Impacts of DER on Transmission Systems

The Distribution/Transmission interface

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Presentation alignment with OMS DER work plan - September 2017 hot topics

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DER Work plan topic

- **Transmission Planning**
  - Need to incorporate DERs so that transmission planning is effective → California Energy Commission - Regional Transmission and Distribution Network Impacts Assessment
  - Consider DERs as non-transmission alternatives → Mason County renewable demand response
- **Transmission System Reliability and Operations**
  - DER amounts and locations must be known for reliable and efficient grid operations → PJM – Sturgis blackout avoidance
  - Rules and standards for DER participation in markets → DERs and wholesale market issues – California ISO
- **Markets**
  - Market based dispatch of DER and associated market products → Agder Energi / Noordpool
  - Application of Information Communications Technology (ICT) → Ontario ISO, Agder Energi

Presentation examples

- California Energy Commission - Regional Transmission and Distribution Network Impacts Assessment
- Mason County renewable demand response
- PJM – Sturgis blackout avoidance
- DERs and wholesale market issues – California ISO
- Agder Energi / Noordpool
- Ontario ISO, Agder Energi

PSC at a Glance

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- Global engineering consulting for transmission, distribution, generation, markets, and system operators
- Founded 1995 in New Zealand
- Delivering a full suite of engineering services
  - DER, Control Systems, Market Systems, Power Networks, HVDC
- Offices in North America, Europe, Australia, Asia, and NZ

PSC North American Clients

- ABB
- aeso Alberta Electric System Operator
- Alabama Power, A Southern Company
- Ameren
- Anbaric Transmission
- AltaLink
- Allegheny Electric Cooperative, Inc.
- ATCO Electric
- Avista
- BC hydro
- Bonneville Power Administration
- Burns & McDonnell, Since 1898
- Cross Sound Cable Company LLC
- Doosan
- Emera
- ERCOT
- ess group
- FirstEnergy
- FPL
- GE
- Georgia Power, A Southern Company
- Grant PUD
- GridMobility
- Idaho Power, An IDACORP Company
- intel
- ISO new england
- NYISO
- ITC, A Fortis Company
- Kansas City BPU
- Kaua'i Island Utility Cooperative
- Lockheed Martin
- Microsoft
- NaturEner
- NextEra Energy
- Pacific Northwest National Laboratory
- Pattern
- PG&E
- pjm
- PSE Puget Sound Energy
- Potomac Economics
- Sapient Global Markets
- Seattle City Light
- Siemens
- Snohomish County PUD, Public Utility District No. 1
- Southern Company
- SPP Southwest Power Pool
- Tacoma Public Utilities
- Tetra Tech
- TBC Trans Bay Cable
- TransCanada

1. DER impacts on Transmission Planning

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What are the primary system reliability considerations due to DER penetration?

- ► Variability of DER power generation
  - Time of day
  - Weather conditions
  - Load forecasting
- ► Reversed power flow from the D feeder onto the T system
- ► Response of DER to bulk system disturbances
  - Ride-through capability
  - Frequency and voltage impacts
  - Coordination with protections such as Under- and Over-Frequency
- ► Displacement of traditional synchronous generation, particularly under light load conditions
  - Potential transition from a bulk grid dominated by traditional generation to a bulk grid dominated by inverter-based generation
  - Can advanced inverter-based generation provide secure/reliable control capability?

Transmission Planning
Transmission and Distribution Overview

- ISO controlled bulk transmission grid
  - Designed to reliably supply power from large-scale, conventional generators to T-D substations over high voltage transmission lines
  - The T-D "seams" define where the T & D systems connect
  - Power flow direction has traditionally been from the T network to the D system to supply load
- Traditional planning practice
  - T & D planning process is mainly separate
    - Applies to both vertically integrated and non-integrated companies
  - Separate simulation software, data bases, and models
  - Certain limited data is shared at the T-D seams

Transmission & Distribution Planning Model - Seams

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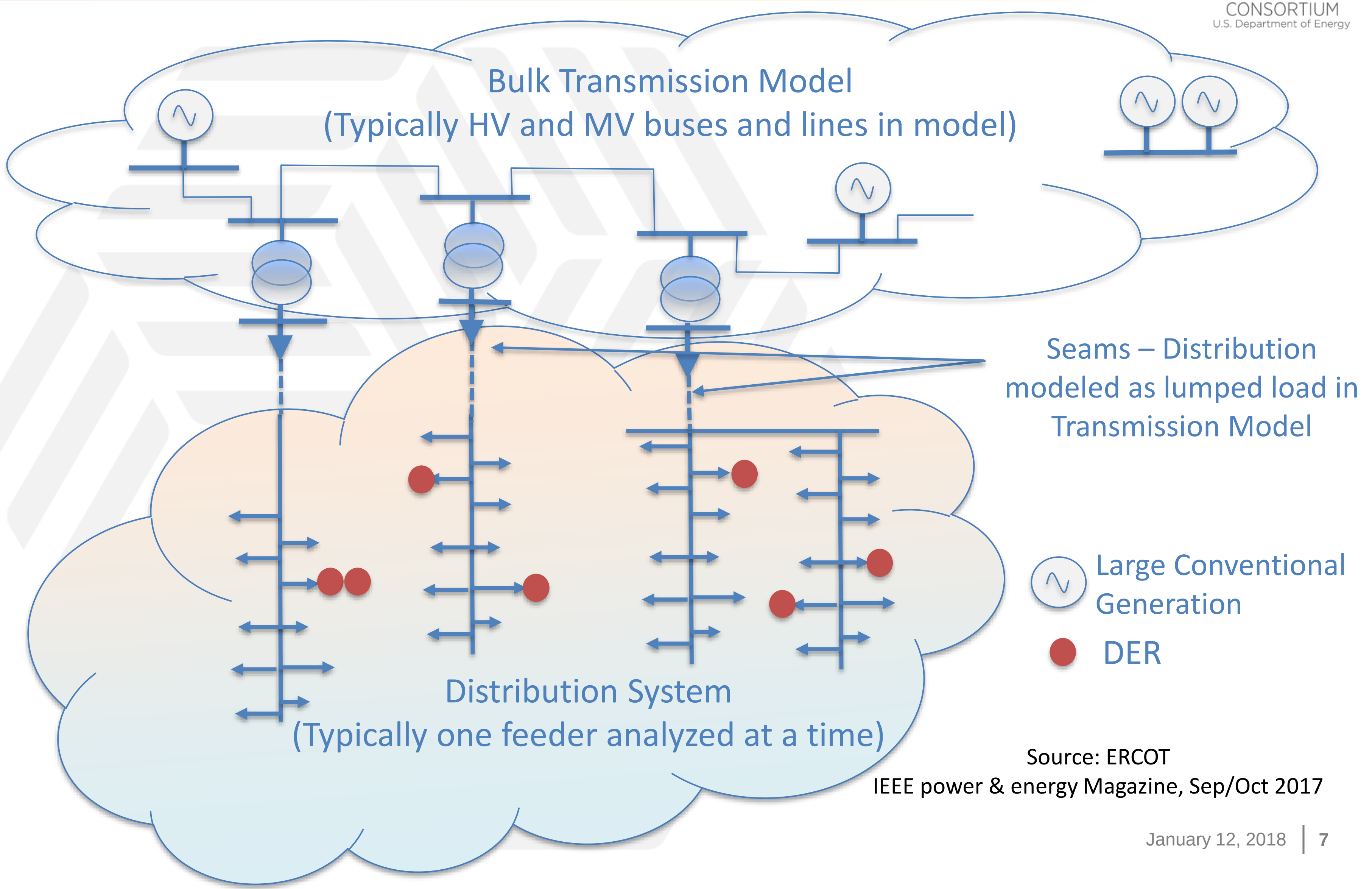
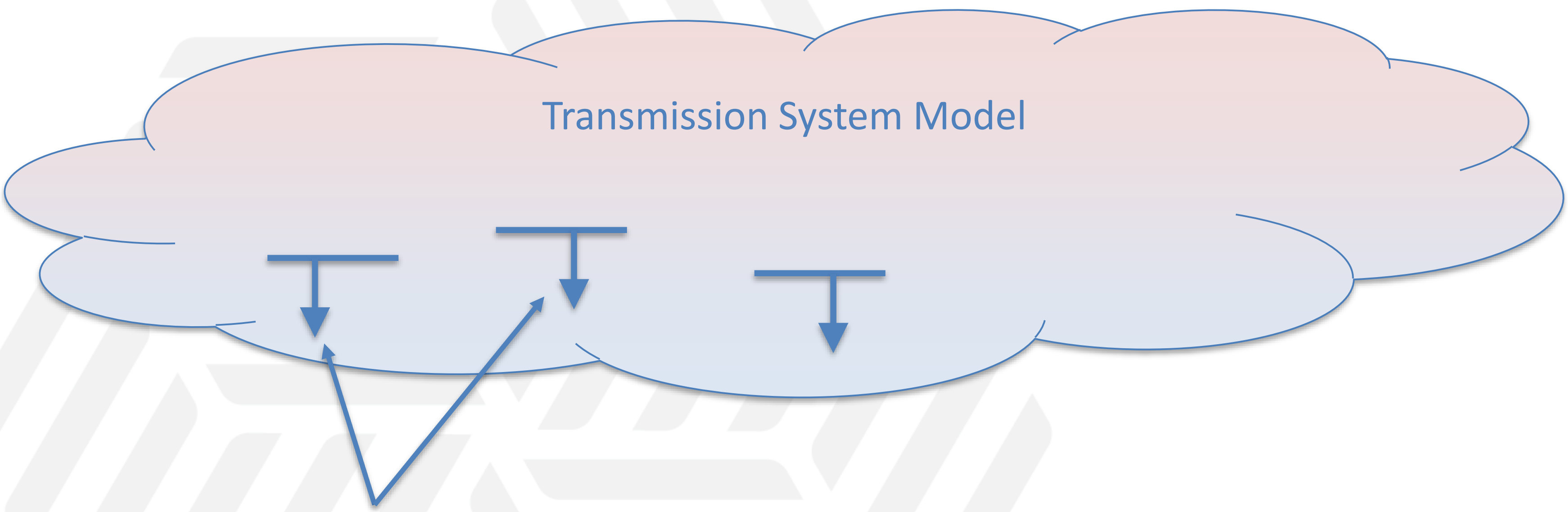


Source: ERCOT
IEEE power & energy Magazine, Sep/Oct 2017

Transmission Planning
Traditional Planning Model



Aggregate Load and DER rolled-up to the nearest substation (seam)

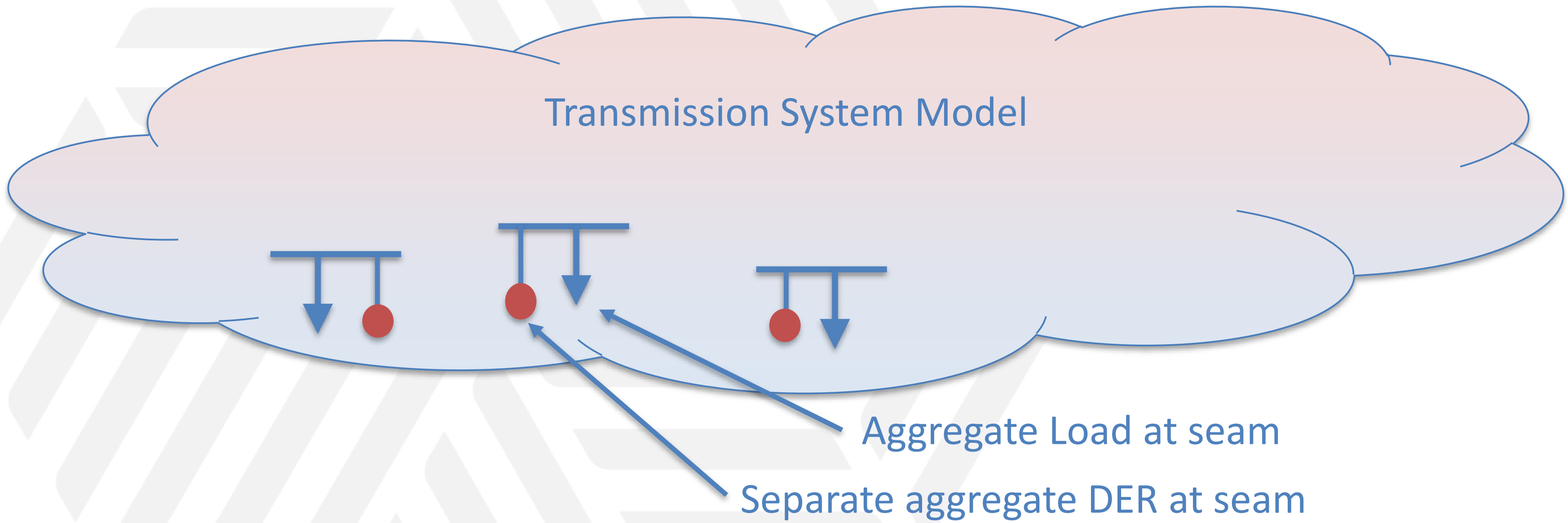
- No separate representation of DER
  - No real visibility as to the size/location of DER
- Load typically based on a snapshot condition (e.g., summer peak, summer light, etc.)
  - No time variability – have to apply general assumptions
- This approach is adequate for low level PV penetration (basic load reduction)

Transmission Planning
Needs for DER Impact Assessment

- ► Visibility of DER
  - More coordination and sharing of data is necessary between T & D entities to facilitate planning and assessment of DER
    - More important as DER penetration levels increase
    - Load and DER profile information beneficial (see “Duck Curve” in Extra Slides)
- ► Process
  - Customary DER project interconnection
    - Queue process often utilized for DER projects
      - ◆ Sequential project evaluation, impacts, and upgrades
      - ◆ When a constraint is identified – project solely on the hook for mitigation/costs and often results in withdrawal
      - ◆ Not necessarily the most efficient process in advancing DER integration
    - Project generally evaluated at the D feeder level only
  - Potential benefits of project clusters and more integrated T & D model
    - Identification of T impacts
      - ◆ Positive - Possible deferral of T expansions
      - ◆ Adverse - Required T upgrades in some cases
    - Sharing of upgrade costs => more potential integration

Transmission & Distribution – Intermediate Planning Model

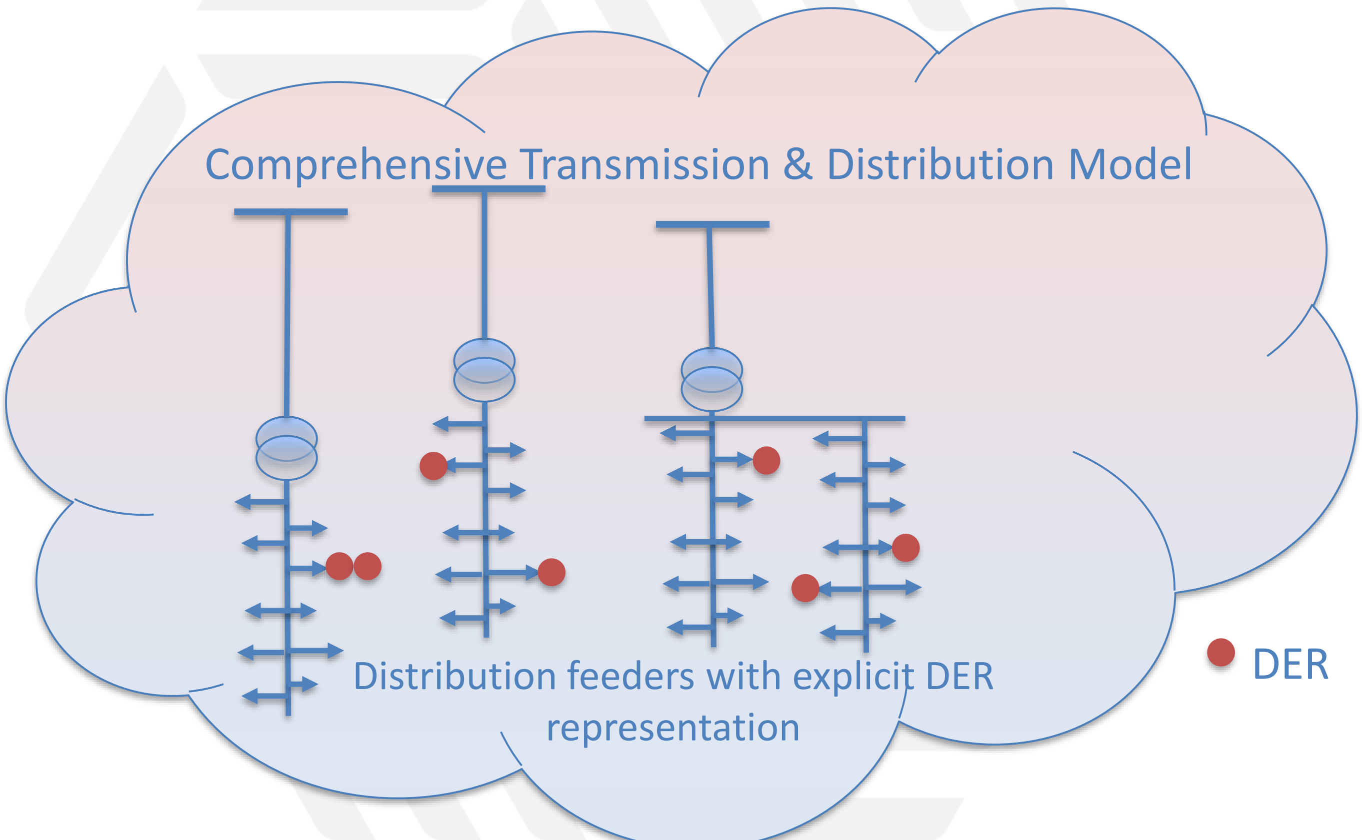
► Better evaluation of DER impacts can be achieved by separating the load and DER representation within the T model



- Separate DER and Load representation, together with time profiles, will allow more fidelity for impact assessment
  - DER variability impacts and project clusters can be evaluated
  - Reserves, ramping requirements and potential changes to traditional thermal unit dispatch can be investigated

Transmission Planning
Comprehensive T & D Planning Model

► Future – Comprehensive T & D model may be necessary for explicit DER representation and more complete impact assessment for high DER penetration



- Requires process and standards for sharing of more data between T & D
- Can be locational based to the study area of interest
- Captures both T & D constraints
- Should be scalable
- Potential to include more advanced DER models by type

Transmission Planning
Comprehensive T & D Planning Model

Example:

Research and testing of comprehensive T & D modeling is on-going:

- ► California Energy Commission – “Regional Transmission and Distribution Network Impacts Assessment for Wholesale PV Generation” – August 2014*
- ► Key findings:
  - ► Adverse impacts due to the distribution located projects onto the transmission system and vice versa were identified
  - ► Each project interconnection is different and it is difficult to generalize about grid impacts – approximations may obscure findings as penetration levels increase

*Please refer to Extra Slides Section for more information on the study area size

Transmission Planning (and Operations) Advanced Technologies and DER

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Role of Advanced Technologies to Support DER Integration

- ► Planning process, tools, and models should be structured to accommodate the potential application of technology advancements:
  - Smart-Grid at the D level
    - Monitoring, Automated Control & Communications
    - Smart Switches – automatic switching to isolate and restore feeder sections
  - Energy Storage/Electric Vehicles/Demand Response
    - Coordination to optimize use of variable DER
  - Inverter control functions
    - Volt-VAR control
    - Frequency control
    - Virtual Synchronous Machines (i.e., synthetic inertia) for grid power-frequency stability control*

* Please refer to Extra Slides Section for more technical explanation

Transmission Planning Recommendations

Recommendations for addressing primary planning considerations:

- ► Establish process and procedures for further coordination between T & D entities required for enhanced modeling of DER
  - As this can be very data intensive, consider a phased-in approach consistent with anticipated schedule of increasing DER penetration levels
  - Collaborate with other organizations and industry experts to keep abreast of advancing tools and methodologies for integrated T & D planning
  - Process of sharing and managing data and models should be scalable and adaptable for use in integrated T & D models, if and when needed
- ► Prepare for the accommodation of evolving technologies to complement higher levels of DER integration
  - Revise Interconnection Standards accordingly
  - Make use of smart technologies such as control and monitoring to compile data for enhanced modeling of DER

2. DER impacts on Transmission Operations

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DER Forecasting

- ► Increasing challenges for transmission operators due to renewable penetration and DERs
- ► Traditional forecasting is based on Heuristics and "similar day" models
  - With DERs our days are no longer "similar" to those of the past
- ► Improved DER forecasting allows improved system operations for T & D
  - Many T & D organizations are using real time weather information to improve short term forecasts for DER
- ► New approaches to forecasting are being investigated
  - Using cloud computing, IoT, big data, data analytics, and machine learning
- ► Advancements in forecasting may help the MISO region improve T & D operations
  - Ontario is using cloud computing and machine learning forecasting tools

Ontario ISO 24 Hour Day Ahead Load Forecast
Using Microsoft Azure and machine learning

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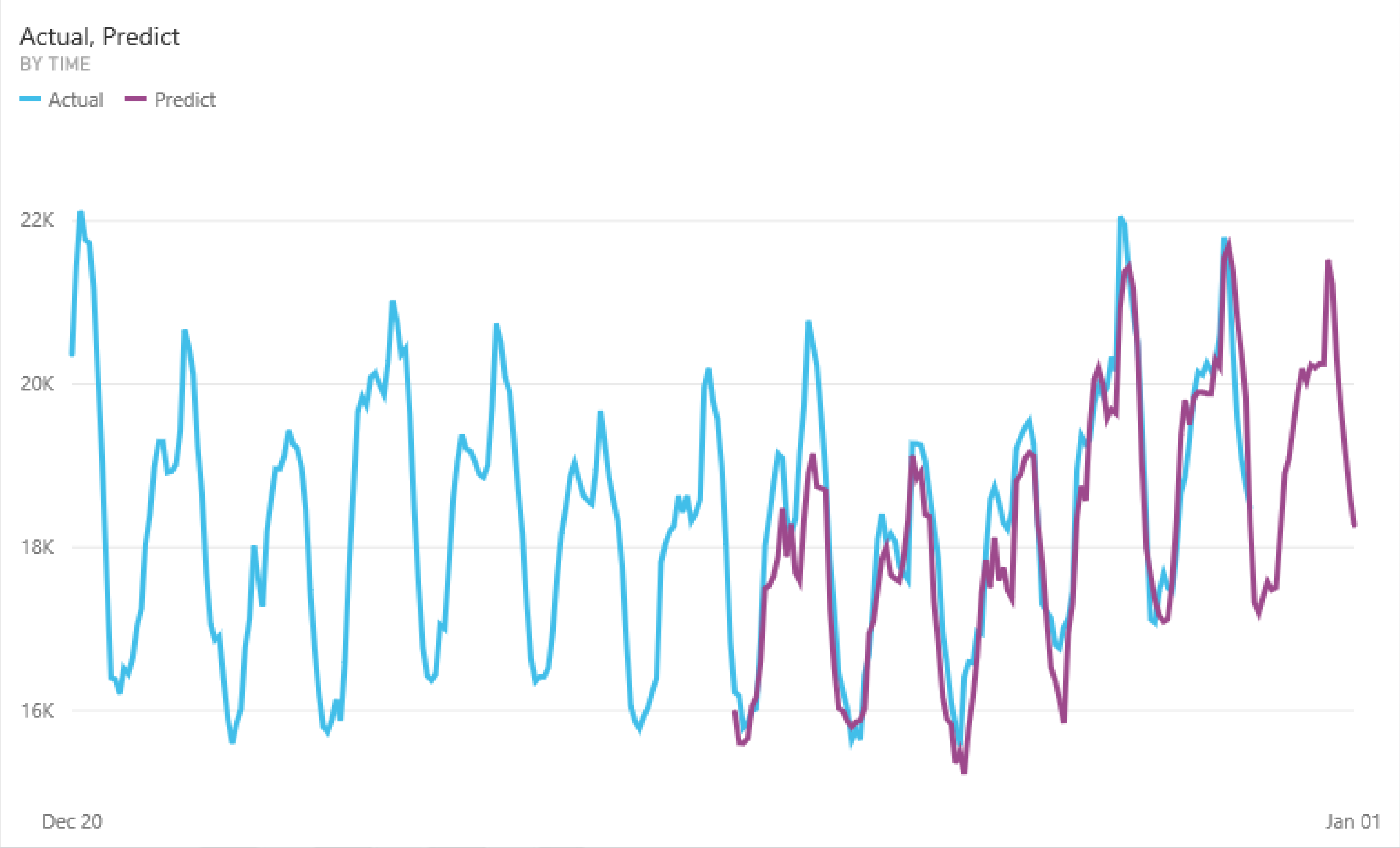
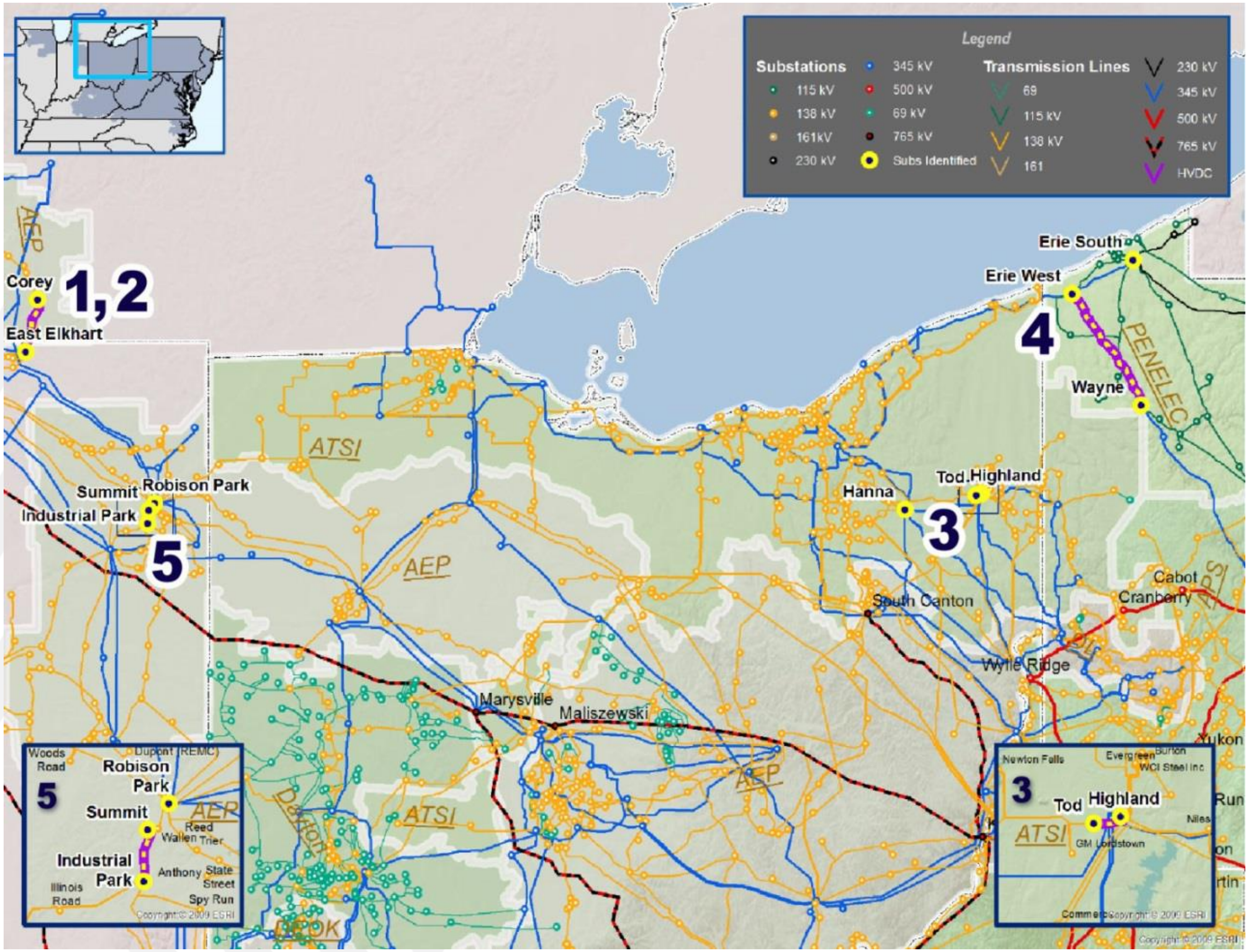


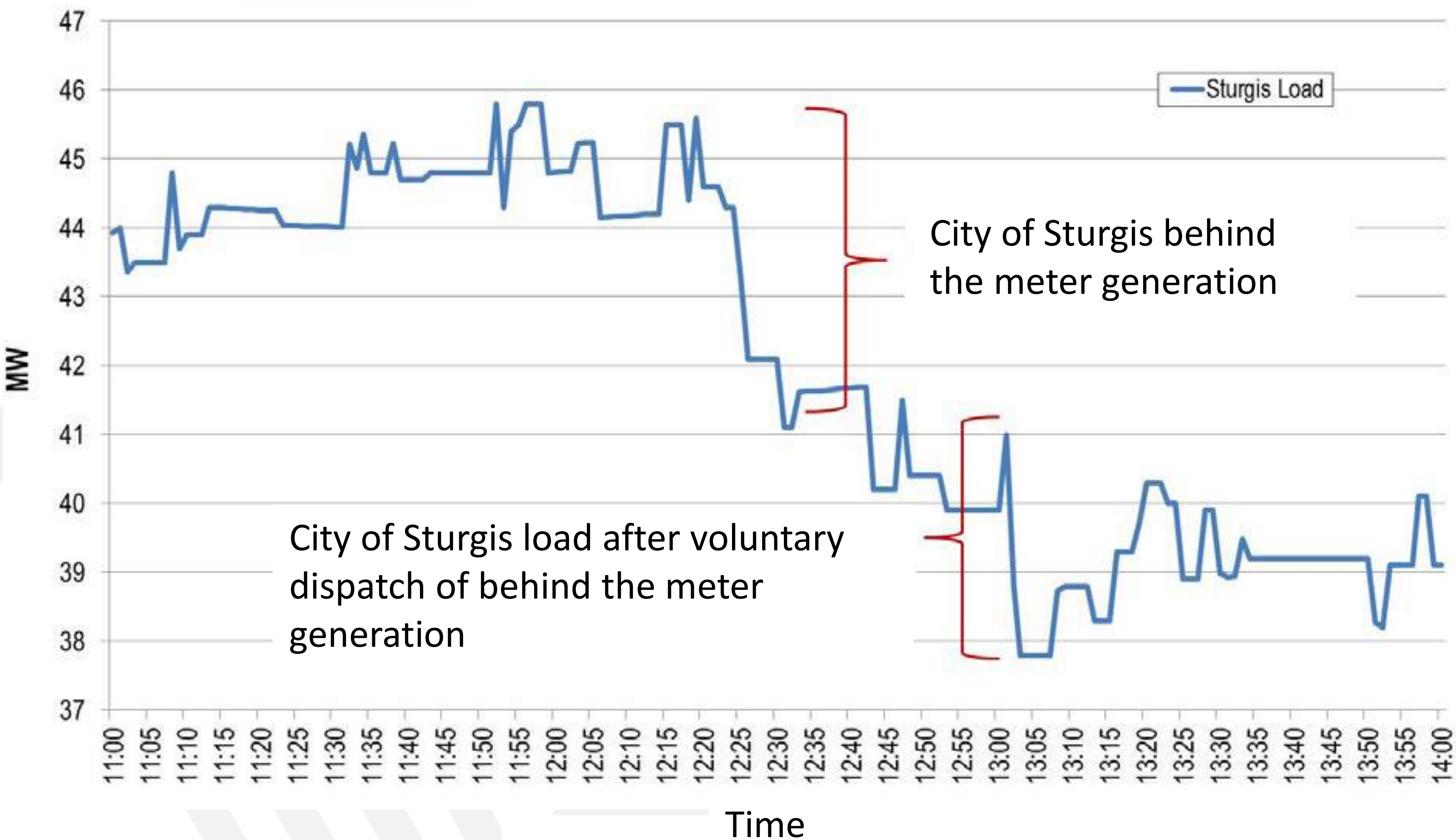
DER impacts on Transmission Operations

- Transmission operations can be improved with DER real time status and schedule status
  - This is an increasing concern as both the Distribution and Transmission networks have increasing variability and uncertainty due to renewables
- DER information that needs to be exchanged with transmission ops
  - System conditions
  - Day ahead schedules and forecasts
  - Constraints that need to be applied or monitored
- There is also an opportunity for transmission operations improvements with DERs during abnormal conditions
  - Example of PJM Transmission operations coordination with Sturgis Michigan distribution grid to use DERs (distributed generation) to avoid a blackout. 6 MWs of DG avoided a 42 MW blackout.
    - http://www.pjm.com/~/media/library/reports-notices/weather-related/20131223-technical-analysis-of-operational-events-and-market-impacts-during-the-september-2013-heat-wave.ashx

PJM - 5 load shedding events totaling 154 MW



Sturgis, Michigan behind the meter impact on load during the event



Recommendations from the Sturgis, Michigan event

- Establish and document approach for collecting behind the meter (DER) information for system planning and system operations
- Improve representation and operation of behind the meter DG (DER) for Transmission dispatchers and incorporation into emergency operating procedures
- Review and improve power system modeling and telemetry to integrate DER with transmission operations

- OMS may wish to consider the value/benefit of DER visibility at the transmission level with regard to improved system reliability and operations

3. DER as a non transmission asset alternative - Mason County DERs and BPA transmission

- BPA transmission operations is concerned about the increase in renewable energy coming on to the bulk power grid and looking at traditional (wires/bulk power) and non-wires alternatives
  - MISO also has a similar situation with increasing renewables connected to the transmission grid
- Most grids operate based on control systems designed to provide load following
- Mason County utilized the concept of generation following to mitigate intermittency by using DERs to offset the intermittency of transmission connected renewables
  - DERs in the form of electric water heaters were controlled based on the real time status of the wind farm
  - MISO's fast ramping products were introduced to address this same issue

DER as a non transmission asset alternative – Mason County DERs and BPA transmission

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- Goals of the project:
  - Demonstrate an automated DR system to selectively manage demand in direct correlation with the availability of intermittent renewable resources
  - Identify the optimal control and shedding strategies that can be automated for seasonal intermittent renewable events, power outages, and control system peaking events
  - Evaluate the economic and socio-economic factors that influence customer participation that will dictate wide-scale future DR deployment
  - https://www.bpa.gov/EE/Technology/demand-response/Pages/residential_demand_response.aspx

DER as a non transmission asset alternative – Mason County DERs and BPA transmission

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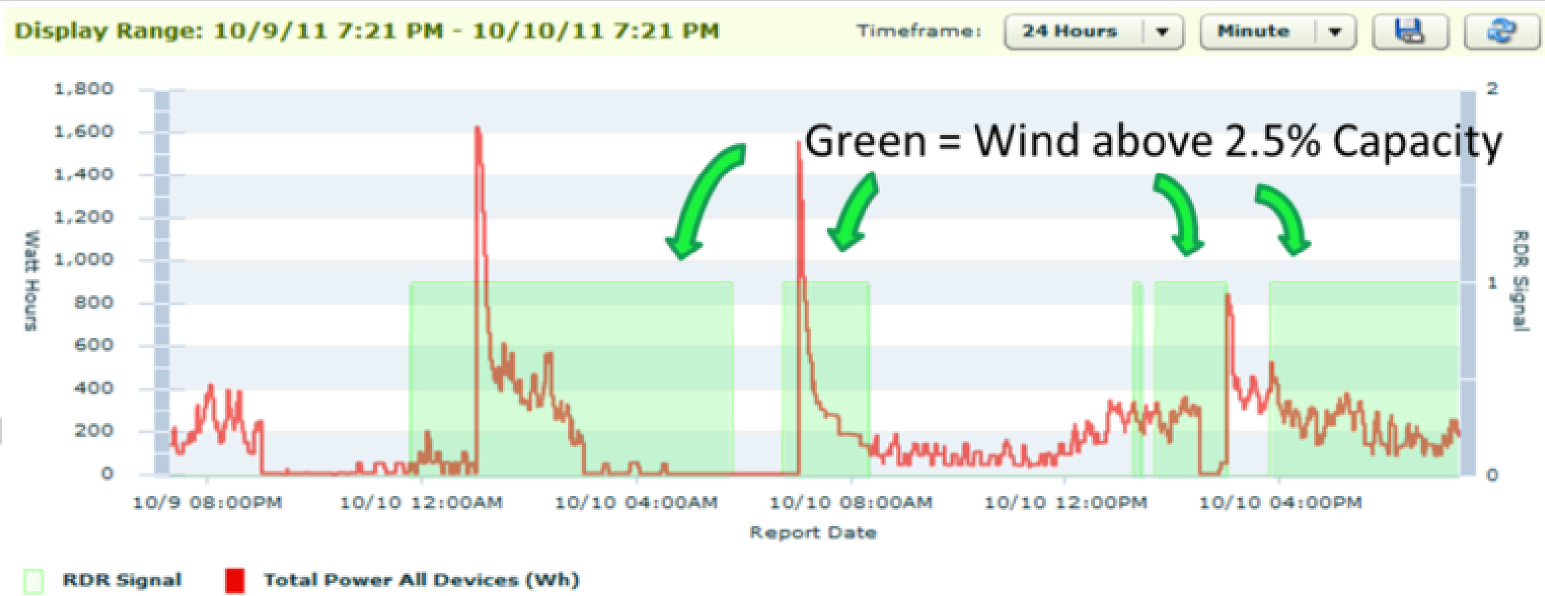
- The distribution utility equipped homes with either an internet or cellular network configured for a renewable demand response signal delivery to their water heater.
- Each home received communication hardware enabling the delivery of load-control information to enhanced hot water heater control systems to preferentially store renewable energy (wind) via a DR protocol that essentially tracks the intermittent renewable supply, or wind generation curve.
- A 10 kW Demand Energy Networks (DEN) Demand Shifter unit with a nominal storage of 40 kWH is also included as part of this project. This three phase unit is located at the Mason County PUD #3 Operations Center and complements renewable generation sources through flexible system scheduling overrides that allow the system to optimize intermittent resources.

DER as a non transmission asset alternative

- The red line is the water heater load. When the red line is in the green shaded area, the load is coincident with wind energy production.



Last Status: All Devices

Serial #	Last Status	Type	F/W	U-Ovrd	S-Ovrd	Switch	Load	Volts	Amps	Watts	Run Mod	Last Power R
C2288038	09/29/11 10:47 F	GSM	1.8	0	NONE	OFF	OFF	247.676	0	0	NORMAL	12/31/08 05
C2288020	09/29/11 10:47 F	ETHERNE	1.8	0	NONE	OFF	OFF	243.858	0	0	NORMAL	12/31/08 05
C2288071	09/29/11 10:46 F	ETHERNE	1.8	0	NONE	ON	OFF	248.758	0.163	40.548	NORMAL	12/31/08 05

4. Wholesale markets design and DERs

DERs impact wholesale market design

- ► DER integration with wholesale markets is an evolving landscape
  - ► NY is taking a loosely coupled approach encouraging distribution level markets with some aggregation into the wholesale market
  - ► CAISO is taking a tightly coupled approach with no distribution level markets and DERs aggregated into the wholesale market
  - ► Noordpool (Europe) is encouraging a hybrid model with distribution level markets integrated into the regional wholesale market

Wholesale markets design and DERs

DERs impact wholesale market technology

- The models and technology used by the wholesale markets cannot accommodate DERs at the granularity of the distribution network
  - Model limitations
  - Performance limitations
  - Software application limitations
- It is unlikely an incremental change will be possible and RTOs/ISOs will require significantly new systems
  - This is a risk, as systems of this size and complexity are not common
  - Some opportunity to adopt solutions from other industries
  - MISO and SPP are implementing settlements using a financial transaction software development company (symphono)

Wholesale markets design and DERs

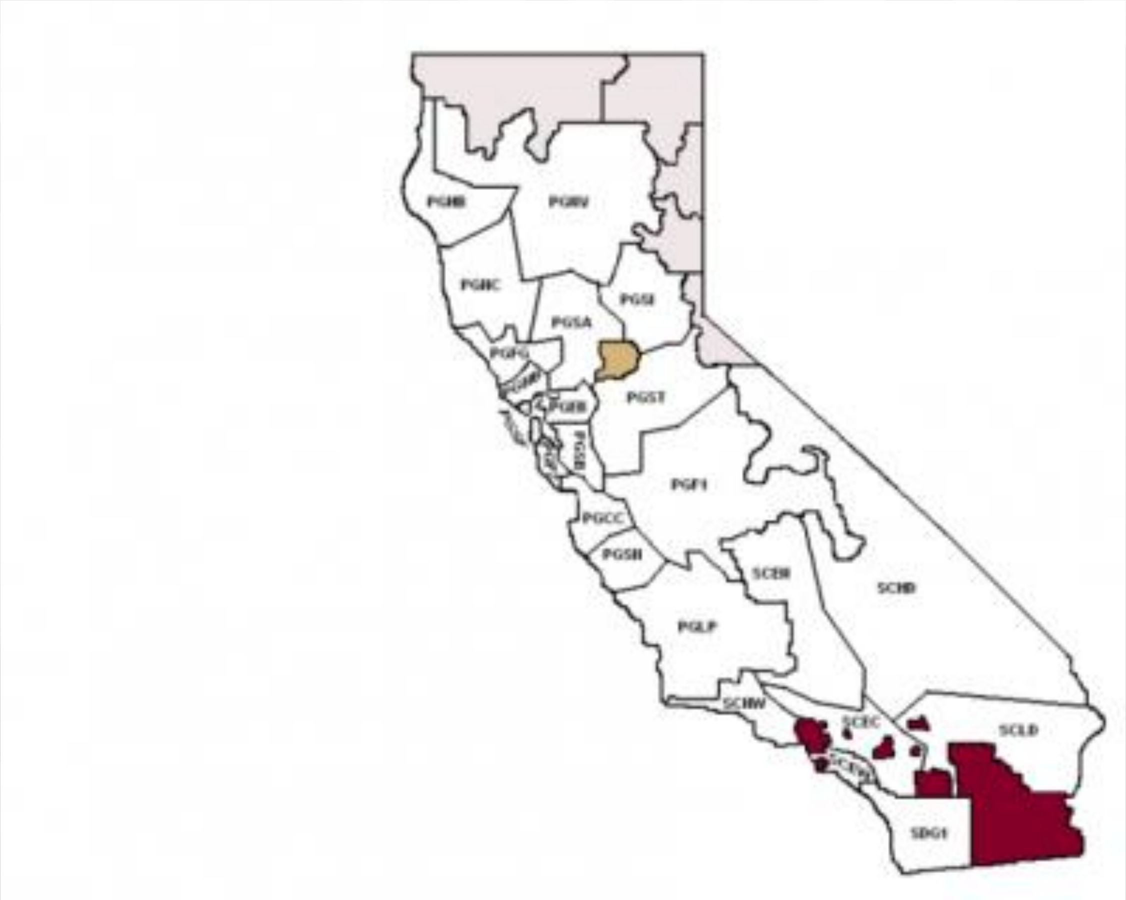
CAISO design to facilitate DERs into the market

- DERs can be aggregated to a single Pnode or across many
  - Pnodes are Price Nodes in an LMP market
- DERs cannot mix different resource types if they span multiple Pnodes
- All resources must act uniformly – i.e. some batteries can't be charging while others discharge
- To manage congestion, Load Aggregation Points are defined within zones and sub regions

Wholesale markets design and DERs

CAISO Zones/Regions for DERs

- ► DERs can not cross sub Load Aggregation Points (LAP) regions to avoid dispatch on the wrong side of a constraint



Wholesale markets design and DERs

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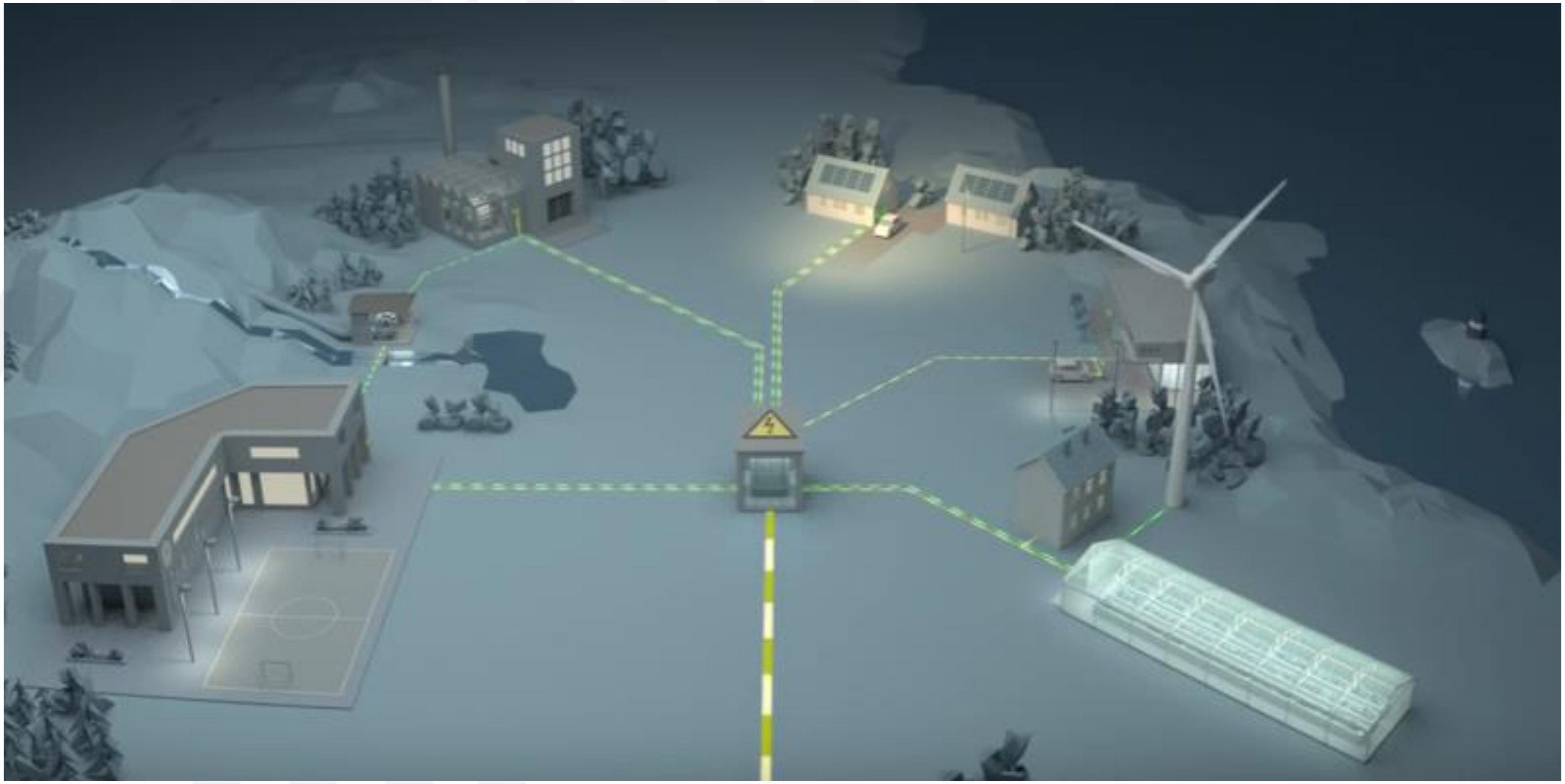
Hybrid approach with distribution markets integrated with wholesale markets

- Agder Energi – DER distribution market within a wholesale market
- Agder Energi has developed market based distribution dispatch to manage congestion
  - The project has the residual benefit of providing flexibility services available to the Wholesale market (Noordpool)
- The information needed by the distribution system operator (DSO) is the same information needed by the transmission system operator (TSO). Once the DSO has the information, the DSO can unlock value held in the distribution network by sharing this information with the TSO.

Wholesale markets design and DERs

Distribution market introduced as a non-wires alternative to specific distribution expansion (transformer upgrades, reconductoring)



Agder Energi Solution Architecture

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Substation load forecast

powel DMS

Solar forecast

Battery Capacity Forecast

Hydro forecast

Demand response (DR) Capacity Forecast

Wind forecast

Resource Profiles & Historical Scan Data

Forecasts
Bids & Offers

DSO/TSO Marketplace

Load, Capacity, & Price Forecasting
Trading Bids & Offers

agder energi

Cost Minimization & Flexibility Maximization

Resource Optimization and Arbitrage

Dispatch Guidance
Selected Bids & Offers

Agder Energi – Noordpool market

Quick Facts

- New technology makes it possible to connect resources at different levels of the power system.
- A digital platform based on cloud technology can use advanced analytics and machine learning to optimize resources.
- In order to exploit flexibility, a new transparent and independent marketplace was developed, capable of providing a link between supply and demand and performing transactions in real time.
- Using flexibility utilities can offer an alternative to investing in grid.
- It also creates opportunities for utility customers by providing new services and enables greater integration of renewable energy.
- A flexibility market is, therefore, an important contribution to Europe’s grid transition.
- The goal of the project is to create a transparent marketplace open to all potential market participants.

What ICT is used by Agder Energi?

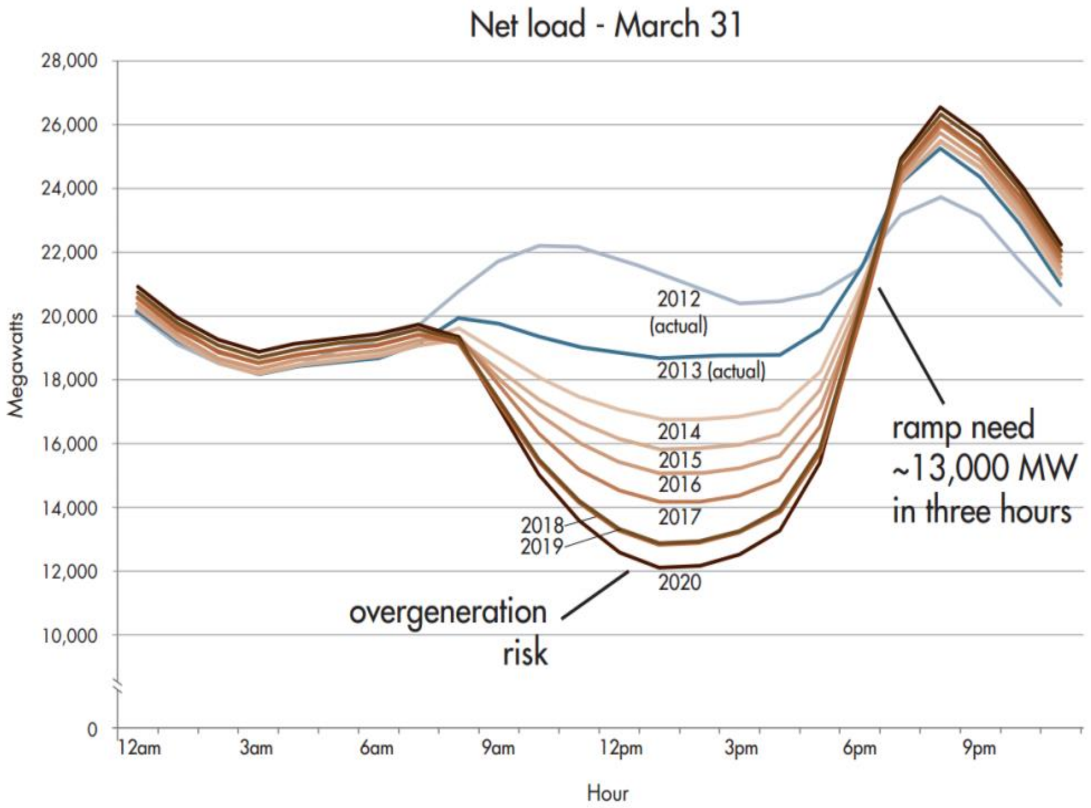
1) The solution architecture is largely out of the box, with innovative integration of the optimization layer into the architecture.
2) Iot Hub facilitates comms and commands from device to machine and machine to device – two way. Its role is as the portal for all the data.
3) Optimization (the brain) is where we have translated the business problem into a mathematical formulation and plugged into a solver running in an Azure VM.
4) PowerBi for the display to the grid operator.
5) Closed loop dispatching of the demand response via IoT Hub

Summary

- DER negative impacts on Transmission can be mitigated, and DER support for Transmission can be gained by:
  - System planning changes to combine T&D models
  - Holistic system planning process
  - Coordination between D operations and T operations
    - Improved grid utilization during normal and abnormal system conditions
- DER impacts on Transmission offer:
  - Opportunity to introduce new market products
  - Opportunity to introduce improved operating practices
- Reliability, Security, Safety, and Durability must remain primary focus

Extra Slides

CALISO "DUCK" Curve



- ► California State-Wide Curve
- ► The same general trend can apply to a more limited area or even to an individual distribution feeder.

Transmission & Distribution – Comprehensive Planning Model

Research and testing of comprehensive modeling is on-going

- California Energy Commission – "Regional Transmission and Distribution Network Impacts Assessment for Wholesale PV Generation" – August 2014
  - 122 project interconnection requests 1.5 -> 100 MW
  - Included 51 D feeders, supporting T over 3,500 sq. miles
  - Successfully captured mutual system impacts

Grid Inertia and Power-Frequency Stability

Grid Inertia and Power-Frequency Stability

- ► Inertia
  - – Stored kinetic energy in the rotating mass of machines
  - – Important property of grid frequency dynamics and stability
  - – Solar DER has no inherent inertia, wind can have some inertia
  - – Grid inertia drops with higher DER penetration, leading to degraded frequency performance
    - • faster dynamics and larger deviations
- ► Frequency control methodology requires attention and new solutions to support high DER integration
  - – Synchronous Generator Must-run limits, demand response, synthetic inertia from inverter control function