

# Impacts of Varying Penetration of Distributed Resources with & without Volt/Var Control: Case Study of Varying Load Types

**D. Tom Rizy<sup>1</sup>, Senior Member,**  
Huijuan Li<sup>2</sup>, Member,  
Fangxing Li<sup>1,3</sup>, Senior Member,  
Yan Xu<sup>1</sup>, Member,  
Sarina Adhikari<sup>3</sup>, Student Member,  
Phil Irminger<sup>2</sup>, Student Member

**2011 IEEE PESGM**

**July 26, 2011**

*<sup>1</sup>ORNL, Power & Energy Systems Group*

*<sup>2</sup>Oak Ridge Associated Universities*

*<sup>3</sup>University of Tennessee, Knoxville*



# Background

- **Follow-up to 2010 paper “Properly Understanding the Impacts of Distributed Resources (DR) on Distribution Systems”**
- **Addresses how DR impacts vary in regards to both DR voltage regulation capability and load mix**
- **Focuses on impacts to distribution capacity, losses and voltage regulation with DR penetration**
- **Comparison of DR with and without volt/var control on 10MVA feeder example with two DRs**
- **Inverter-based volt/var controls based on ORNL R&D work at the DECC Lab.**

# Impacts Of Distributed Resources (DR) On Distribution System

The connection of DR systems to the distribution system will have an impact on

- **Feeder Capacity**
- **Line Losses**
- **Voltage Regulation**
- **System Protection**
- **Safety**

A steady-state analysis of DR impacts may not be adequate for addressing the full impacts of DR in a distribution system.

# Dynamic versus Steady-State Analysis of DR Impacts

- **Standard approach is to use a power-flow-based program to calculate the network voltages with different DR sizes, penetration and feeder loadings.**
- **Used to be quite difficult to dynamically model a small system not to mention a large distribution system.**
- **However, new tools such as EMTP-RV make the modeling of large systems possible along with their dynamic behavior.**

# Issues that Merit Consideration for DR Impact Assessment

- **Voltage Sensitivity of the Feeder Loads**
  - Impacts on feeder capacity, losses and voltage regulation depend on feeder load voltage sensitivity.
  - To what degree?
  - Load mix and distribution for each phase may be important.
- **Variable Distributed Resource (DR) Output**
  - Concern with the variability of renewable DR (i.e., wind and PV) that does not have an energy storage component.
  - May not be a concern with penetration level lower than 10%
  - Penetration level of 20% or greater, intermittent DR may quickly change the feeder voltage profile.

# Issues that Merit Consideration for a DR Impacts Assessment (cont.)

- **Representation of Multiple DR**
  - A big question is a usable and accurate aggregation model.
- **Protection Changes with DR**
  - Not expected to be an impact at low DR penetration (i.e. 10% or less)
  - Becomes a concern at higher DR penetration especially if the DR type is a generator-based system.
  - Inverter-based DRs are inherently current limited; but may need new modeling and protection methods for high penetration.
- **DR with Reactive Power Capability**
  - DRs not allowed (i.e., per 1547) to regulate voltage on the distribution system unless authorized by the utility.
  - Being amended by both IEEE Standards (1547.8) and NIST (P2030).

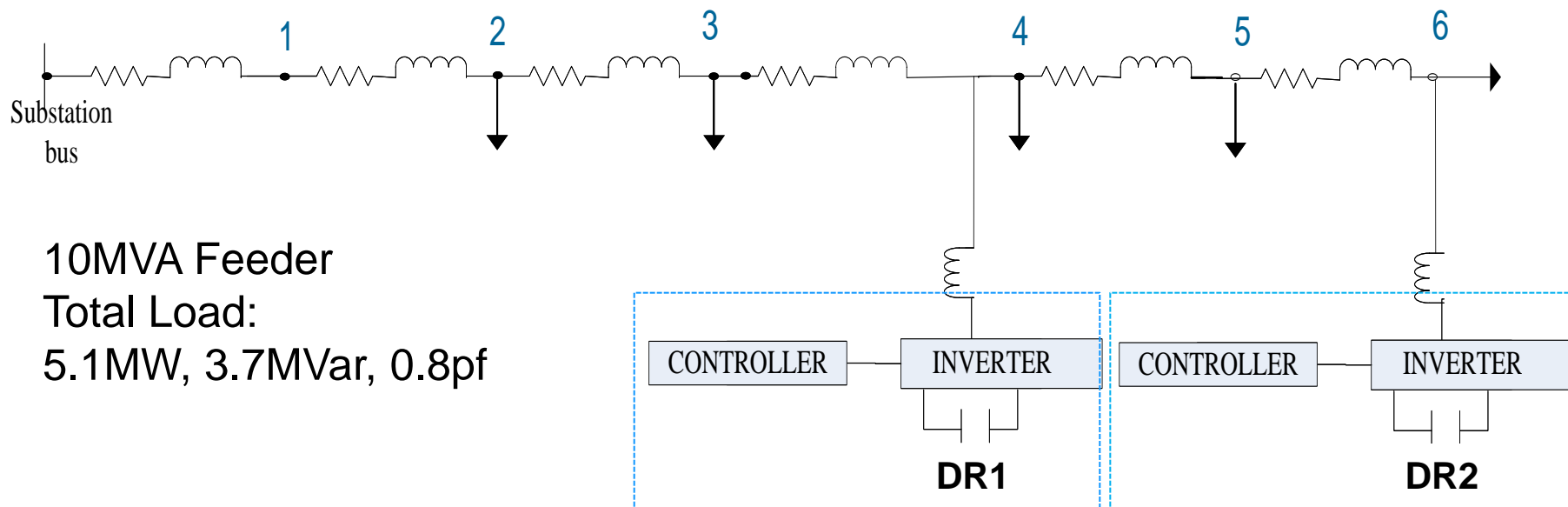
# Advantages of Allowing DR to Provide Volt/Var Control

- Provides reactive power locally instead of delivery over transmission lines from central power plants.
- Provides reactive power needed to maintain a steady voltage profile at the load.
- Respond to voltage transients (i.e., motor starts or load step changes) to maintain voltage.
- Improves feeder capacity by reducing reactive current flow from substation to load.
- Reduces line losses along with line flows due to local reactive power injection for voltage regulation.

# Impacts Study Approach

- **DR with and without voltage regulation capability**
  - No regulation – only active power injection from DR
  - Regulation – both active and reactive power injection (to maintain voltage reference)
- **Distribution feeder impacts with increasing DR levels**
  - Total line flow (used capacity)
  - Line losses
  - Voltage profile
- **Repeated for different feeder load compositions**
  - Constant Power – served as the benchmark
  - Constant Impedance
  - Constant Current
  - ZIP – equal combination of the previous ones

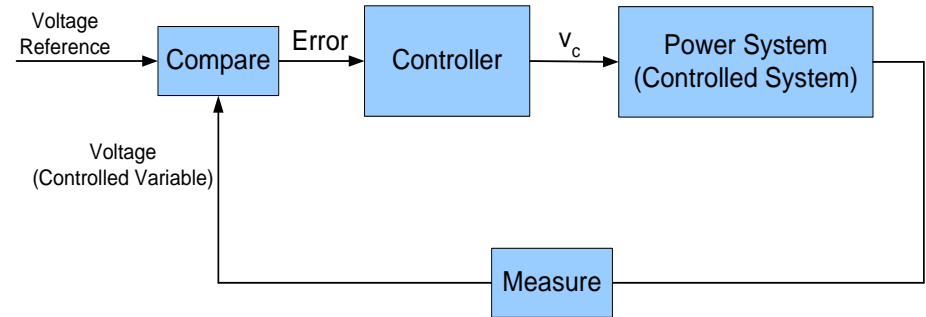
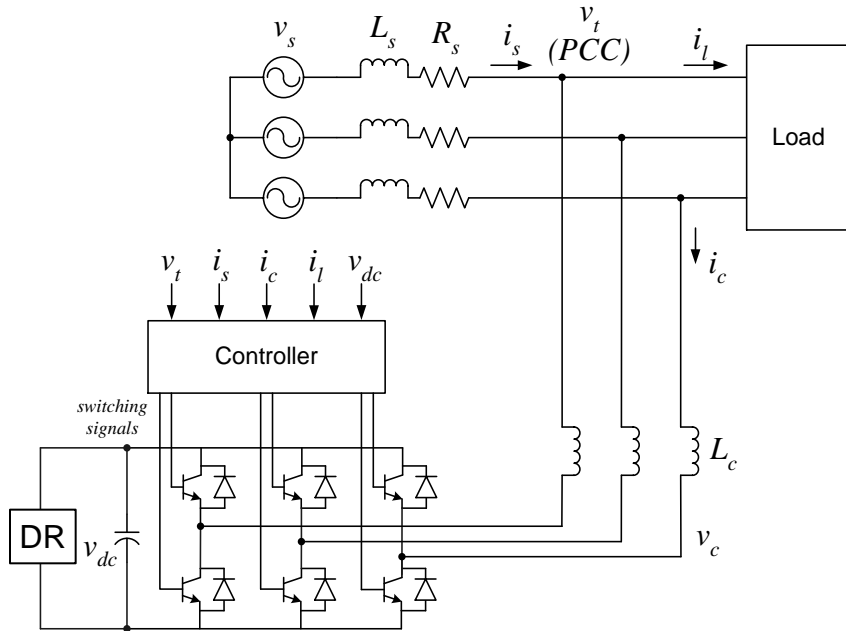
# Example Used to Evaluate DR Impacts on Distribution System



- Inverter-based DR controls<sup>1</sup> used to compare impacts of DR with and without voltage regulation capability.
- DR penetration level (% of total DR output to feeder capacity) varied to analyze impacts.
- Repeated for the four different loading cases.

<sup>1</sup>Developed and tested by ORNL

# Inverter-Based DR Voltage Control



**DR:** Distributed Energy Resource

**Control variable:** the PCC voltage

**Reference:** the desired value of the PCC voltage

**Error:** difference between reference and measured PCC voltage

- **Fixed control:**

PI control with  $K_p$  and  $K_i$  fixed

$K_p$  and  $K_i$  typically by trial & error

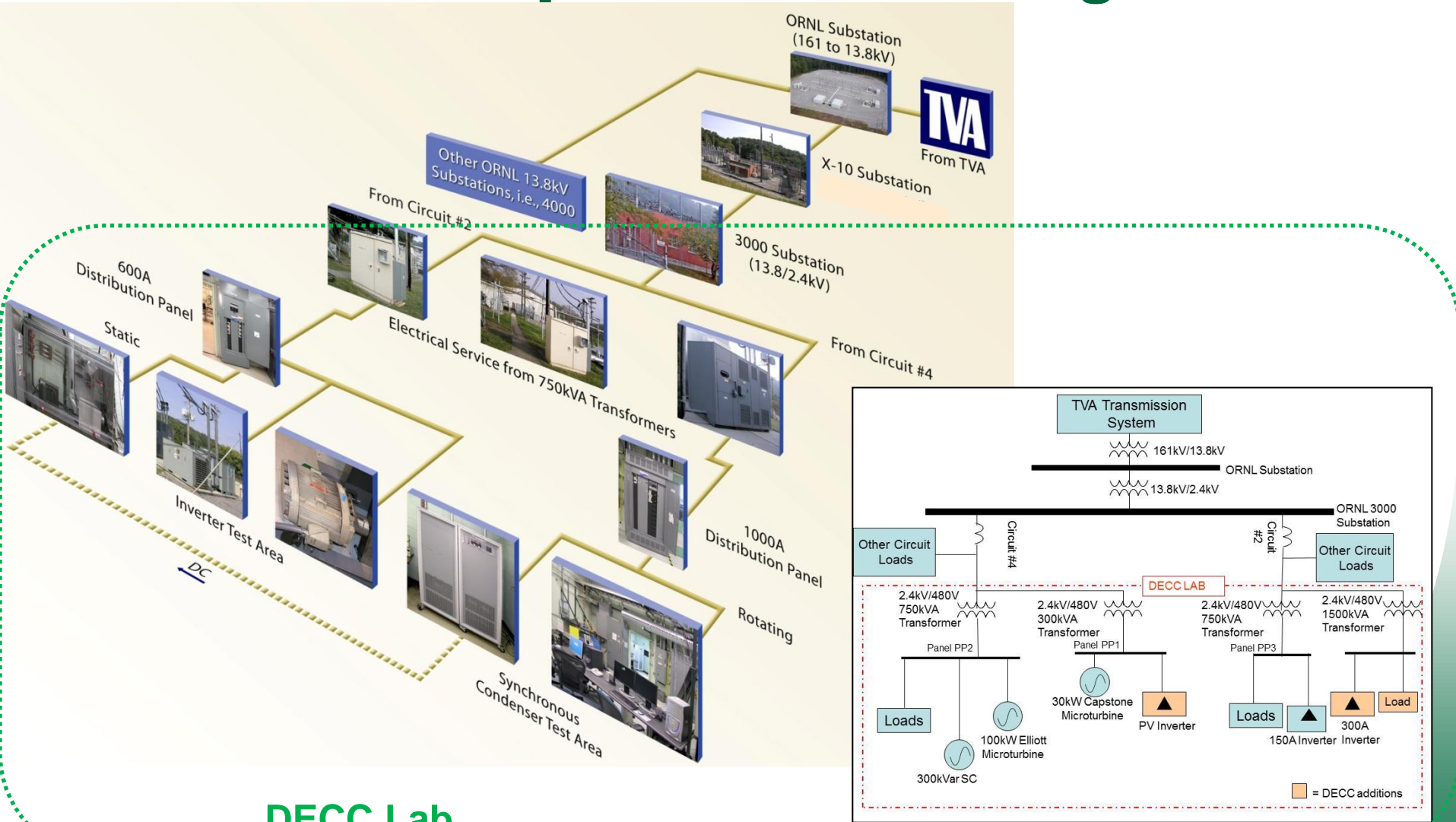
*Incorrect gains result in under-performance, oscillation, or instability*

- **Adaptive control:**

$K_p$  and  $K_i$  values are initially conservative but adjusted in real-time to achieve desired system response time

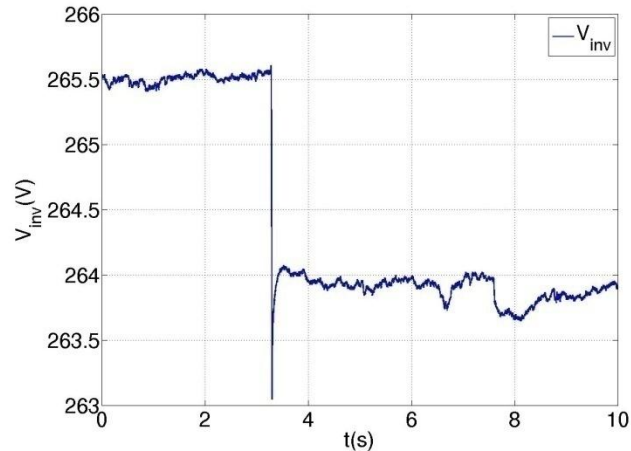
*Voltage stability is ensured*

# DECC Lab interfaced with Actual Distribution System Supports Volt/Var Control Development and Testing.

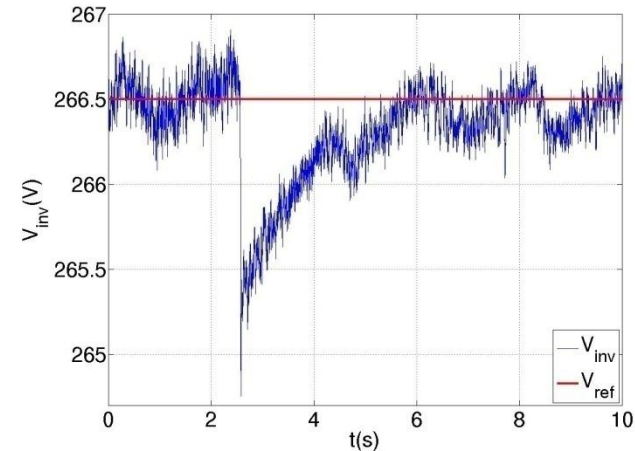


DECC Lab

# Voltage Regulation with both Fixed and Adaptive Gain Control

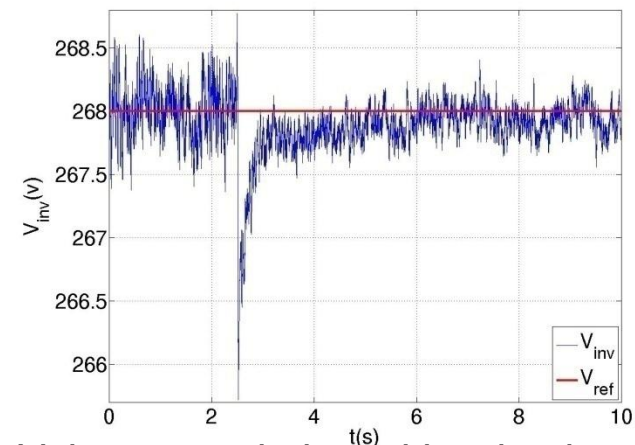


(a) No voltage regulation.



(b) Voltage regulation with fixed gains.

- **Response to two- volt (2V) local voltage transient.**
- **Tested on ORNL distribution system at DECC Lab.**
- **Faster voltage regulation achieved with adaptive gains.**

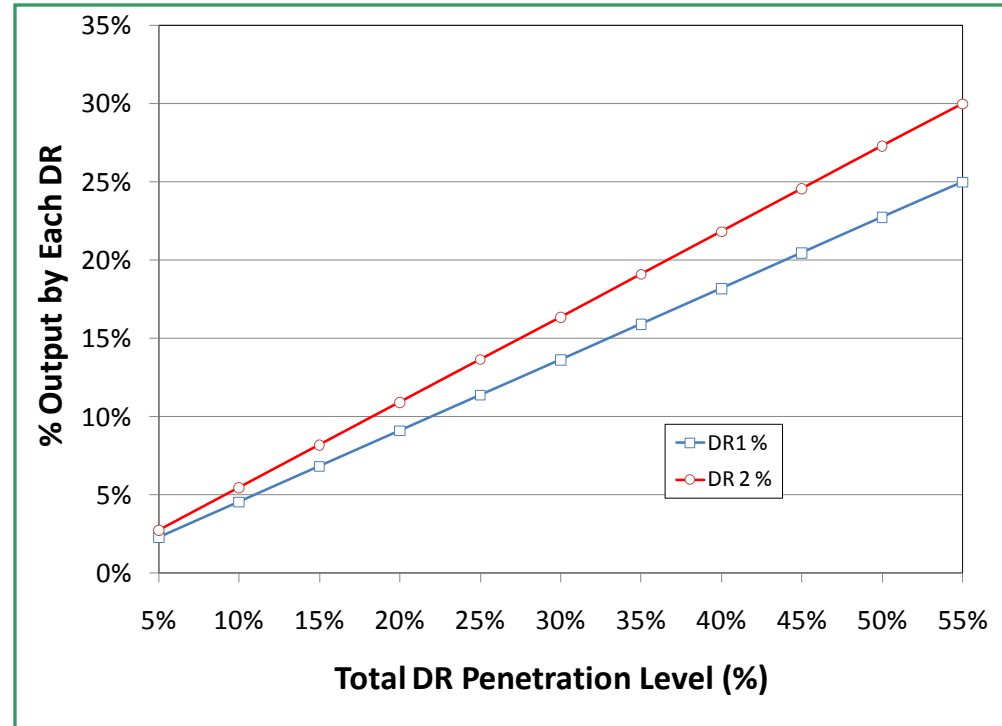


(c) Voltage regulation with adaptive gains.

*The voltage scales are different since under different distribution system operating conditions on different days.*

# Study Assumptions

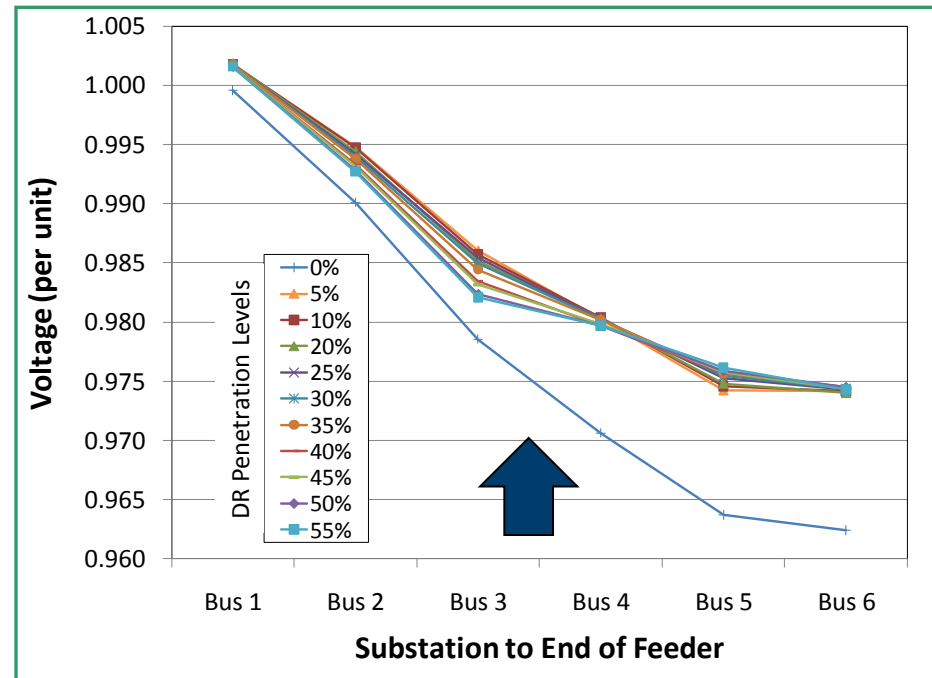
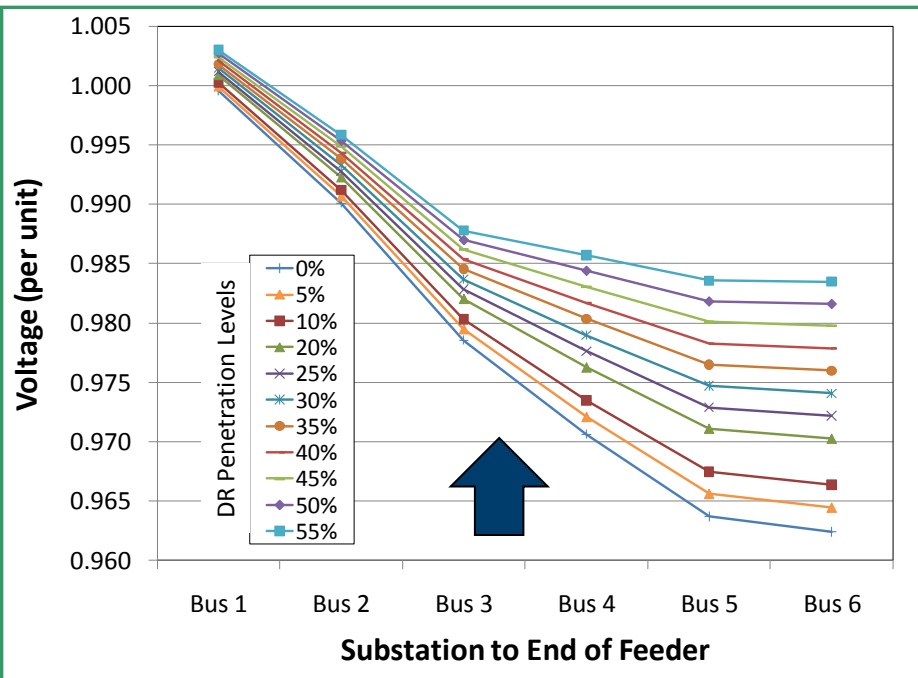
- **10MW Radial Feeder with 63% used capacity**
- **DR penetration from 5% to 55% in 5% increments**
- **Feeder load is fixed for each loading case**
- **DRs provide -1.5MVAR to 1.5MVAR to regulate voltage**
  - **0.980pu for DR at bus 4**
  - **0.975pu for DR at bus 6**
- **Capacitors both at substation and on circuit assumed to be fixed**
- **DR active power scaled up instead of adding more DRs**



# Voltage Feeder Profiles for the Constant Power Load Case

- Voltage profiles with increasing DR without voltage regulation

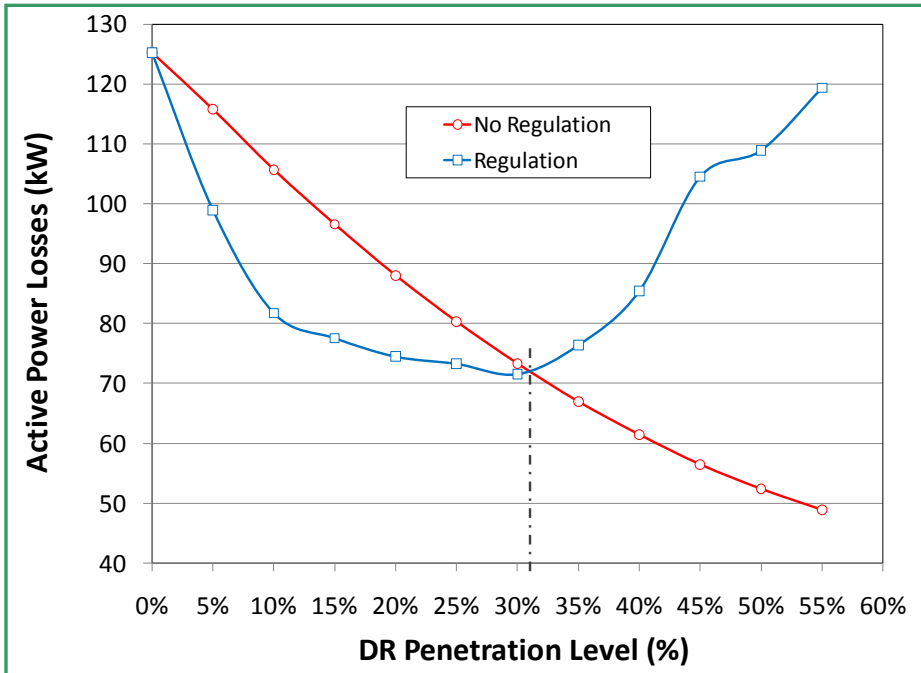
- Voltage profiles with increasing DR with voltage regulation



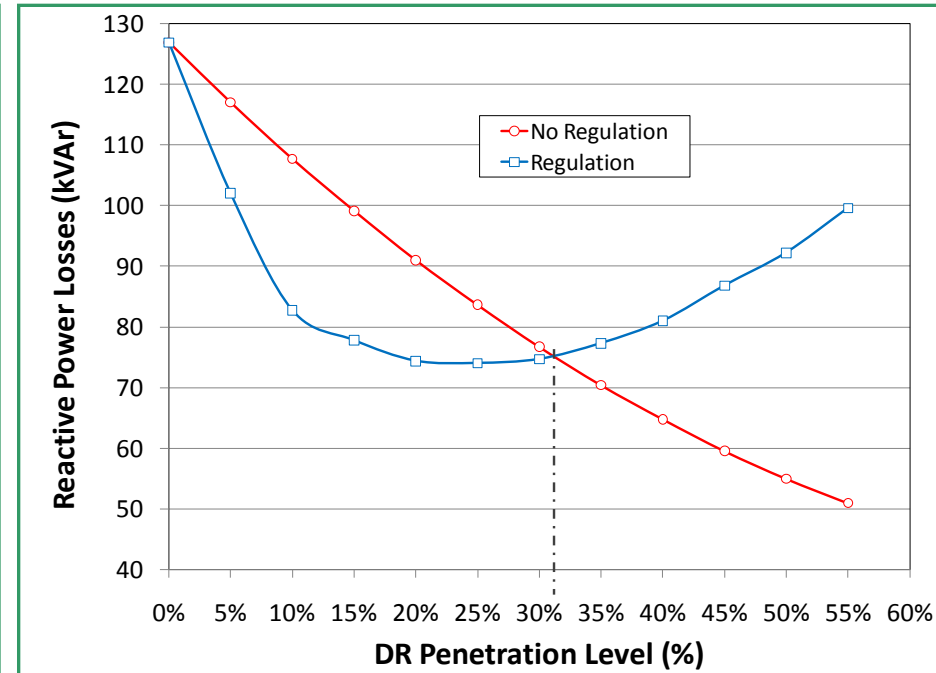
 *Direction of Increasing DR Penetration*

# DR Impacts on Distribution Losses for Constant Power load

- Active power losses with and without DR voltage regulation



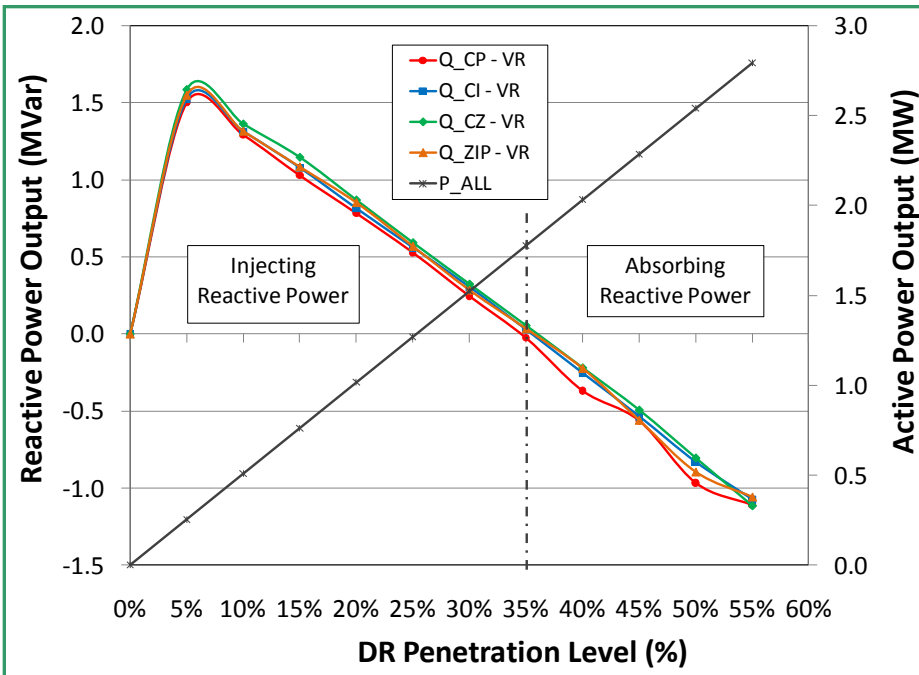
- Reactive power losses with and without DR voltage regulation



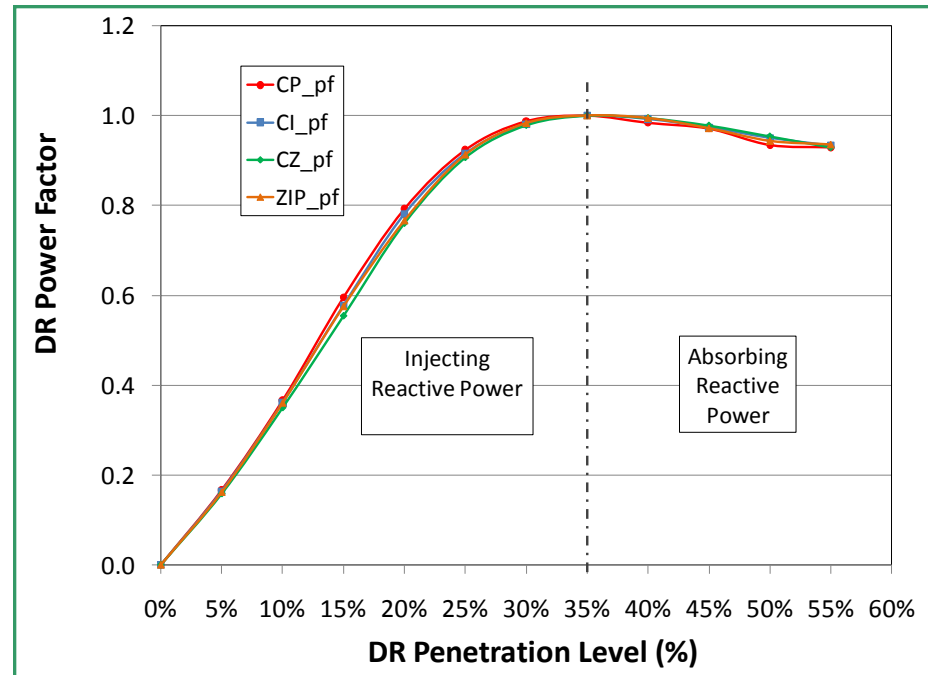
*Dashed line shows where DR with voltage regulation compared to DR without voltage regulation no longer provides benefit. Losses increase.*

# DR Output with Voltage Regulation for the Load Cases

- DR active/reactive power with increasing penetration



- DR power factor with increasing penetration

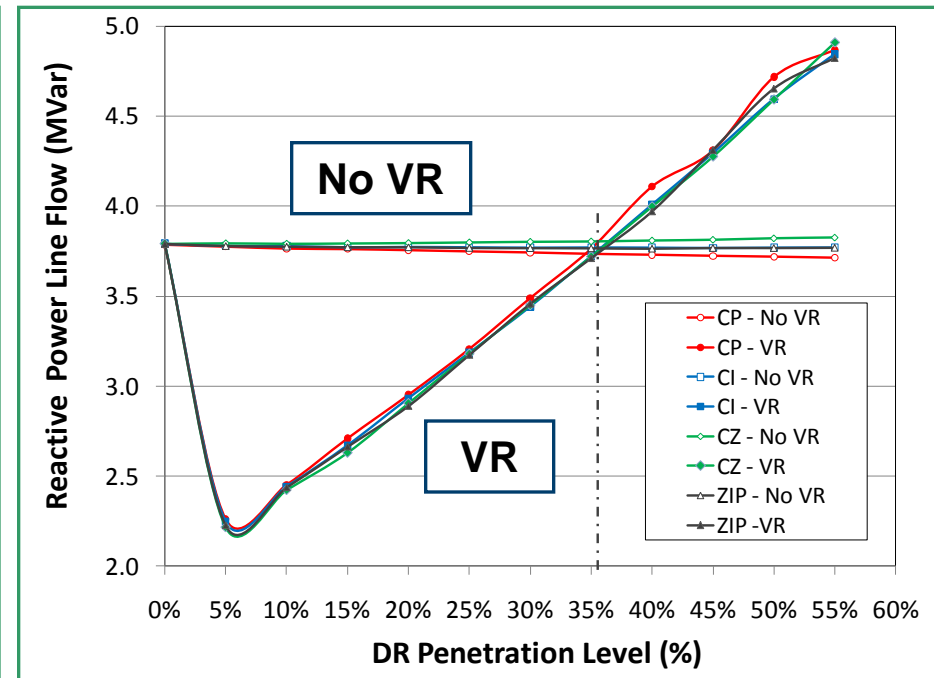
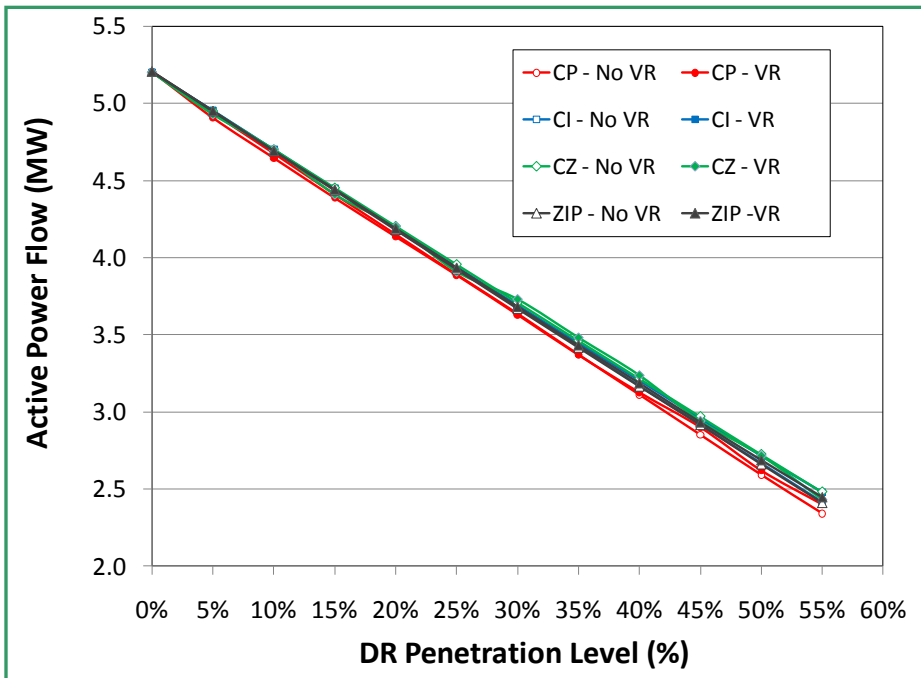


*Dashed line shows where DR with voltage regulation absorbs reactive power instead of injecting reactive power.*

# DR Impacts on Distribution Power Flow for the Load Cases

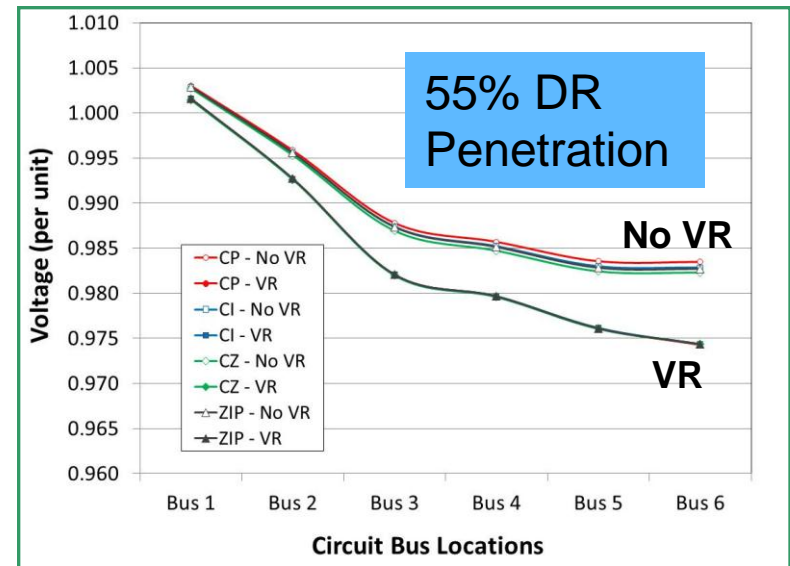
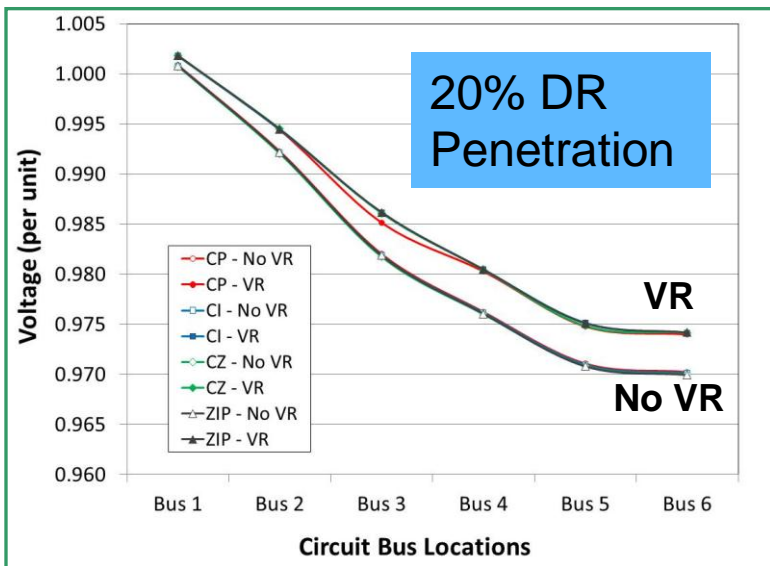
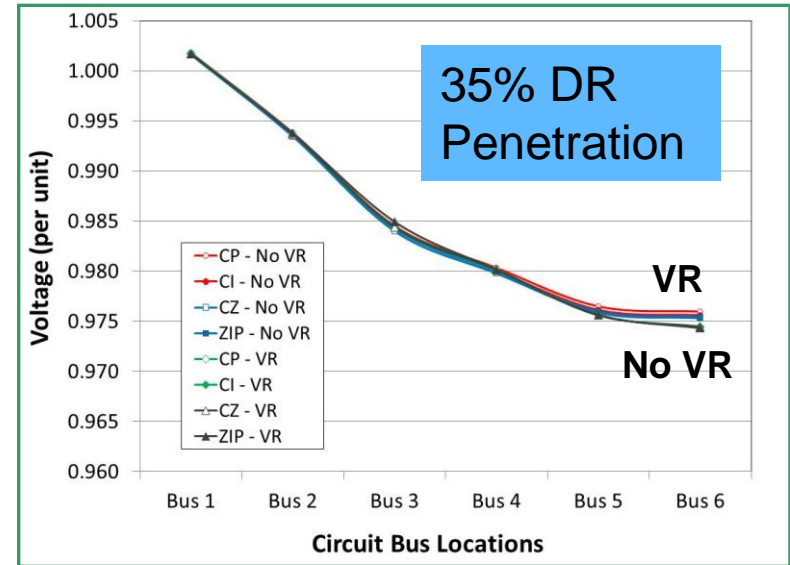
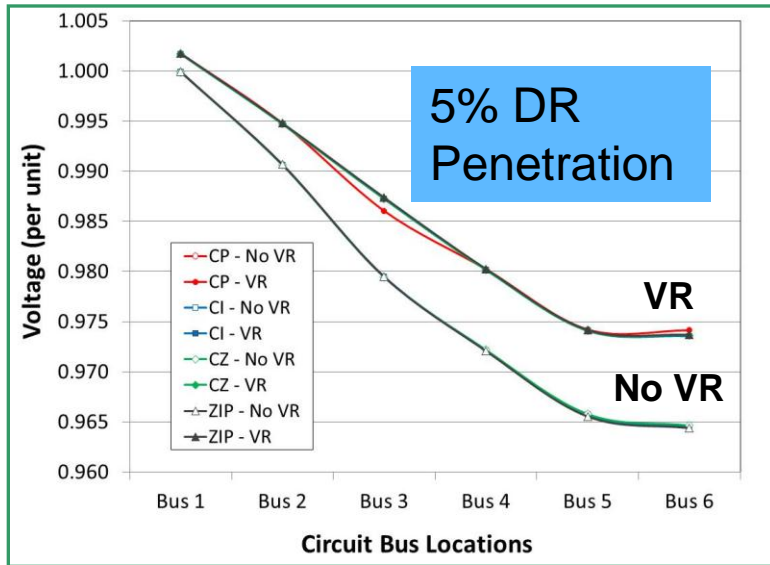
- Active power flow with and without DR voltage regulation

- Reactive power flow with and without DR voltage regulation



*Dashed line shows where DR with voltage regulation compared to without voltage regulation no longer provides benefit. Reactive load increases.*

# Voltage Profiles for the Four Different Load Cases



# Results

- **Observed slight differences in distribution impacts for the four load cases.**
- **Most difference was in losses - maximum variation of 8.3% between load cases.**
- **Maximum variation of 6.0% for line flows between load cases.**
- **Similar voltage responses for the four load cases.**
- **Reach a point of diminishing return using high penetration DR to provide local voltage regulation.**

# Results (cont.)

- **At 35% or greater DR penetration:**
  - **Active power from DR causes mode change.**
  - **DR voltage regulation mode reverses from injecting to absorbing reactive power.**
  - **DR becomes additional reactive load.**
- **Penetration trigger point could be higher if voltage references are allowed to be higher.**
- **However at 30%, reactive power losses increase above no regulation case.**
- **Analysis is based on our specific example and on fixed DR voltage references.**

# Summary

- **A number of distribution system impacts merit consideration for DR interconnection (i.e., losses, feeder capacity, voltage regulation, protection and safety).**
- **If some DRs can provide reactive power in addition to active power, they can provide voltage regulation and support.**
- **If voltage regulation is dynamic, DRs can respond to a voltage transient in 0.5 or less and be transparent to system voltage controls.**
- **Local voltage regulation done correctly can lower feeder line flows and losses and increase capacity.**
- **Standards are being developed to determine when DR volt/var control is appropriate.**

# Possible Future Considerations

- **Impacts as loading and distribution is varied (rather than fixed) with high DR penetration.**
- **Impacts of intermittent DR (i.e., PV) penetration.**
- **Impacts of air-conditioning stall and DR impacts together.**
- **Impacts of multiple inverter-based DR control to address possible interaction.**
- **More complex distribution network.**

# Q&A



# OAK RIDGE NATIONAL LABORATORY

Managed By UT-Battelle for the Department of Energy

## **D. Tom Rizy, Research Staff**

Power & Energy Systems Group

Energy & Transportation Science Division

One Bethel Valley Road, MS-6070

Oak Ridge, Tennessee 37831-6070

(865) 574-5203 Voice, 575-7643 Fax

(865) 207-6769 Cell

Email: [rizydt@ornl.gov](mailto:rizydt@ornl.gov)

[www.ornl.gov](http://www.ornl.gov), [www.ornl.gov/sci/decc](http://www.ornl.gov/sci/decc)