Effects of Intermittency on the Electric Power Grid and the Role of Storage

Presentation to the
U.S. Department of Energy
by the IEEE Joint Task Force on QER

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Building Careers & Shaping Public Policy

U.S. DOE requested insights on:

- Effects of renewable intermittency on the electric power grid

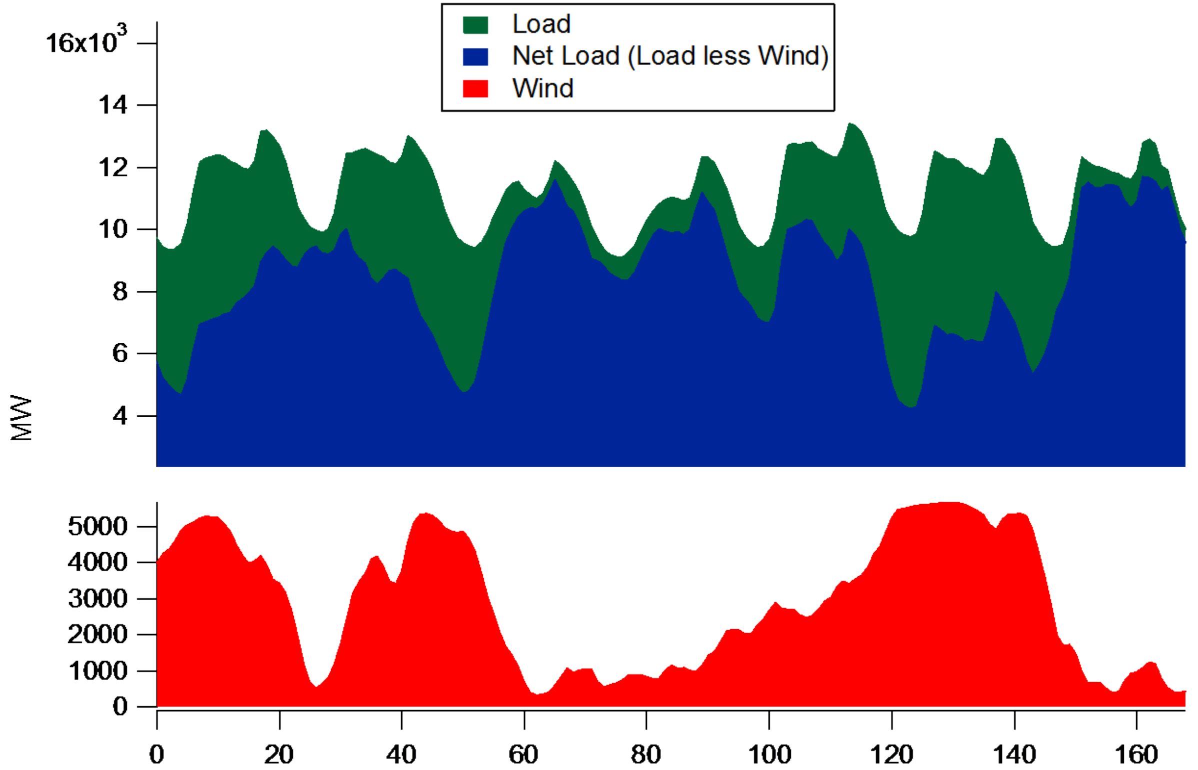
- The potential role of storage in addressing these effects.

Intermittent renewables defined

"Intermittent" renewables are those renewable energy resources and associated energy conversion devices that are:

- Output is variable and uncertain (less predictable than load)
- systems whose output is not fully under control of the operators and not "dispatchable"
- Wind and solar photovoltaics (PV) are the primary examples.
- Concentrating solar thermal power (CSP) is also in this category but can be designed with thermal storage or co-firing with fuel and made dispatchable
- Run-of-river-hydro, tidal and wave also fall into this category.
- For simplicity, this discussion focuses on wind and PV

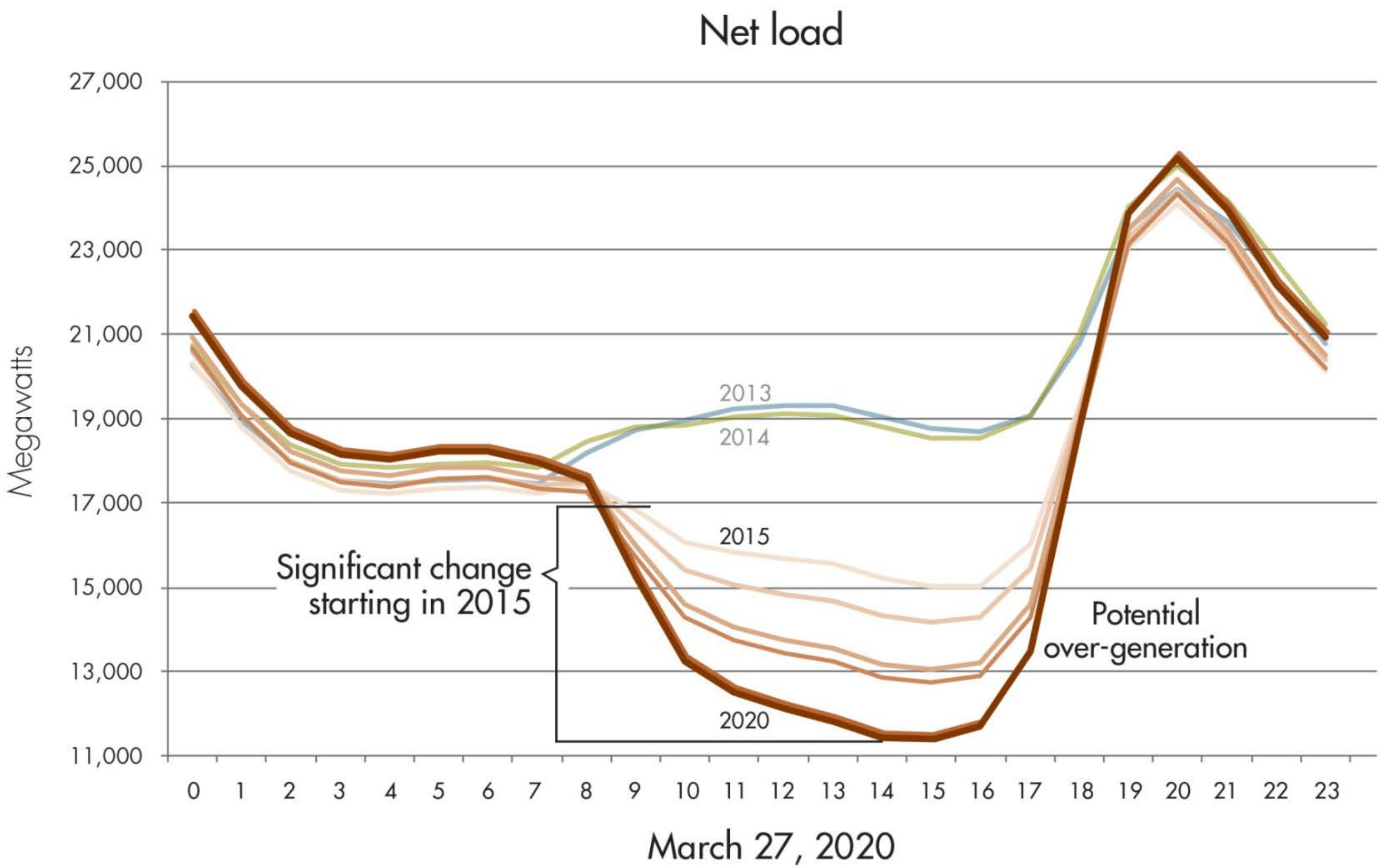
Impact of high penetration of wind: Example



Steeper ramps and lower turndown levels in some cases (top) are examples of the increased flexibility required by systems with large amounts of wind energy.

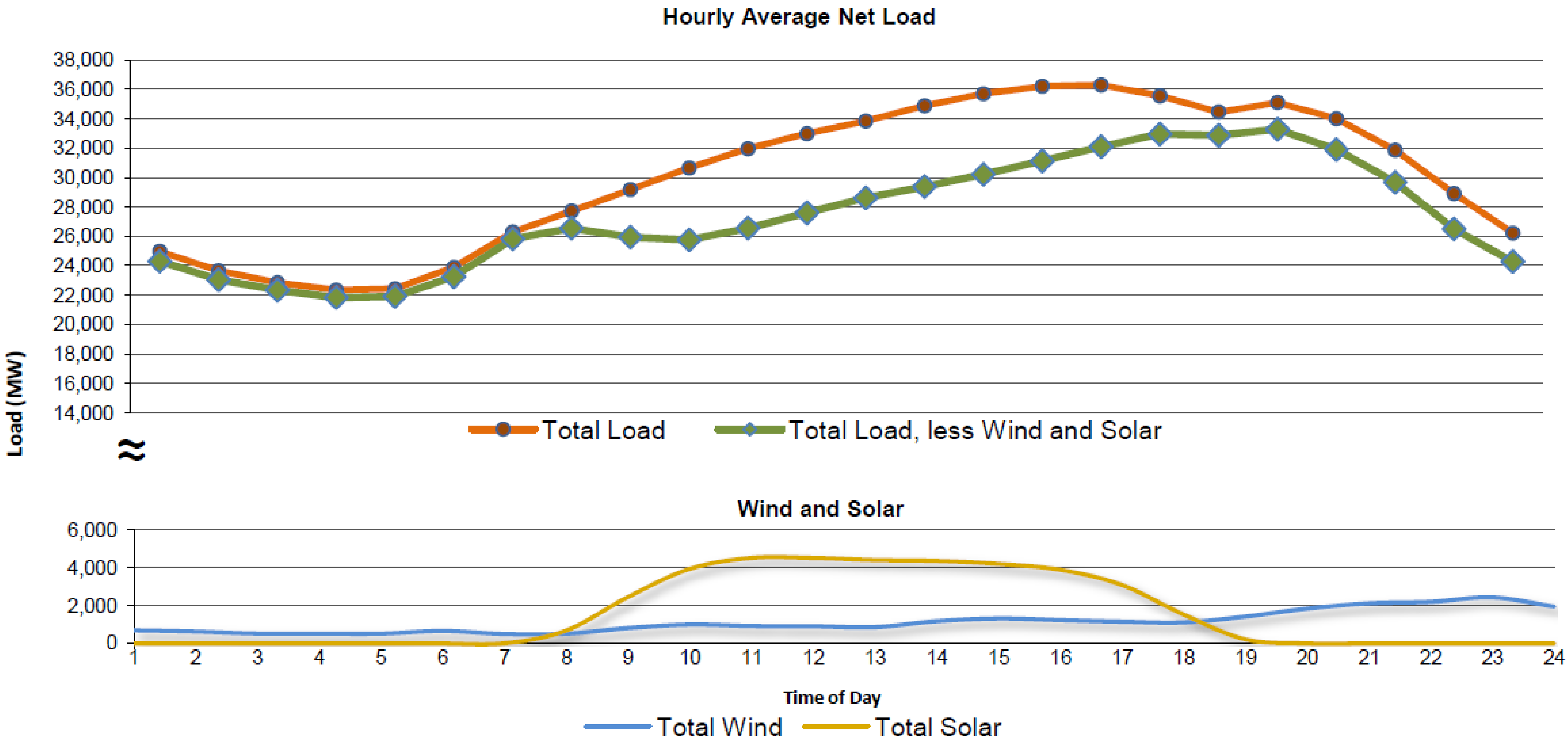
Source: Volume 4 Renewable Energy Futures

Industry trends – renewable generation proliferation



Source: CAISO http://www.caiso.com/Documents/2020_Flexible_Capacity_Needs.pdf

Daily Renewables Watch – California ISO (9/25/14)



Source: CAISO http://content.caiso.com/green/renewrpt/DailyRenewablesWatch.pdf

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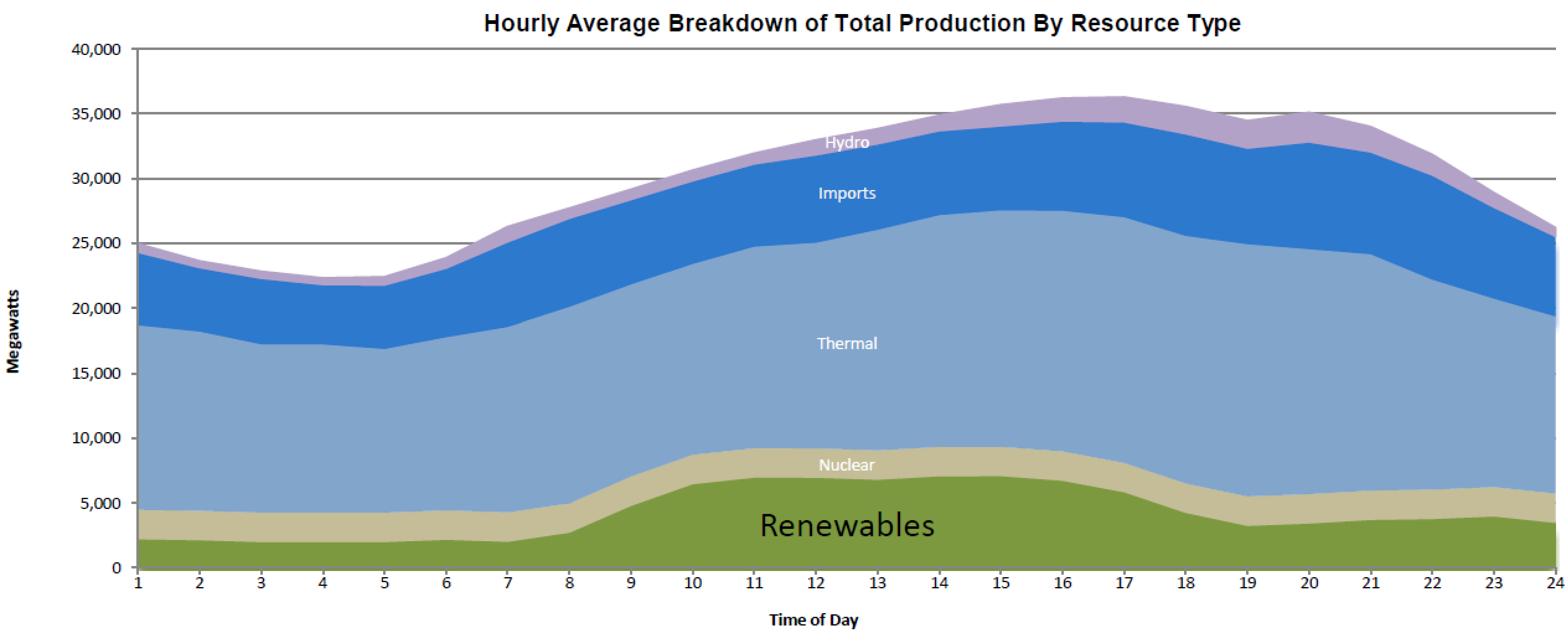

Source: CAISO http://content.caiso.com/green/renewrpt/DailyRenewablesWatch.pdf

Overall Findings

- At low levels of penetration, variable and uncertain output is not a serious issue as bulk power systems are designed to accommodate the uncertainty of load and contingencies of outages
- At penetration levels, mandated by Renewable Portfolio Standards (RPS), power system studies and real world experience show that variability and uncertainty can be tolerated if **traditional power system planning and operations are updated**

Findings: Energy Storage

- At RPS levels of penetration, energy storage, while a useful and flexible system tool, is not essential as other, often more cost-effective options are available
- At very high penetration levels (80-100%) of intermittent renewables studies seeking to maximize use and minimize curtailment incorporate substantial (seasonal) levels of storage
- The alternative at these very high levels and probably less expensive solution is significant “overbuilding” (200-300%) and curtailment

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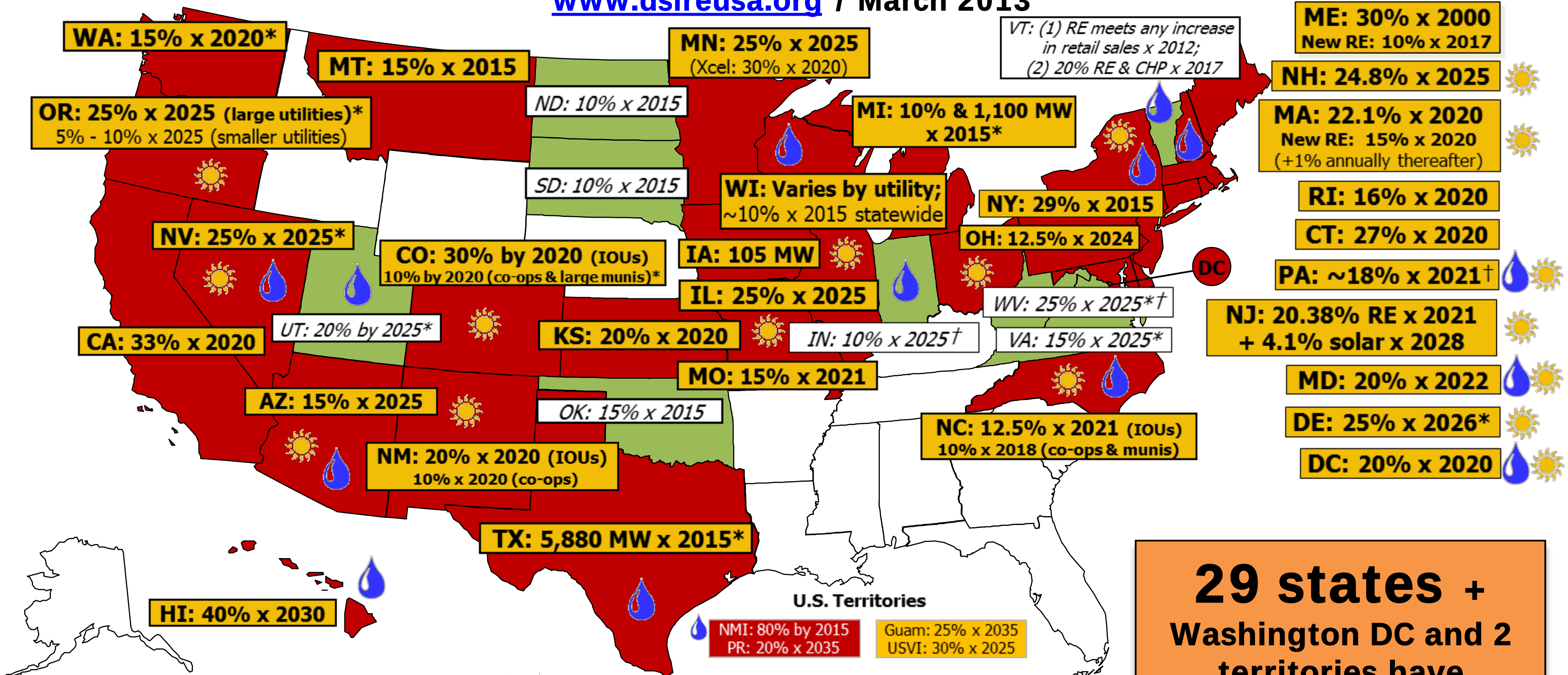
Renewable Portfolio Standard Policies

www.dsireusa.org / March 2013



Renewable portfolio standard

Renewable portfolio goal

Solar water heating eligible

Minimum solar or customer-sited requirement

† Includes non-renewable alternative resources

* Extra credit for solar or customer-sited renewables

29 states + Washington DC and 2 territories have Renewable Portfolio Standards

(8 states and 2 territories have renewable portfolio goals)

Bulk Power System Intermittency impact: Examples

- Significant penetration of intermittent renewables increases the operating reserve requirements provided via conventional generation and increases the frequency of utilization of these resources
  - Increases requirements for regulation and spinning reserves
- Increase in planning reserve can be significant as the capacity contribution of both wind and solar PV is substantially lower than their nameplate rating.
  - The capacity value needs to be evaluated based on system loads, renewable resource characteristics and degree of penetration
- As the intermittent renewables have low variable O&M costs, the integration of intermittent renewables results in lower production costs and lower zonal and locational marginal prices
- Conventional generation realizes lower revenues as a result of lower hours of operation

Non-storage options can mitigate intermittency on Bulk Power System 1 (2)

- The impact of variability and limited predictability of intermittent renewables is reduced by integrating these resources over a larger geographical footprint.
  - Consolidation and cooperation among balancing areas and expanded transmission is an essential step in integrating increasing levels of intermittent renewables (as has occurred in Texas, PJM, and MISO)
- More efficient markets with shorter clearing periods, down to 5–10 minutes (as is the case already in MISO, PJM, and other regions)
- New ancillary service markets covering a wider range of needs (e.g., flexibility—faster ramp rates) beyond regulation and reserves markets already operating in portions of the United States
- New conventional generation technologies or modifications to existing generators that allow faster ramp rates, lower minimum output levels, quicker start times and shorter minimum-off times

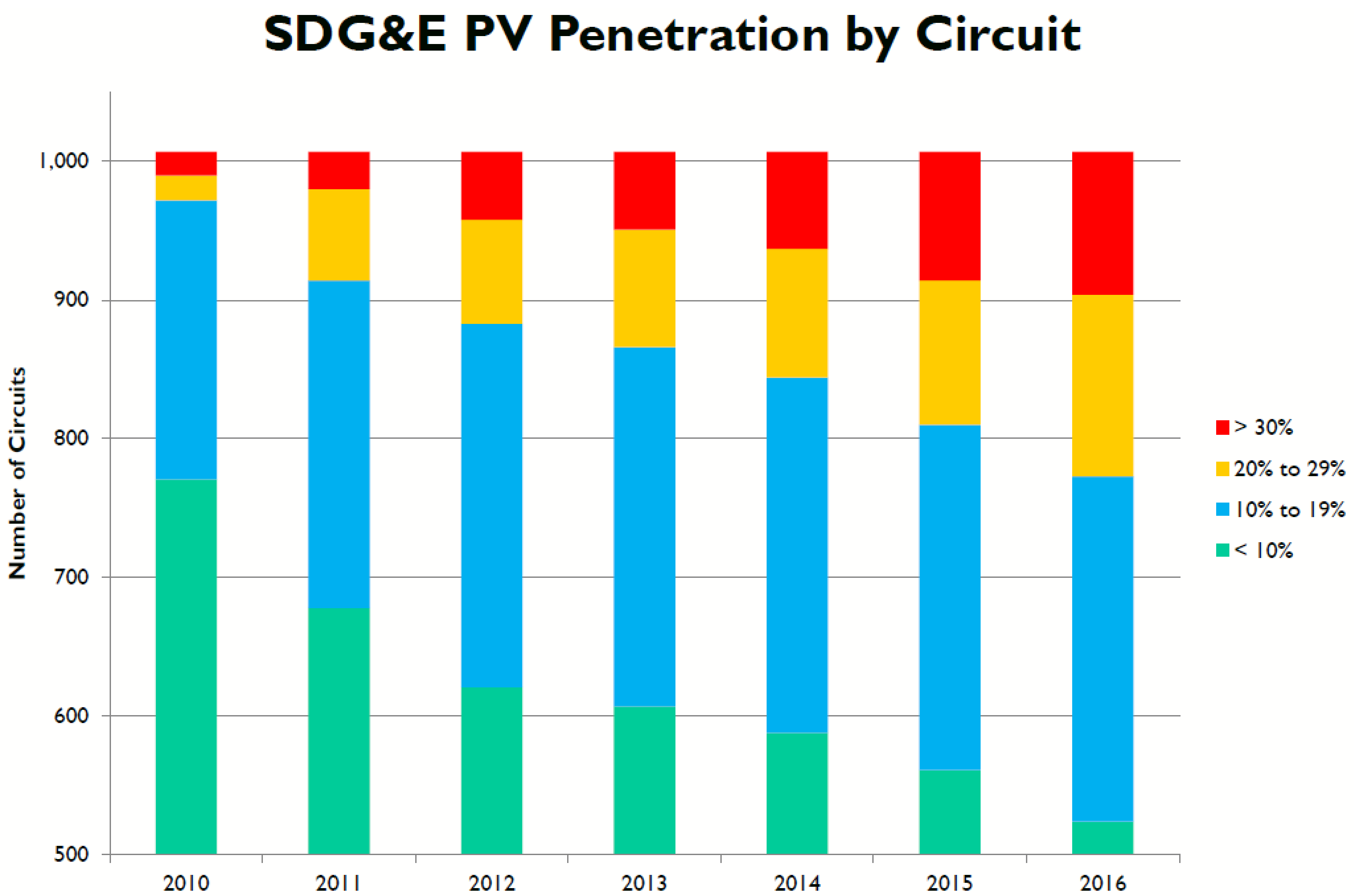
Non-storage options can mitigate intermittency on Bulk Power System 2 (2)

- Increased transmission connectivity among neighboring and distant regions
- Increased use of demand response (as is occurring now in PJM, ERCOT, California, and other regions)
- New, manageable electrical loads such as electric vehicle charging or wider use of older demand management technologies such as storage water heaters or cool storage for air conditioning loads.
- Improved visibility of distribution level PV output at the system level
- Addition of a mid-term commitment (e.g., 4 hours-ahead) with updated and accurate wind and PV forecasts will allow adjustment of commitments from intermediate units, resulting in significantly less combustion turbine commitment in real-time

Findings: Distribution

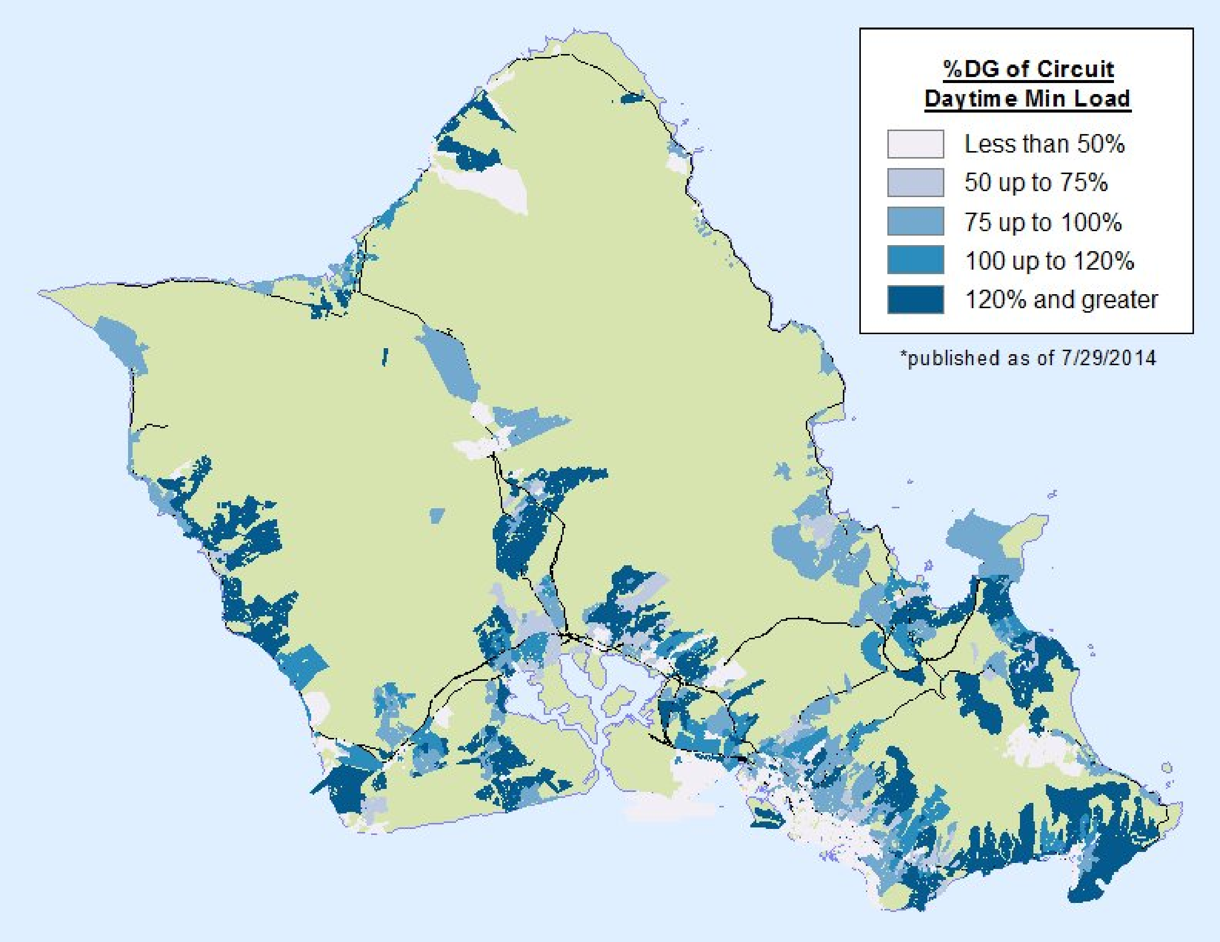
- High penetration levels of intermittent renewable Distributed Generation (DG) creates a set of challenges
- Generally designed to be operated in a radial fashion and DG interconnection with a potential for bidirectional power flows and fault current injection from multiple sources violates this assumption
- Battery storage systems, advanced power electronics-based technologies, such as distribution class FACTS devices, and increased real-time monitoring, control and automation can play an important role in alleviating these issues and facilitating integration

DG proliferation in distribution grids



Source: T. Bialek, CPUC Workshop on Smart Inverters, June 21, 2013

DG proliferation in distribution grids



Hawaii Electric Company (HECO): Locational Value Maps (LVM)

Source: http://www.hawaiianelectric.com/heco/Clean-Energy/Integration-Tools-and-Resources/Locational-Value-Maps

Summary Recommendations

- **Support technology RD&D and development of industry consensus standards** as a central Federal RD&D policy
- **Support software development** for forecasting, real-time, coordinated and integrated operation of distribution, sub-transmission, and transmission systems
- **Foster coordination and cooperation across and among state and Federal jurisdictions** and between Federal Agencies

Recommendations: Technology

- Promotion of new initiatives and support of existing R&D activities for development and implementation of advanced functions in smart inverters
- Power electronics-based equipment to replace or complement conventional transformers, load tap changers, voltage regulators, and capacitor banks for more efficient voltage regulation and control on the distribution system
- Low-cost distributed energy storage technologies and other solutions such as demand response to facilitate integration of high penetration levels of intermittent renewable DG in the distribution grid
- Distribution system designs that are suitable for active and highly dynamic grids and consider DG as an intrinsic component, and corresponding analysis, engineering, planning and operations practices

Recommendations: Standards

- Unified and enforced renewable generation interconnection standards based on analysis of operational (including dynamic) system conditions to define necessary integration requirements
- Interconnection standards for integration of distributed energy resources and implementation of concepts such as microgrids in distribution systems
- Standards and common practices for using and handling large volumes of data available from real-time-measurements, e.g. synchrophasor, as well as business case for justifying use of those measurements based on application needs

Recommendations: Standards (see also Microgrids)

- DG proliferation (incl. PV) depends on revisions to IEEE 1547, which governs how DG is connected to the grid
- SGIP 2.0, Inc. leads an effort to identify gaps in standards via its Priority Action Plans to coordinate the work of standard development organizations on Smart Grid standards
- Federal support of the above is welcome

Recommendations: Modeling and Software

- Software tools and processes for renewable resource forecasting, energy load forecasting and market price forecasting
- Software tools and processes for real-time, coordinated and integrated operation of distribution, sub-transmission, and transmission systems (e.g., EMS/DMS)
- Improvements in current software tools for
  - Comprehensive modeling and analysis of distribution systems with high proliferation of DG, e.g., development of joint models for steady-state and dynamic/transient analyses and development of detailed models of inverters
  - Integrated modeling and analysis of distribution, sub-transmission, and transmission systems that lead to more consistent results among these power system components

Recommendations: Policy

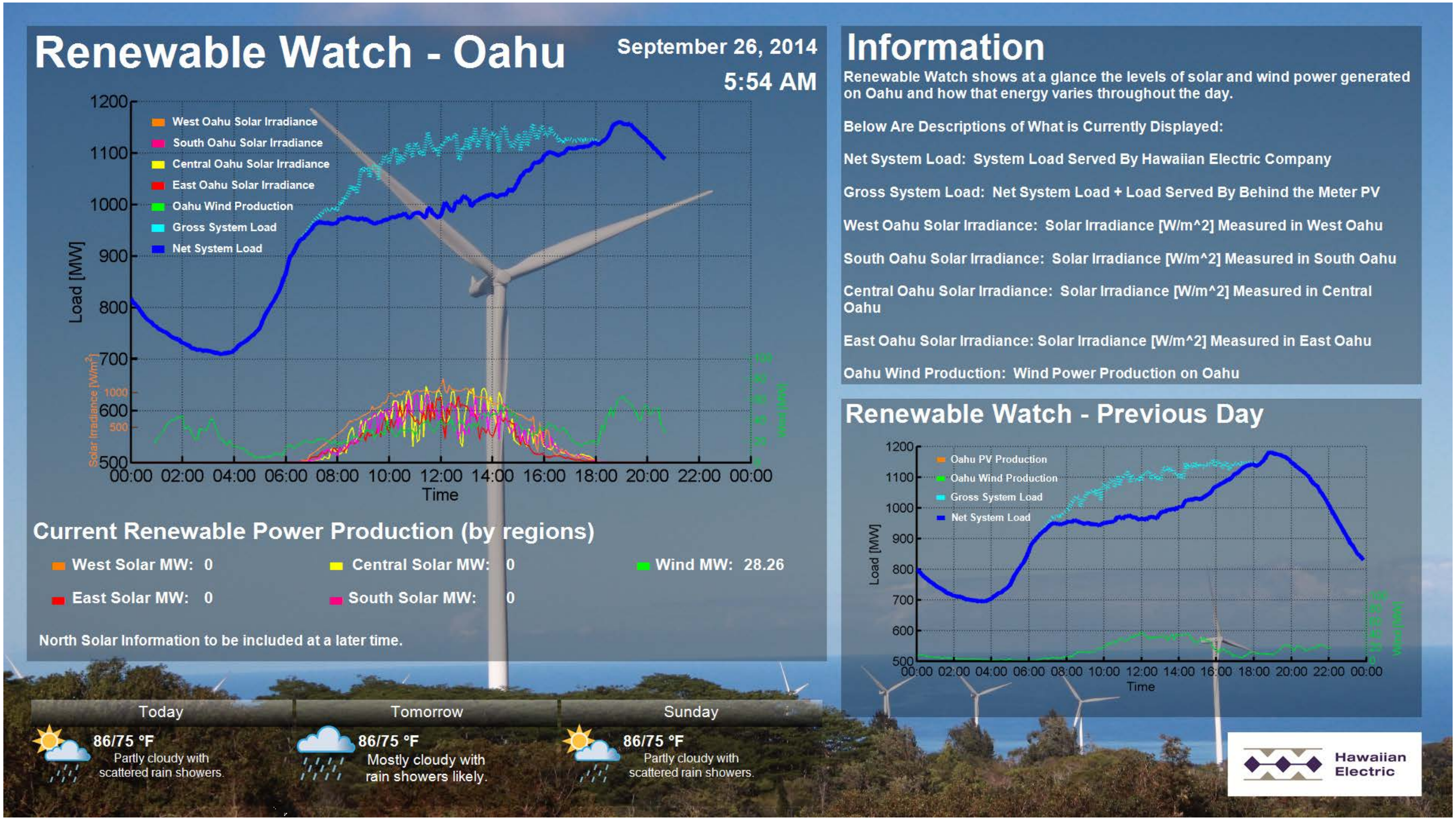
- Resolve technical and jurisdictional issues associated with devices, such as batteries and PV inverters, and concepts such as microgrids, that simultaneously serve both the distribution and transmission grids; and operate across institutional, regulatory, and information architectural boundaries
- Support and accelerate regional and interconnection-wide transmission planning and expansion practices and system operating procedures, to support integration of intermittent renewable generation for public benefit
- Support a multi-agency State and Federal Collaborative to develop model regulations and integration policy to plan for operational issues
- Explore opportunities for collaboration in existing projects and support new joint projects with existing network of industry's R&D organizations

Conclusions

- At low levels of penetration and levels mandated by Renewable Portfolio Standards (RPS), intermittent renewables can be integrated if traditional power system planning and operations are updated
- At RPS levels on distribution feeders significant technical issues exist which are not easy to resolve without important updates to design, planning, operations and engineering practices
- US Gov can assist with RD&D, support for standards development and policies that facilitates coordination and cooperation among state and Federal jurisdictions

TECHNICAL SUPPLEMENT

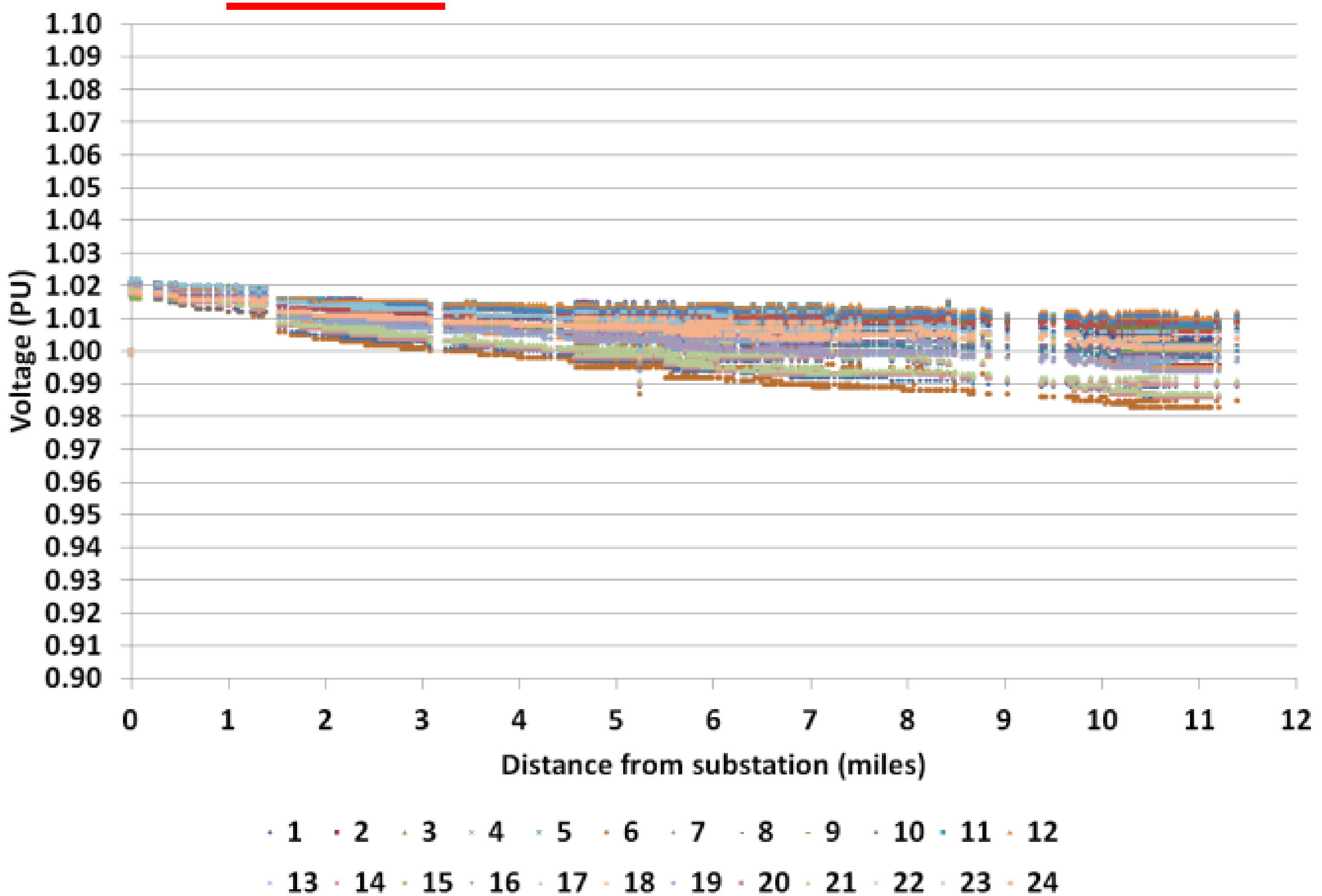
DG proliferation in distribution grids



Hawaii Electric Company (HECO): Renewable Watch Oahu

Source: http://www.hawaiianelectric.com/images/OahuReWatch.png

DG impacts – feeder hourly voltage profile **before** DG interconnection



Source: J. Romero Agüero, L. Xu, "Review of Industry Experiences with PV Impact Studies", 2014 IEEE PES T&D Conference and Exposition, Chicago, IL, Apr. 2014

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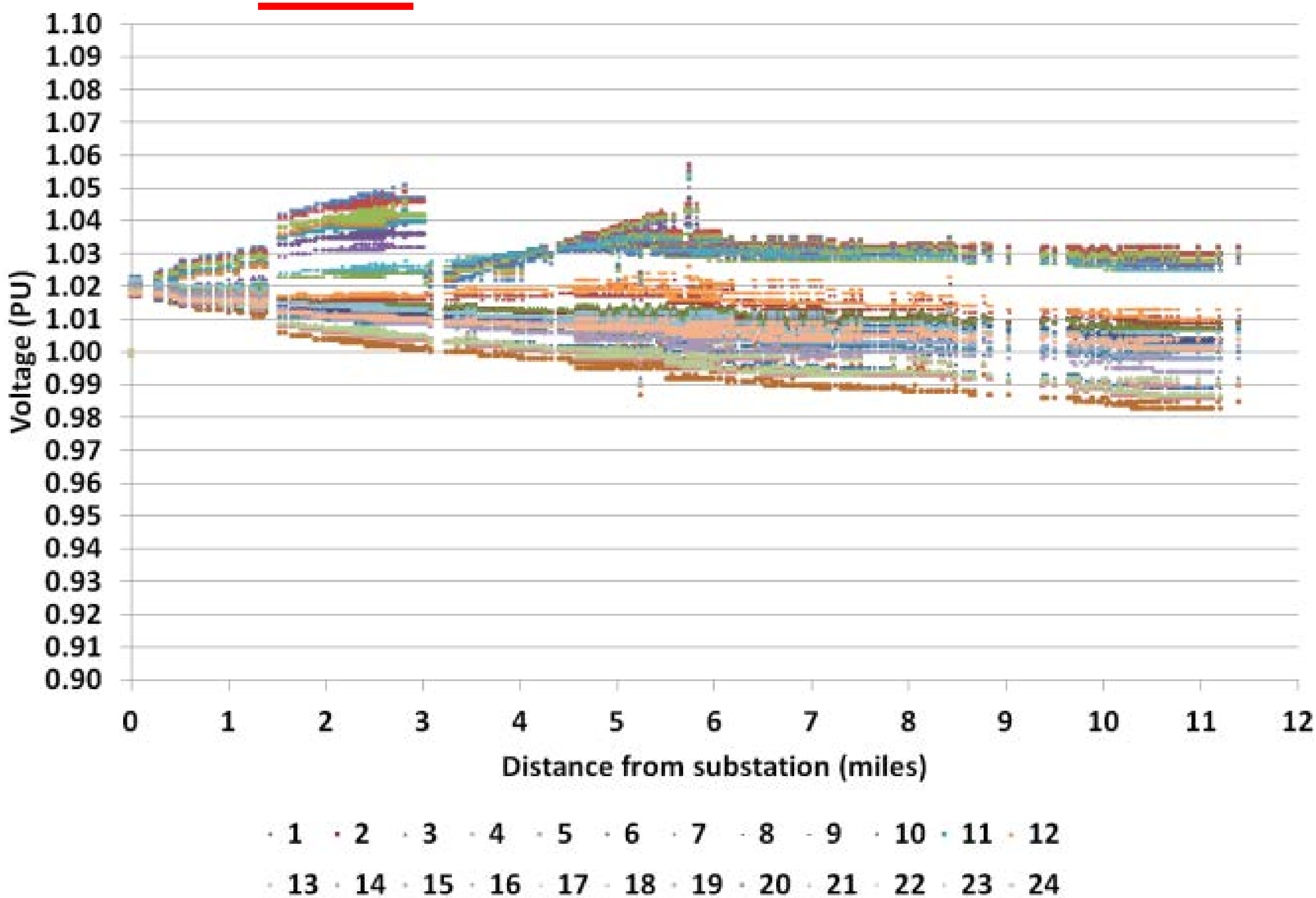
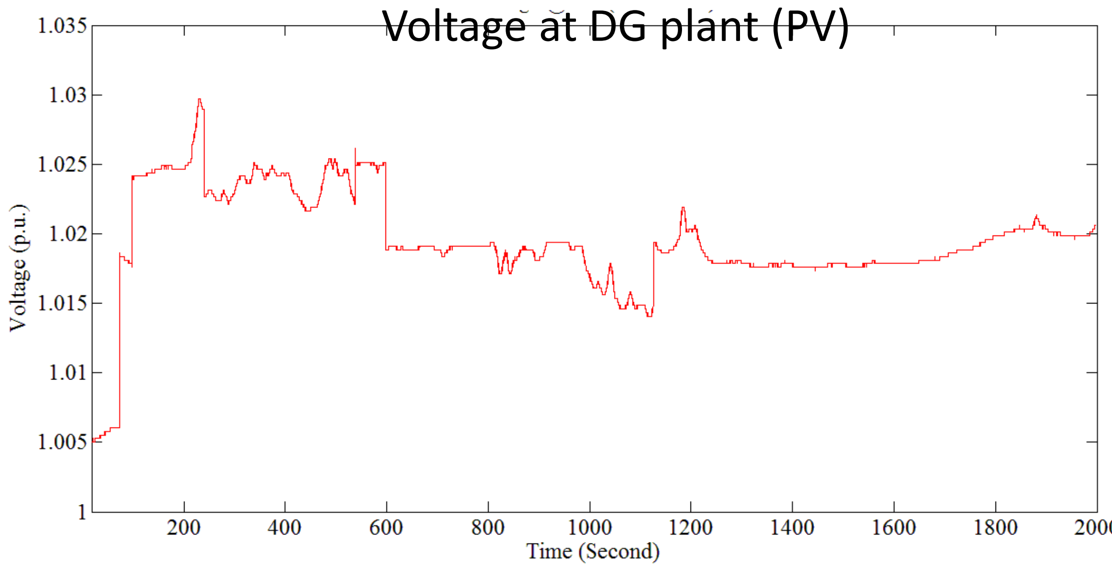
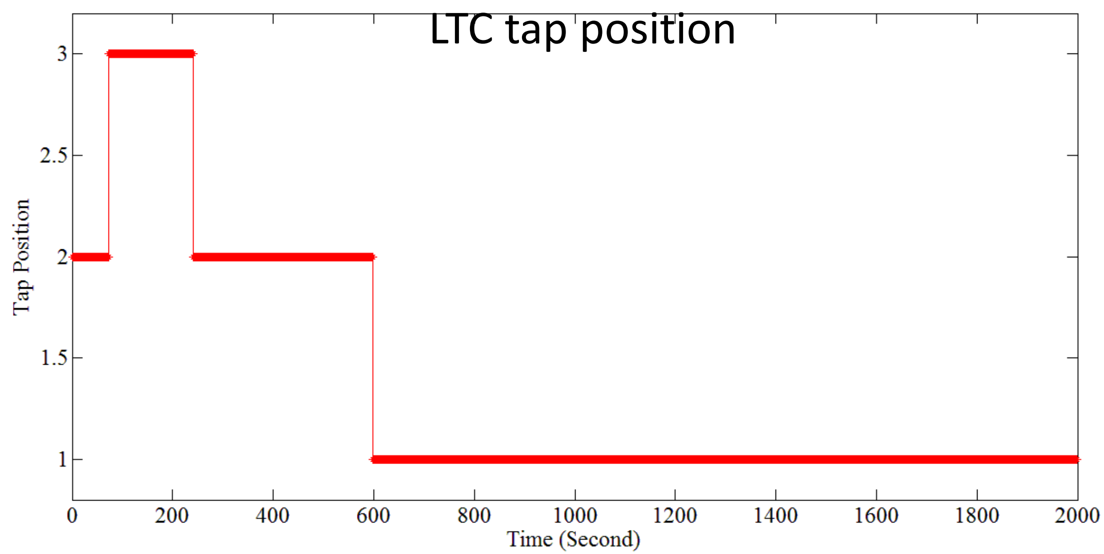
DG impacts – feeder hourly voltage profile **after** DG interconnection



Source: J. Romero Agüero, L. Xu, "Review of Industry Experiences with PV Impact Studies", 2014 IEEE PES T&D Conference and Exposition, Chicago, IL, Apr. 2014

Interaction with voltage regulation equipment





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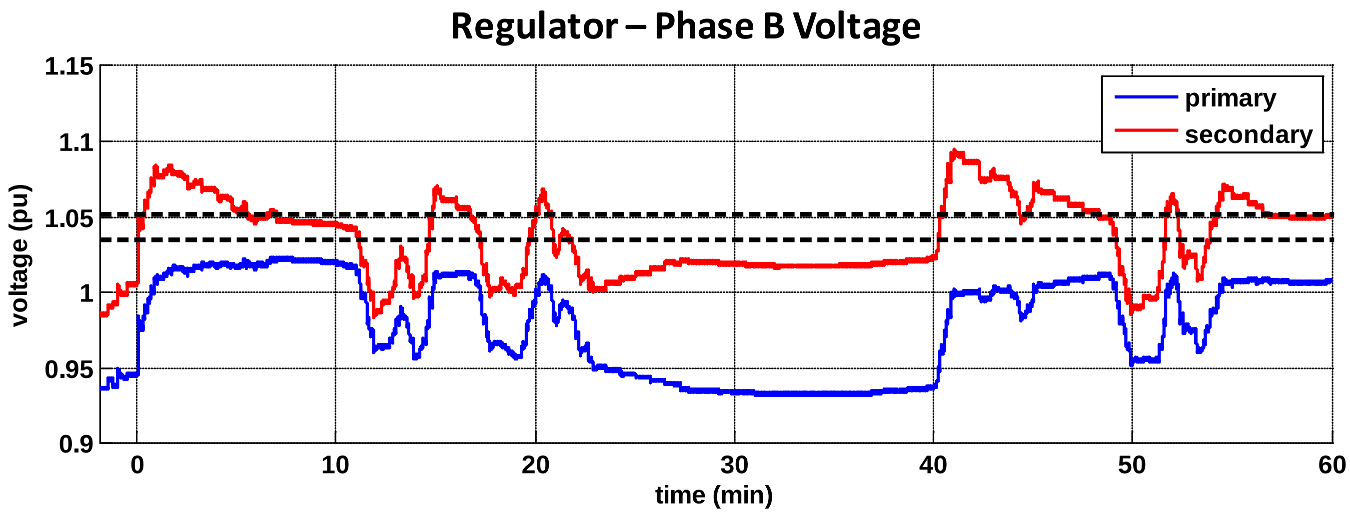
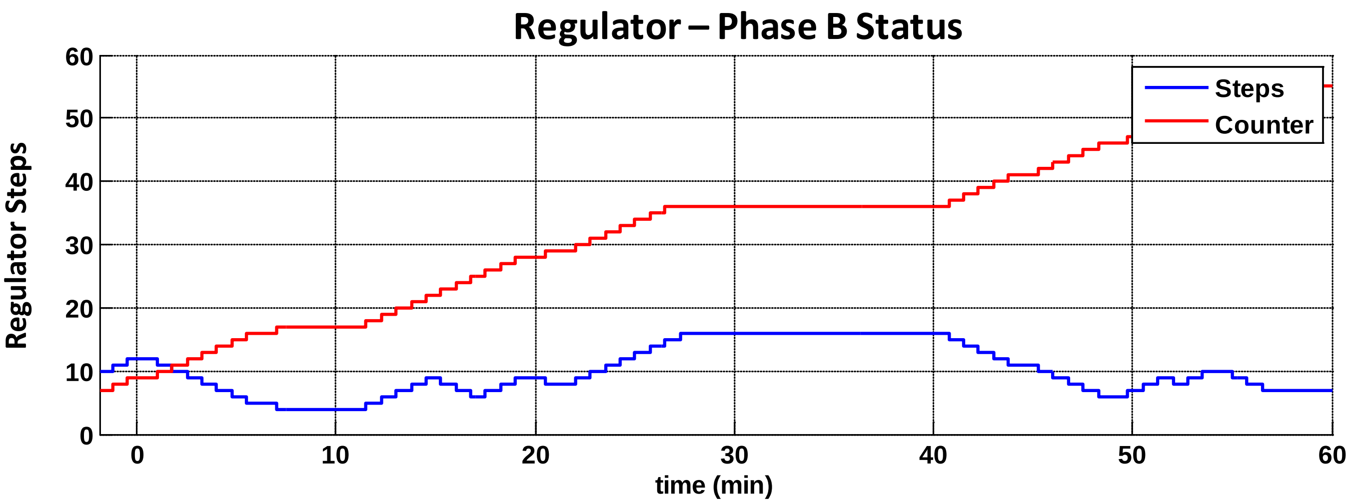
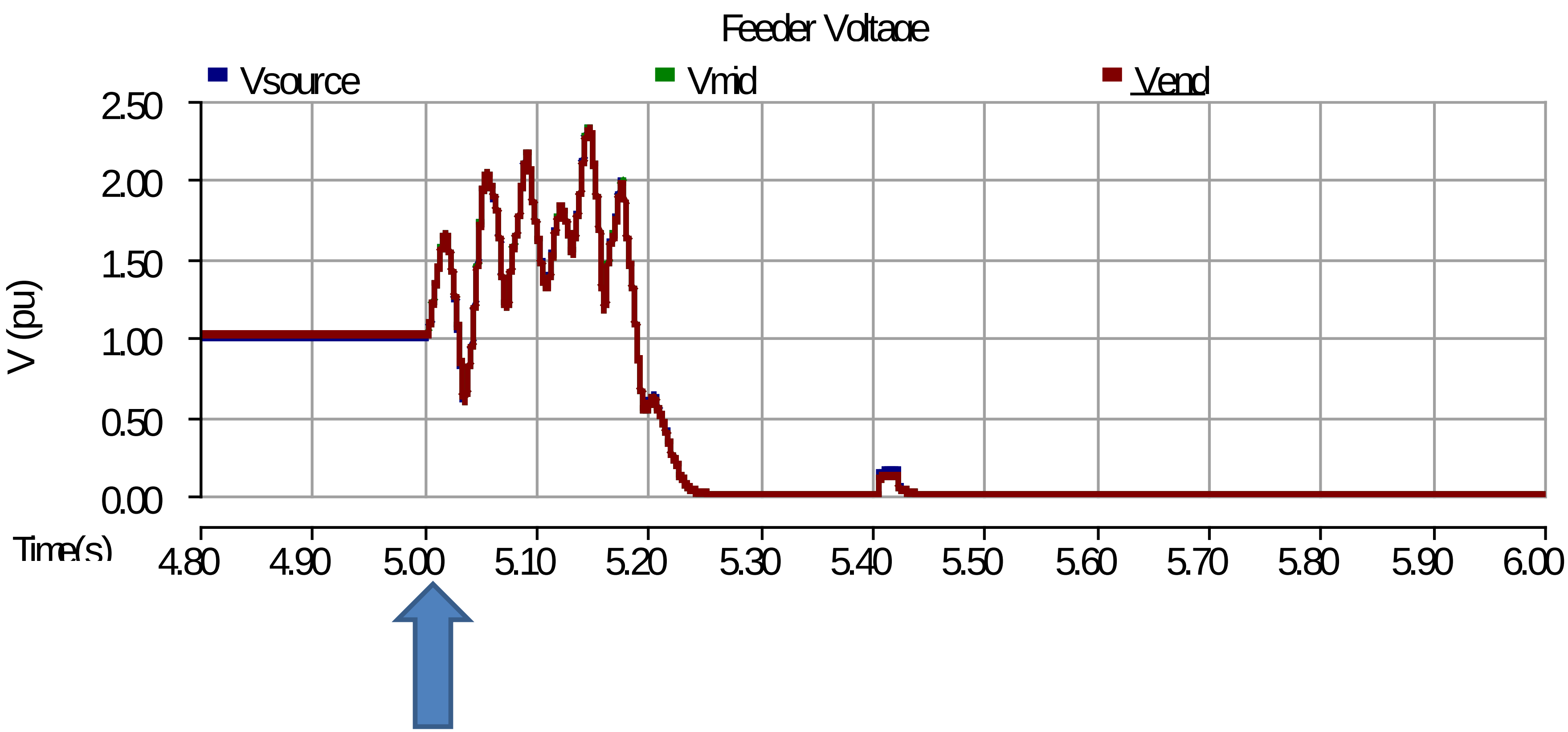




Temporary overvoltage



Feeder breaker opens
and creates
“accidental island”

Additional Presentation Materials

The following slides further discuss some of these topics in more detail:

- J. Romero Agüero, S. Steffel, "Integration Challenges of Solar Photovoltaic Distributed Generation on Power Distribution Systems", 2011 IEEE Power and Energy Society General Meeting, Detroit, MI, Jul. 2011 https://www.smartgrid.gov/document/integration_challenges_photovoltaic_distributed_generation_power_distribution_systems
- J. Romero Agüero, L. Xu, "Review of Industry Experiences with PV Impact Studies", 2014 IEEE PES T&D Conference and Exposition, Chicago, IL, Apr. 2014 http://www.ieee-pes.org/presentations/td2014/td2014p-000546.pdf
- L. Dow, J. Romero Agüero, "Integration of Plug-in Electric Vehicles (PEV) and Photovoltaic (PV) Sources into the Electric Distribution System", 2011 IEEE PES General Meeting, Detroit, MI, Jul 2011, http://www.ieee-pes.org/images/pdf/pesgm2011/supersessions/thurs/7_Integration-of-PEV-and-PV-Sources-into-the-Electric-Distribution-System.pdf
- Results from the DOE-CPUC High Penetration Solar Forum http://energy.gov/eere/solar/downloads/results-doe-cpuc-high-penetration-solar-forum

IEEE REPORT TO DOE QER ON PRIORITY ISSUES

www.ieee-pes.org/qer