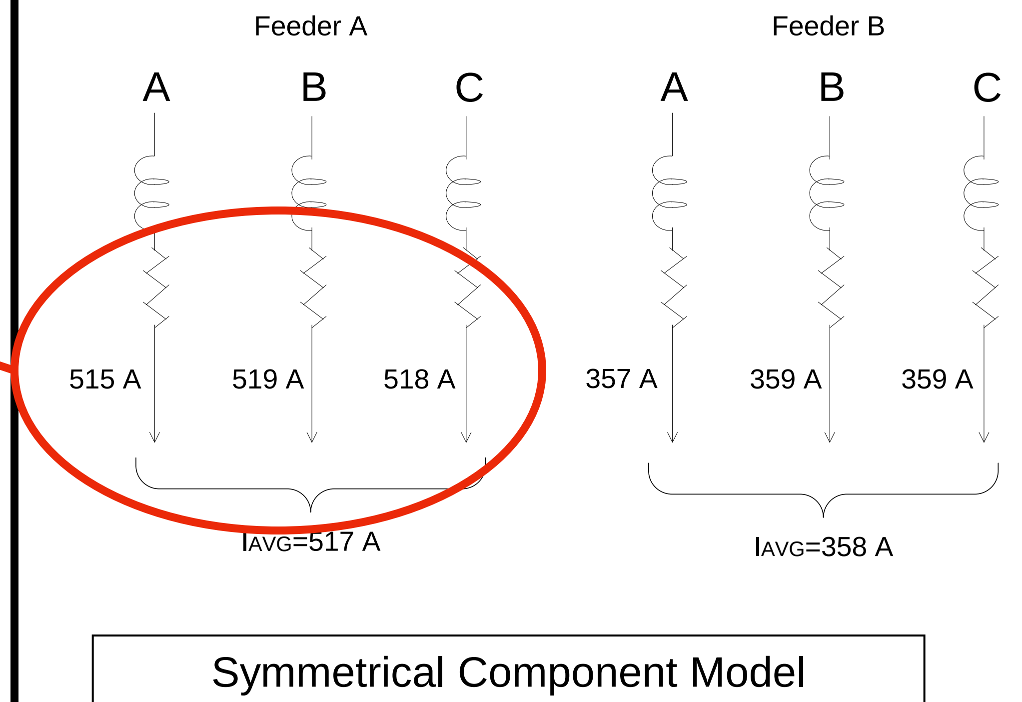
Modeling for Unbalances

- **Symmetrical component** model and an unbalanced phase-domain model can yield quite different results.
- A symmetrical component model uses only the positive- and zero-sequence impedances – **assumes balance**
  - Asymmetries yield impedances that are not balanced between phases.
- Many distribution system analysis tools can perform full 3-phase analysis;
  - A few programs can go beyond 3-phases.
  - Many circuits include multiple feeders sharing right-of-ways
  - We have analyzed circuits with **17 conductors** on the same pole sharing a common neutral
    - (as well as several communications messengers).

Example



54.4 A
FEEDER A
Shield
FEEDER B
543.7 A
A
A
380.0 A
525.2 A
B
B
364.6 A
509.6 A
C
C
348.6 A
%I2/I1= 3.85%
%I2/I1= 4.09%
Unbalanced model
I2 = Negative Sequence
I1 = Positive Sequence



Feeder A
Feeder B
A
B
C
A
B
C
515 A
519 A
518 A
357 A
359 A
359 A
IAVG=517 A
IAVG=358 A
Symmetrical Component Model

Large Systems

- A key capability
- 5000 – 10000 bus systems are routine today
- Smart Grid requires solution of multiple feeders simultaneously

- Goal:
  - **100,000 to 800,000 nodes**
- Parallel computing could enable this
  - Requires new algorithms

Distribution State Estimation (DSE)

- Key feature for Smart Grid
- Robust estimation more feasible with AMI, sensors
- Transmission state estimation mature
- Barriers to DSE
  - Low X/R
  - Phase unbalances
  - Magnitude (V, I) measurements in line sensors
  - Communications latency and bandwidth
  - Non-coincident samples
  - Insuffcient samples to make feeder observable

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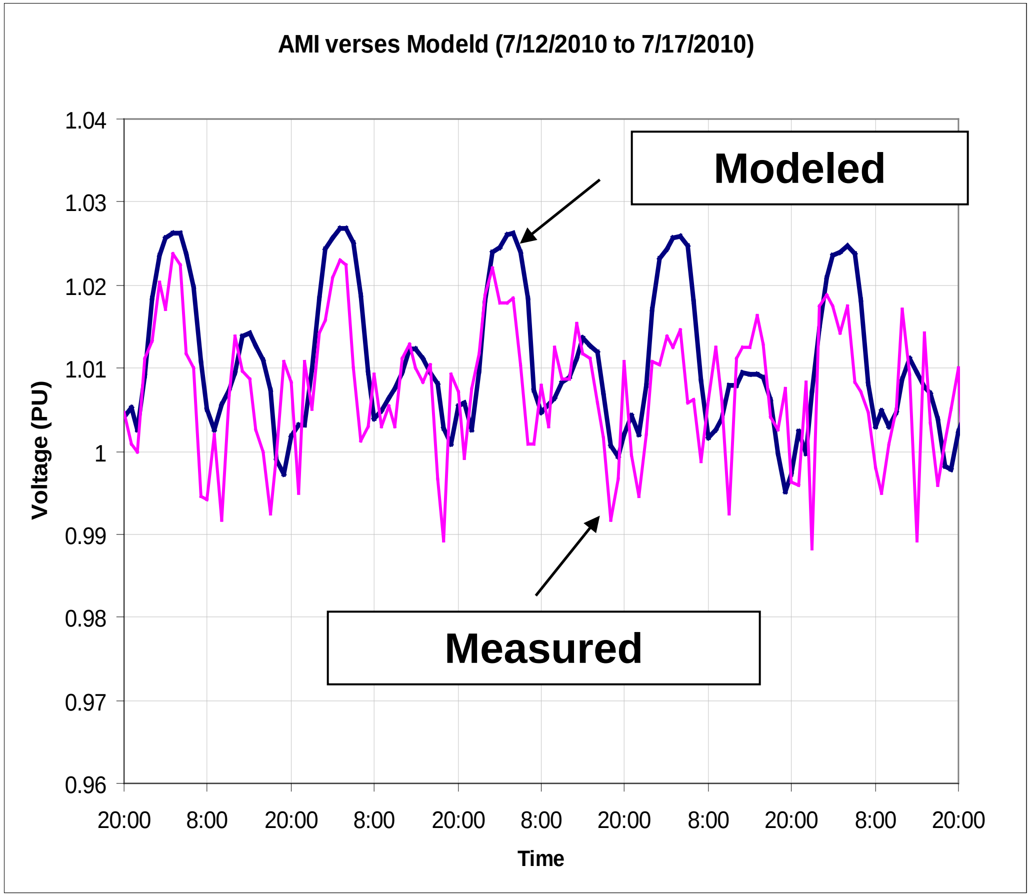
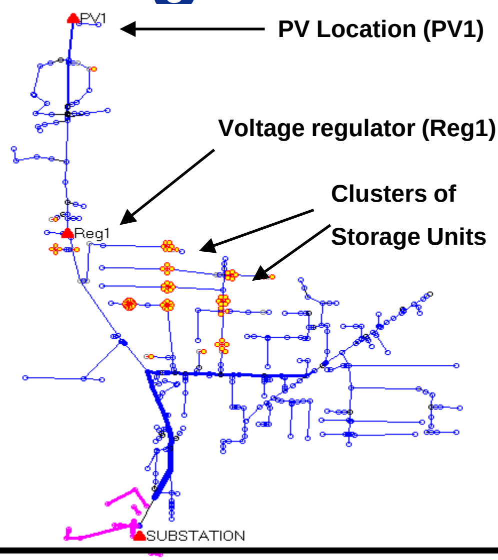
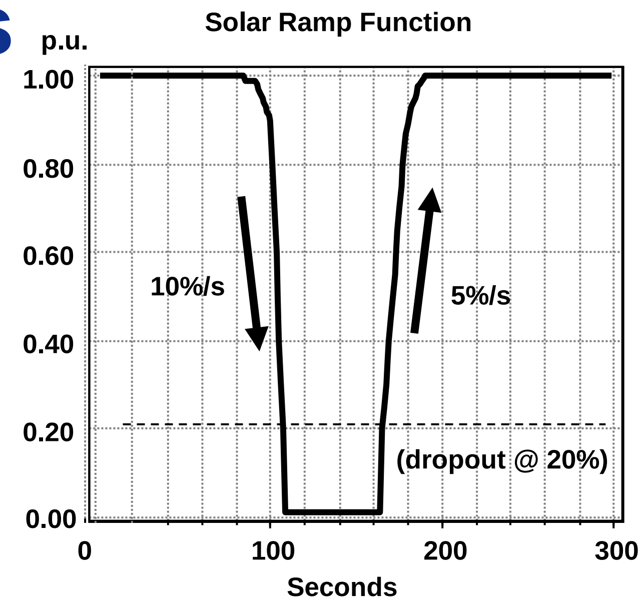
Simulating with AMI Load Data

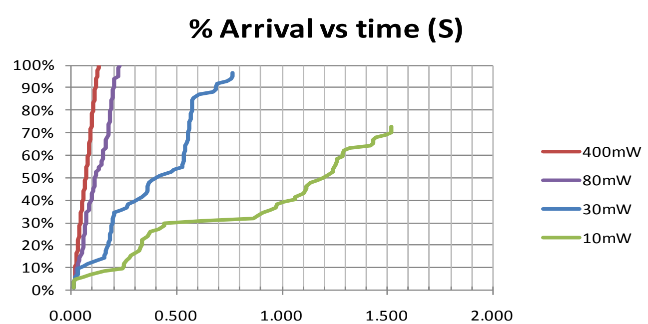


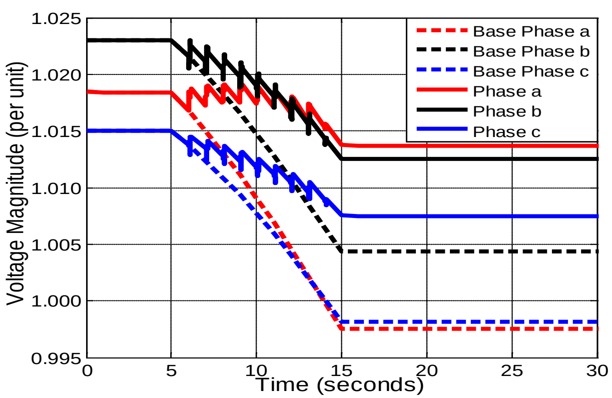
DUGAN –Smart Distribution Systems Workshop

Modeling Communications









Next Steps

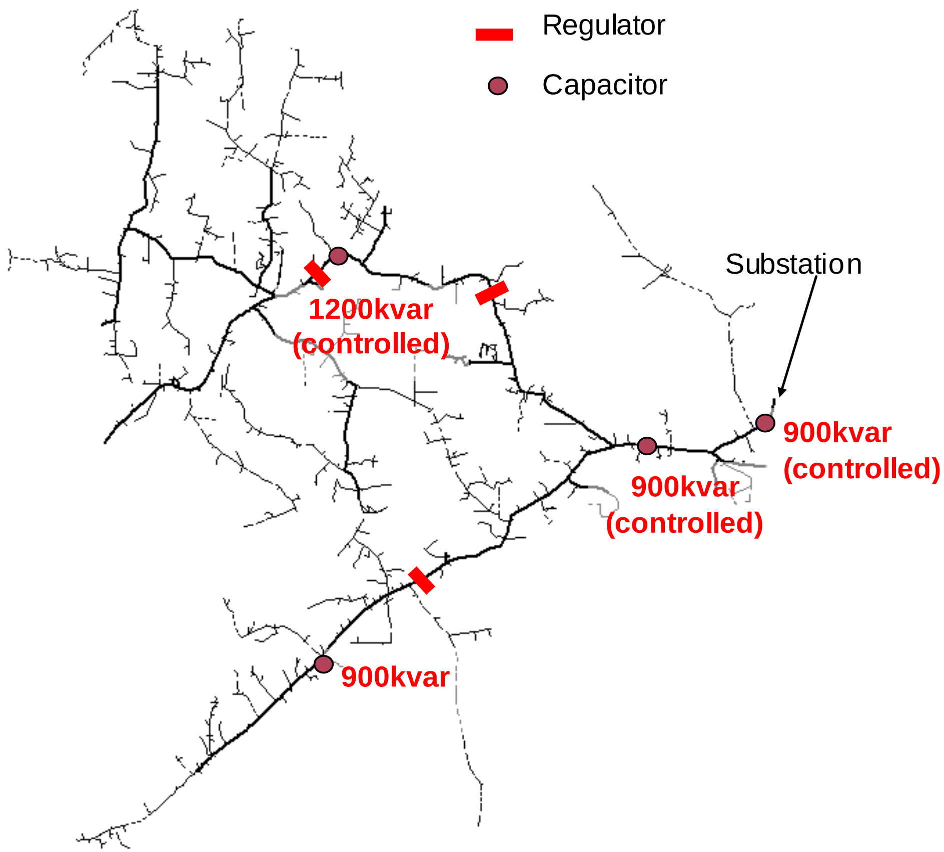
IEEE PES Distribution System Analysis Subcommittee (DSAS)

- Advancing Distribution System Analysis Tools
  - Developing new benchmarks (test feeders)
  - Supporting data exchange standards
    - IEC 61968 and **CIM**
    - **Multispeak**
  - Producing IEEE Recommended Practice
    - IEEE Std P1729
  - Organizing paper and panel sessions

IEEE Test Feeders

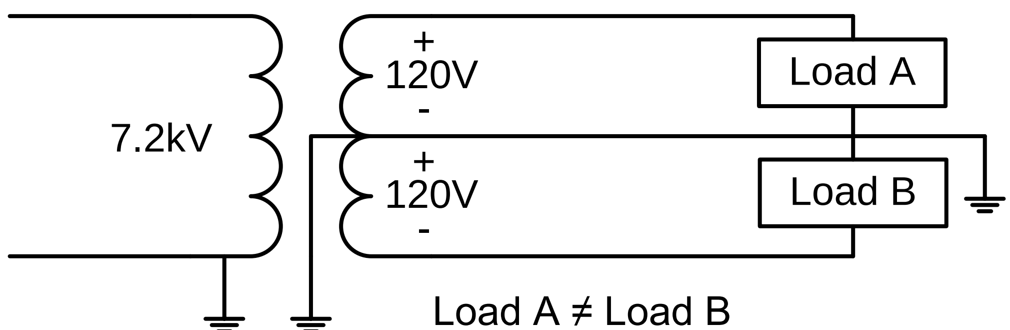
- Original set from Prof. Kersting
  - 4-, 13-, 34-, 37-, 123-bus test feeders
- Recent Additions
  - NEV Test Feeder
  - 8500-node Test Feeder
  - Comprehensive Test Feeder (later in program)
- Coming soon …
  - DG Protection Test Feeder
  - Large urban LV network

8500-Node Test Feeder



8500-Node Test Feeder

- Challenges for DSA programs/algorithms
  - Modeling large unbalanced distribution systems
  - Solving large unbalanced distribution systems
  - Modeling secondaries
  - Heavily loaded system close to convergence limits
  - Advanced controls (capacitors, regulators)
  - Modeling the 120/240V transformer



Key Challenges for the Future

- Merging planning and real-time analysis
- Time series simulations
- Very large system models (100,000 – 1,000,000)
- System communication simulation
- Handling a large volume of AMI data
- AMI-based decision making

Key Challenges (cont'd)

- Distribution State Estimation (DSE)
- Detailed modeling (service transformers, service wiring)
- Distribution models including the effects of
  - multiple feeders,
  - transmission, sub-transmission systems
- DG integration and protection
  - Generator and inverter models
- Regulatory time pressures

Questions?