A TOOL-SUITE FOR IMPROVING RELIABILITY AND PERFORMANCE OF COMBINED TRANSMISSION-DISTRIBUTION UNDER HIGH SOLAR PENETRATION

OBJECTIVES

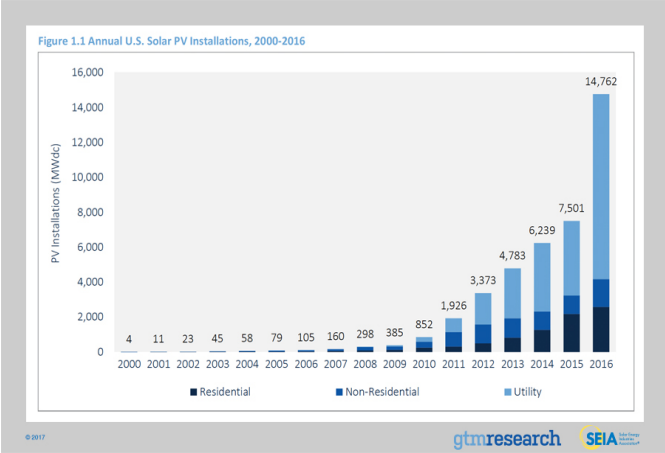
Protection Co-ordination

System dynamics

Volt-Var control, Reverse power flow

State estimation

Impacts on transmission



Address grid challenges impeding high solar integration

APPROACH

Steady-state analysis Tool

- Combined transmission-distribution
- New models of subtransmission/distribution substation
- Quasi-static analysis (less than 5 second time-step)

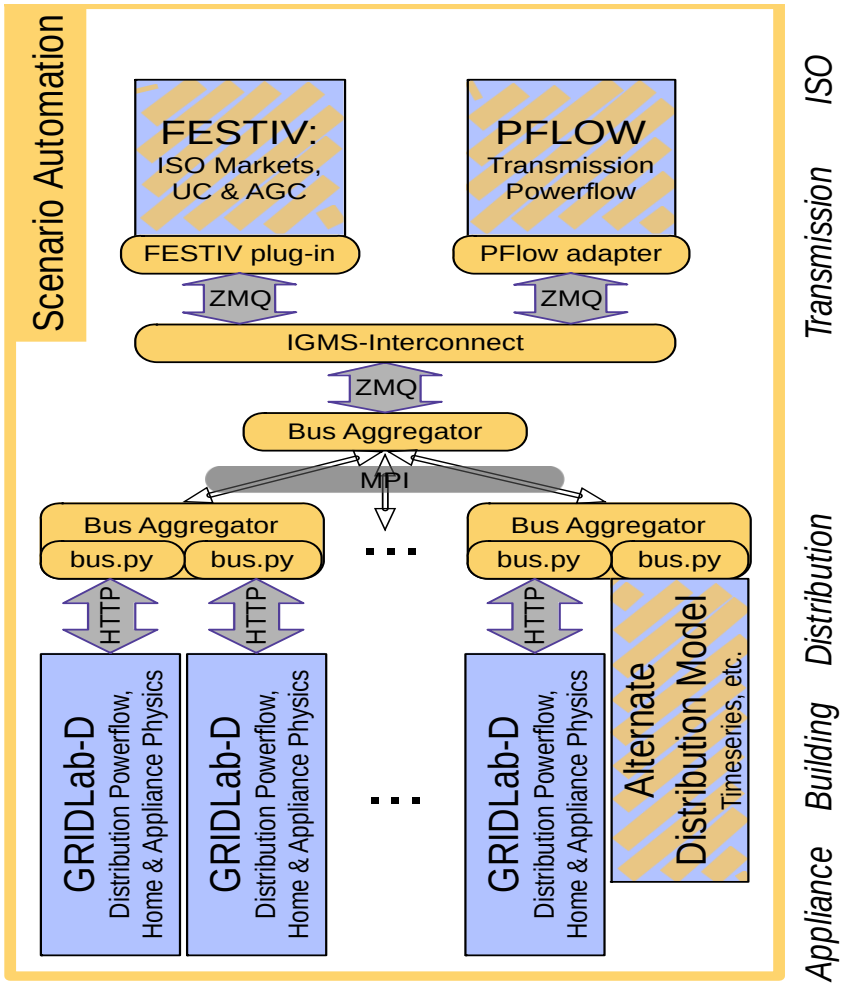
Dynamics Tool

- Combined transmission-distribution
- Simultaneous solution approach
- Integration with protection models
- New solar PV models using dynamic phasors

State Estimation Tool

- Unbalanced distribution system state estimation
- Inclusion of AMI, PMU, and other sensor measurements
- Semi-definite programming based approach

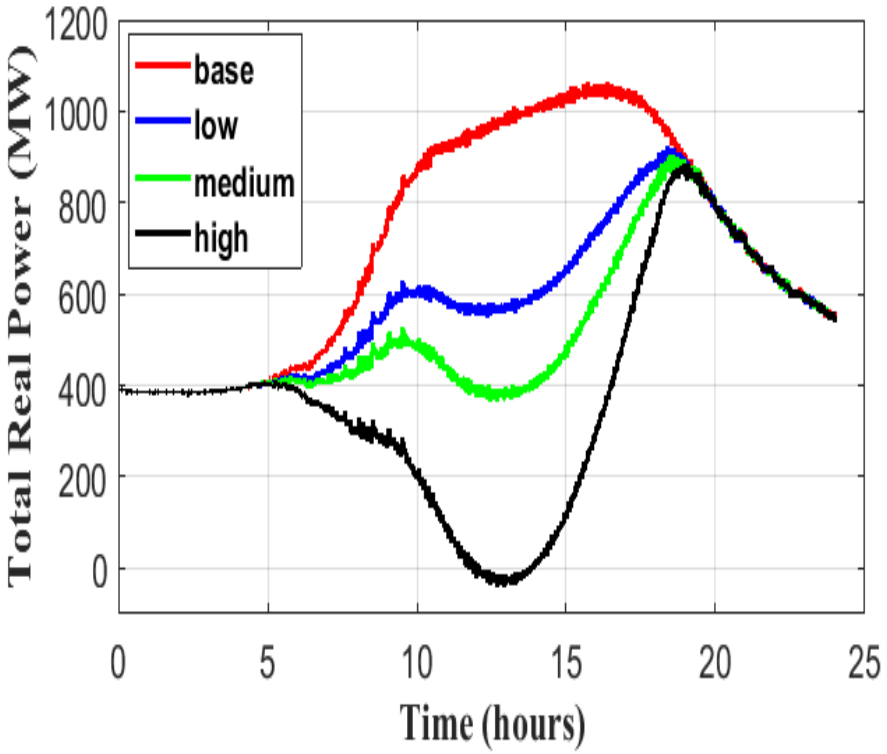
T&D STEADY-STATE ANALYSIS TOOL



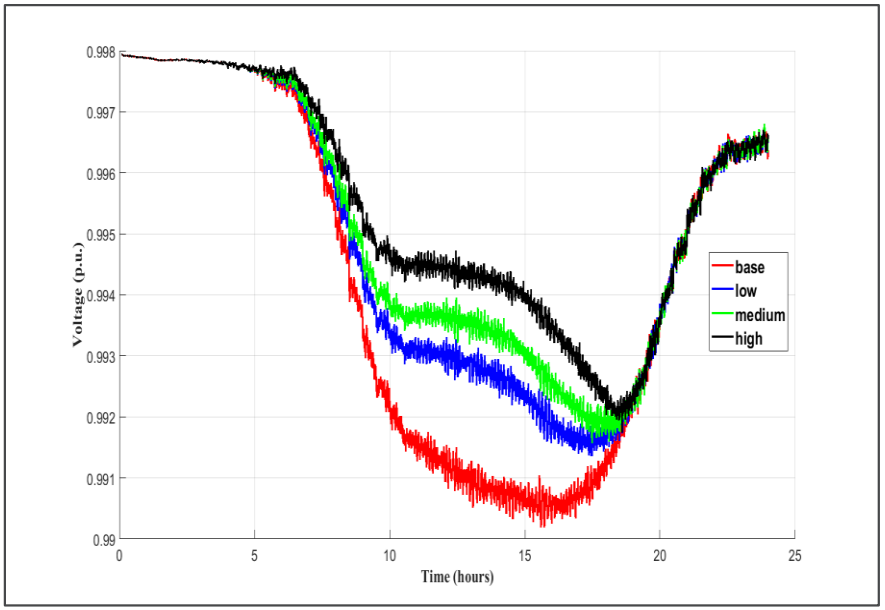
Steady-state T&D analysis tool

- FESTIV (Market)
  - Day-ahead UC, Real-time dispatch, AGC
- PFLOW (Transmission)
  - AC Power Flow
- GridLab-D (Distribution)
  - D power flow

TRANSMISSION SYSTEM IMPACTS DUE TO INCREASING SOLAR



LOAD DUCK CURVE



INCREASE IN VOLTAGES

Base–0% Low–10% Medium–50% High–80%

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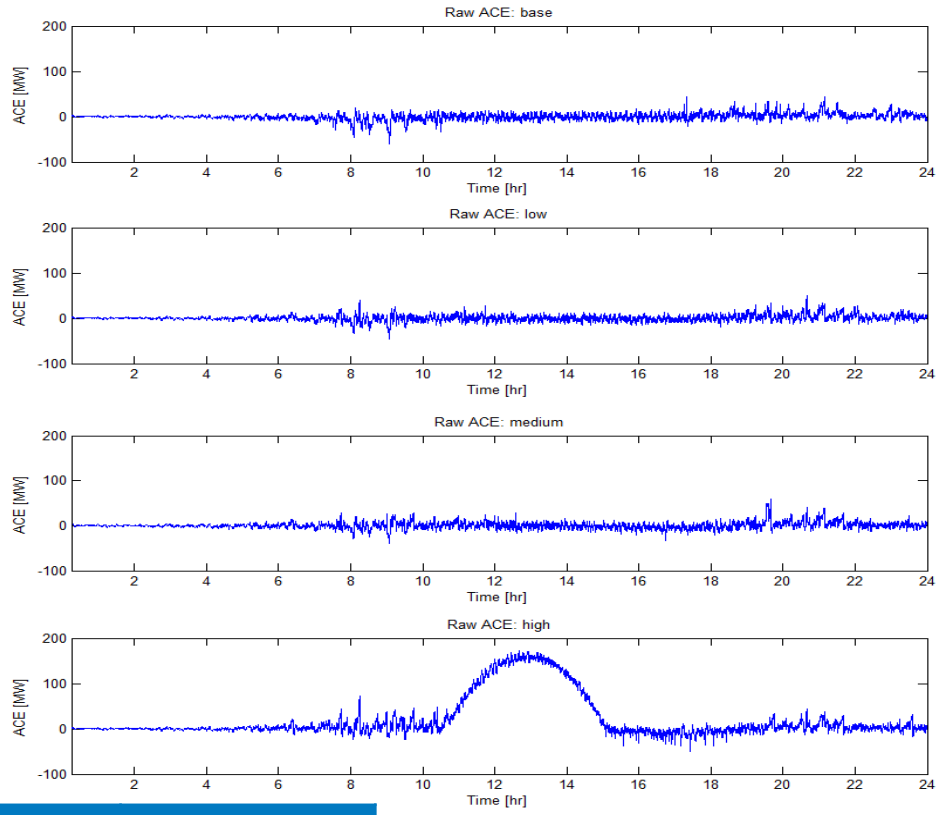
TRANSMISSION SYSTEM IMPACTS: AREA CONTROL ERROR (ACE)

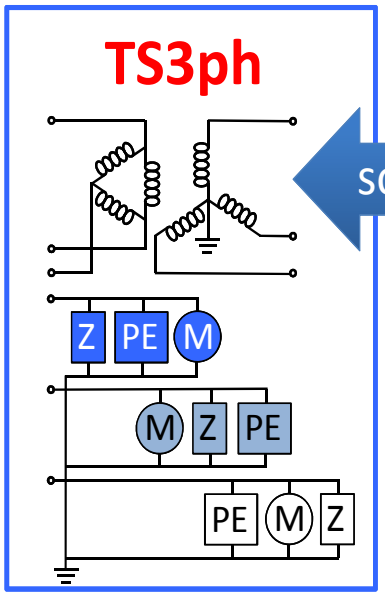
Generation cost reduces but Area Control Error (ACE) worsens with Increasing solar penetration



Case	base	low	medium	high
Cost [$]	$274,349	$207,497	$187,853	$147,551
AACEE [MWh]	134	126	132	613
Sigma ACE [MW]	13.5	13.1	13.3	47.7
CPS2 [%]	99	99	99	81

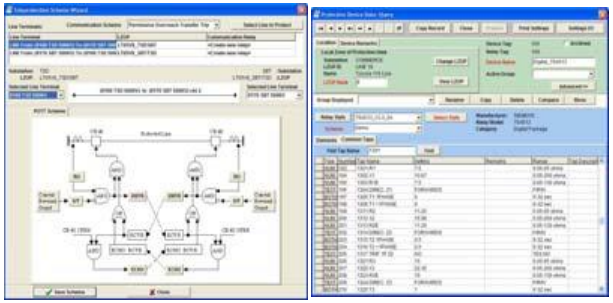
T&D DYNAMICS AND PROTECTION TOOL

- Three-phase network model (transmission and distribution)
- Unbalanced faults
- Single-phase induction motor



socket

electrocon international incorporated CAPE



- Protection system models
- Relay database

PETSc

- High-performance computing solvers

- S. Abhyankar, E. Constantinescu, B. Smith, A. Flueck, and A. Maldonado "Parallel Dynamics Simulation using Krylov-Schwarz Linear Solution Scheme", *Special Issue on HPC in IEEE Transactions on Smart Grid.*
- http://www.energy.gov/sites/prod/files/2014/07/f17/4-2014-AGM-Review-Flueck_2.pdf

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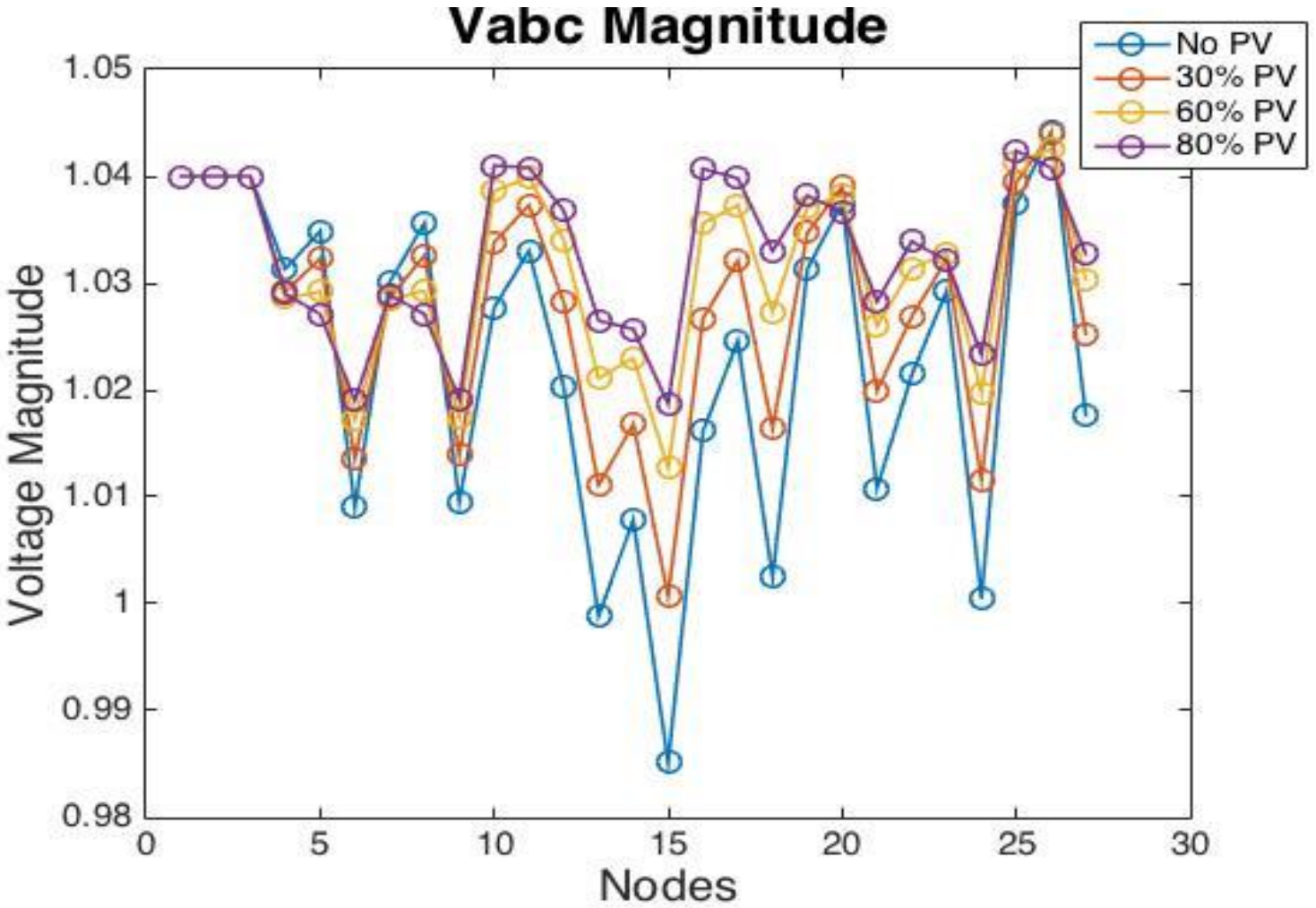
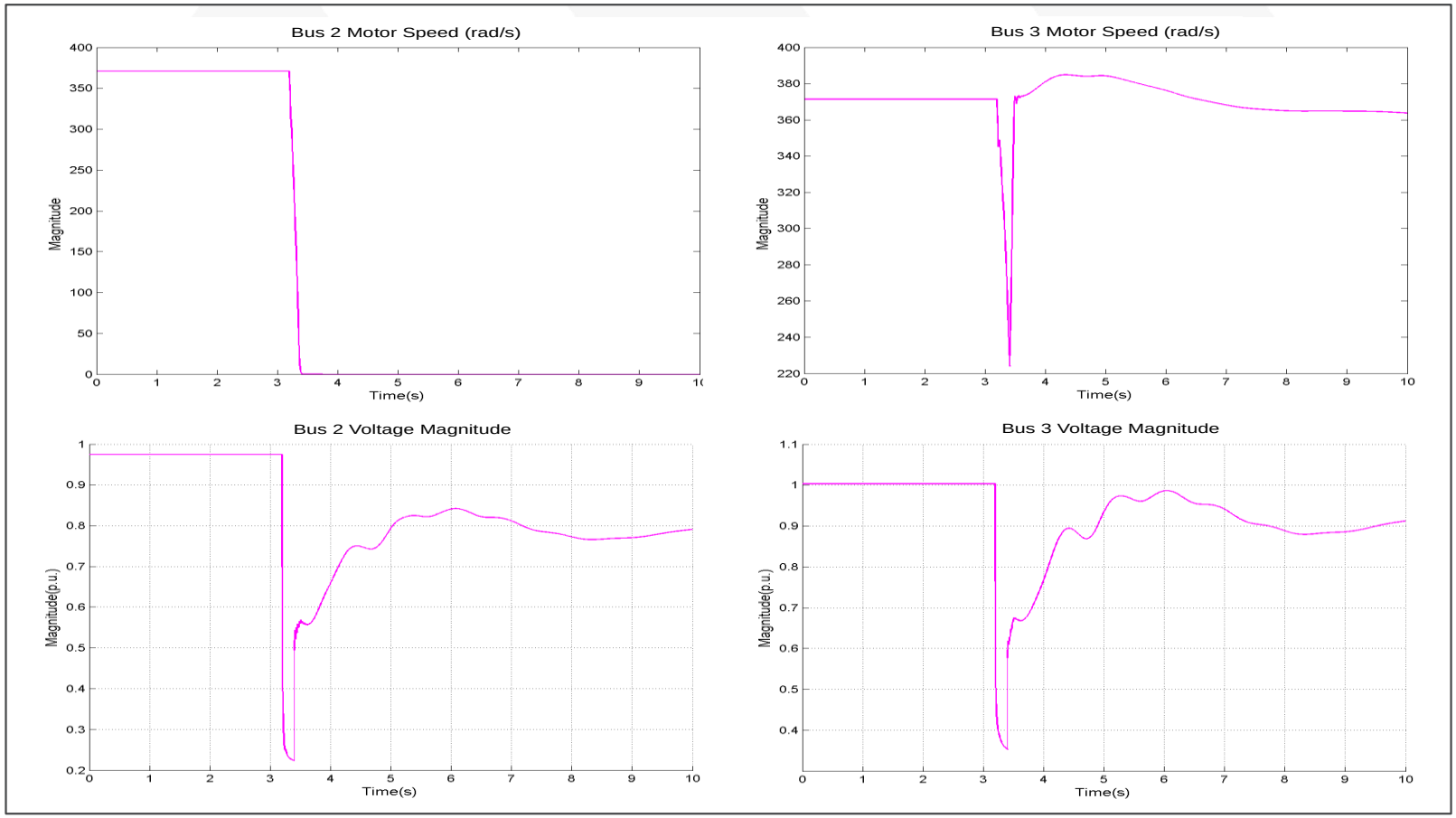
T&D DYNAMICS AND PROTECTION TOOL



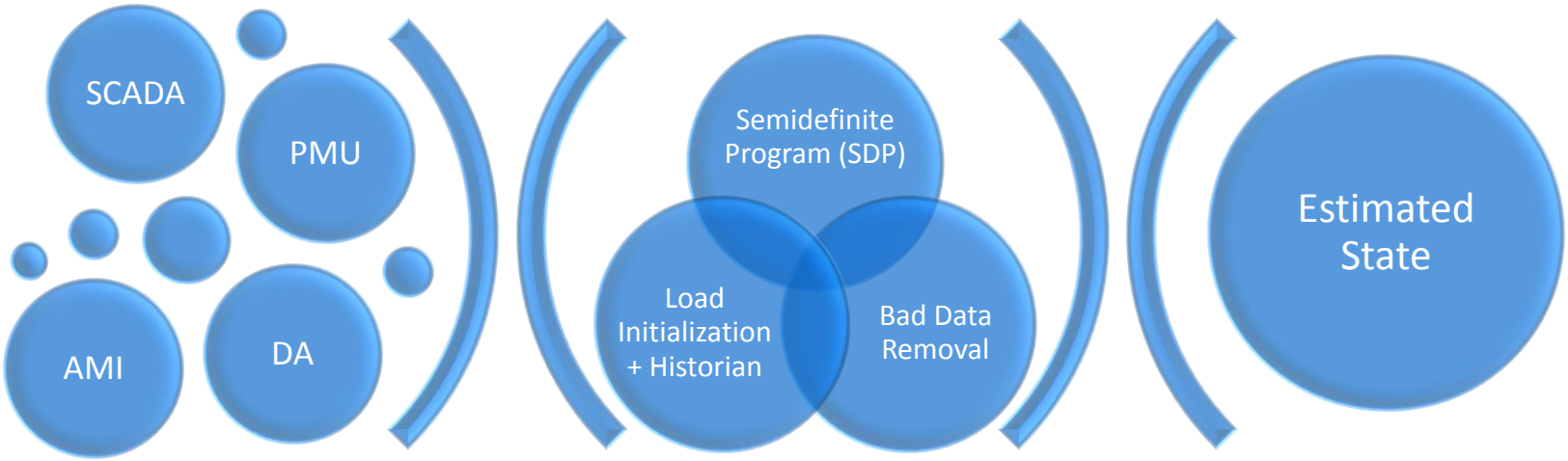
Unbalanced transmission voltages, even though transmission network impedances are balanced

T&D DYNAMICS AND PROTECTION TOOL



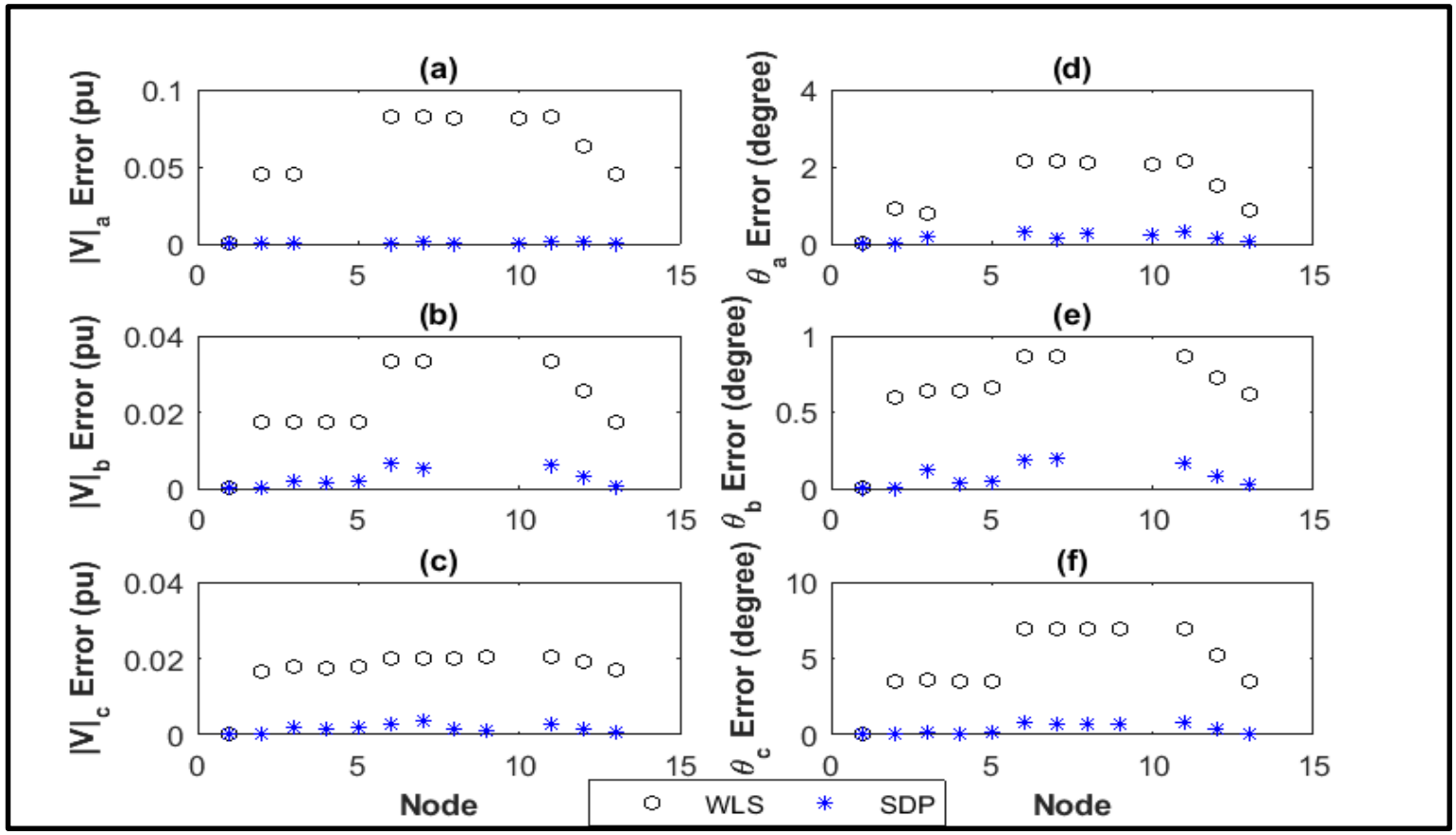
Single-phase induction motor with stall feature (Bus 1 fault)

DISTRIBUTION SYSTEM STATE ESTIMATOR



- Unbalanced distribution system state estimation
- Semi-definite programming approach
- Bad-data substitution
- Incorporate data sources with time-scales that vary by 10^5

Distribution system state estimator – with bad data



All SDP errors are within 1% of the true power flow solution

QUESTIONS

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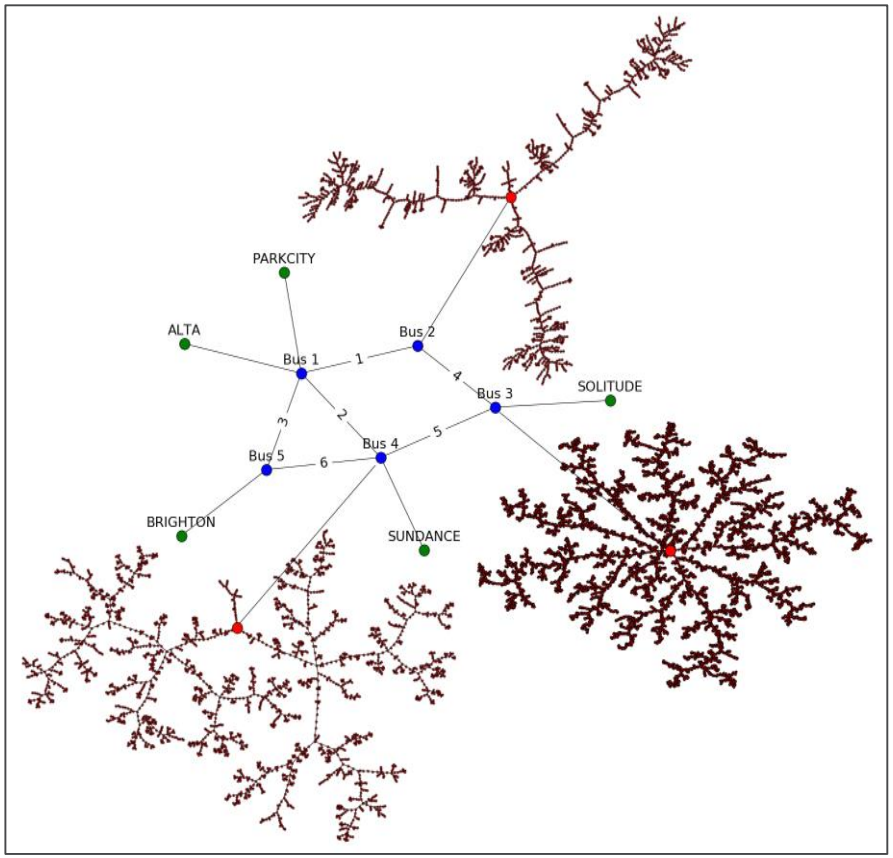
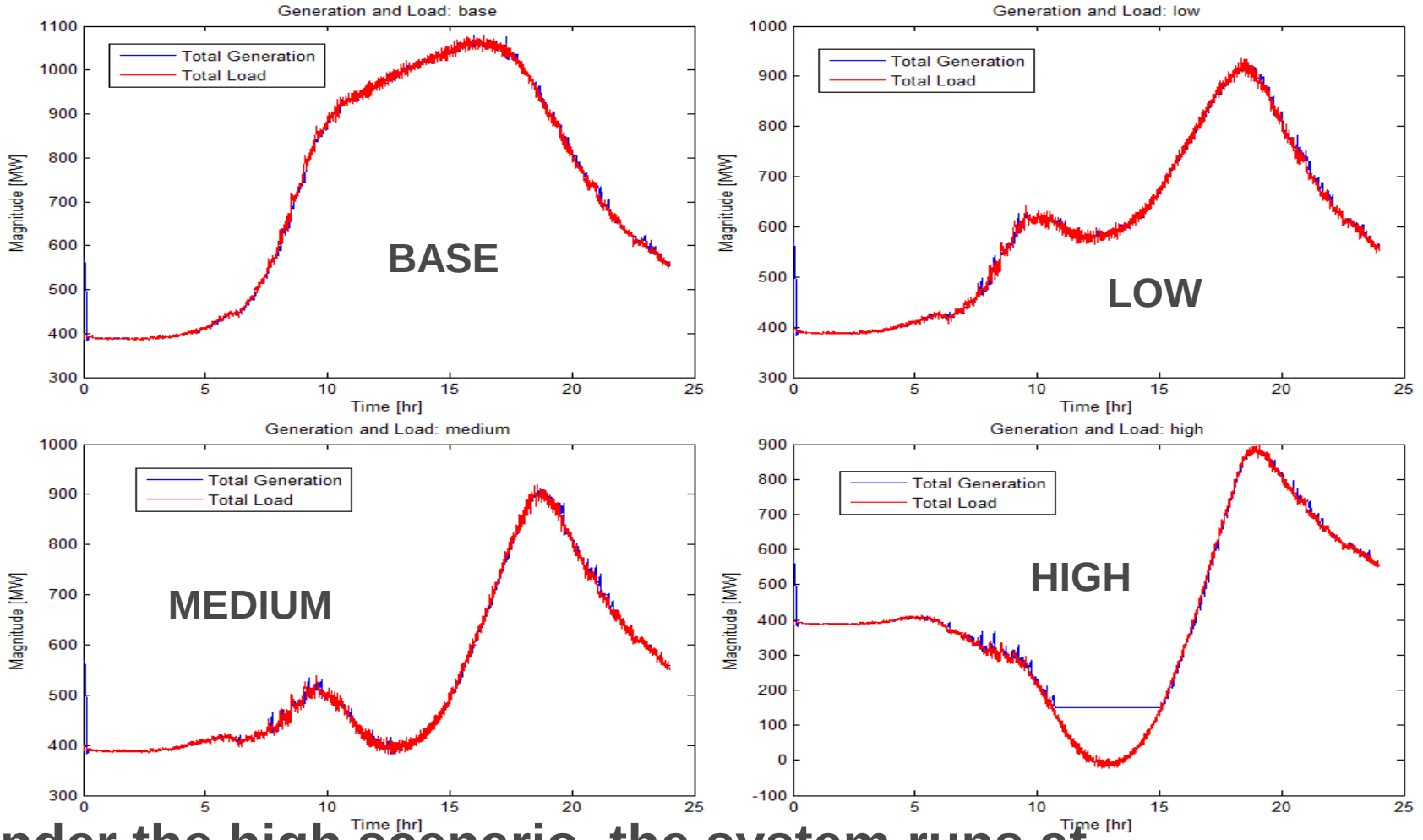
T-D SIMULATION TEST SYSTEM



PJM-5 bus, 11 distribution feeders

- T: PJM 5-bus transmission network
- D: 11 PNNL taxonomy feeders
- Four scenarios
  - Base case (no solar)
  - Low solar distributed PV penetration (~30 %)
  - Medium solar distributed PV penetration (~50%)
  - High solar distributed PV penetration (~80%)
- 24-hour horizon

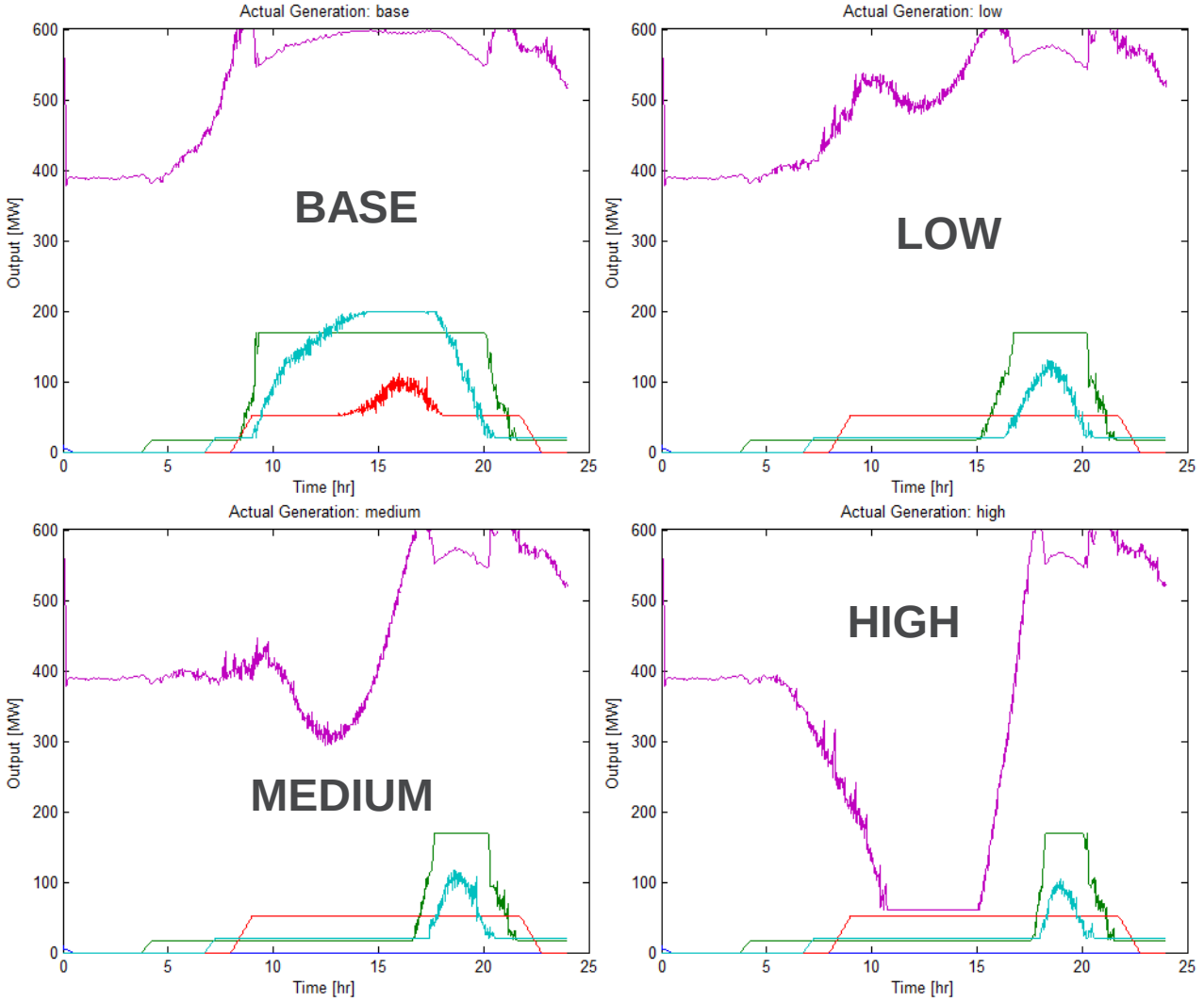
STEADY-STATE IMPACTS: GENERATION-LOAD IMBALANCE



Under the high scenario, the system runs at minimum generation levels to ride out the high solar production.

STEADY-STATE IMPACTS: REDUCED BULK GENERATION PROFILE

Due to operational constraints (e.g. minimum run/down times, start-up/shut-down times, etc.) as well as operator visibility, the generators cannot be shutdown during the middle of the day and the best option for the operator is just to reduce the generators to their minimum generation levels.



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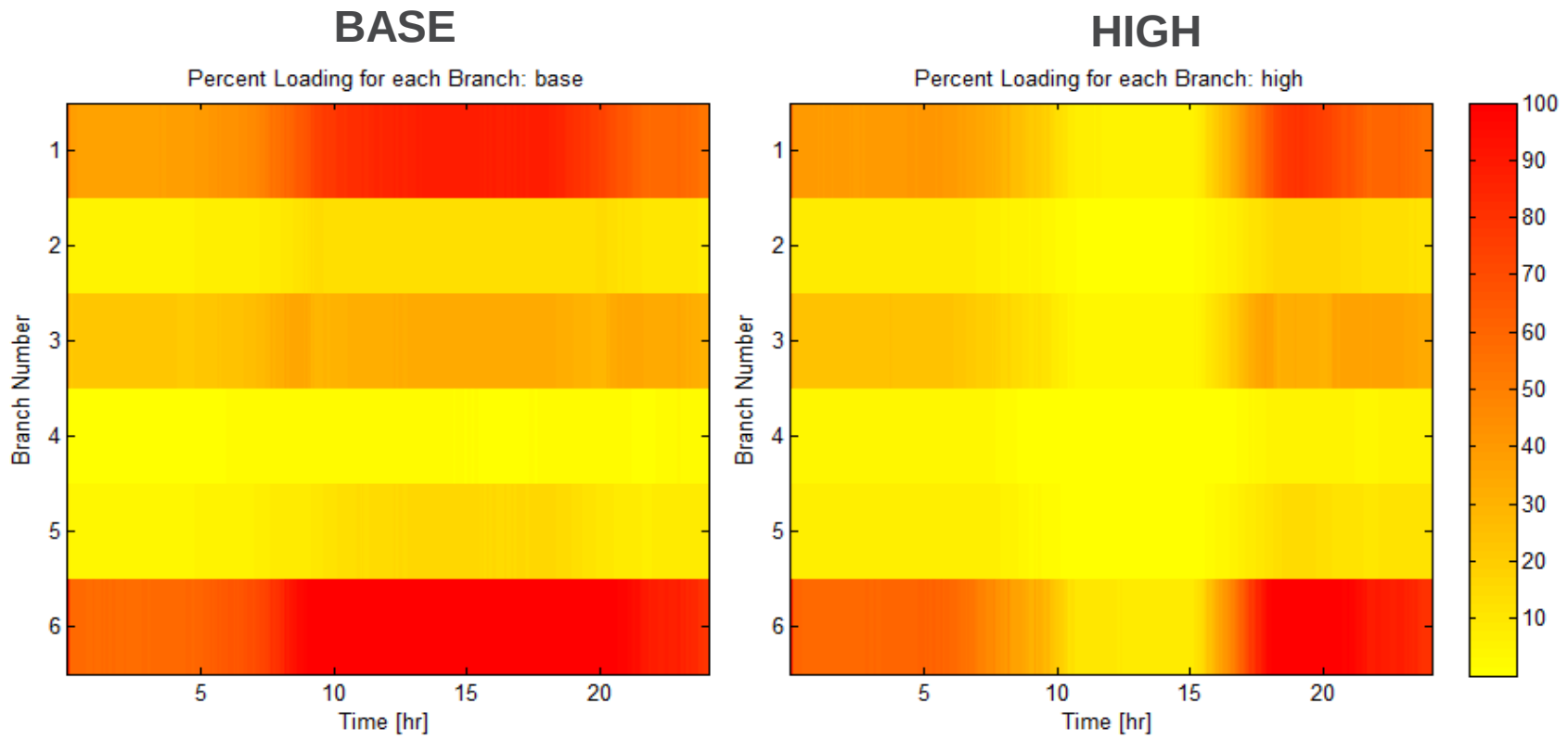
STEADY-STATE IMPACTS: TRANSMISSION CONGESTION



Transmission congestion reduces with increasing solar penetration resulting in (a) reduced costs (LMPs), (b) better voltage profile, and (c) reduced reactive power supply