# Smart grids: technologies, markets and communities

The Open University
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DE MONTFORT UNIVERSITY
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EPSRC
Pioneering research and skills

Agent-based Modelling of Electricity Networks

CASCADE
Complex Adaptive Systems, Cognitive Agents and Distributed Energy

## Transition to a Smart Grid…

- “A **smart grid** is an electricity network that can efficiently integrate the behaviour and actions of all users connected to it — generators, consumers and generator/consumers — in order to ensure an economically efficient, sustainable power system with low losses and a high quality and security of supply and safety.” - EC Smart Grid Task Force, 2010


*Courtesy: Electric Power Research Institute*

**S**mart

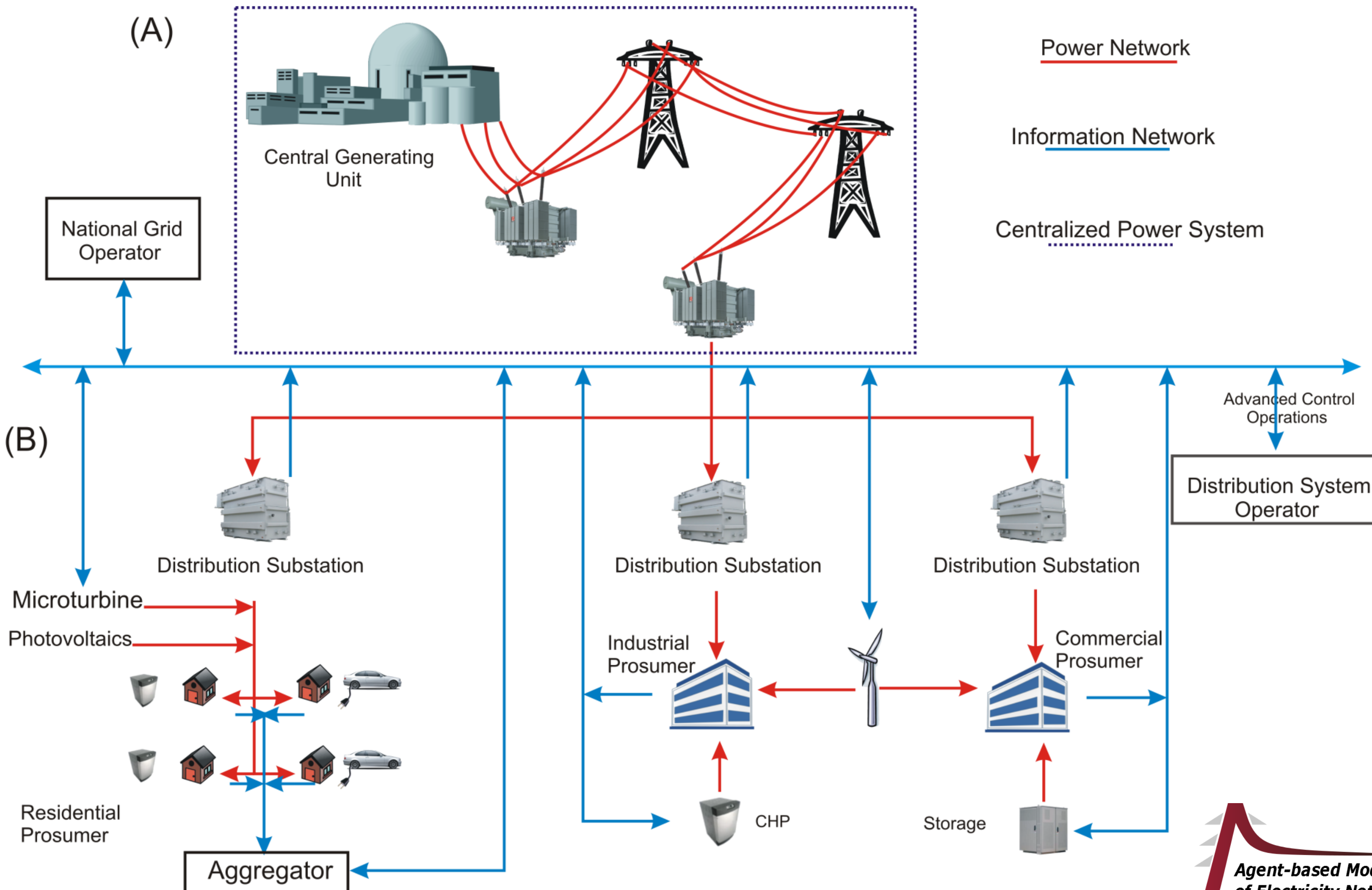
**E**fficient

**E**conomical

**R**eliable

**S**ustainable

# Transition to a Smart Grid…

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**Smart Grid will make possible high levels of penetration of renewables by:**

- Balancing intermittency with demand side resources and storage
- Better monitoring and forecasting for enhancing the predictability of impacts of intermittent generation
- Managing complicated power flows from DG
- Using advanced technologies for communication and control for managing operational issues such as system balancing, voltage control, short-circuit protection, ancillary services, etc.

## Smart Grid Operational Packages

- SCADA (Supervisory Control and Data Acquisition)
  - System that collects data from sensors within a plant or remote locations and processes centrally to manage and control devices on the field

- EMS (Energy Management Systems)
  - Topology processor
  - State Estimation
  - Three phase balanced power flow
  - OPF (Optimal Power Flow)
  - Contingency analysis
  - Short circuit analysis
  - Relay protection coordination

- DMS (Distribution Management System)
  - Optimal Network Reconfiguration
  - Integrated volt/VAR control
  - Optimal Capacitor and VR sizing and placement
  - Optimal DG sizing and placement
  - Load Modelling and Estimation
  - State Estimation
  - Outage Management Systems
  - Fault Detection, Isolation and Restoration
  - Interface to GIS
- DRMS (Demand Response Management Systems)
- AMI (Advanced Metering Infrastructure)

# Dynamic Pricing schemes

- Time-of-Use (**TOU**): A schedule of rates for each period of the day, the simplest case being peak and off-peak periods. There is certainty over the rates and time-periods.

- Critical Peak Pricing (**CPP**): Customers pay higher peak period prices than they would during peak hours on the few days when wholesale prices are the highest. CPP effectively transfers the cost of generations especially for those few hundred hours when supply costs are very high.

- Peak Time Rebate (**PTR**): Customers participate at the existing rate but are given a cash rebate for reducing critical-peak usage. A baseline load needs to be established beforehand.

- CPP-Variable (**CPP-V**): Similar to CPP except that the peak period is notified to the customer only a day-ahead of the critical event, thus allowing the operational flexibility for the utilities and DSOs.

- Variable CPP (**VPP**): Similar to CPP but with variable critical peak price signals reflecting real-time system conditions and marginal costs if any.

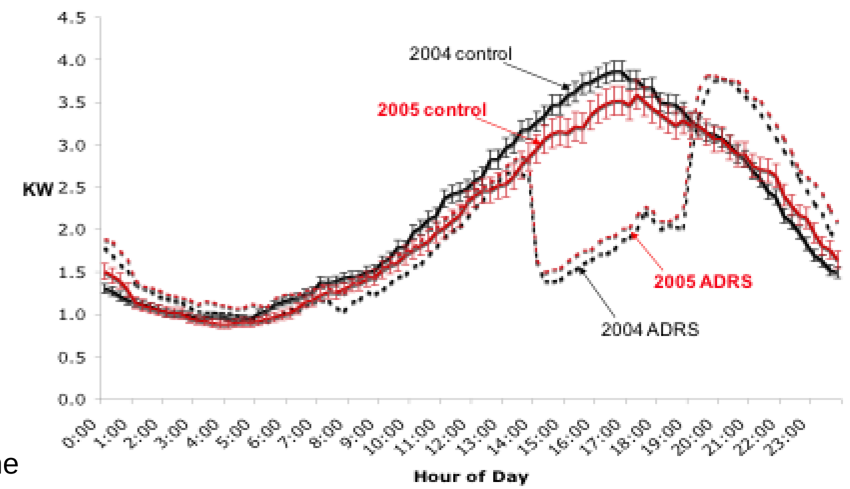
- Real-Time Pricing (**RTP**): Prices directly linked to the hourly / half-hourly market price for electricity. Price signals transmitted to consumers either a day-ahead or hour-ahead the actual time of delivery.

# The Community Energy Cooperative's Energy-Smart Pricing Plan (Illinois) 2003 – 2005

- Residential **RTP** with nearly 1500 customers
- Customers charged day-ahead hourly prices
- Customers were found to be more price responsive during the evening hours (4 p.m. to midnight) and on "high price days" when provided with additional notifications.
- Customers mostly responded to blocks of days rather than hour-to-hour variations in the electricity price.
- Similarly, customers responded to notification of high priced days, rather than responding to a spike in a single hourly price.
- A simple period based rate such as TOU or CPP would be more appropriate in influencing customers.

# California Automated Demand Response System Pilot

- **CPP** with high prices between 2pm - 7pm
- Customers notified during the day before a Super Peak event.
- Users able to view current electricity price on-line or via thermostat.
- Devices could be set to automatically respond to prices.
- 12 Super Peak events in 2004 and 11 in 2005.




Average Load Profiles of High Consumption Households on Super Peak Event Days, 2004 - 2005

The energy management technology included the following components:

- wireless RF communications network connecting all system components
- two-way communicating whole-house interval electricity meter capable of recording consumption data in 15-minute intervals
- wireless internet gateway and cable modem
- programmable smart thermostats used to control air conditioning loads
- load control and monitoring devices to manage other selected loads (eg pool pumps and spas)
- web-enabled user interface and data management software.

- Shifting just 5% of peak demand reduces prices substantially for all users, as expensive peak power plants are not turned on and even need not be built.
- Brattle group found that TOU rates cut peak demand by 3% - 6% and CPP cut peak demand by 27% - 44%.
- A PNNL pilot using autonomous controls on dryers and water heaters responding to ancillary service signals achieved peak demand reduction of 16% on domestic sector and 9%-10% over extended periods.
- Oklahoma Gas and Electric's pilot achieved demand reductions of 57%

## Innovative Network Technologies and Tools

- iTESLA – Innovative Tools for Electrical System Security within Large Areas – EU
  - To develop a common toolbox, allowing pan-European TSOs to increase coordination and harmonise operating procedures.
  - To carry-out the operational dynamic simulations in the context of a full probabilistic approach, thus going beyond the current 'N-1' approach and optimising the transit capacities of the grid over different areas (national, regional, pan-European) and timescales (two-days ahead, day-ahead, intra-day, real-time).

- Flexible networks for a Low Carbon Future – UK (Low Carbon Networks)
  - Objective to increase network capacity by 20%
  - To target energy efficiency and demand reduction measures for industrial and commercial customers in cooperation with the buildings research establishment, energy supply companies and an independent party.
  - Focus on voltage optimisation, power factor correction and low energy appliances that do not directly require customer behaviour change.
  - Dynamic rating of network assets to create additional headroom where possible
  - Flexible network control to help re-balance network loading using neighbouring network groups to support demand
  - Integration of voltage regulation and power compensation equipment to release voltage constrained capacity, and to assist with re-balancing the network.

## Storage Integration

- *MILLENER* project – France, EDF, 2012 – 2016

    - Installation of 500 Li-ion energy storage systems (total 3 MWh of energy) at customers' premises together with PV and energy load controllers.

    - Energy load controllers, connected through a communication link with the system operator, will then be used to optimise storage and PV generation according to demand and grid conditions.

    - Control of local storage is to ensure the real-time balance between electricity demand and production at consumers' premises.

# Projects at IESD

- CASCADE:
  - Complex Adaptive Systems Cognitive Agents and Distributed Energy
  - 3-year EPSRC sponsored project
  - Partners: E.On, Ecotricity, Cranfield Univ, CSIRO (Australia), NEF
  - Complexity Science based investigation into the Smart Grid concept
  - Predominantly at the Distribution level

- AMEN:
  - Agent-based Modelling of Electricity Networks
  - 3-year EPSRC sponsored project
  - Partners: E.On, NEF, EIFER (Karlsruhe), E.On, Western Power
  - Builds on the CASCADE model, but predominantly at the Transmission level.

Agent-based Modelling of Electricity Networks

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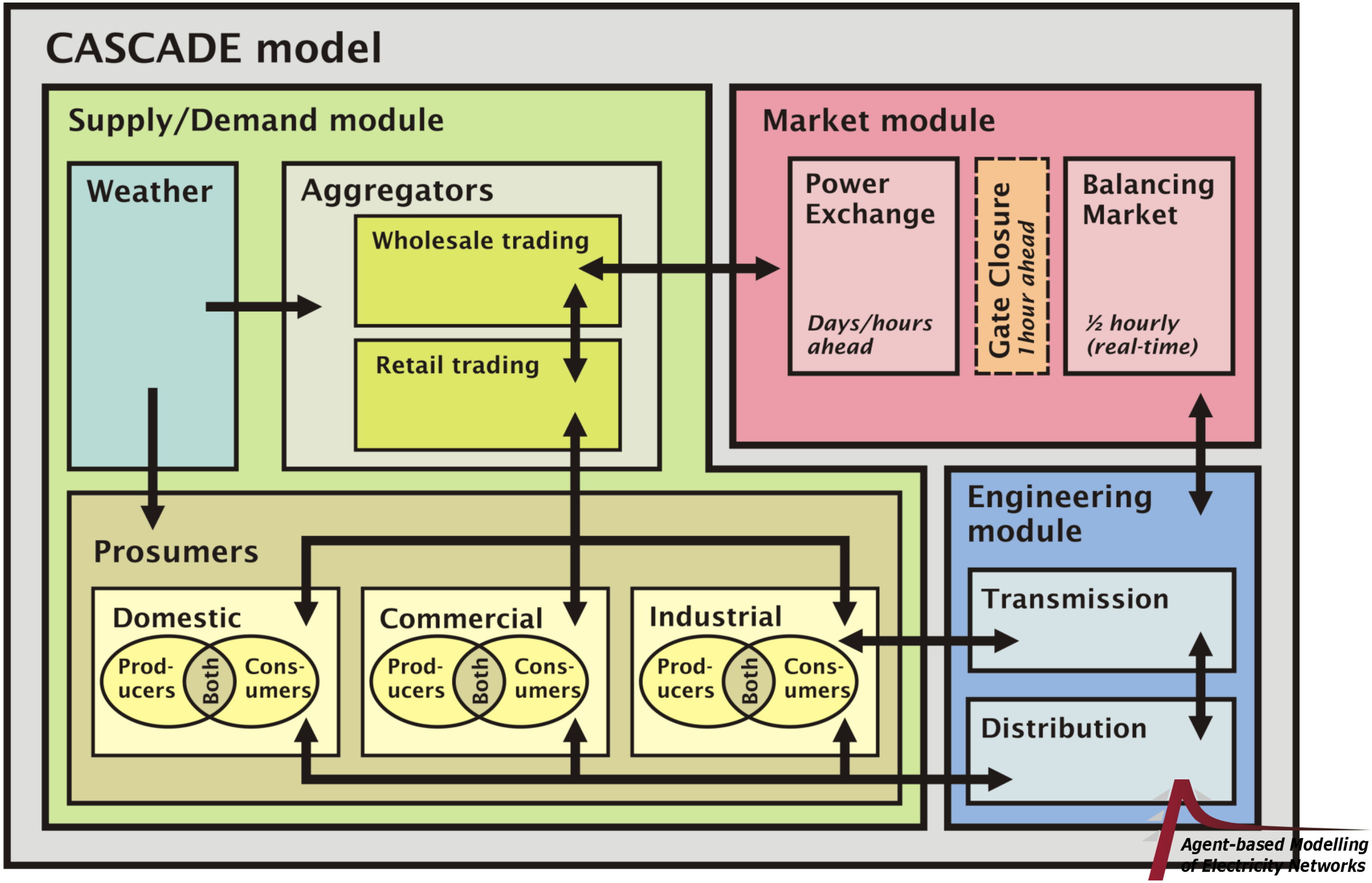
# Model Description: Overview

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# Framework Components

- Players:
  - Central & Distributed Generators
  - Traders
  - Suppliers
  - System Operators
  - Consumers

- Assets:
  - Networks: Electrical networks, Communication networks
  - Transformers and Voltage Regulators
  - Switches, Capacitors
  - Loads
  - Smart meters Intelligent programmable devices

- Processes:
  - Information transfer and signalling processes
  - Power flow and optimal dispatch calculations
  - Trading rules and market mechanisms

# Aggregator

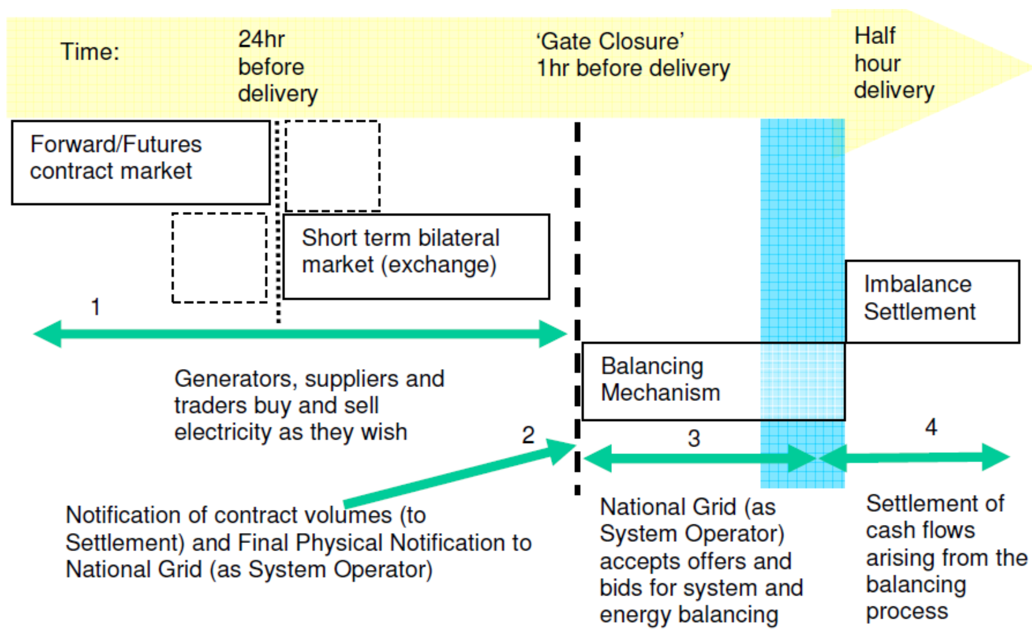
- ✓ Commercial aggregation of demand profiles of Prosumers
- ✓ Market participation: Bids and Offers based on aggregate profiles
- ✓ Derives and transmits smart signal to Prosumers
- ✓ Aggregates change in demand
- ✓ Learns new price signal based on earnings
- ✓ Satisfies physical constraints of distribution network

# Ancillary Services of Virtual Power Plants

| Local services | System wide services |
|---|---|
| ▪ Voltage control through reactive power supply and tap changers<br>▪ Minimize grid losses, local power quality<br>▪ Distribution network congestion management<br>▪ Stable islanded operation | ▪ Frequency control<br>▪ Active power reserve<br>▪ Network restoration |

# UK Electricity Market

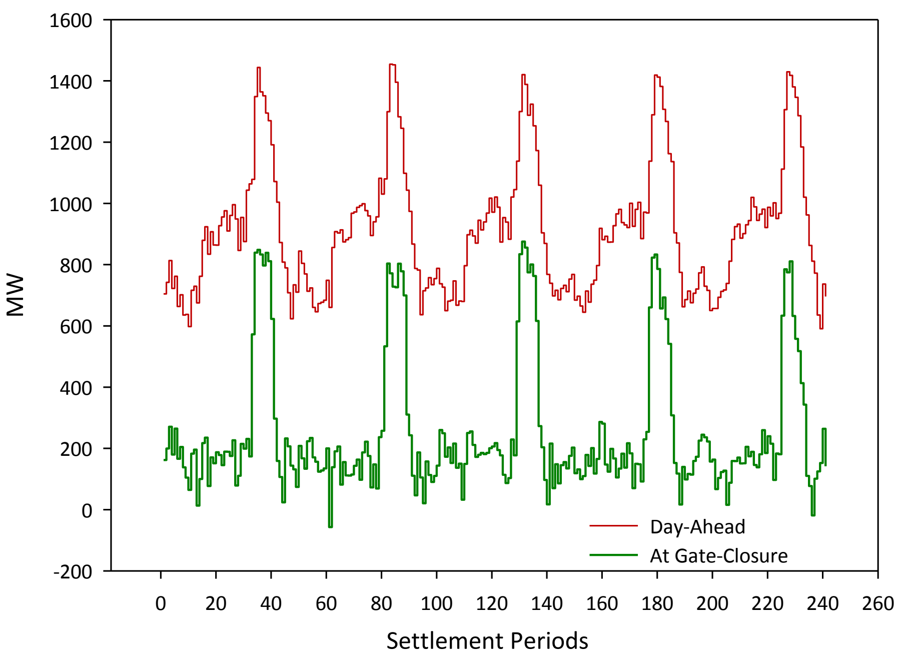
- Bilateral, OTCs
- Spot Market, Power Exchange
- Balancing Market



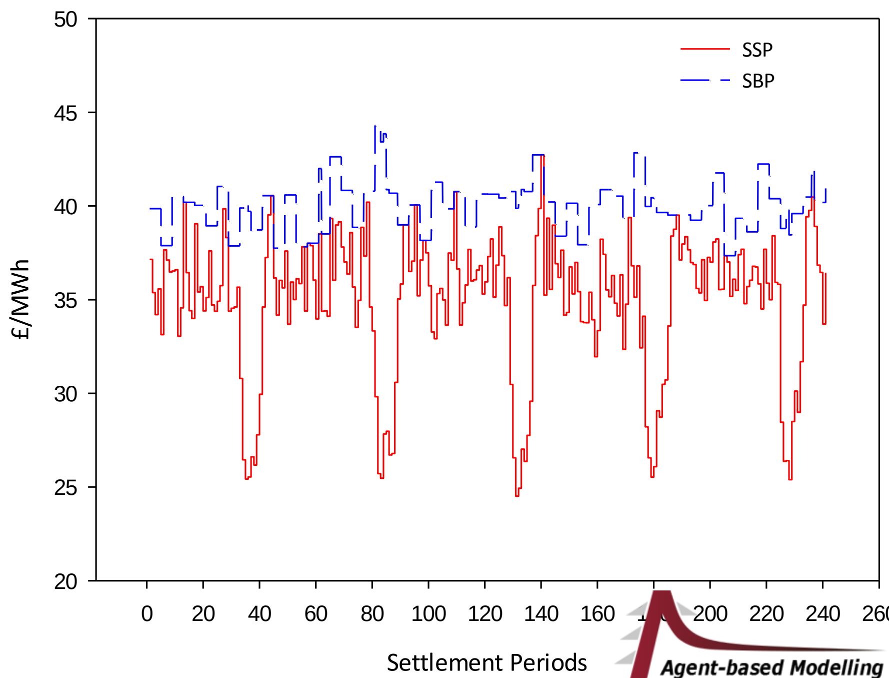
## Case A:

**Coal Plants = 4**
**CCGT Plants = 7**
**Wind Farms = 3**

System Imbalance




System Prices

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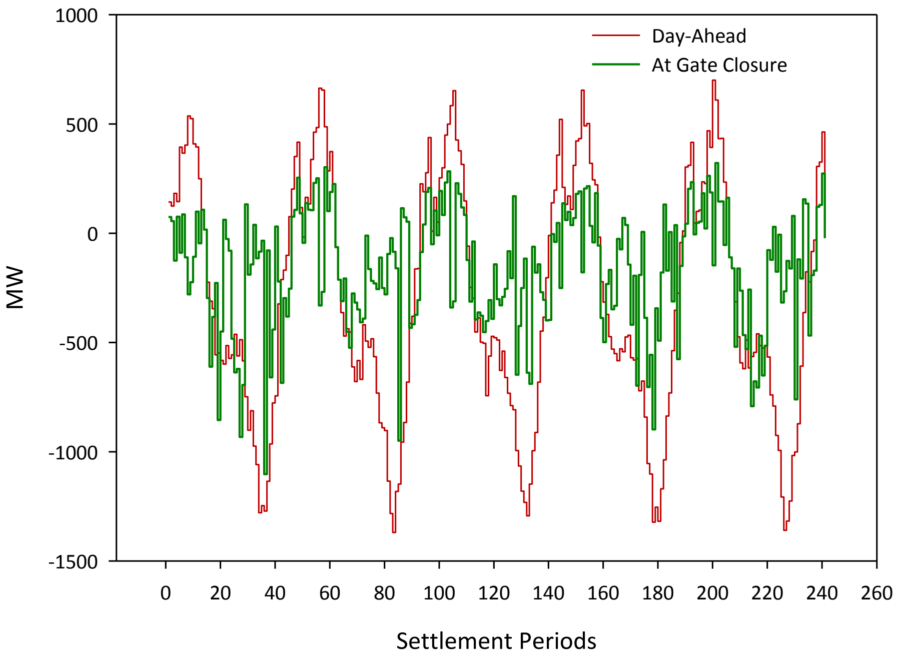
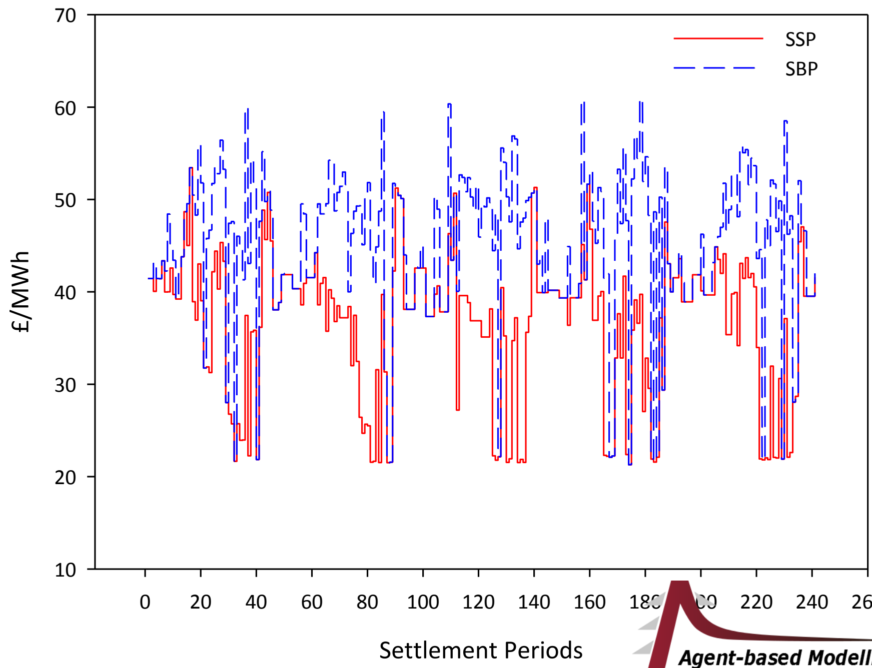
# Case B:

**Coal Plants = 2**
**CCGT Plants = 3**
**Wind Farms = 44**

System Imbalance




System Prices

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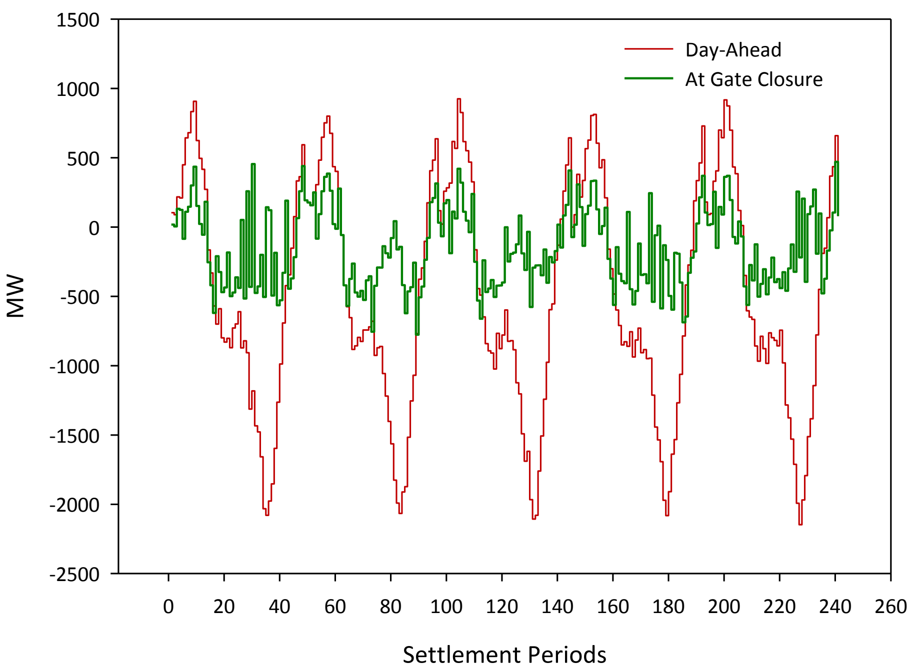
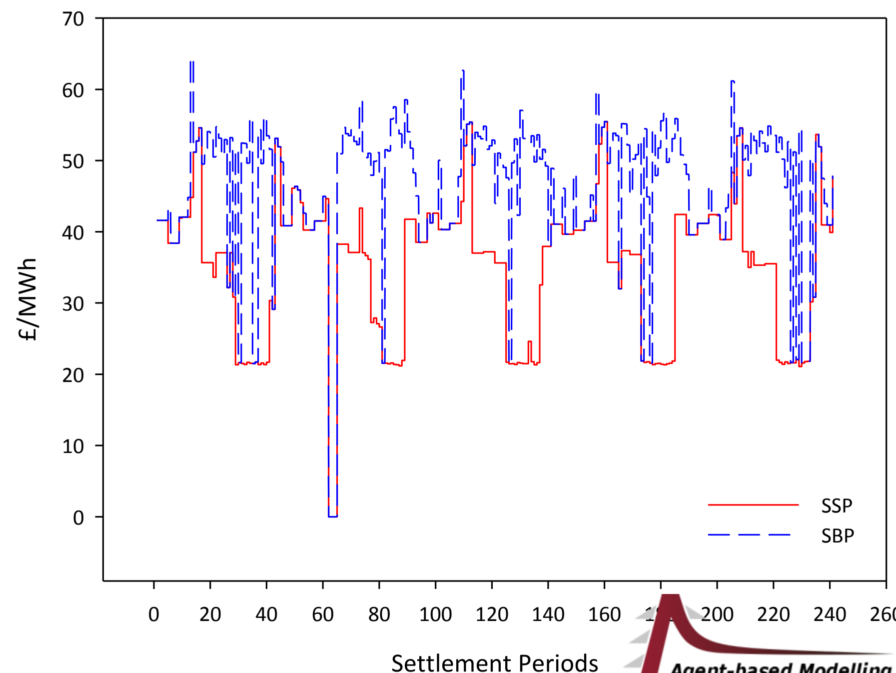
## Case C:

**Coal Plants = 1**
**CCGT Plants = 2**
**Wind Farms = 64**

System Imbalance




System Prices

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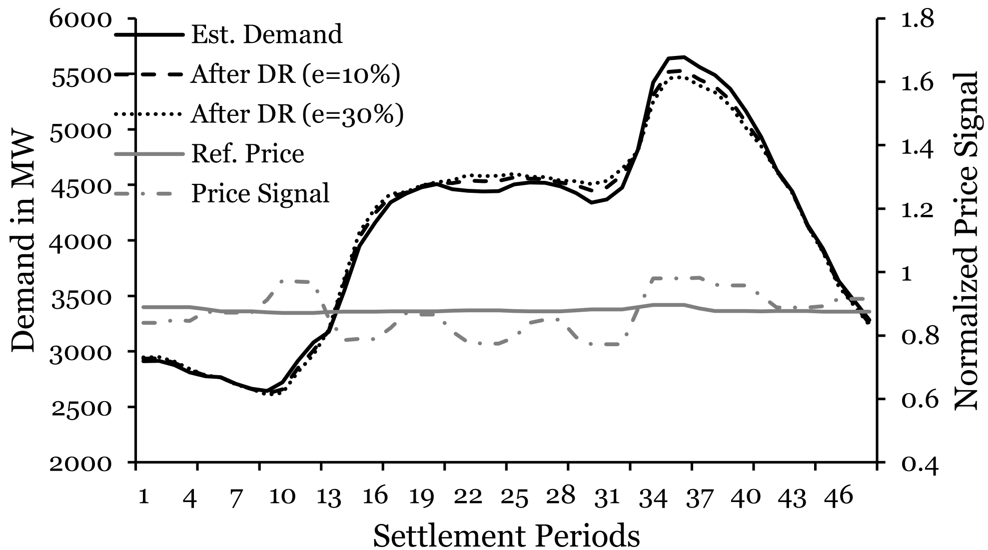
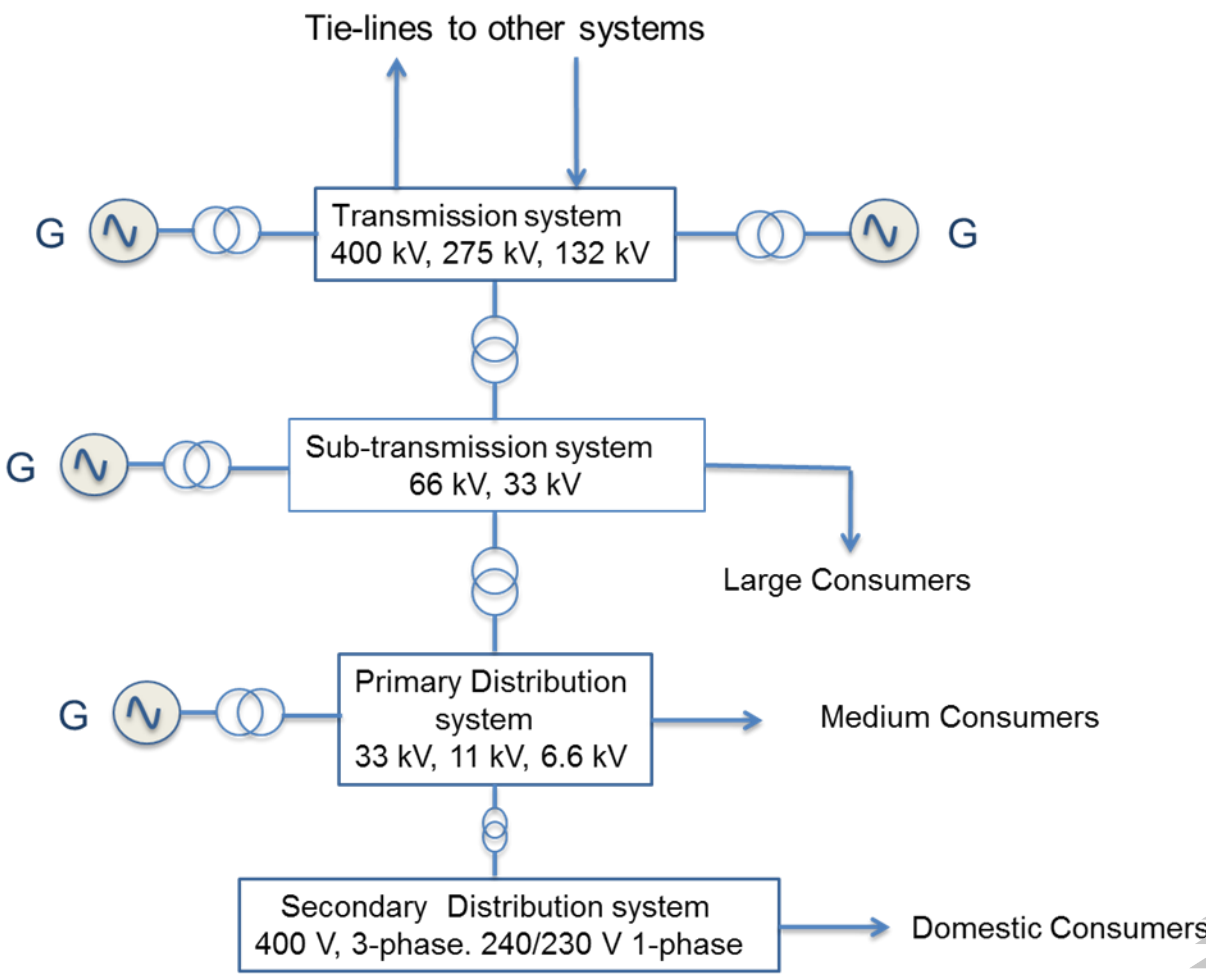
- *5 LARGE_DEM, 3 SMALL_DEM* sites
- *COAL, CCGT, WIND* Generators
- Scenario with aggregated elasticity factors of 10% and 30%
- For increase in price signal, aggregate demand reduces
- Deviation of actual price signal from reference price is substantial with less wind penetration




| | Price Elasticity |
|---|---|
| Residential | -0.05 to -0.12 |
| Commercial | -0.01 to -0.28 |
| Industrial | -0.01 to -0.38 |

Coal plants – 4, CCGT – 7, Wind farms – 3

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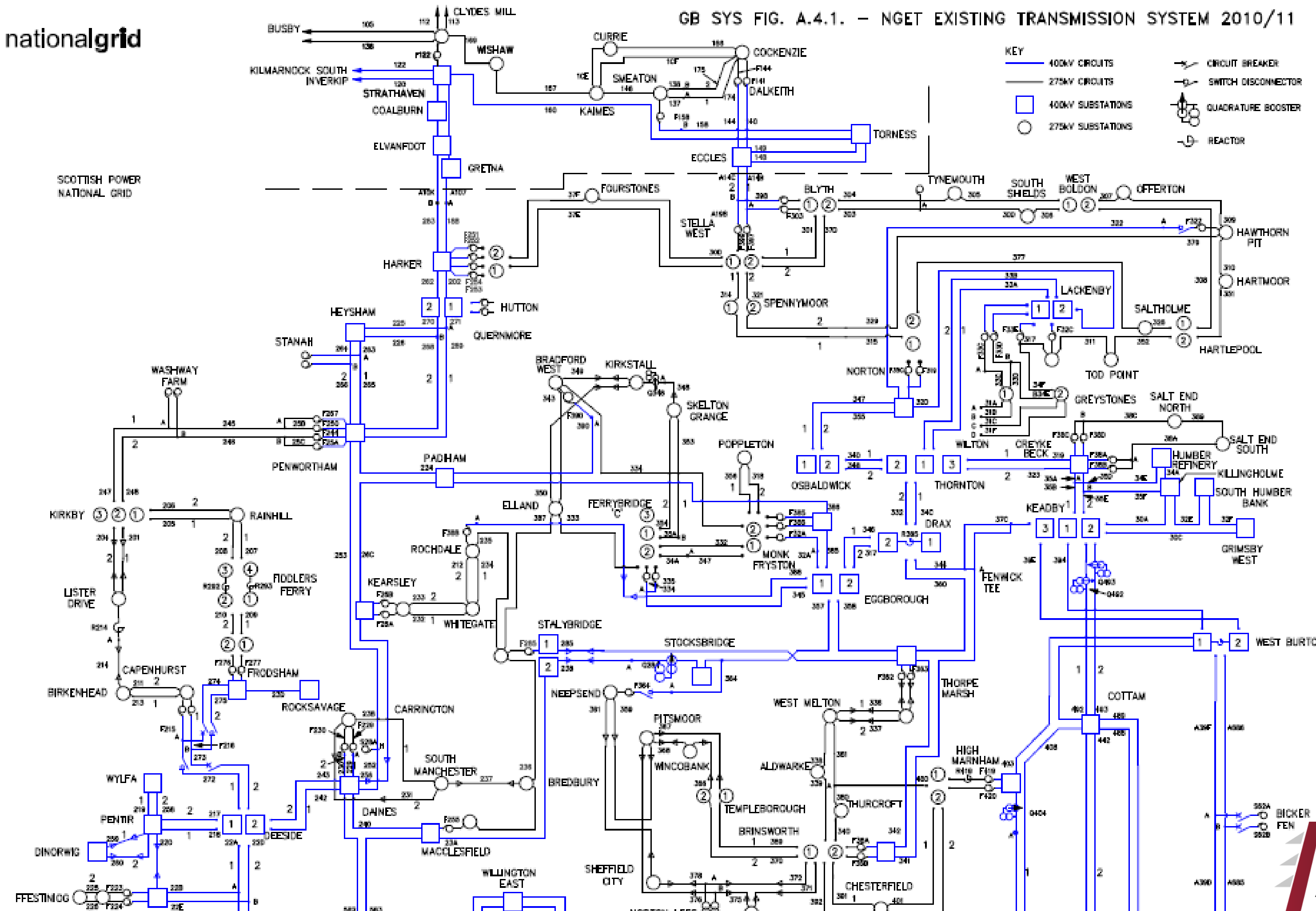


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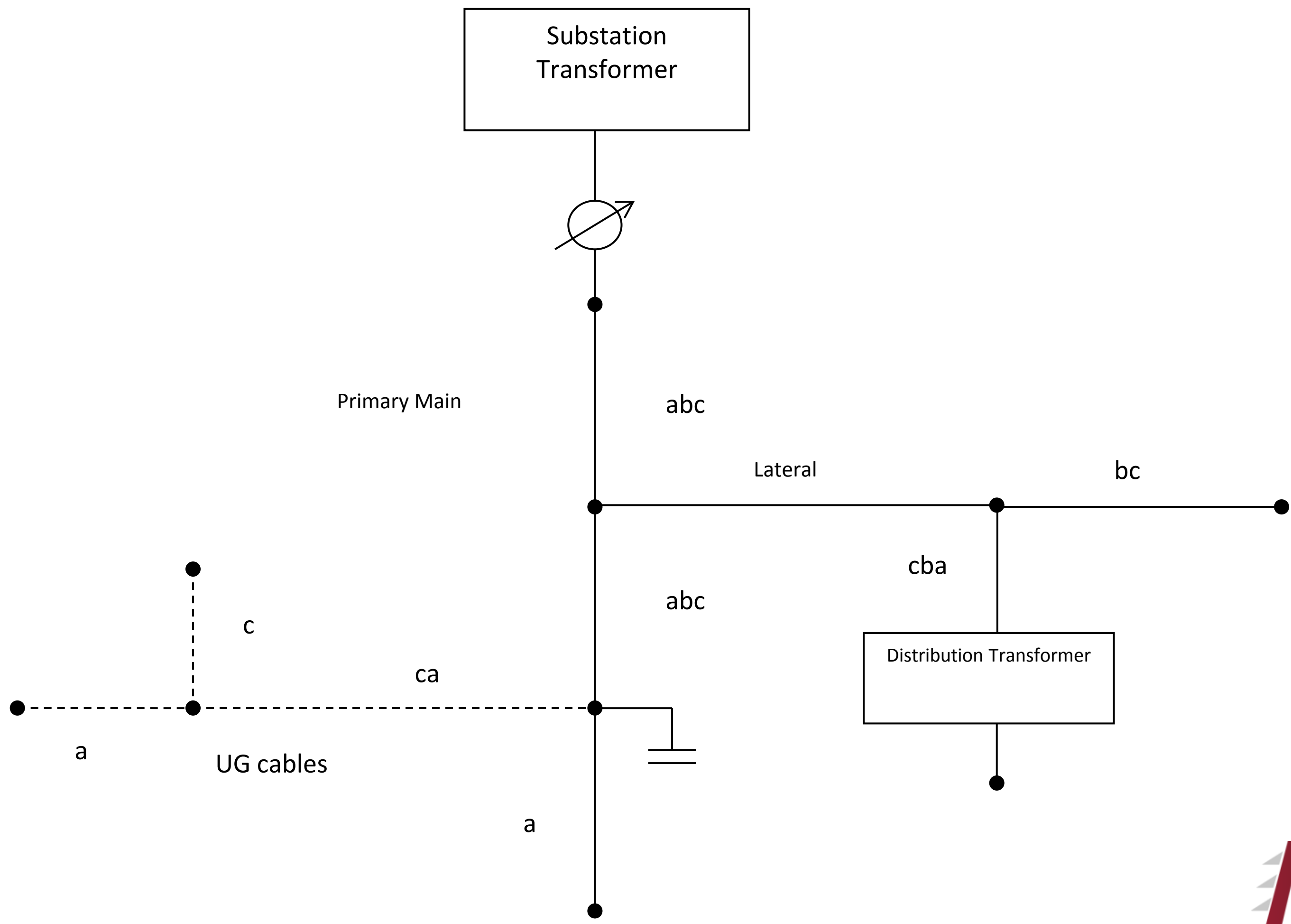
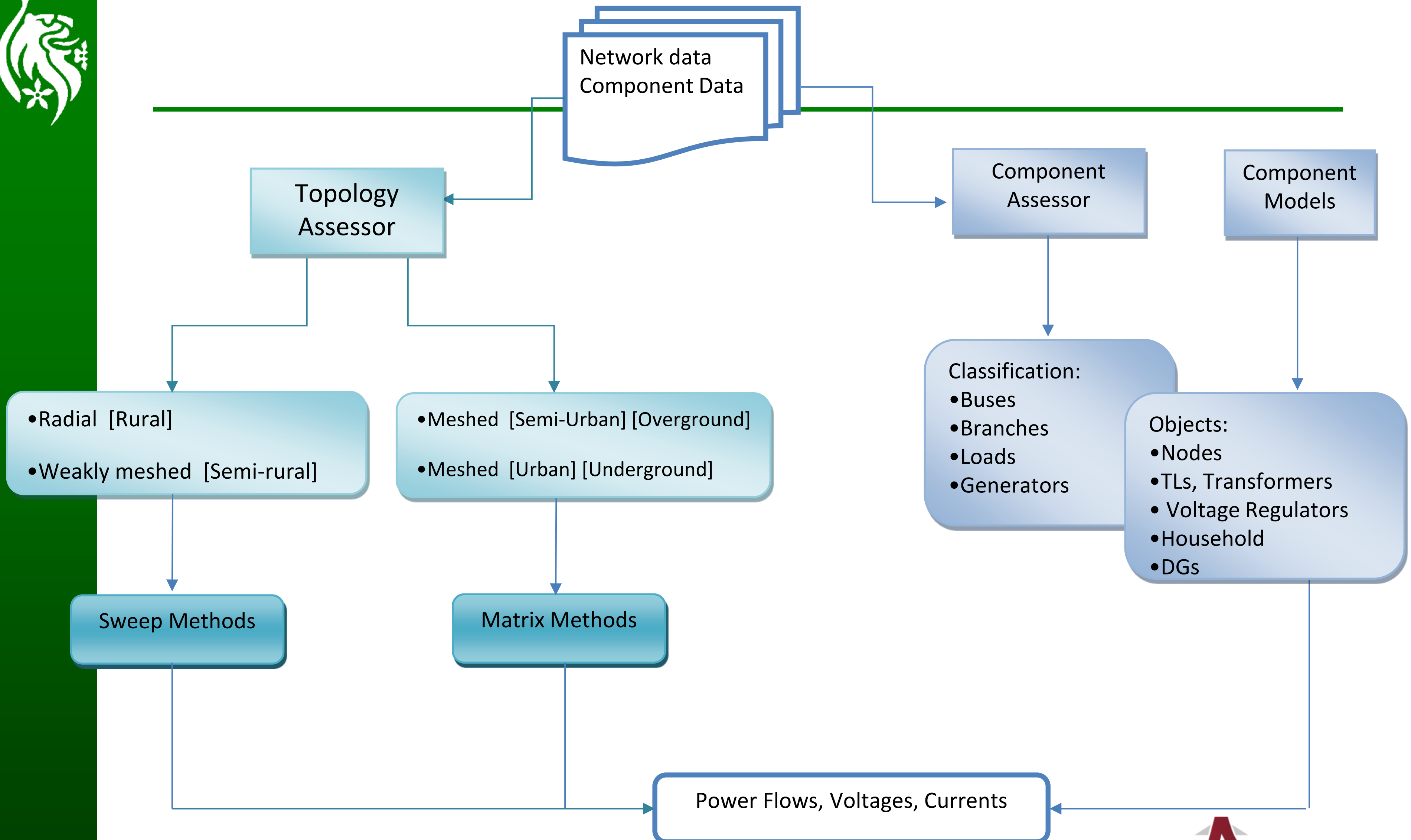
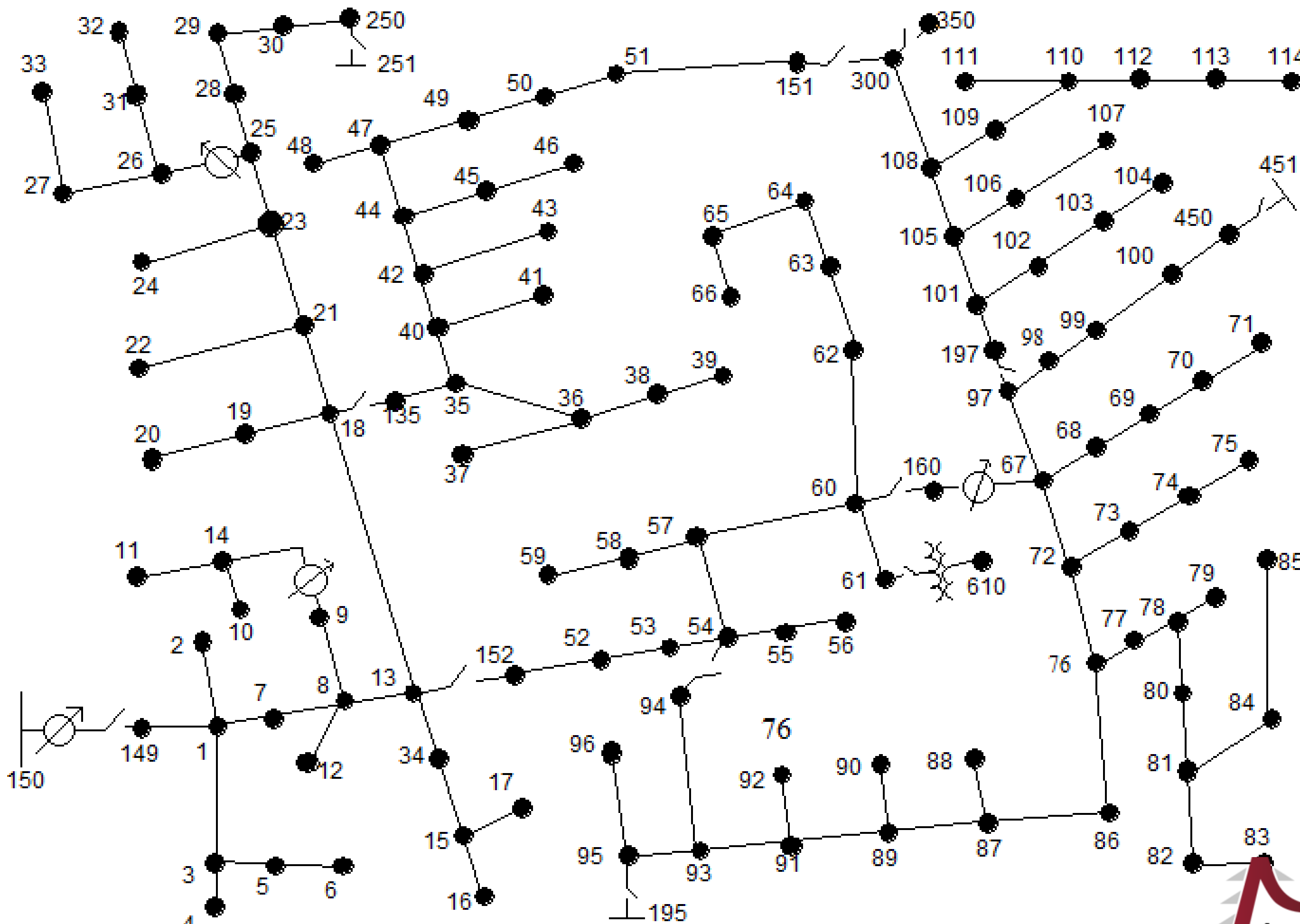
# Sample Radial Distribution Network





Network data
Component Data
Topology Assessor
Component Assessor
Component Models
•Radial [Rural]
•Weakly meshed [Semi-rural]
•Meshed [Semi-Urban] [Overground]
•Meshed [Urban] [Underground]
Classification:
•Buses
•Branches
•Loads
•Generators
Objects:
•Nodes
•TLs, Transformers
• Voltage Regulators
•Household
•DGs
Sweep Methods
Matrix Methods
Power Flows, Voltages, Currents

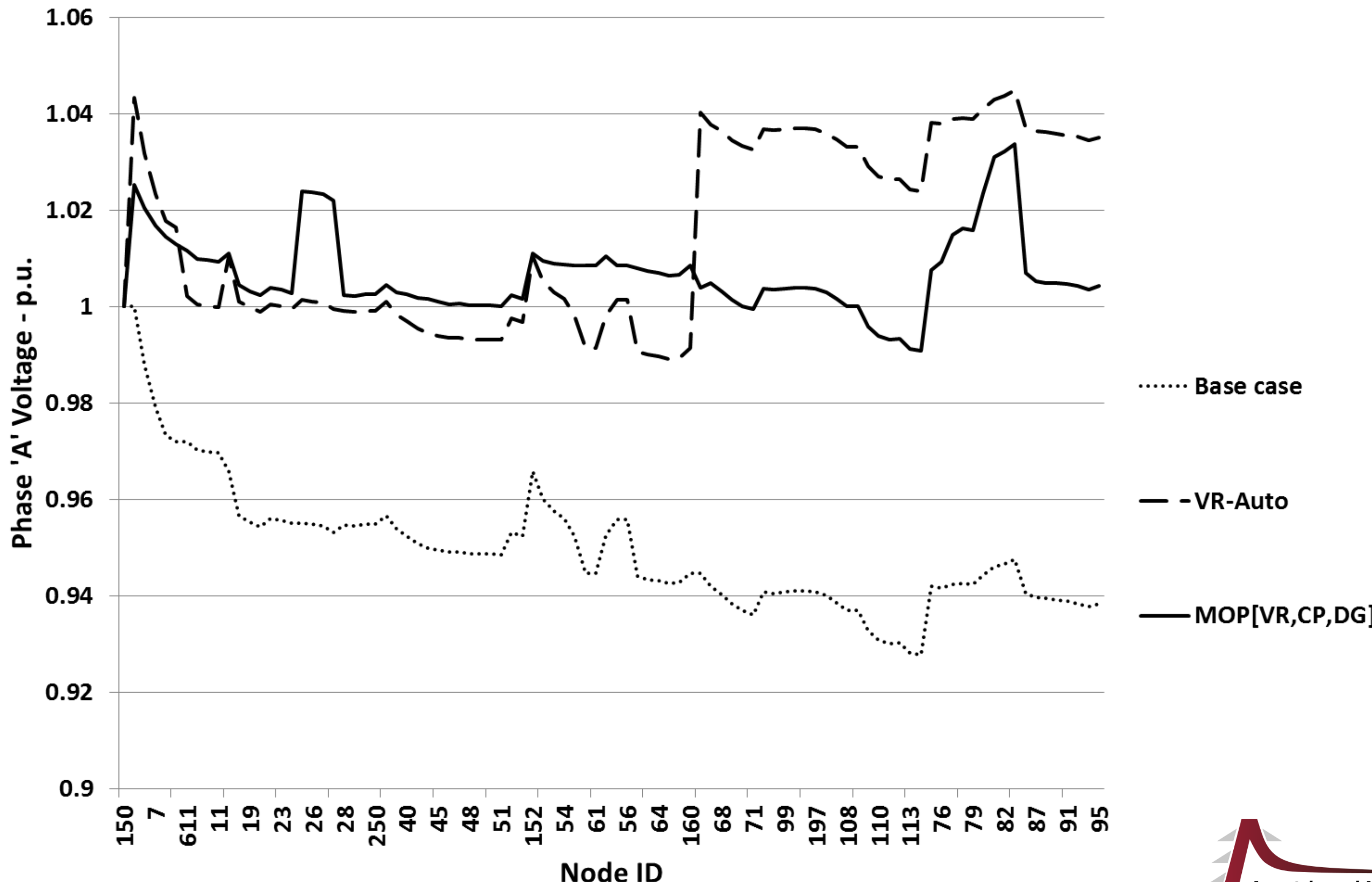
- Component Models (in 3 phase):
  - Distribution Lines:
    - Overhead Lines
    - Underground Lines:
      - Tape Shield Cables
      - Concentric Neutral Cables
  - Transformers:
    - Δ-Y Grounded and Ungrounded
  - Voltage Regulators
  - Capacitors
  - Switches, Circuit Breakers
  - Loads:
    - ZIP Models
    - Exponential Models
- Topology Assessor
- Iterative Sweep Method



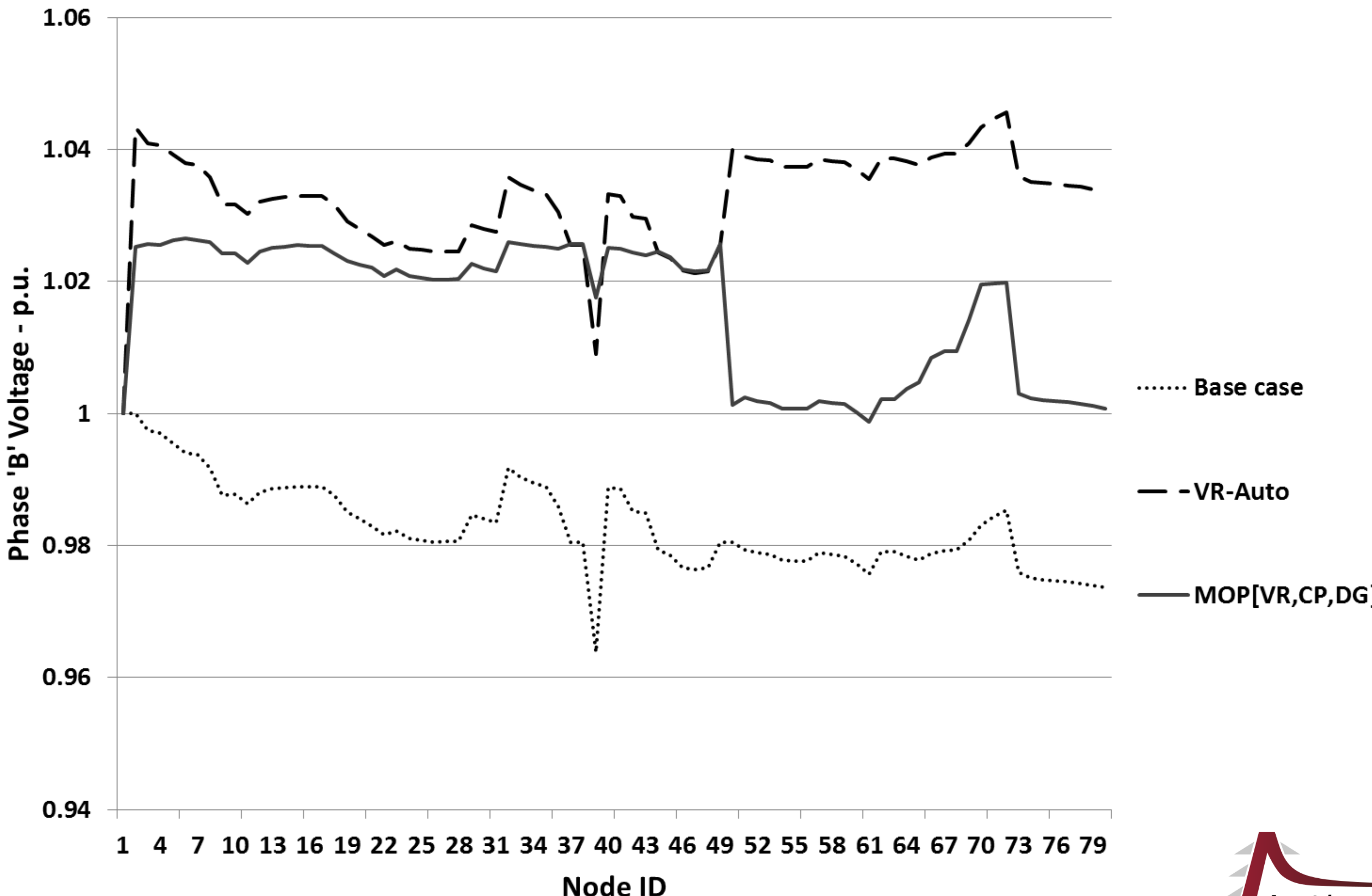
32 29 30 250 350
33 251 51 111 110 112 113 114
31 28 49 50 151 300
25 48 47 46 109 107
26 45 108
27 44 43 64 106 104 451
23 65 105 103 450
24 42 41 63 102 100
21 40 66 62 101 99 71
22 39 197 98
38 36 97 70
20 19 18 135 35 69 68
37 160 67 75
11 14 60 74
57 73
58 72
59 61 610 79 85
9 10 78 77
2 52 53 54 56 55 76
7 8 13 152 80 84
94 76
150 149 1 12 34 96 81
17 92 90 88
95 93 91 89 87 86 82 83
15
3 5 6 16 195
4

## Voltage Control by DNO:

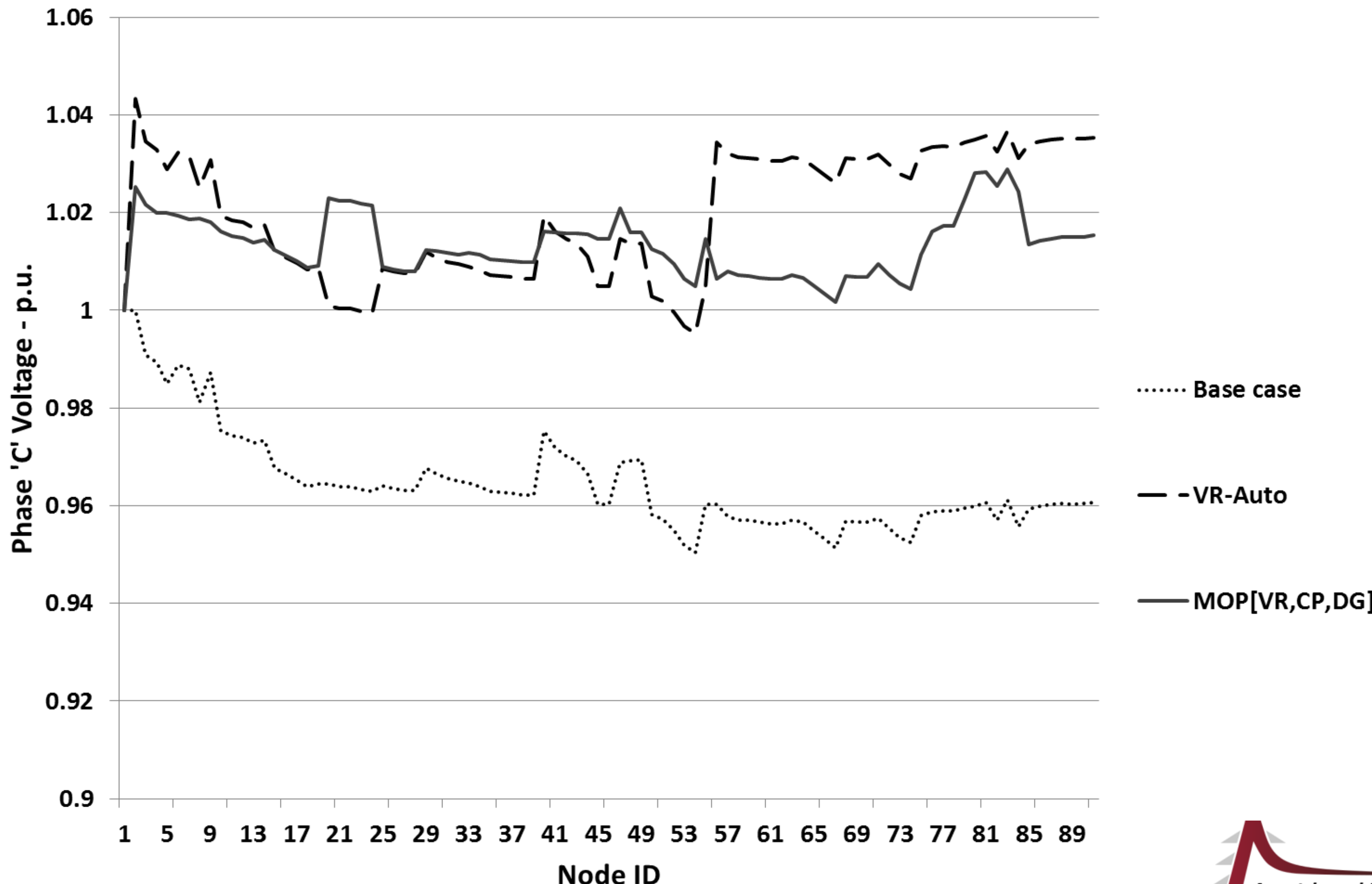
- Substation Transformer Tap Changing (OLTC)
- Voltage regulator tap changes across the feeders
- Shunt capacitor switching
- Reactive power control at DG nodes
- Network reconfiguration
- Phase-shifting and shedding of loads



1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
Phase 'A' Voltage - p.u.
150
7
611
11
19
23
26
28
250
40
45
48
51
152
54
61
56
64
160
68
71
99
197
108
110
113
76
79
82
87
91
95
Node ID
Base case
VR-Auto
MOP[VR,CP,DG]



1.06
1.04
1.02
1
0.98
0.96
0.94
Phase 'B' Voltage - p.u.
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79
Node ID
Base case
VR-Auto
MOP[VR,CP,DG]



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## Questions / Comments ?

# *Thank You*

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