Grid Edge Control – Extracting Value from the Distribution System

DOE – Quadrennial Energy Review Panel Presentation, Atlanta, GA, May 24, 2016

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The Evolving Grid:

The grid is the largest machine built by man, delivering reliable affordable power for all, and has been the engine of growth for the last 100 years. Electrical users view the power grid as being stable, 'infinite' & predictable. This has allowed industry and commerce to establish an efficient operational infrastructure and cadence that has provided high levels of operational and economic efficiency, and has supported sustained growth of the US economy and GDP.

However, the power infrastructure, especially the distribution network, is poised for dramatic change. Drivers include:

- rapid growth in non-schedulable non-dispatchable distributed generation caused by declining prices in solar and wind energy resources, and by increased focus on reducing carbon emissions
- need for improved economic, operational and energy efficiency for utilities driven by Smart Grid and Internet of Things (IoT) initiatives which are trying to augment existing centralized command & control w/ sensors (AMI, V/I), big data analytics & demand/system optimization
- need for improved grid resiliency under cyber-attacks and natural disasters through the use of microgrids and improved cyber-physical security measures

As utilities are looking at the data from their networks, e.g. from AMI meters, significant gaps are becoming visible in terms of the ability of existing utility models to explain these measurements. In particular, the measured voltages at the edge of the grid (i.e. at customer meter locations), a parameter that has typically not been measured in the past, is seen to have high level of volatility that has not been anticipated. These voltage dynamics cause voltage limit violations and dramatically limit the level of demand control, energy conservation and PV hosting on distribution feeders. The data also show that centralized control is too slow and in any case cannot address the distributed nature of the observed voltage volatility.

Grid-Edge Voltage Volatility:

As much as 40% of the total benefit of DOE Smart Grid initiatives was to result from advanced Volt-VAR Control. This includes peak demand control, energy conservation through voltage reduction, technical loss minimization, and lost revenue reduction. The voltage volatility at the grid edge has substantially reduced the level of these benefits. Further, in the case of PV hosting, all utilities facing high PV levels (including Hawaii, California, Germany and Australia) are grappling with 'voltage constraints' that dramatically limit PV hosting capability for distribution feeders, with little success in tackling it with traditional centralized control techniques.

After a decade of trying various centralized solutions, the industry is moving towards 'smart inverters'. For the first time this shift acknowledges several key issues –

- distributed control is needed;
- inverters will 'fight' each other when operated autonomously; and
- coordination with utility is required to achieve overall local and system objectives

However, by dedicating the inverter control effort to voltage regulation based purely on local voltage measurements, the utility may no longer be able to realize value from existing centralized Volt-VAR Control investments they have made in terms of operational and energy efficiency initiatives. Secondly, the questions of where the inverter is located along the feeder and if the VAR support is where the utility needs it, and if the inverter owner chooses to support the grid (assuming the right algorithms are used), are outside the utility's control. Finally, at the current rate of deployment of PV inverters, even if a universally acceptable solution was devised, time to implement would result in wide deployment of non-optimal inverters – necessitating substantial remediation from the utility.

At the same time, there is significant ongoing research effort on the use of energy storage to achieve some of the same objectives of grid integration of distributed energy resources using 'brute-force' techniques. Energy storage, particularly at the right price point, could certainly be an enabler of high penetration of DER. It can play a role in voltage regulation, dynamic balancing, ramp rate control, and peak demand management. The challenge today for energy storage is the first and operational cost of the storage device and the balance of system, as well as its end-of-life life replacement costs. It is likely that as energy storage costs come down, it will play an increasingly important role in grid management and control. This is expected to take several decades, with wide deployment of DERs occurring at scale prior to that. An alternate interim solution is needed, one that can be deployed rapidly to provide benefits now, and can also reduce the amount of storage needed to achieve the desired level of grid control.

Distributed Grid-Edge Control:

Distributed solutions deployed at the grid-edge (such as those from Varentec and Gridco) are available today, that have the ability to not only measure the local voltage, but can inject dynamic voltage and VARs locally, to mitigate the voltage constraints while providing the level of precise voltage control needed to realize the benefits accruing from Volt-VAR Control, while simultaneously enabling high levels of PV hosting on distribution feeders. These solutions need to have the following attributes:

- Inject local dynamic VARs with 'no-fighting' and 'zero droop' algorithm to realize a flat voltage profile along the length of the distribution feeder

- Realize autonomous operation with no peer-to-peer communications, but with slow communications with a central coordinator to realize system level objectives

- Coordinate with legacy utility assets (e.g. LTC, LVR, cap banks) to realize unprecedented grid-side volt-VAR control
- Eliminate voltage constraints caused by load and solar variability to allow high levels of PV hosting without using energy storage

An example of voltage actually measured along a 5 MW/12 mile normally operated distribution feeder is shown below in Fig 1a. Fig 1b shows the injected VARs along the feeder based purely on local measurements, showing dynamic uncorrelated activity at each device that cannot be predicted or estimated at a central level. Fig 1c shows the voltage on the same feeder with the distributed VAR injection applied. (Images courtesy Varentec)

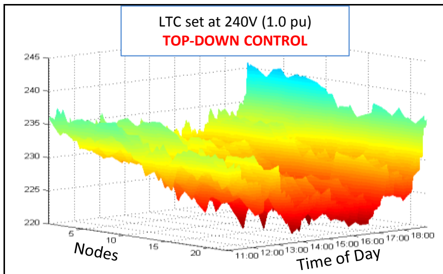

Fig 1a: Normal feeder voltage profile with 24 nodes – 8 hours

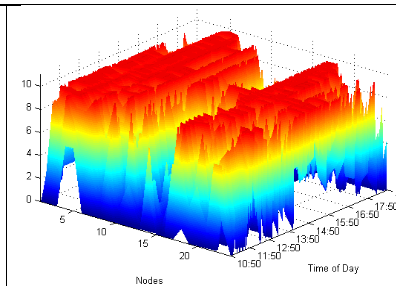

Fig 1b: VARs injected at 24 nodes, local measurements

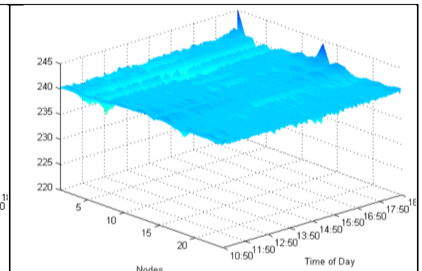

Fig 1c: Flattened voltage profile showing wide control range

Implementation of such a grid-edge volt-VAR control strategy can underpin the transition of the utility power delivery infrastructure from centralized control to distributed control, supporting the complex transaction-oriented prosumer-based power system of the future.

Centralized Control	To	Distributed Control
• Scheduled Generation • Centralized Top-Down Control • Planning Based, Dispatched • Unidirectional Flows, Consumers • Redundancy, N-X Contingencies	→	• Non-Dispatchable Variable Generation • Distributed Edge-Up Real-Time Control • Flexible, Secure, Predictable, Virtual Resources • Bidirectional Flows, Dynamic Optimization • Prosumers, Transactive and Ancillary Services

Value Enabled by Grid Edge Control:

Implementing grid-edge control, and minimizing voltage-volatility and voltage-constraint violations, can dramatically add value to grid control and operations. Some of the benefits realized are shown below:

- Minimize distribution level constraints and expand size/liquidity of distribution level markets
- +/-5% demand management and energy conservation without impacting Quality of Service
- Reduce technical loss (10%), lost revenue (1.5-2%)

- Host high levels of distributed PV on the grid (>100%)
- Absorb high penetration of microgrids to improve supply resiliency and reliability
- Implement effective centralized DERMS or planning based DLMP programs
- Use the distribution grid as a predictable dispatchable dynamic virtual resource
    - *generation, storage, ramp rate, (N-X) contingency, DER balancing, VAR support, FIDVR*

Through dozens of commercial deployments, companies such as Varentec and Gridco have demonstrated the viability of distributed volt-VAR control technologies, and the economic value streams that can be unlocked through grid-edge control.

The Distributed Grid as a Living Ecosystem:

It is important to think about the complex grid, with intelligent autonomous sources, controllers and prosumers connected to it, as a 'living ecosystem'. As in the case of complex biological systems, there is a central coordinating intelligence that works at a slower pace to achieve overall system objectives, but sensors and actuators at the edge operate fast and autonomously to implement their core function, while ensuring that the living ecosystem (in this case the grid) is strong and meets the overall community's needs sustainably. As we move from a centralized system to a distributed autonomous system, such a transition will be critical to implement.

Examples of source and load behavior considering the grid to be a living ecosystem, are shown below:

- In a 'prosumer' world, with high levels of variable non-dispatchable generation, all actors (sources/loads) must support the grid, while ensuring that their own needs are met
- Autonomous device action based on local parameter measurements with behavior driven by granular real-time distribution locational margin pricing (DLMP) signals from 'market'
- Distinguish between critical, non-critical and flexible loads – HVACs, EVs, heaters, pumps, fans, lights – should operate as 'grid-friendly' or flexible loads (potential impact > Energy Star)
- Use distributed grid-connected loads and control devices to enable use of the distribution grid itself as a predictable, dispatchable and dynamic virtual resource
- Dramatic impact on renewable integration, spinning reserve, DER balancing, demand reduction, ramp rate (CA duck curve), emissions, capital costs & efficiency

Recommendations for DOE:

- Grid is an ecosystem – *needs incentives and granular real-time financial signals to make grid-connected assets grid-supporting to preserve investments & maximize value*
- Grid assets need to have distributed real-time control capability – *needs power electronics research for power flow control, dynamic voltage and VAR control*

- Dynamic and distributed grid models and simulation tools needed to understand complex system controlled by autonomous controllers – *need new tools to manage the new system*
- Interaction of massively distributed autonomous assets with each other & with existing grid control poorly understood – *need new research initiative*
- Mixed market model – *central → dispatch; mid-level → transactive; edge → autonomous*
- Fast real-time grid-edge voltage support enables PV hosting and energy transactions – *need to make part of ancillary services*
- Power community needs to be educated on new skills required to operate the utility of the future – *support educational programs*

Grid Edge Control: Extracting Value from the Distribution System

QER Atlanta Panel Presentation

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The Evolving Grid

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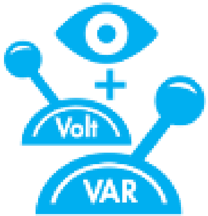
- The grid is the largest machine built by man, delivering reliable affordable power for all - has been the engine of growth for the last 100 years
- Stable, ‘infinite’ & predictable grid has supported sustained GDP growth

BUT……

- Power infrastructure is poised for dramatic change. Drivers include:
  - ✓ growth in non-schedulable non-dispatchable distributed generation
  - ✓ need for improved economic, operational and energy efficiency
  - ✓ grid resiliency under cyber-attacks and natural disasters



- Only two control levers for grid control – Volts/VARs
- Smart Grid & IoT initiatives trying to augment existing centralized command & control w/ sensors (AMI, V/I), big data analytics & demand/system optimization

Gaps in Utility Models Becoming Visible

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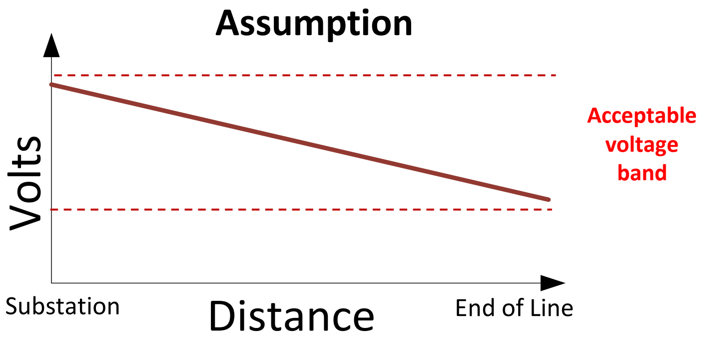

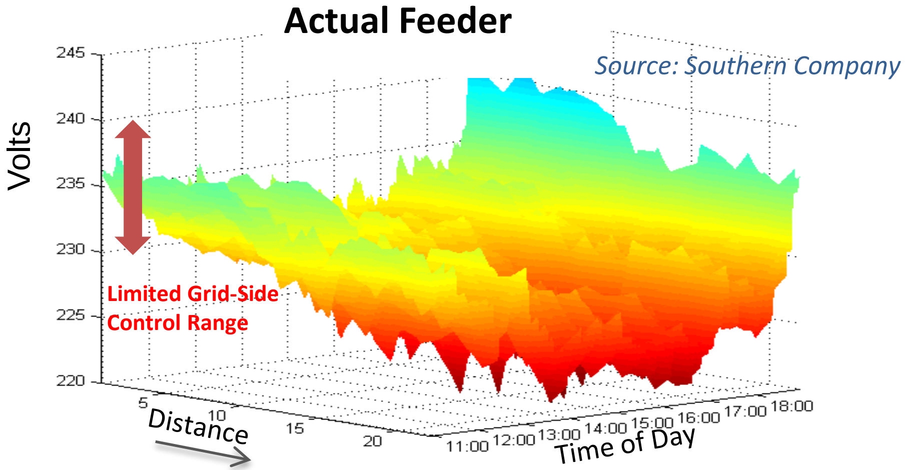

- **Secondary Voltage Volatility**: Voltage volatility & ANSI violations not explained by current models
- **Distributed Problem:** Different control action needed at different points, cannot fix with centralized control
- **Slow Central Control**: Primary equipment can only respond to slow variations (caps switch 3 times/day)
- **Distributed Controllers Interact:** Local autonomous control needed – cannot be dispatched/scheduled
- **Solar PV**: Voltage violations limit PV hosting and high PV severely degrades benefits of VVC investments

Utilities need dynamic distributed control to manage grid edge issues

Architecture for Distributed Control

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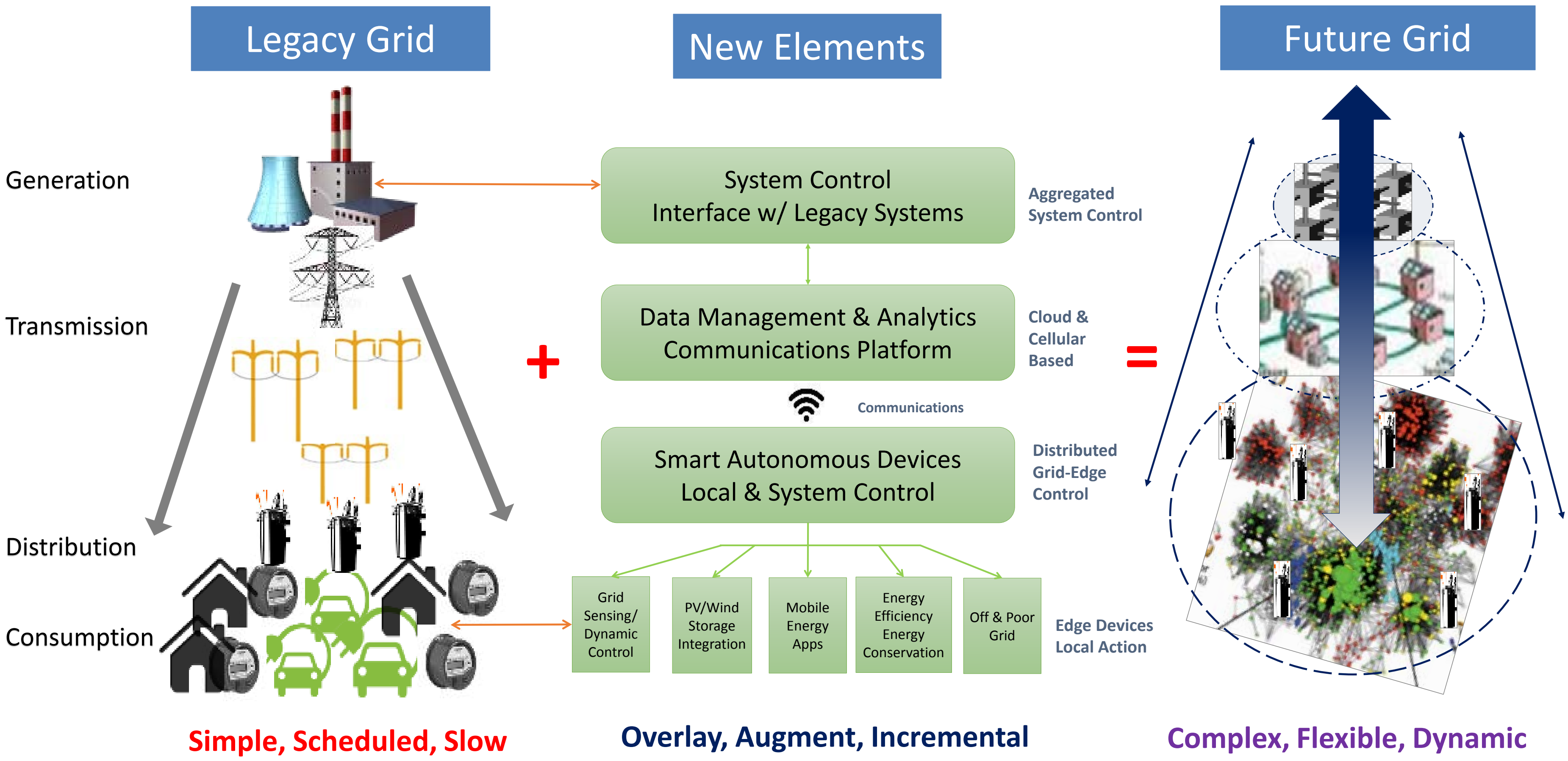
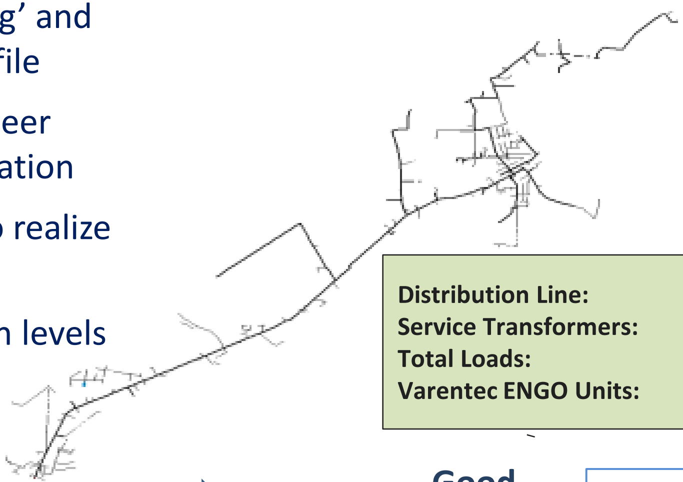


Distributed Grid-Edge Control – Approach

Source: Southern Company and Varentec

- Inject local dynamic VARs with ‘no-fighting’ and ‘zero droop’ algorithm → flat voltage profile
- Autonomous operation with no peer-to-peer comms, but with slow comms for coordination
- Coordinate with utility assets (LTC/LVR) to realize unprecedented grid-side volt-VAR control
- Eliminate voltage constraints to allow high levels of PV hosting without energy storage

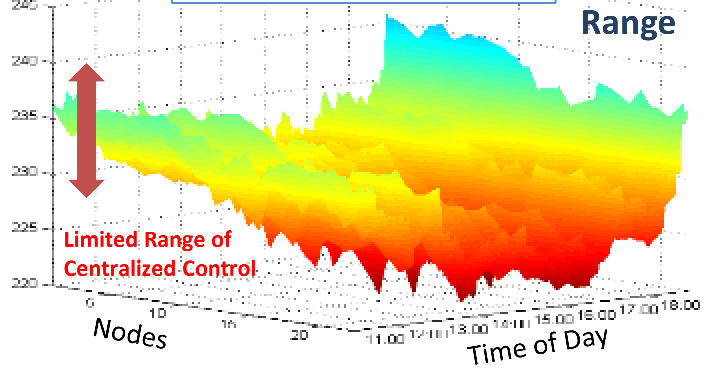


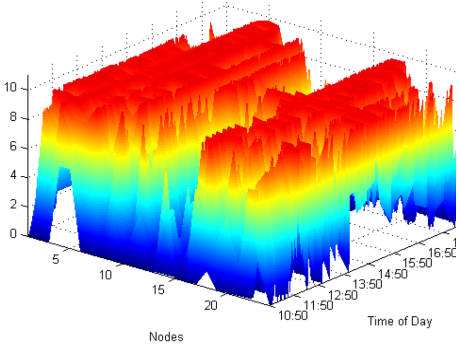
Proven at 20+ utilities

Distribution Line:	5 MW 12 mile
Service Transformers:	421
Total Loads:	4760 KVA
Varentec ENGO Units:	91 * 10 kVARs

LTC set at 240V (1.0 pu)
TOP-DOWN CONTROL

Poor Control Range

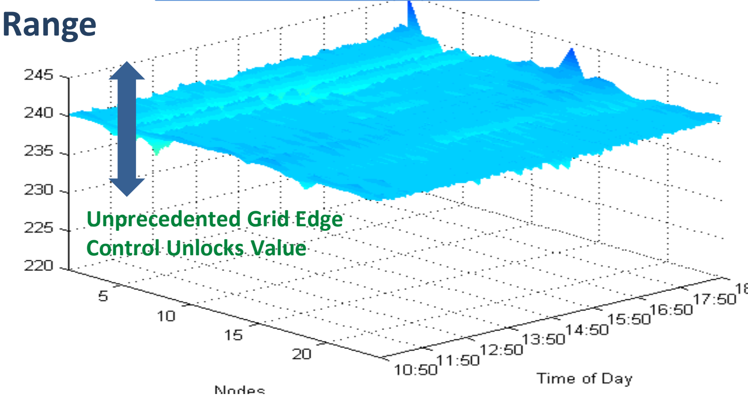




Grid-Edge VAR Injection

Good Control Range

LTC set at 240V (1.0 pu)
EDGE-UP CONTROL



Enable Cost-Effective PV Hosting

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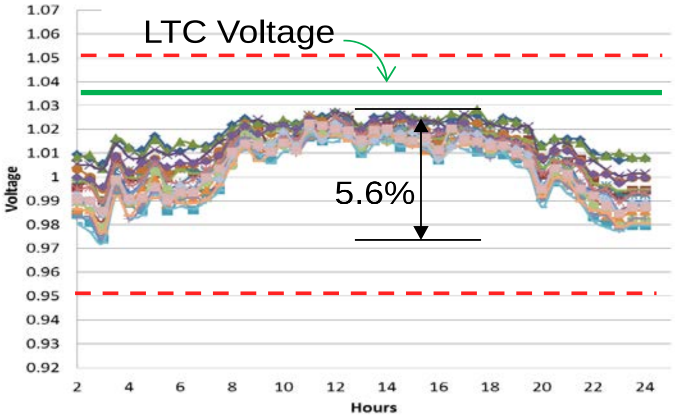
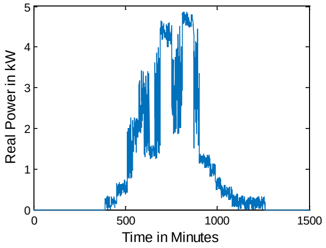
Voltage Profile on Feeder **without PV**

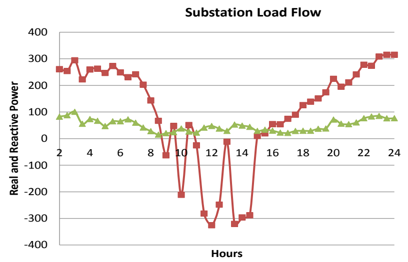


Conventional Feeder Operation

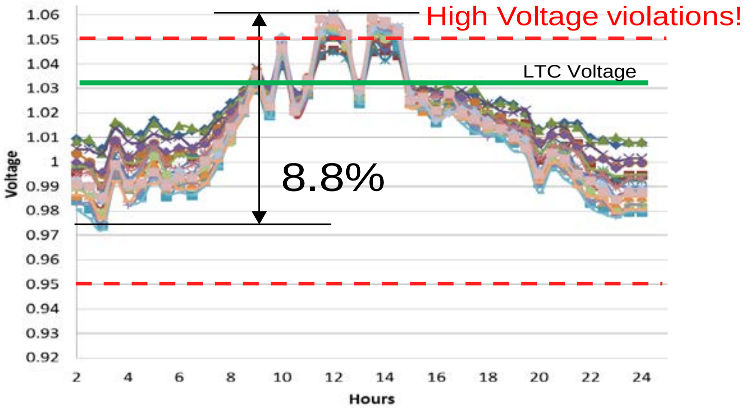
- LTC voltage set point nominally at ~1.035 pu
- 20 node voltages shown along a feeder over 24 hours
- Voltage constraints limit PV hosting capacity



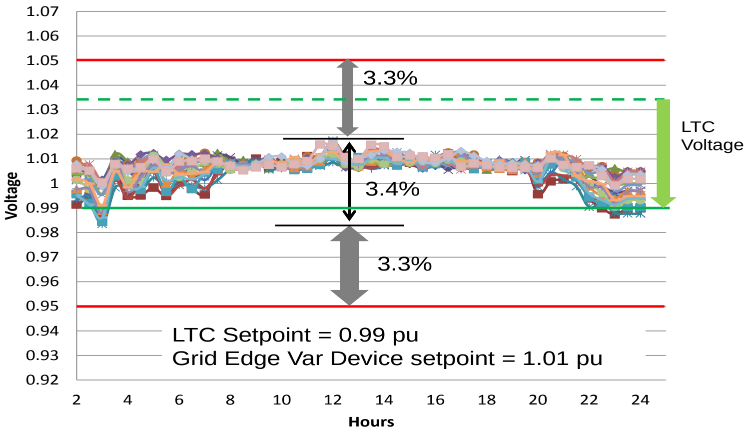
Recorded solar radiation



Voltage Profile **with >150% PV penetration**



Voltage Profile **with >150% PV & Grid Edge Control**



Distributed Control … *a new paradigm*

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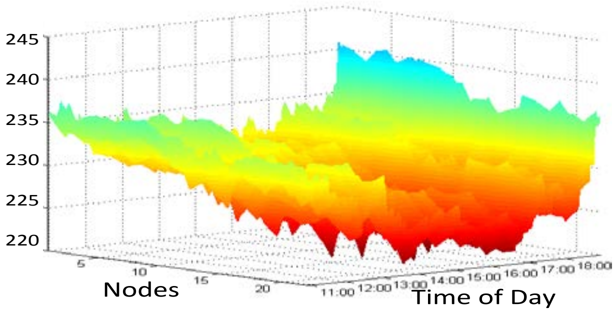
Centralized Control

Now …

- Scheduled Generation
- Centralized Top-Down Control
- Planning Based, Dispatched
- Unidirectional Flows, Consumers
- Redundancy, N-X Contingencies

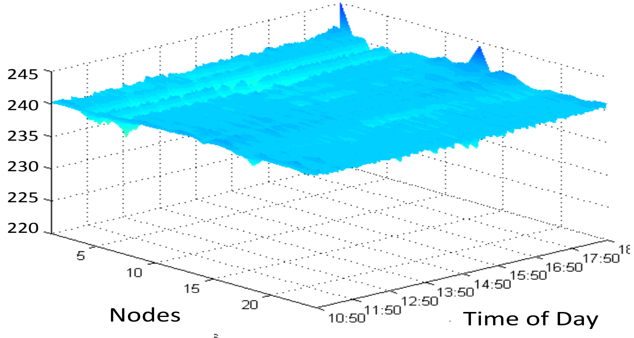


Centralized top-down control – poor system performance

Distributed Control

Need …

- Non-Dispatchable Variable Generation
- Distributed Edge-Up Real-Time Control
- Flexible, Secure, Predictable, Virtual Resources
- Bidirectional Flows, Dynamic Optimization
- Prosumers, Transactive and Ancillary Services



Real-time distributed control - local & system benefits

Source: Southern Company and Varentec

Value Enabled by Grid-Edge Control

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  - ✓ *generation, storage, ramp rate, contingency management, DER balancing, VAR support, FIDVR*

Grid as a Living Ecosystem

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Recommendations

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Questions?

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