1st International Symposium on Smart Grid Methods, Tools, and Technologies

A Journey from Wide Area Monitoring to Wide Area Protection and Control of Future Power Systems

Prof Vladimir Terzija
The University of Manchester, UK

Lecture Outline

- **160th Anniversary Nikola Tesla**
- **UK Challenges Today**
- **Wide Area Monitoring System Examples**
- **Smart Frequency Control**
- **Intentional System Islanding**
- **Conclusion**

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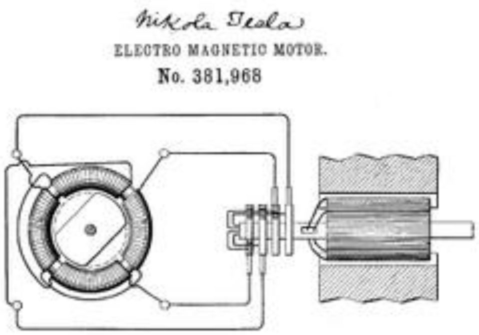
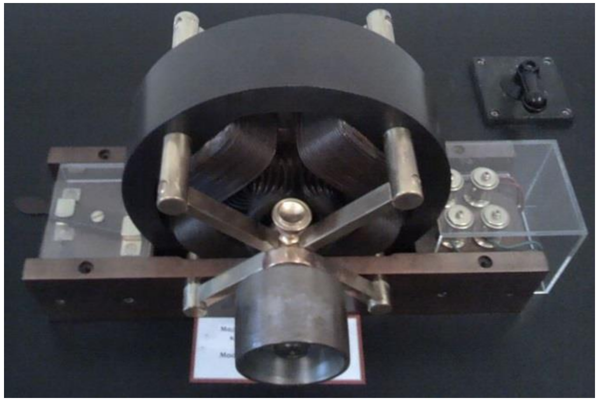
Nikola Tesla (1956-1943)

Tesla wearing the Serbian national costume, c.1880.





AC induction Motor

(drawing and the original Induction Motor exposed at Imperial College London)

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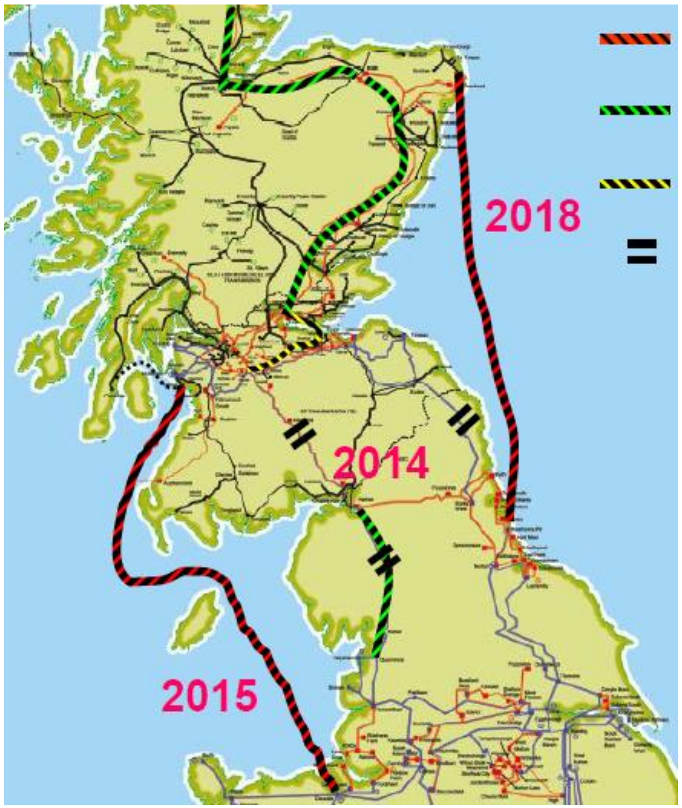
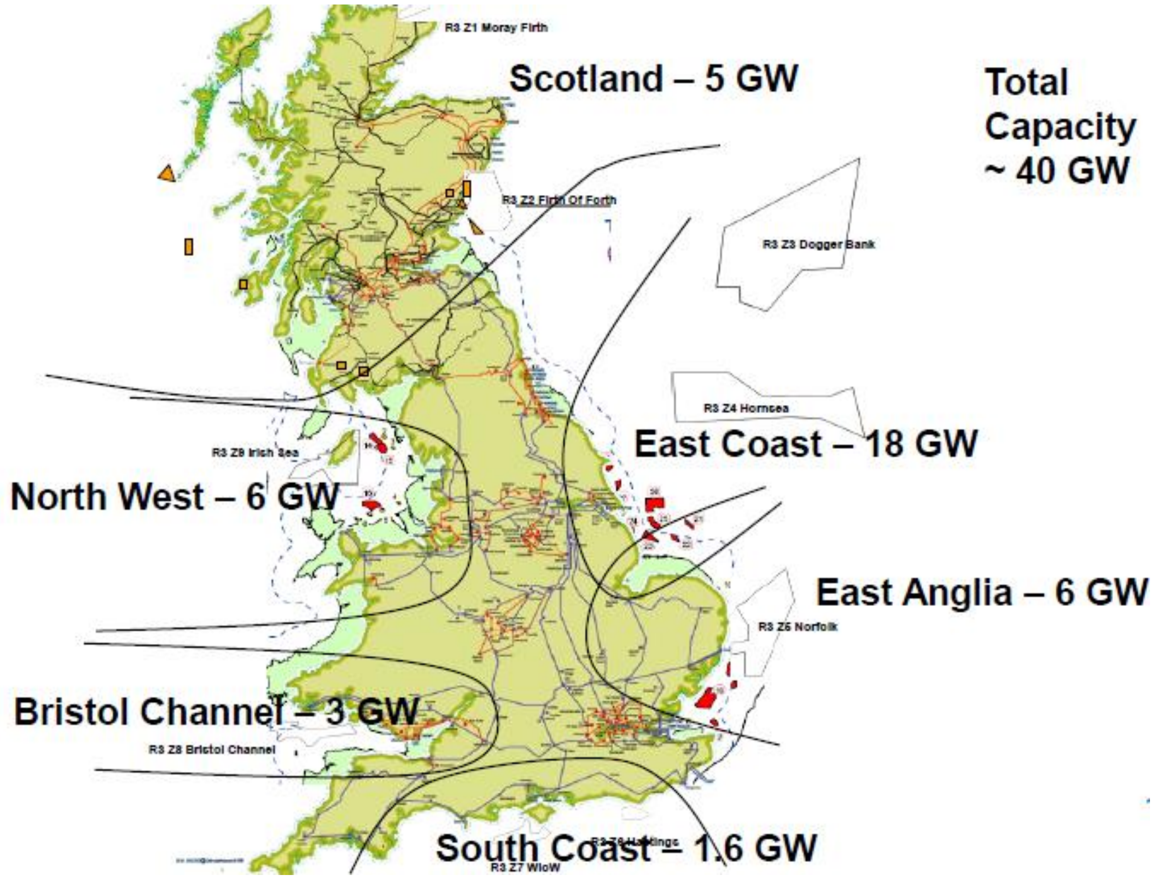
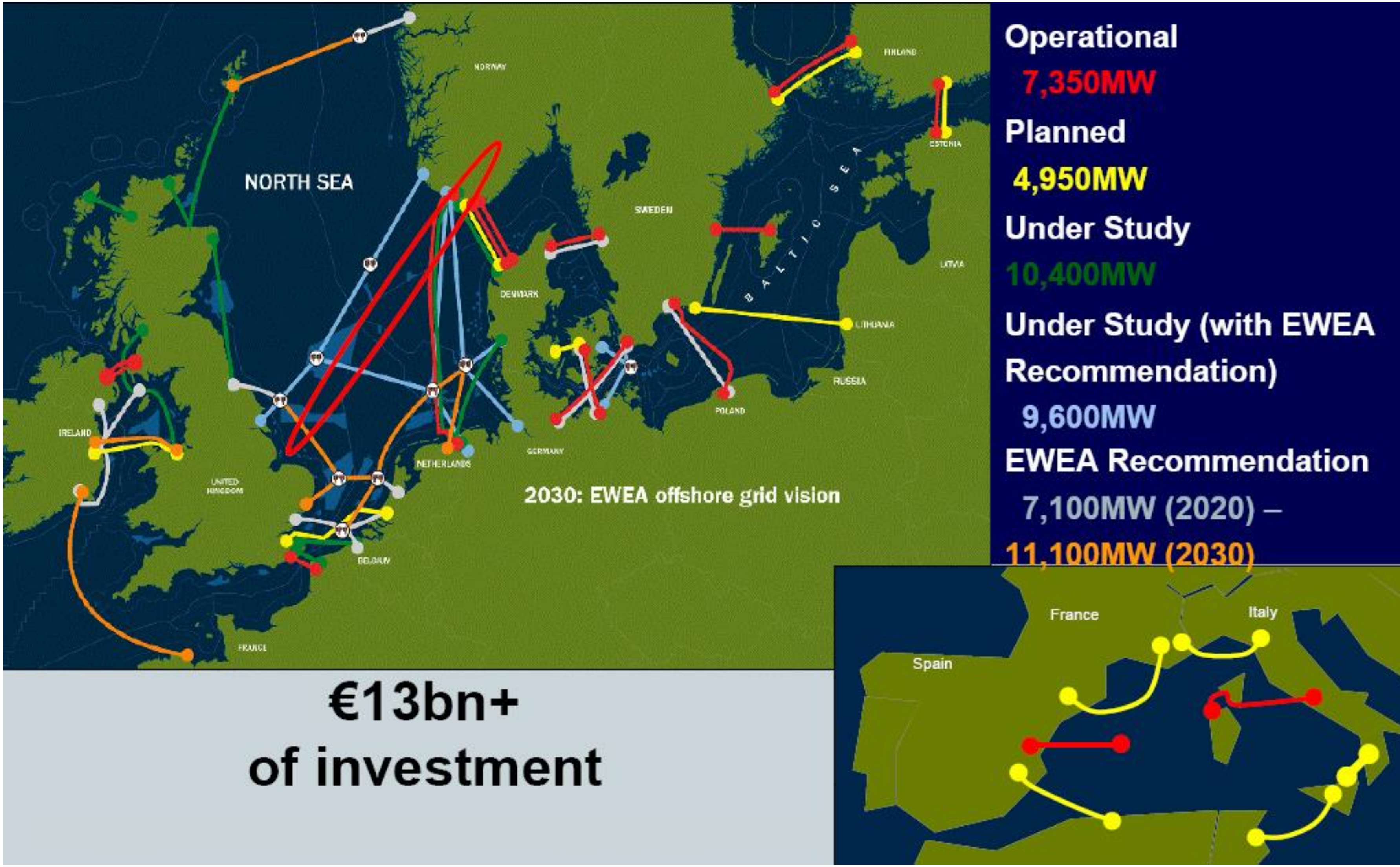
National Grid - UK Challenges

Onshore investment, Off Shore Wind Farms





The European SUPERGRID



Conclusion:

In such a complex environment there is a very strong case to develop a Smart Grid based on ICT, novel sensors and new solutions.

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Wide Area Monitoring, Protection and Control

V.Terzija, G.Valverde, D.Cai, P.Regulski, V.Madani, J.Fitch, S.Skok, M.Begovic, A.Phadke, "Wide Area Monitoring, Protection and Control of Future Electric Power Networks", Proceedings of IEEE, Volume: 99, Issue: 1, pp 80-93, 2011

INVITED PAPER

Wide-Area Monitoring, Protection, and Control of Future Electric Power Networks

The authors of this paper point out that data concentrators are now being designed and deployed and they explain why future networks should make use of synchronized measurement technology.

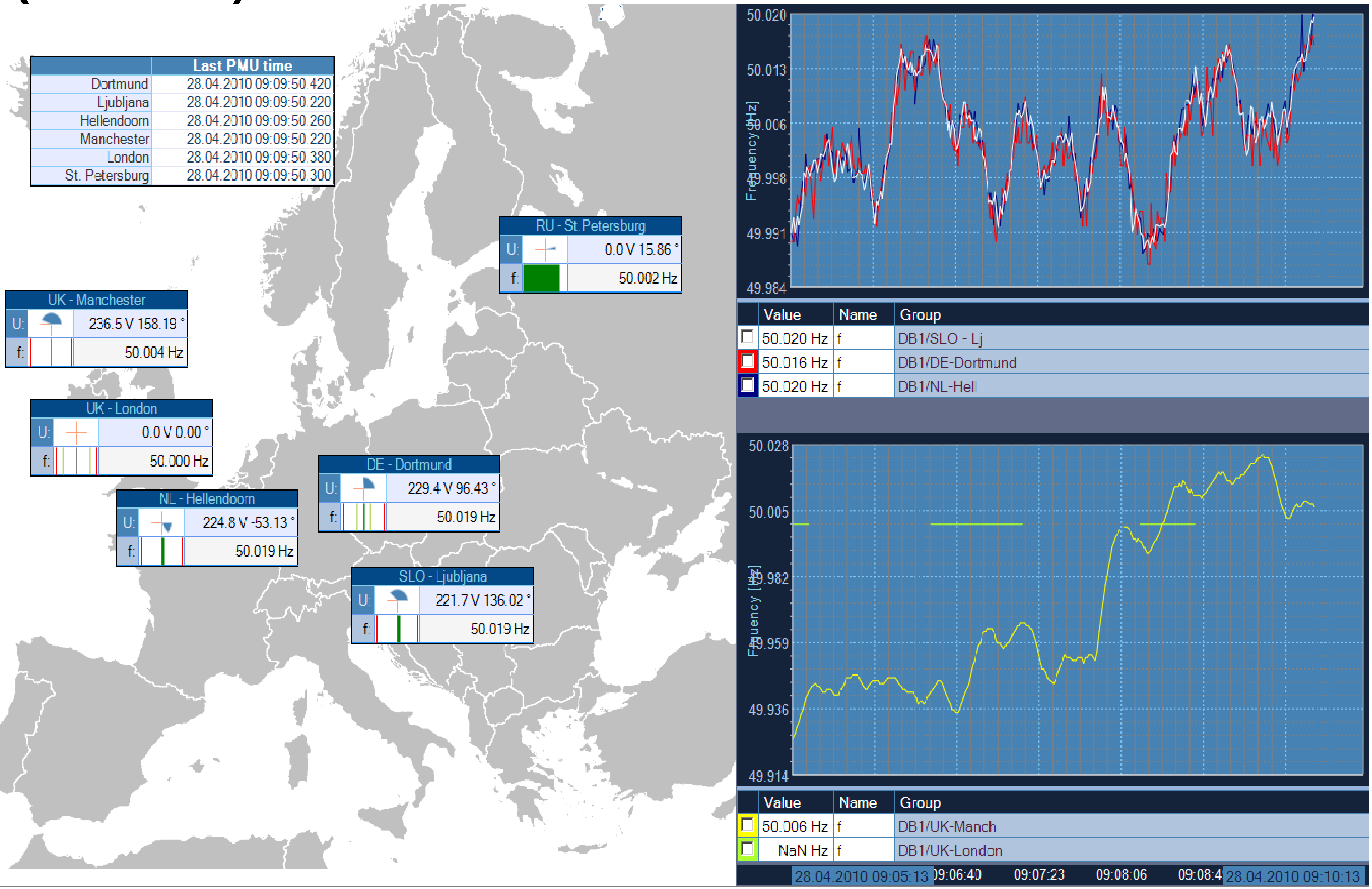
By Vladimir Terzija, *Senior Member IEEE*, Gustavo Valverde, *Student Member IEEE*, Deyu Cai, Pawel Regulski, Vahid Madani, *Fellow IEEE*, John Fitch, *Member IEEE*, Srdjan Skok, *Member IEEE*, Miroslav M. Begovic, *Fellow IEEE*, and Arun Phadke, *Life Fellow IEEE*

Flex-Net WAMS

(EPSRC Project)

Supergen/FlexNet Research Project

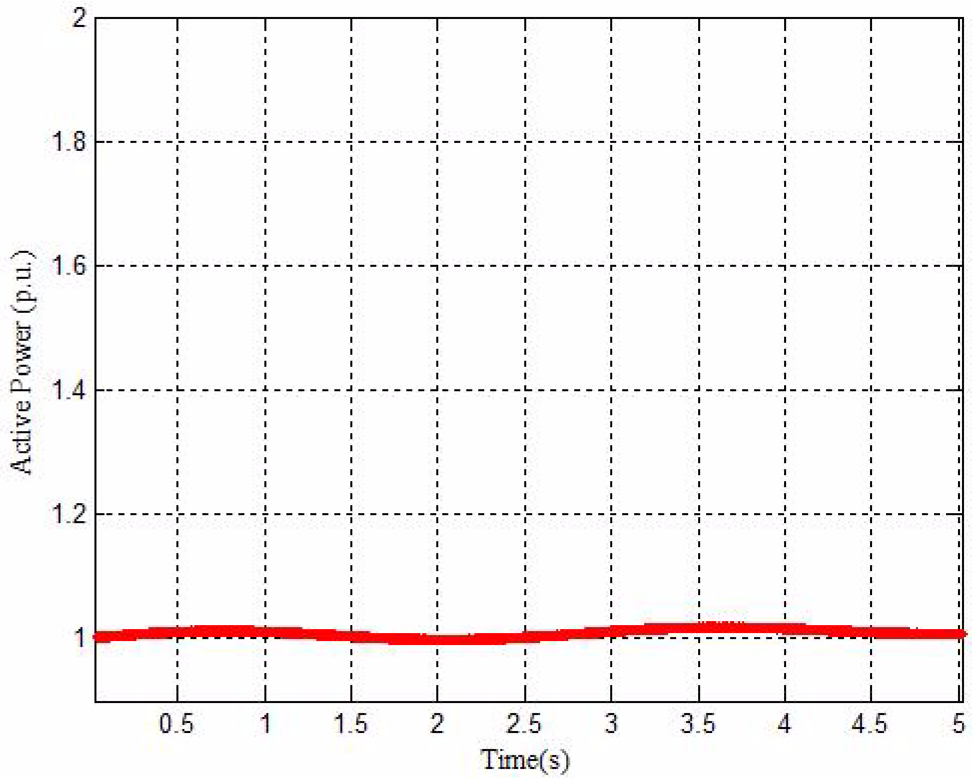
How it Works Integrated Into the FlexNet WAM System (28/4/2010)



Wide Area Monitoring – Oscillation Monitoring Example

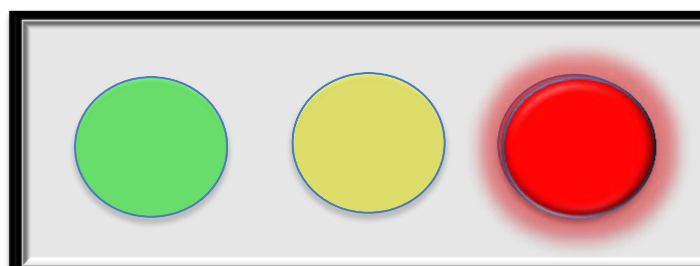
A Matlab Simulation Example

- WAMS applications are key to exploiting this new data



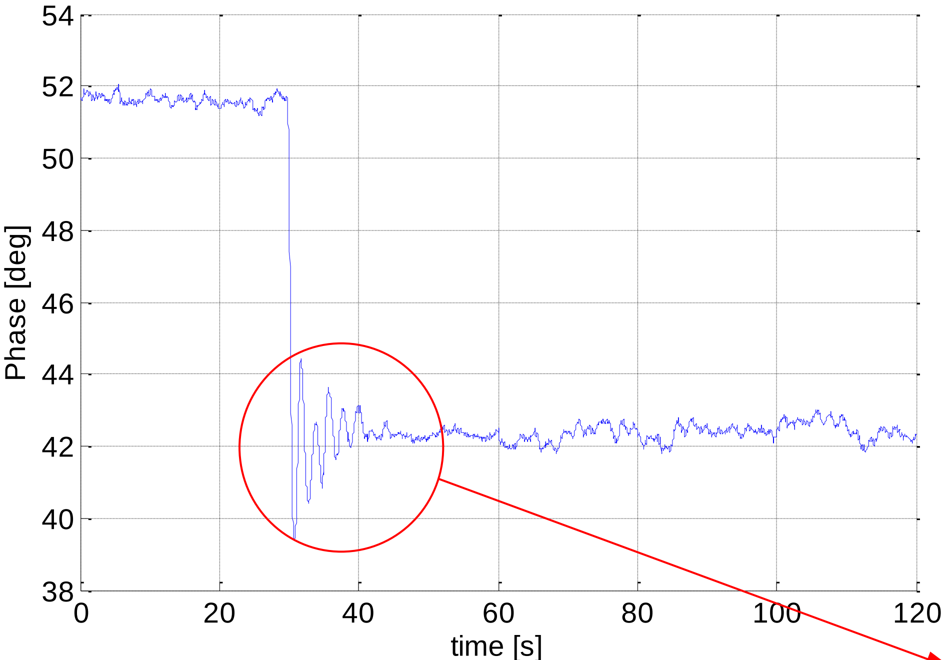
Oscillation Monitoring

Frequency	0.35 Hz
Amplitude	**0.03 p.u.**
Damping	**-3 %**



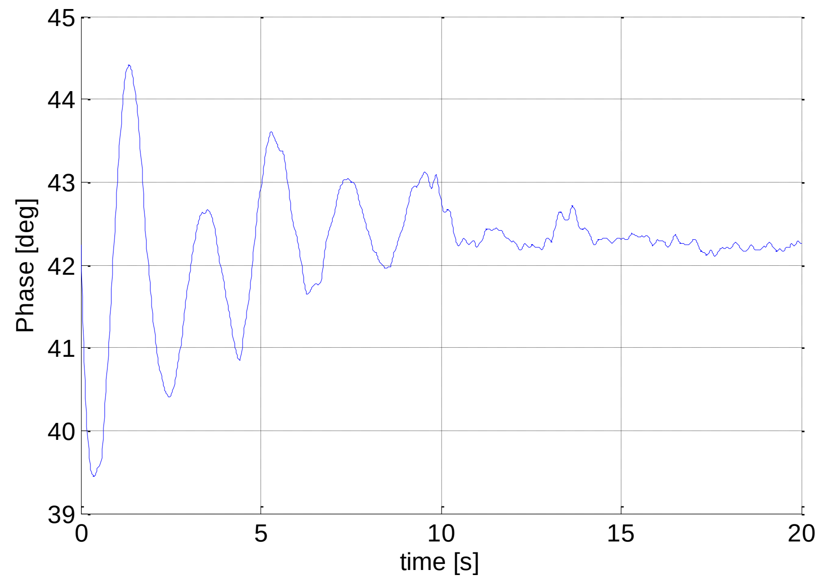
Monitoring of Inter-Area Oscillations

Event captured on the 2nd November 2010



Phase angle difference between London and Glasgow

Loss of generation causing a rapid change in phase angle followed by an inter-area oscillation

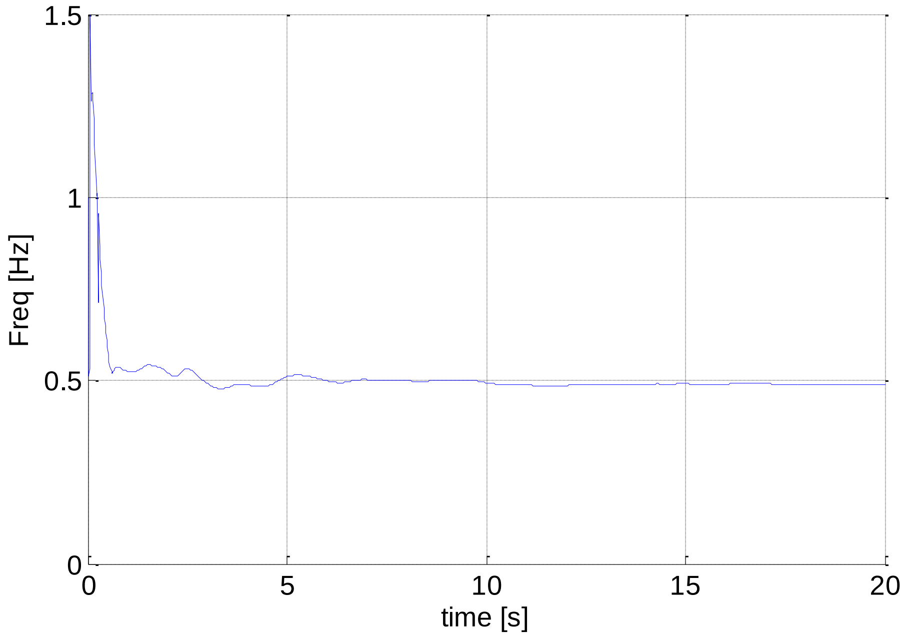


Phase angle difference between London and Glasgow (zoomed)

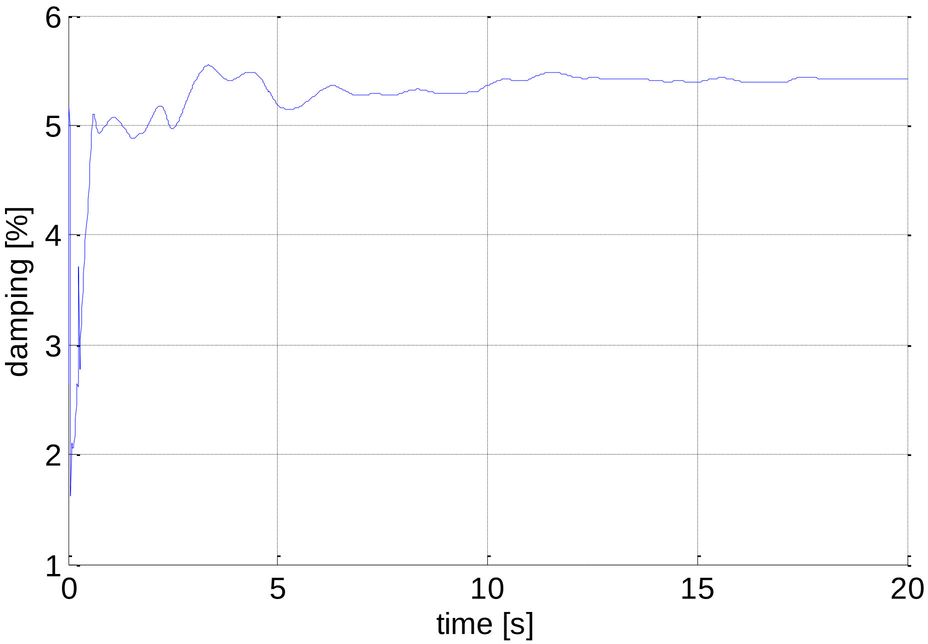
Monitoring of Inter-Area Oscillations

Event captured on the 2nd November 2010

Improved Recursive Newton Type Algorithm (IRNTA) application



Frequency of the oscillation



Damping ratio of the oscillation

Monitoring of Load Dynamics

(E.oN Project)

Generic Loads Model

Exponential Recovery Load Model

$$T_P \dot{z}_P = \left(\frac{V}{V_0}\right)^{\alpha_s} - z_P \left(\frac{V}{V_0}\right)^{\alpha_t}$$

$$T_Q \dot{z}_Q = \left(\frac{V}{V_0}\right)^{\beta_s} - z_Q \left(\frac{V}{V_0}\right)^{\beta_t}$$

$$P_d = z_P \cdot P_0 \left(\frac{V}{V_0}\right)^{\alpha_t}$$

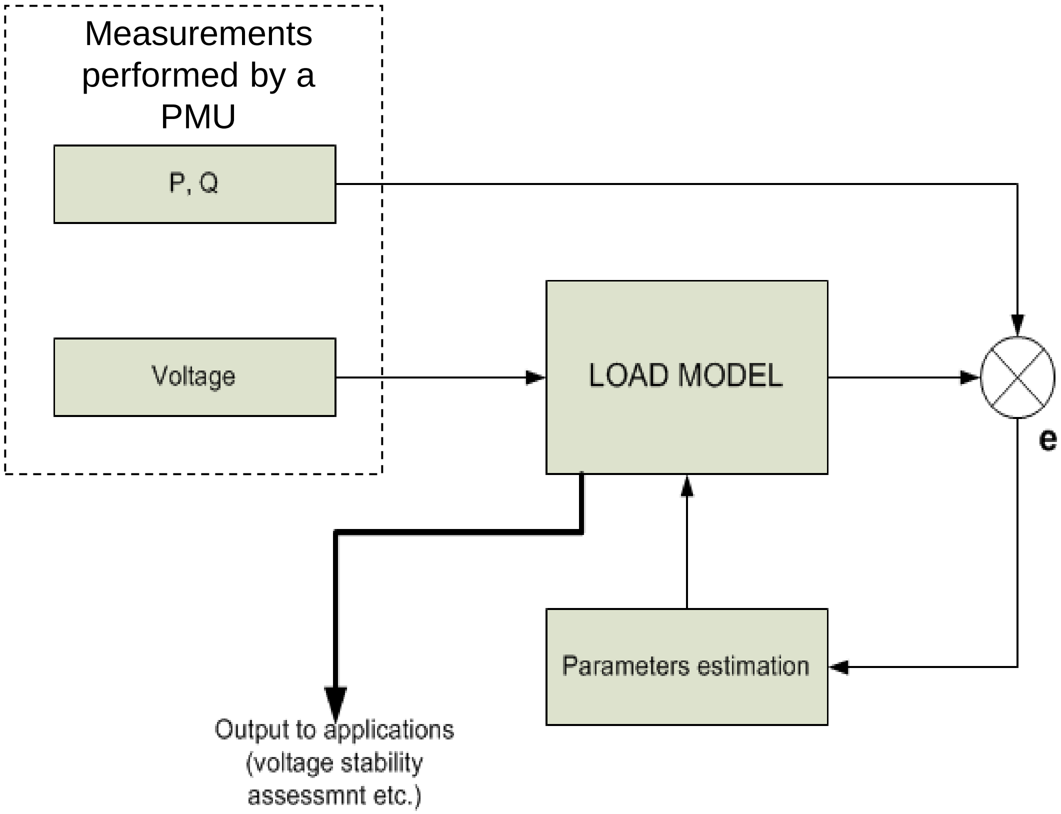
$$Q_d = z_Q \cdot Q_0 \left(\frac{V}{V_0}\right)^{\beta_t}$$

Active Power

Reactive Power

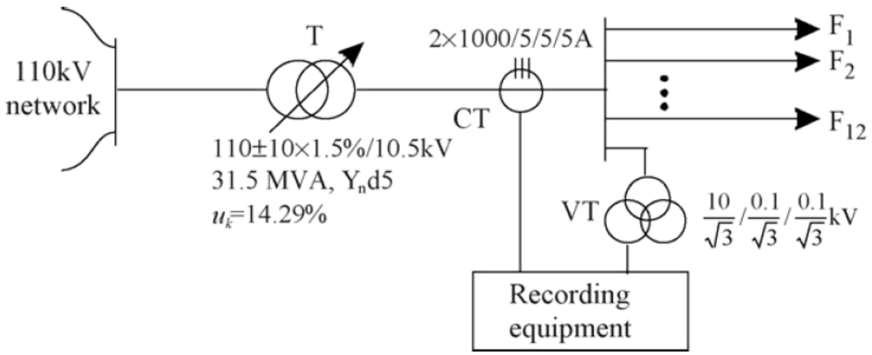
Estimation Methodology

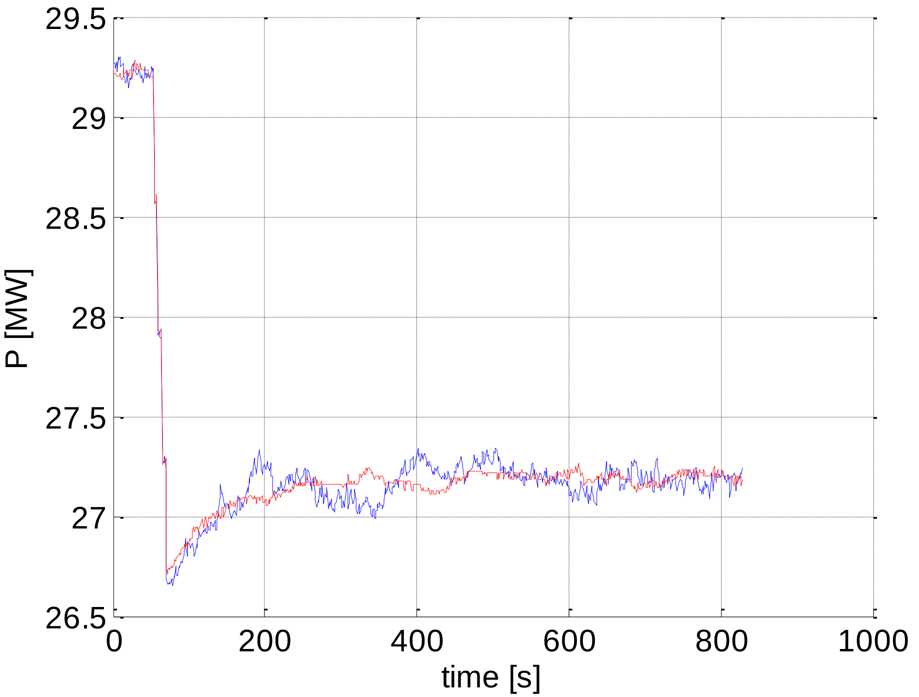
Estimation process



Example of Load Model Parameters Estimation (System Measurements)

Real-life example obtained from distribution network in Serbia (step change achieved by four quick transformer tap changes)





blue – measurement
red – estimated (GA)

VISOR Project

Network Innovation Competition, Ofgem UK funded project

- **Project name: Visualisation of real time system dynamics using enhanced monitoring**
- A £7.44m Network Innovation Competition (NIC) project that is led by Scottish Power Energy Networks
- A collaborative project that includes all three GB Transmission Owners, the System Operator, researchers and suppliers.
- Began January 2014, Reporting March 2017
- Website: http://visor-project.org.uk/

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The Inertia Constant, *H*

A Matlab Simulation Example

- The Inertia Constant (H) is defined as the stored energy in the rotating mass normalised to the Power base (S_n), so it has units of seconds:

Linear

$$E_K = \tfrac{1}{2} m v^2$$

Rotational

$$H = \frac{\tfrac{1}{2} J \omega_n^2}{S_n}$$

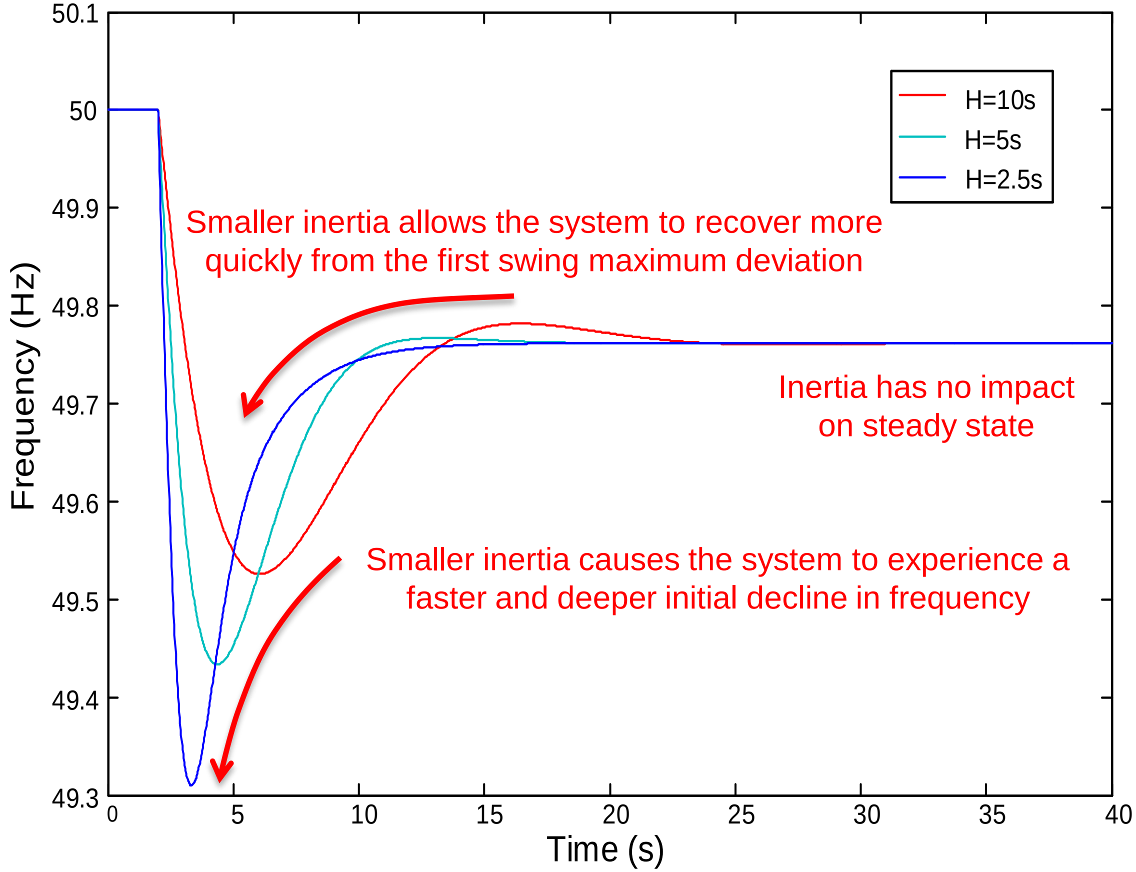
- Substituting H into the **swing equation** gives:

$$P_m - P_e = 2H \frac{df}{dt}$$

System Frequency Response Model

Impact of the System Inertia to Frequency Response

System Frequency Response Model: Reduced Inertia

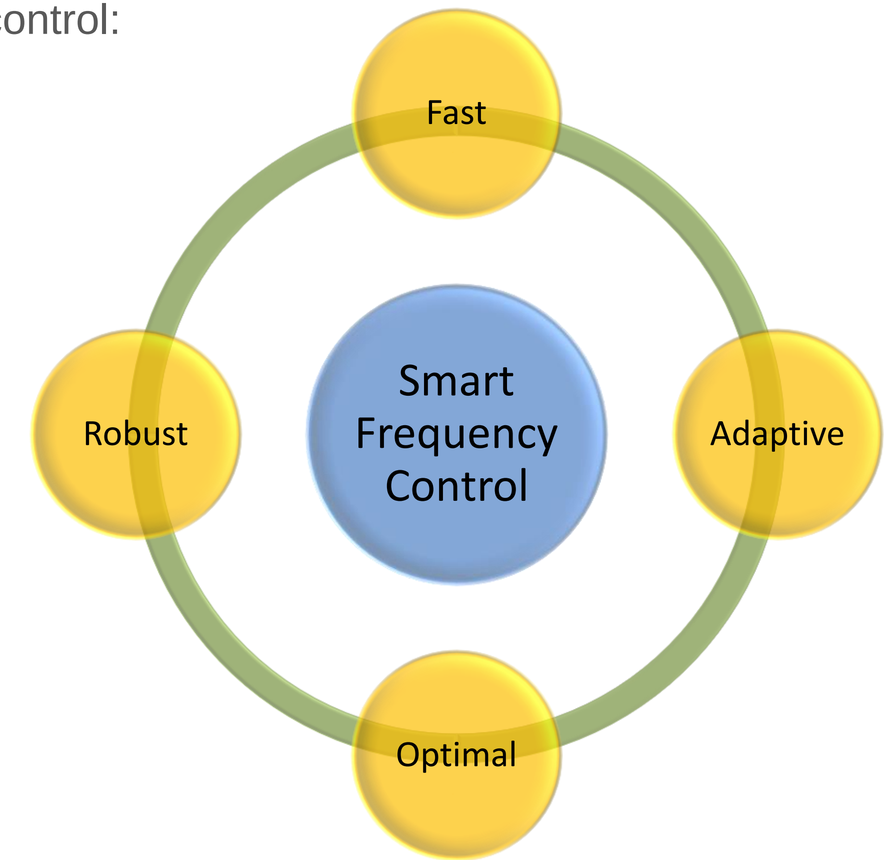


SFR Model

Generalised view of Smart Frequency Control

National Grid, UK, £9.6m Research Project

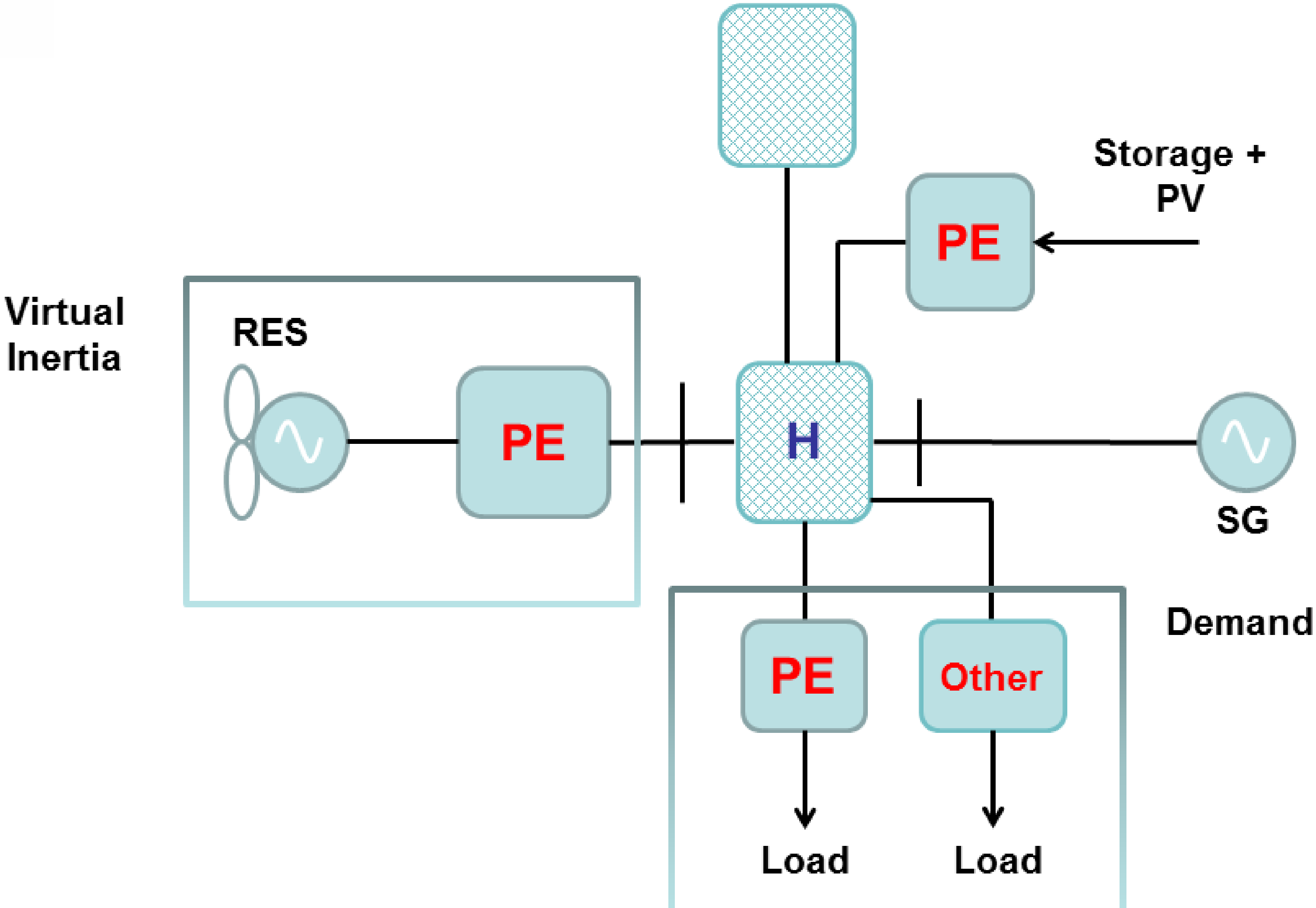
- Need for faster and higher volume of primary response (governor) to compensate for reduced inertial response
- This can be delivered using more traditional governor response, or this can be delivered using smart frequency control:
- **Fast**: SFC must support inertial response
- **Adaptive**: Variable inertia will require a variable response or the control action could jeopardise frequency security
- **Optimal**: The cost of service provision must be limited where possible
- **Robust**: Many elements of the system controlled in a short time (<1s), so consequences of failures will be high



- Website:http://www.nationalgridconnecting.com/The_balance_of_power/

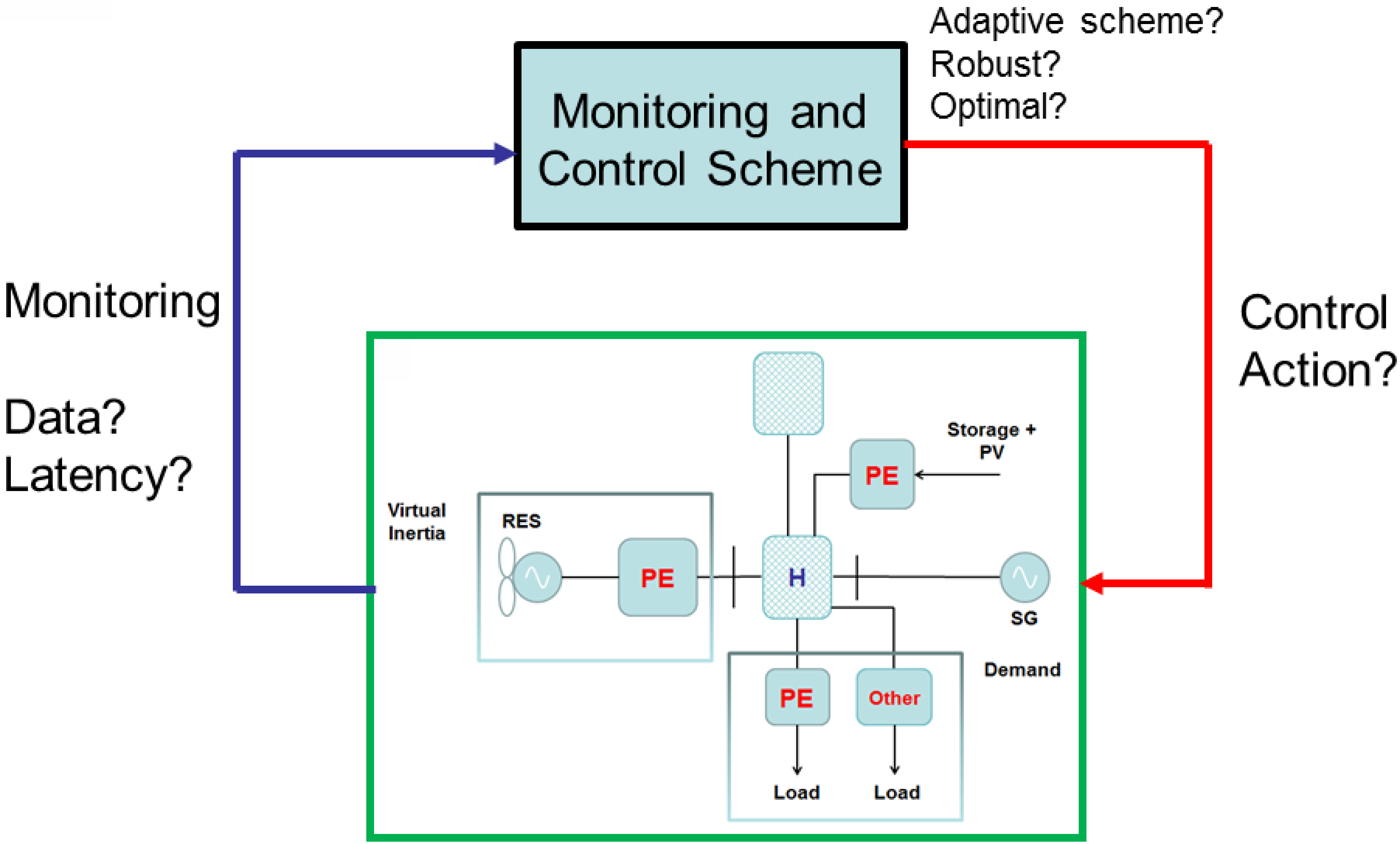
Our Ambition

Enhanced Frequency Control Capabilities



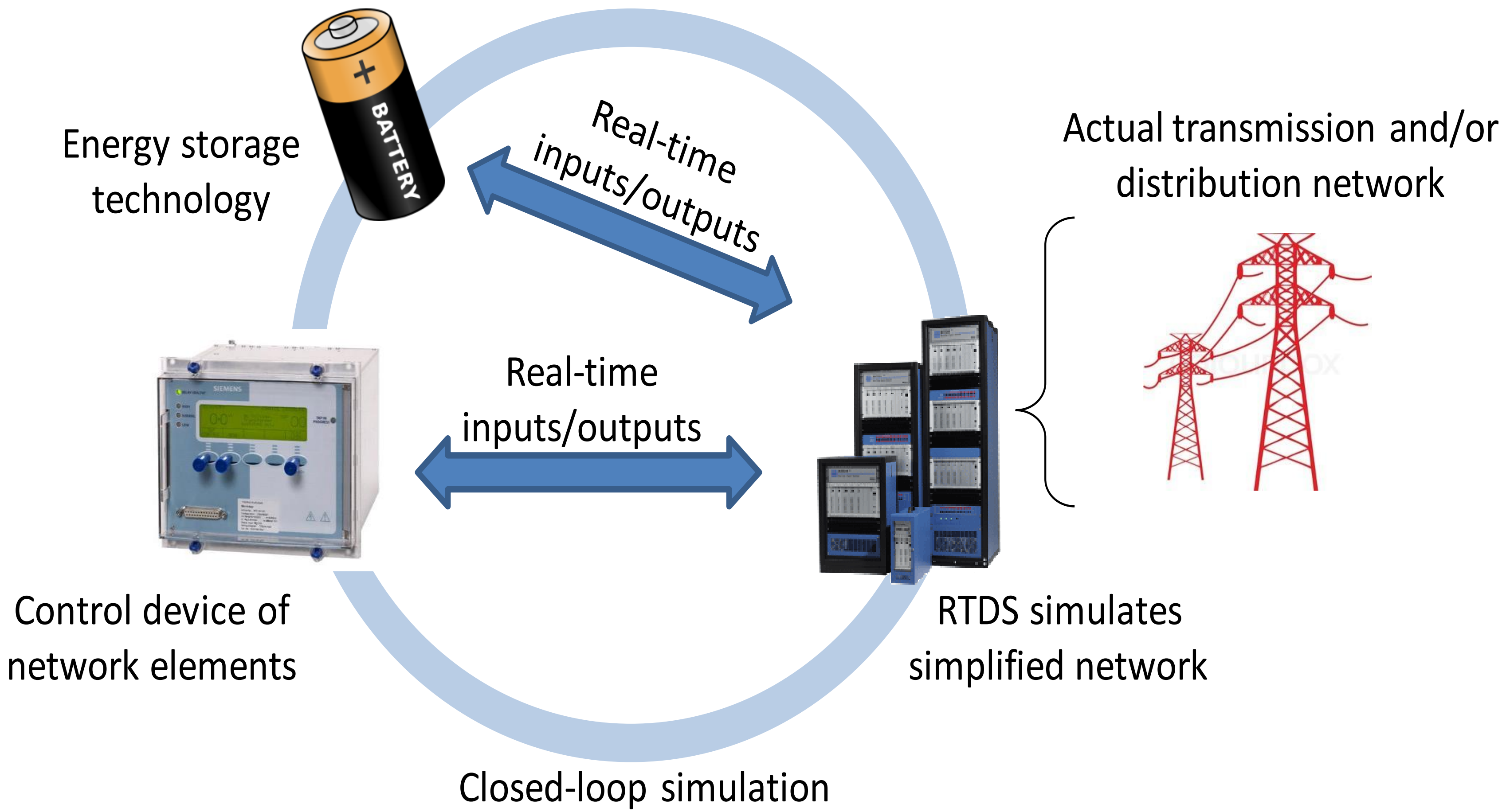
Monitoring and Control Scheme

Enhanced Frequency Control Capabilities



Hardware in the Loop Validation

The Manchester RTDS (6 racks with 30 PB5 Processor Cards)



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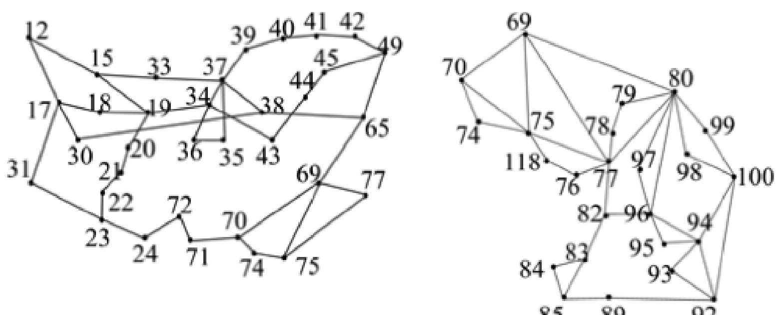
Wide Area Monitoring, Protection and Control

L.Ding, F.Gonzalez-Longatt, P.Wall, and V.Terzija, "Two-Step Spectral Clustering Controlled Islanding Algorithm", IEEE Trans. on Power Systems, VOL. 28, NO. 1, Feb 2013, pp. 75-84

IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 28, NO. 1, FEBRUARY 2013

Two-Step Spectral Clustering Controlled Islanding Algorithm

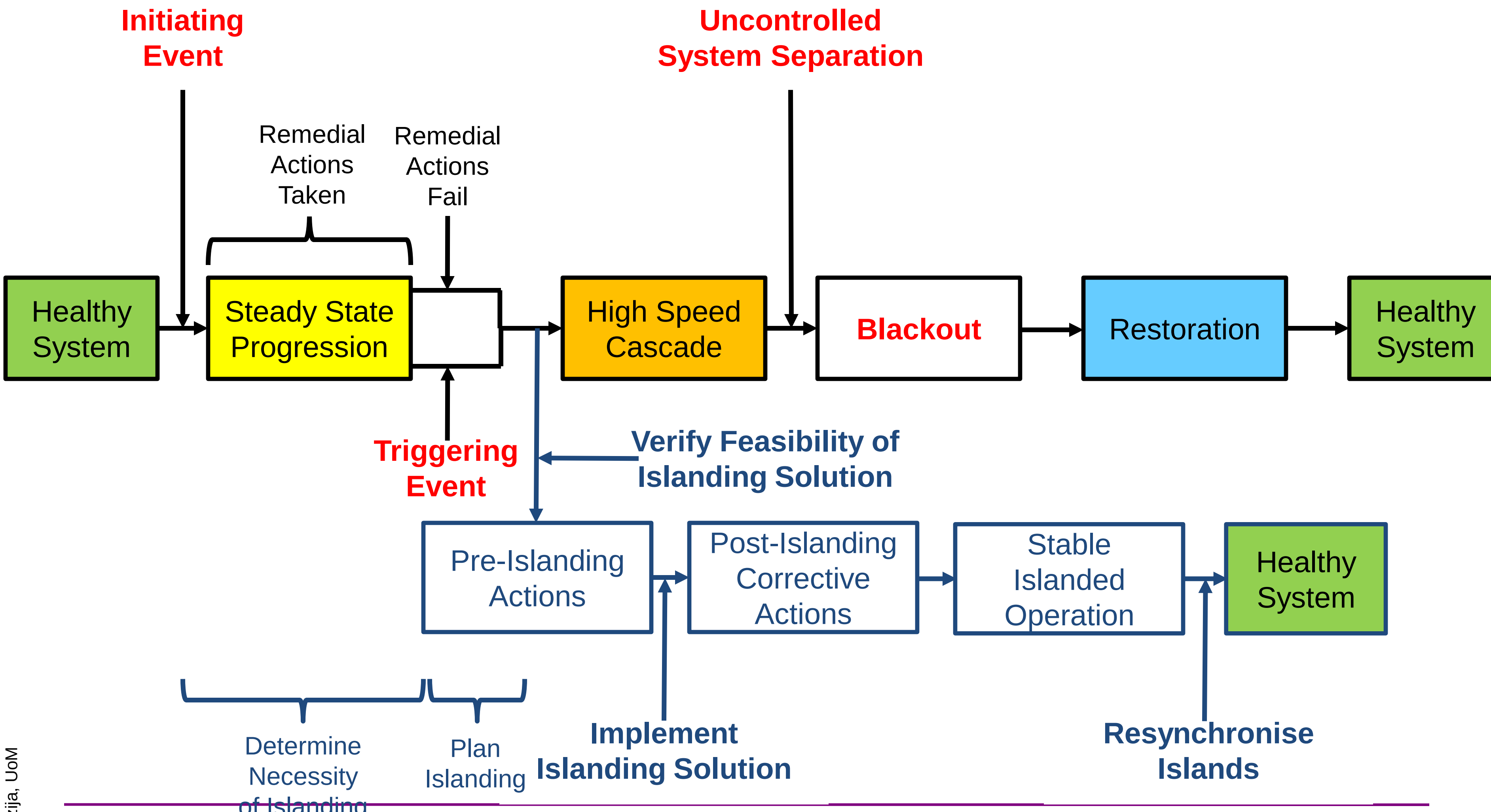
Lei Ding, *Member, IEEE*, Francisco M. Gonzalez-Longatt, *Senior Member, IEEE*, Peter Wall, and Vladimir Terzija, *Senior Member, IEEE*



(a) (b)

Intentional Islanding Mechanism

Discussion of Different Mechanisms

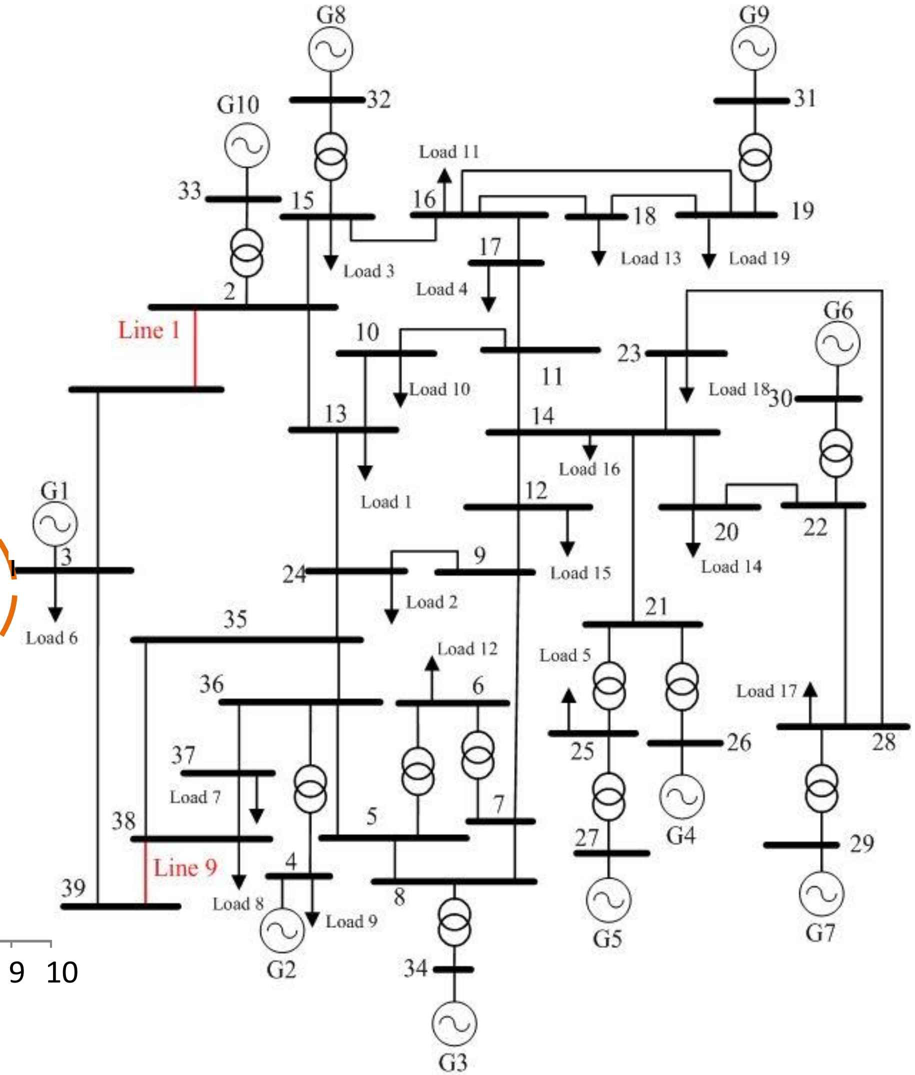


Cascading Outages Example

1

Wind Speed >= Cut Out Speed

Disconnection of Wind Farms



Initiating Event

Time(s) 0 1 2 3 4 5 6 7 8 9 10

Cascading Outages Example

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Wind Speed >= Cut Out Speed

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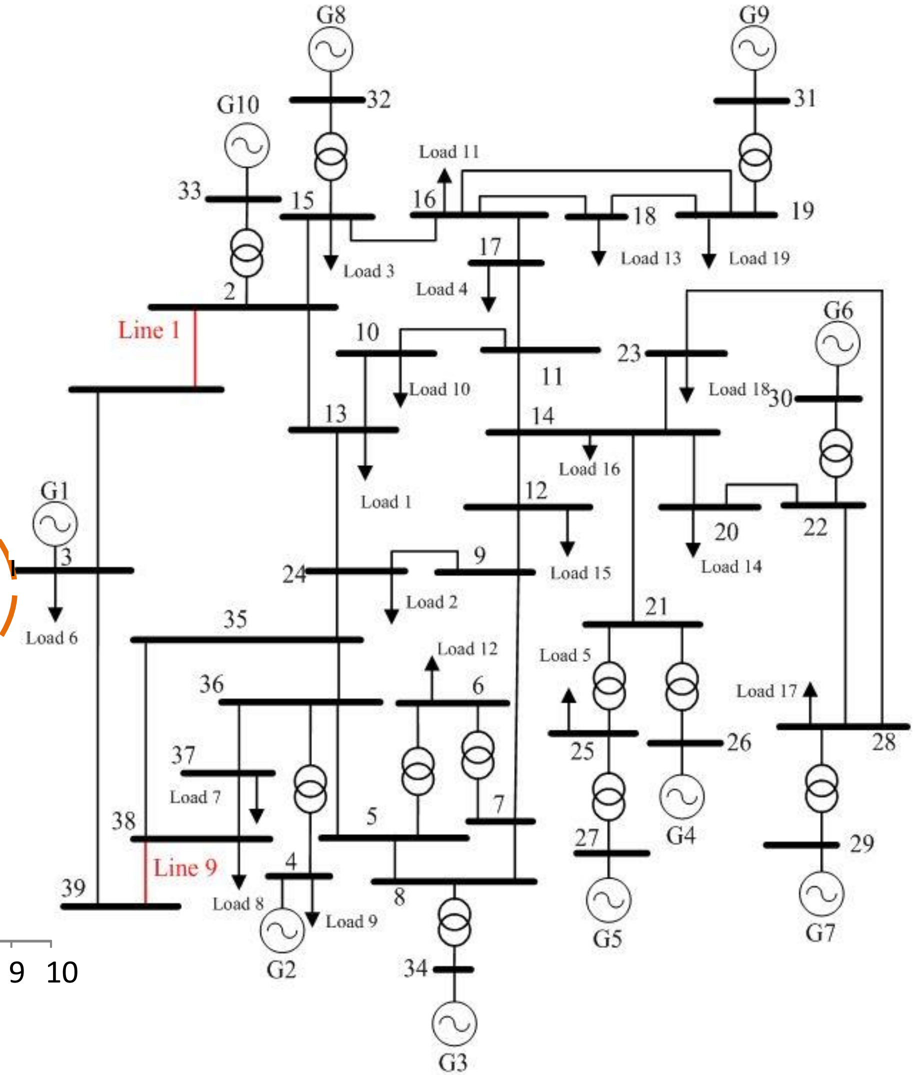
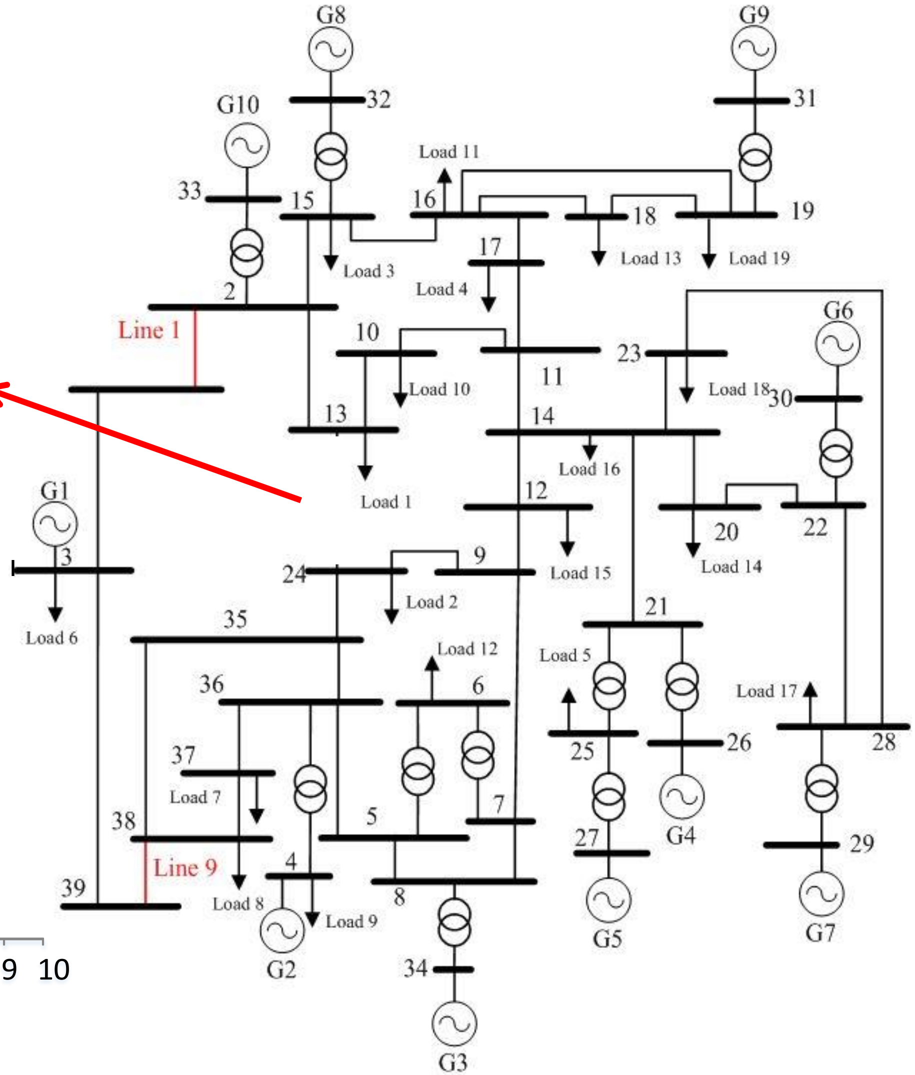
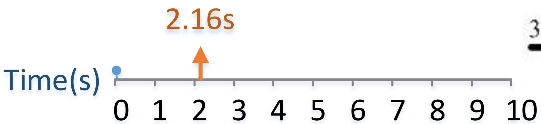


Cascading Outages Example

2

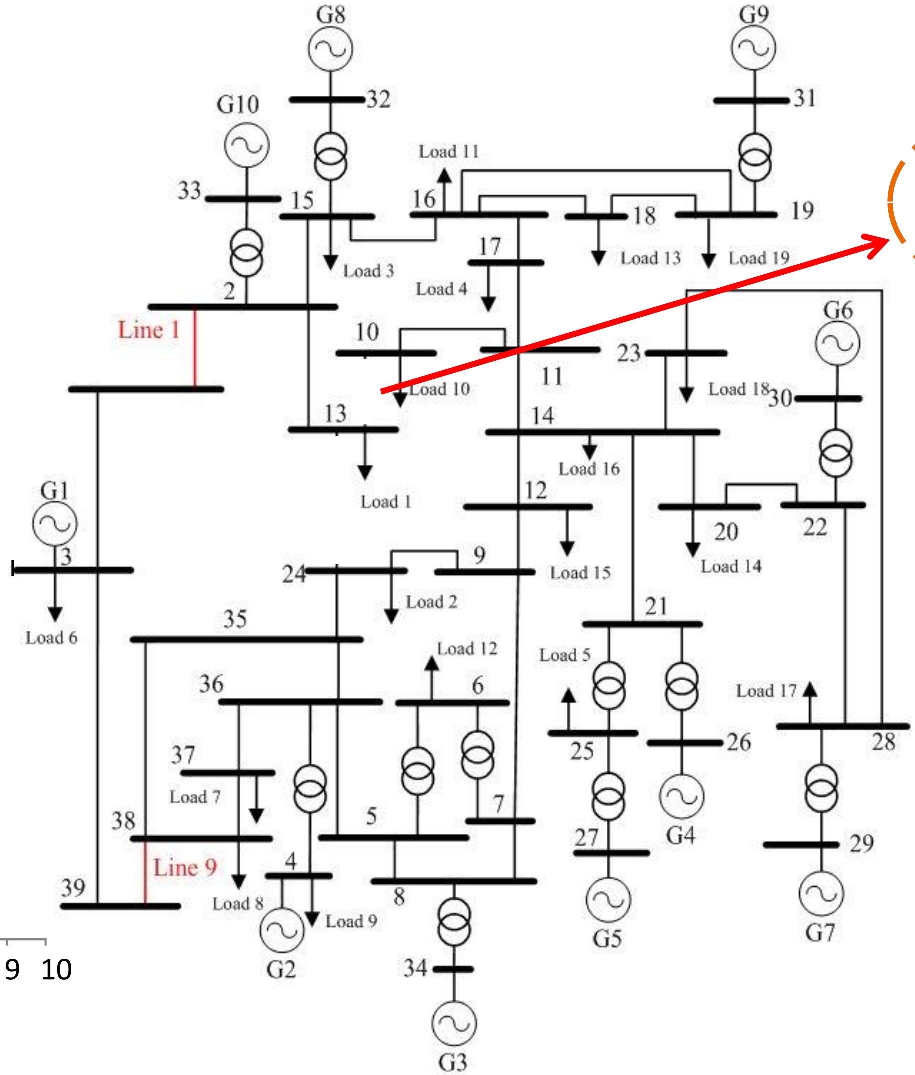
Line trips due to overload





Cascading Outages Example

3



Line trips due to overload

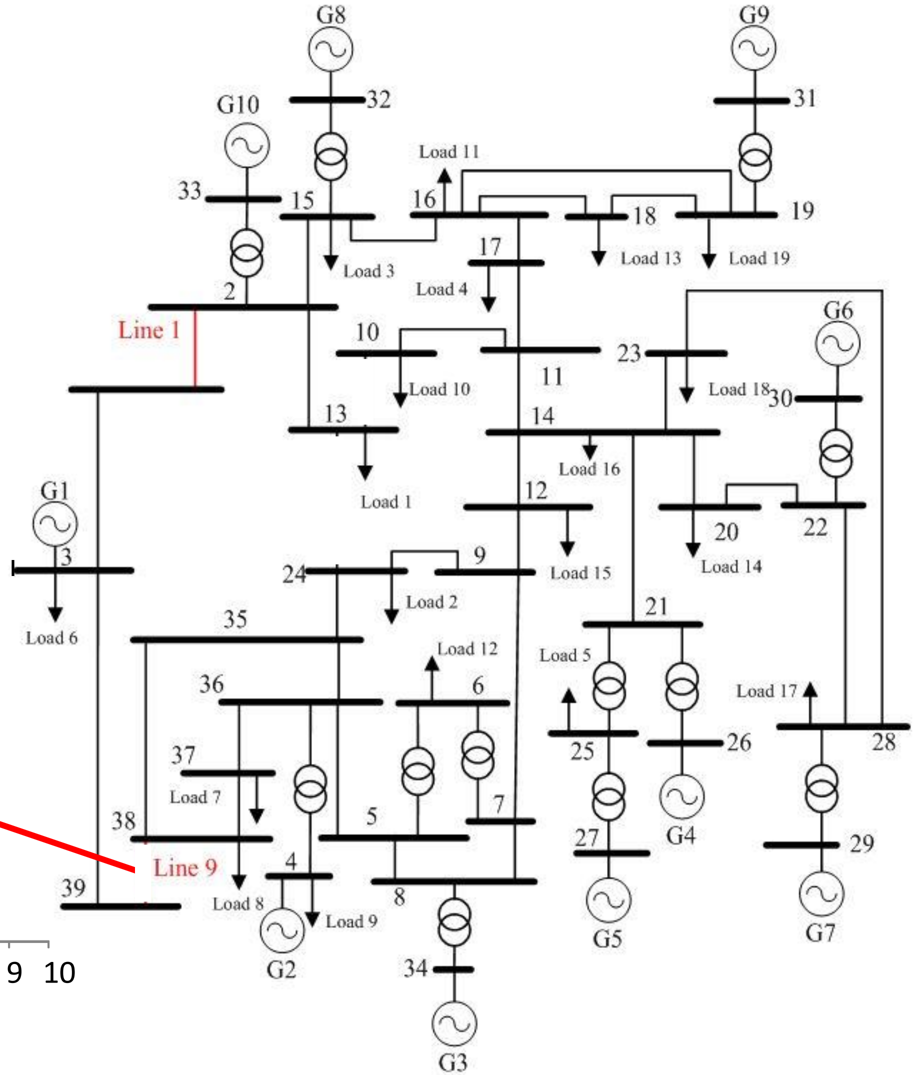
2.22 s

Time(s)

0 1 2 3 4 5 6 7 8 9 10

Cascading Outages Example

4



Line trips due to overload

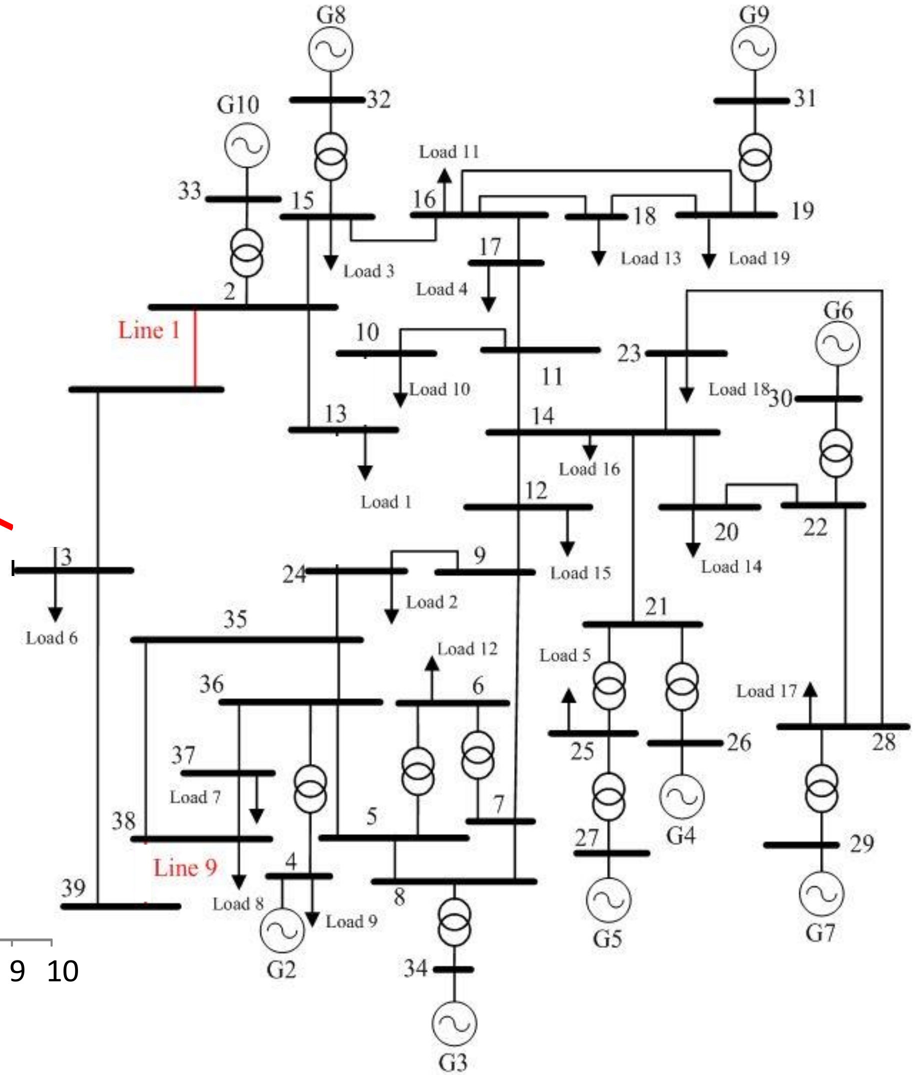
2.29 s

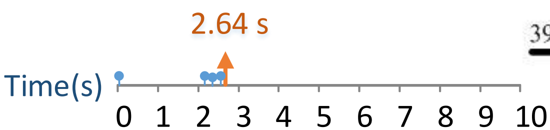
Time(s) 0 1 2 3 4 5 6 7 8 9 10

Cascading Outages Example

5

Generator trips due to out of step operation





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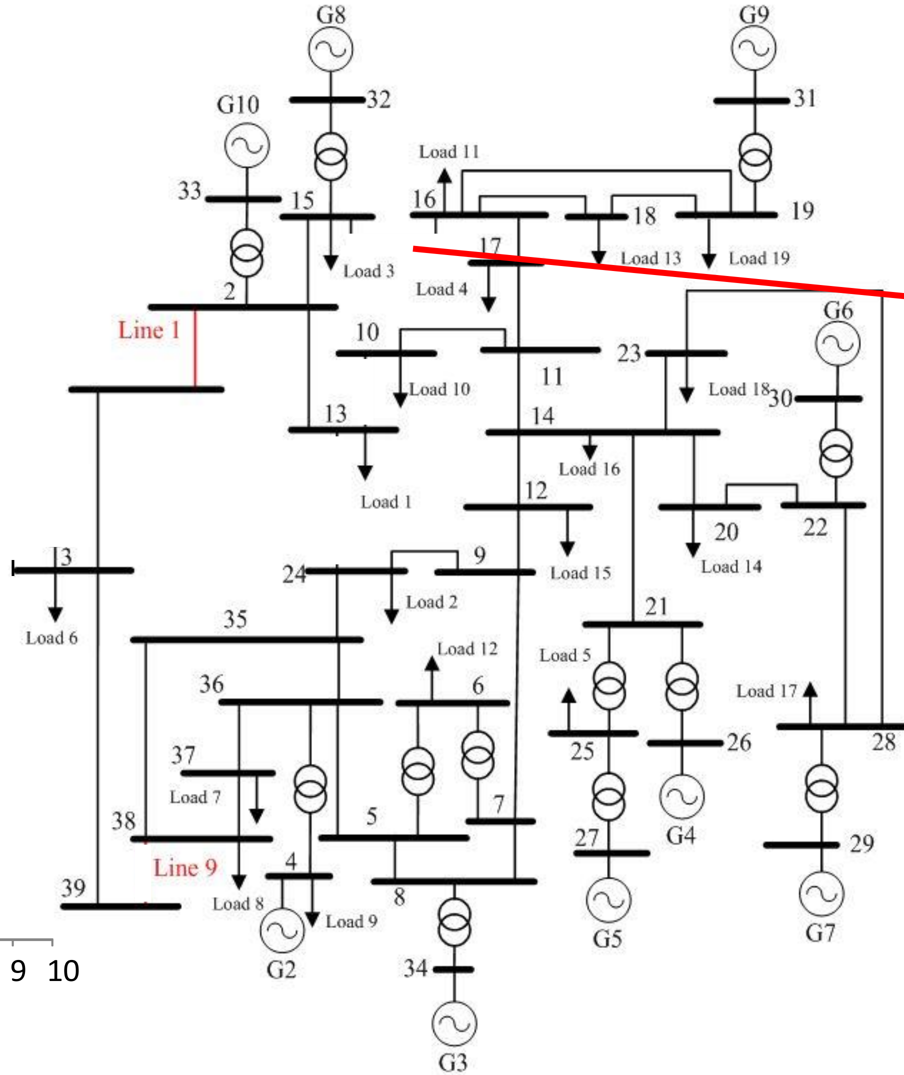
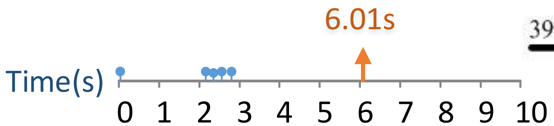
Cascading Outages Example

6

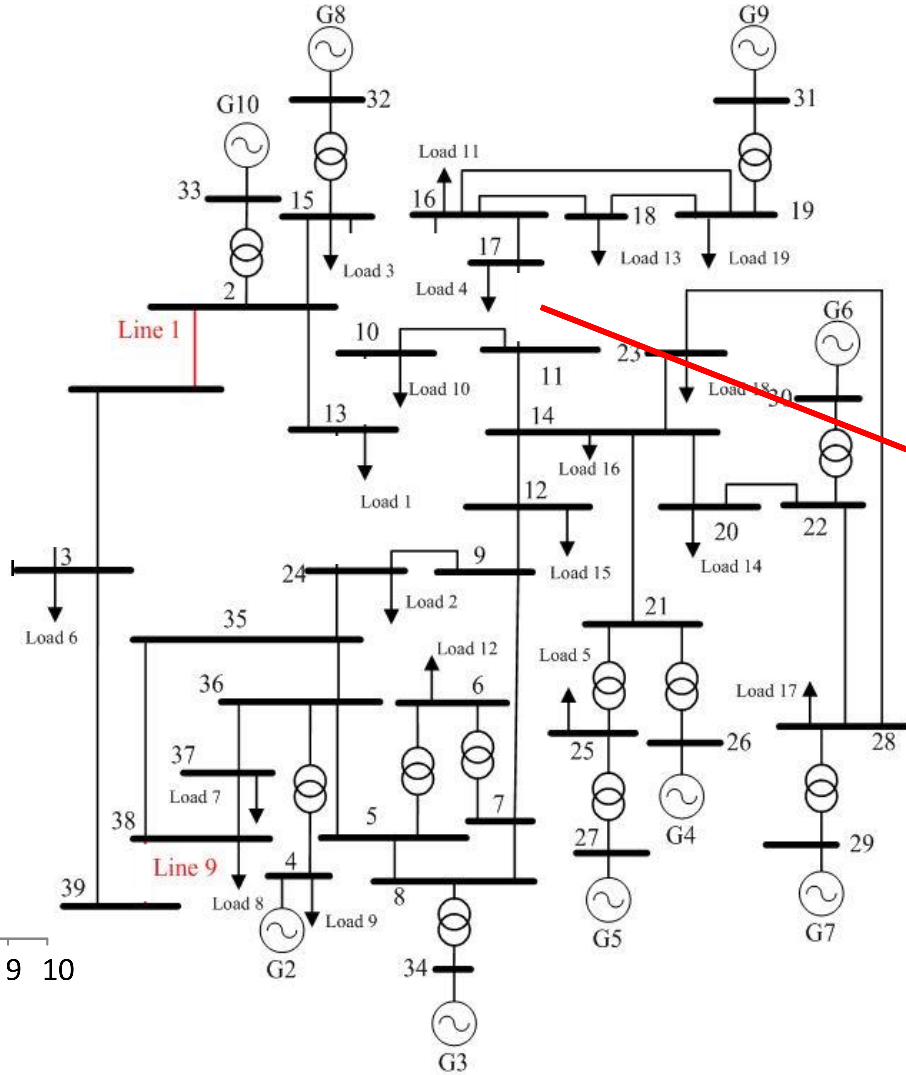


Line trips due to overload

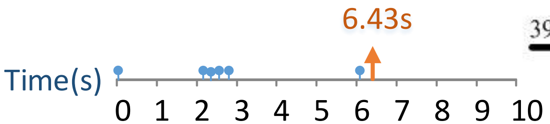


Cascading Outages Example

7



Line trips due to overload

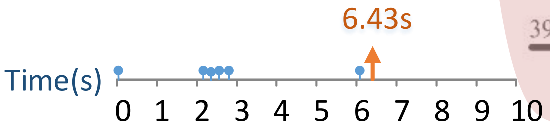


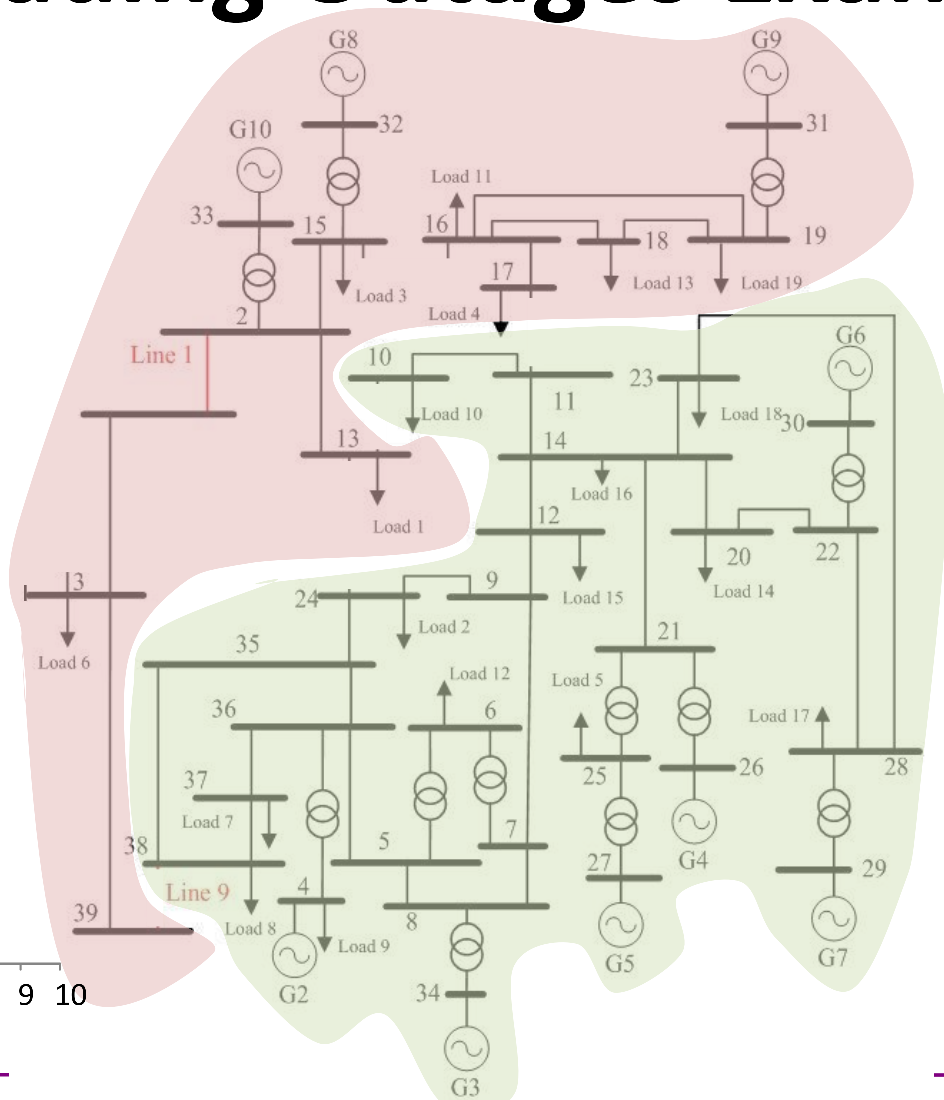
MANCHESTER 1824

Cascading Outages Example

7

Unintentional Island Formation

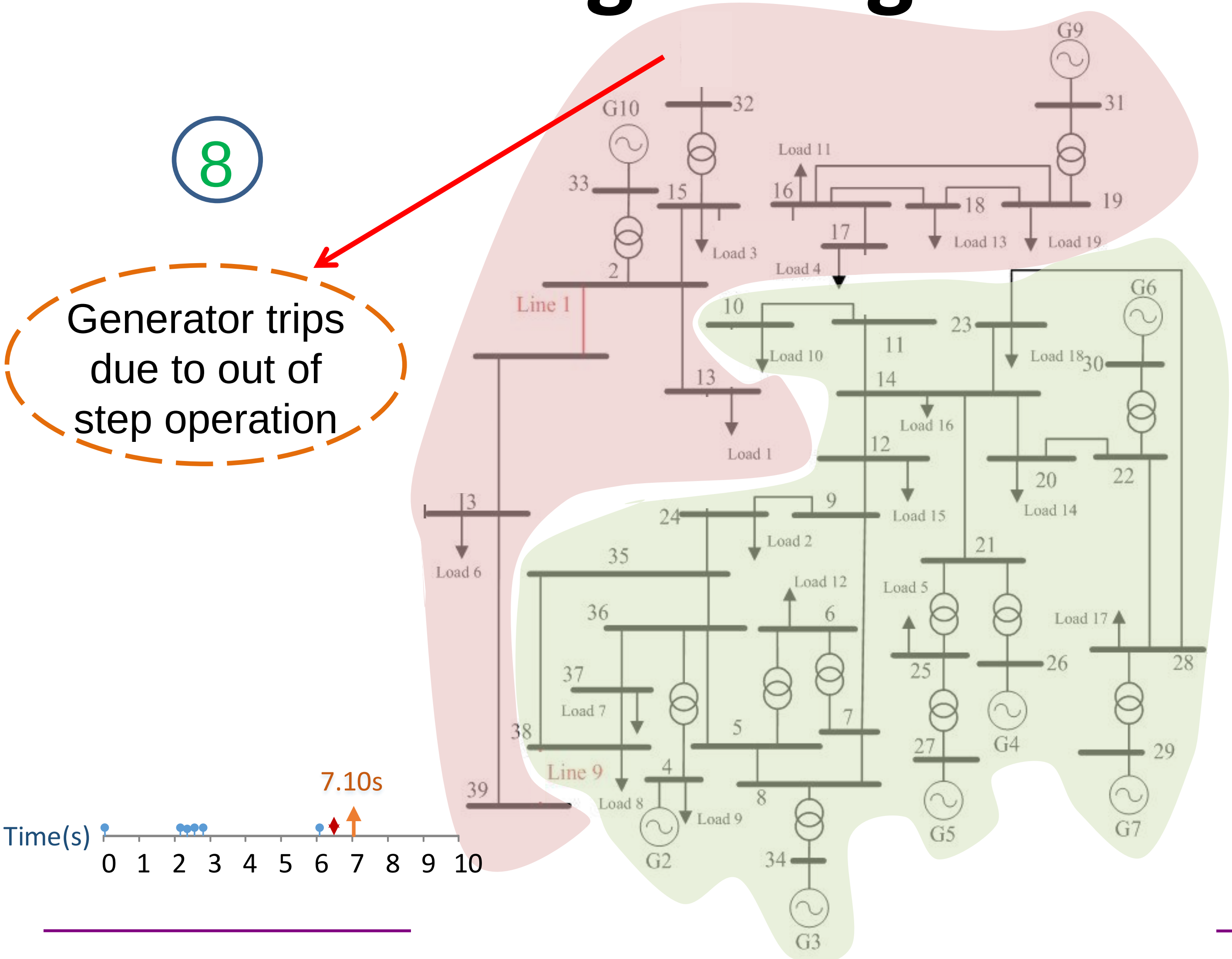




Cascading Outages Example

8

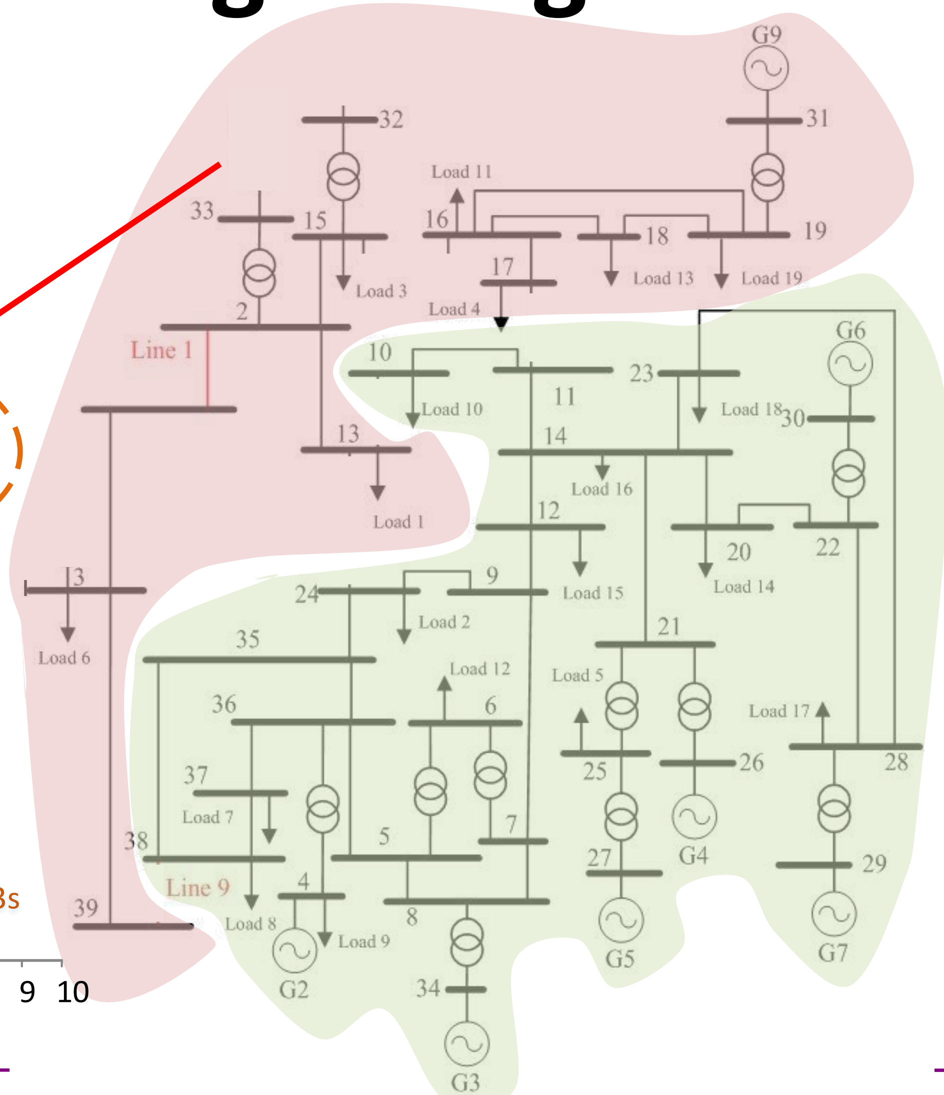
Generator trips due to out of step operation

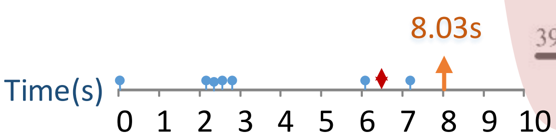


Cascading Outages Example

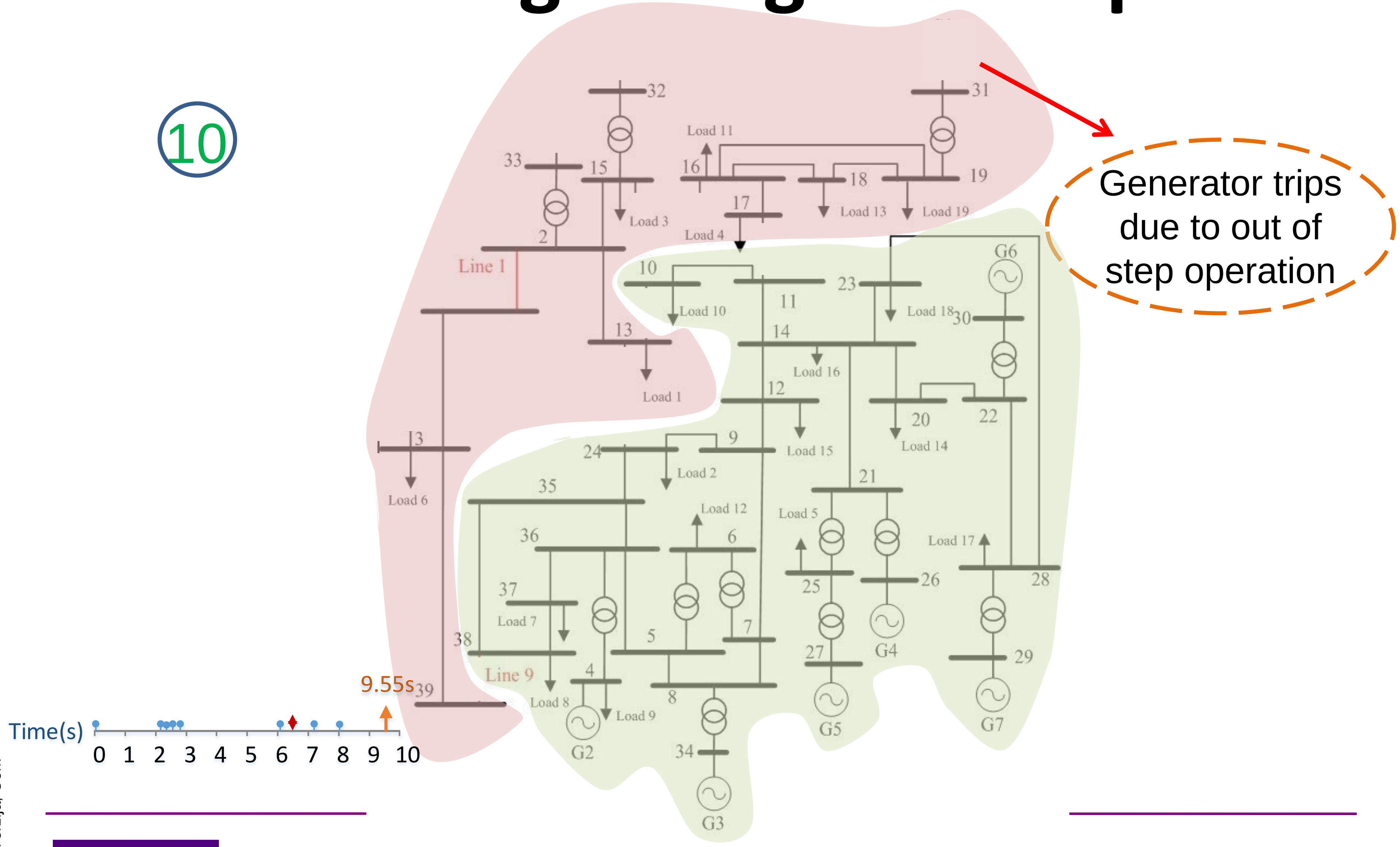
9

Generator trips due to out of step operation

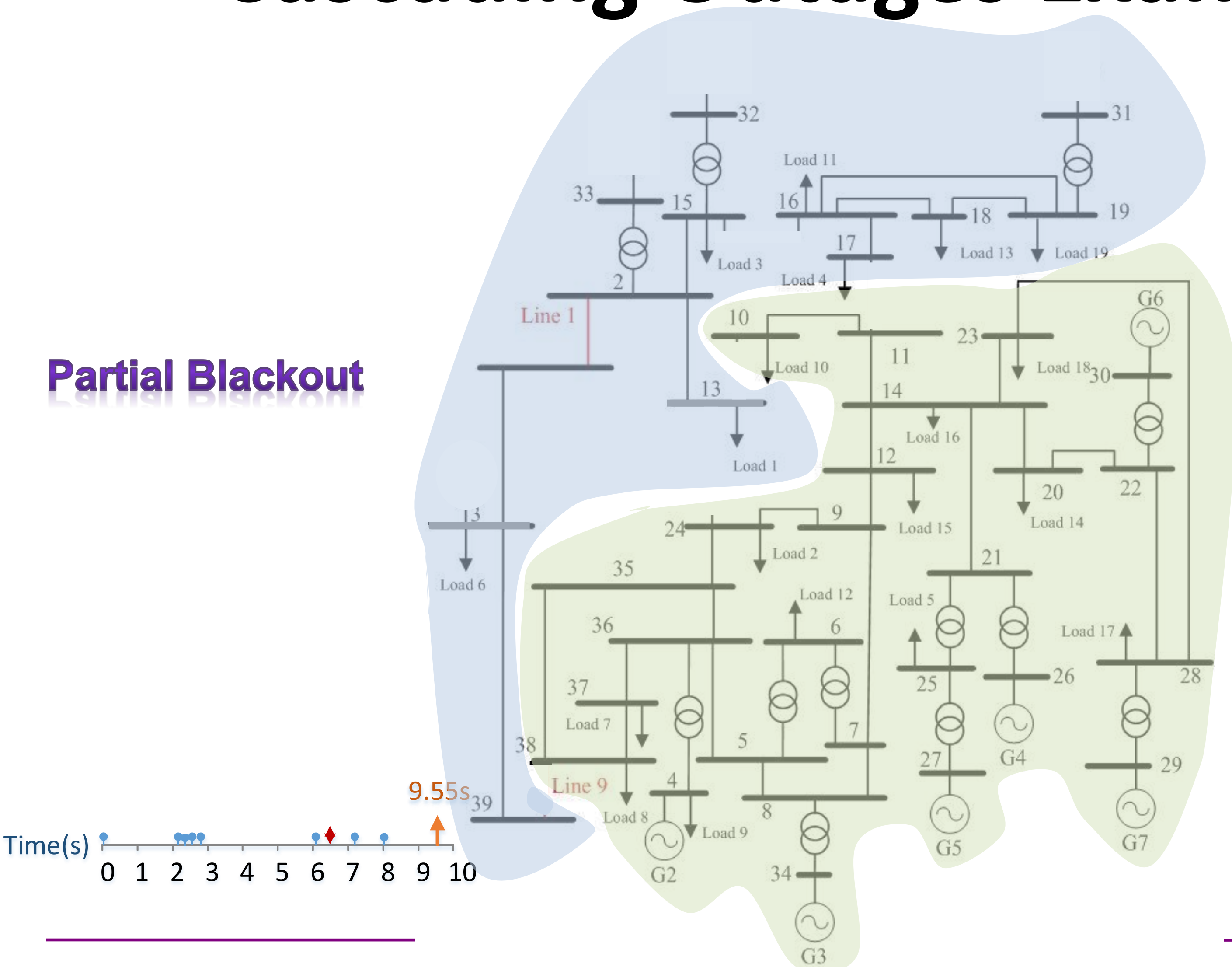




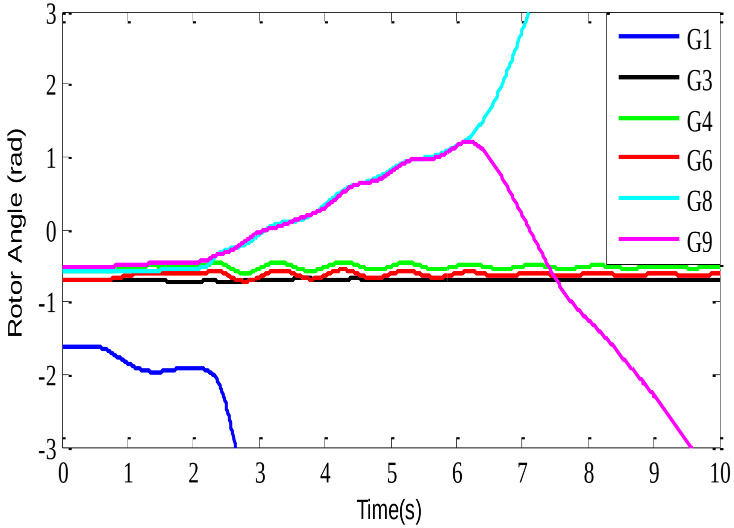
Cascading Outages Example

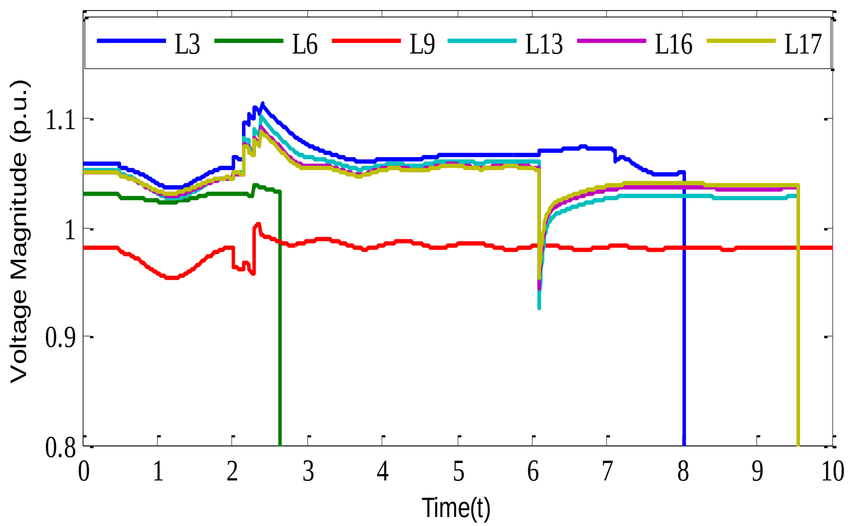


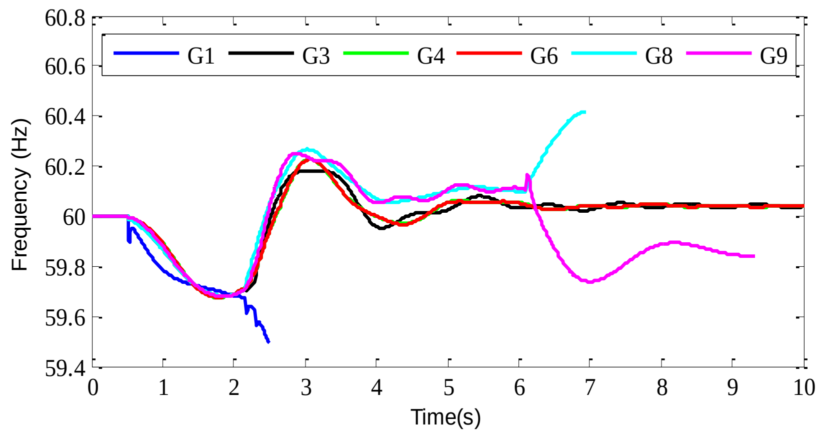
Cascading Outages Example



Cascading Outage Example





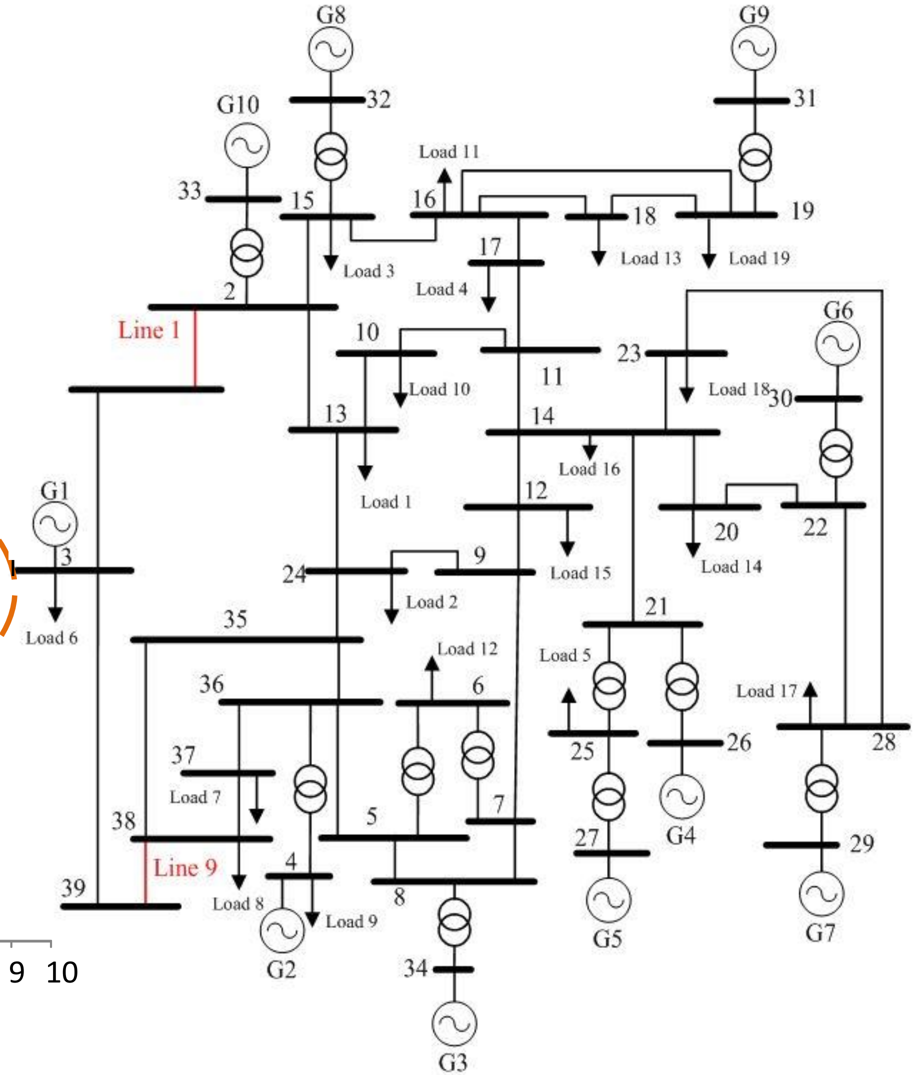


Controlled Islanding Example

1

Wind Speed >= Cut Out Speed

Disconnection of Wind Farms

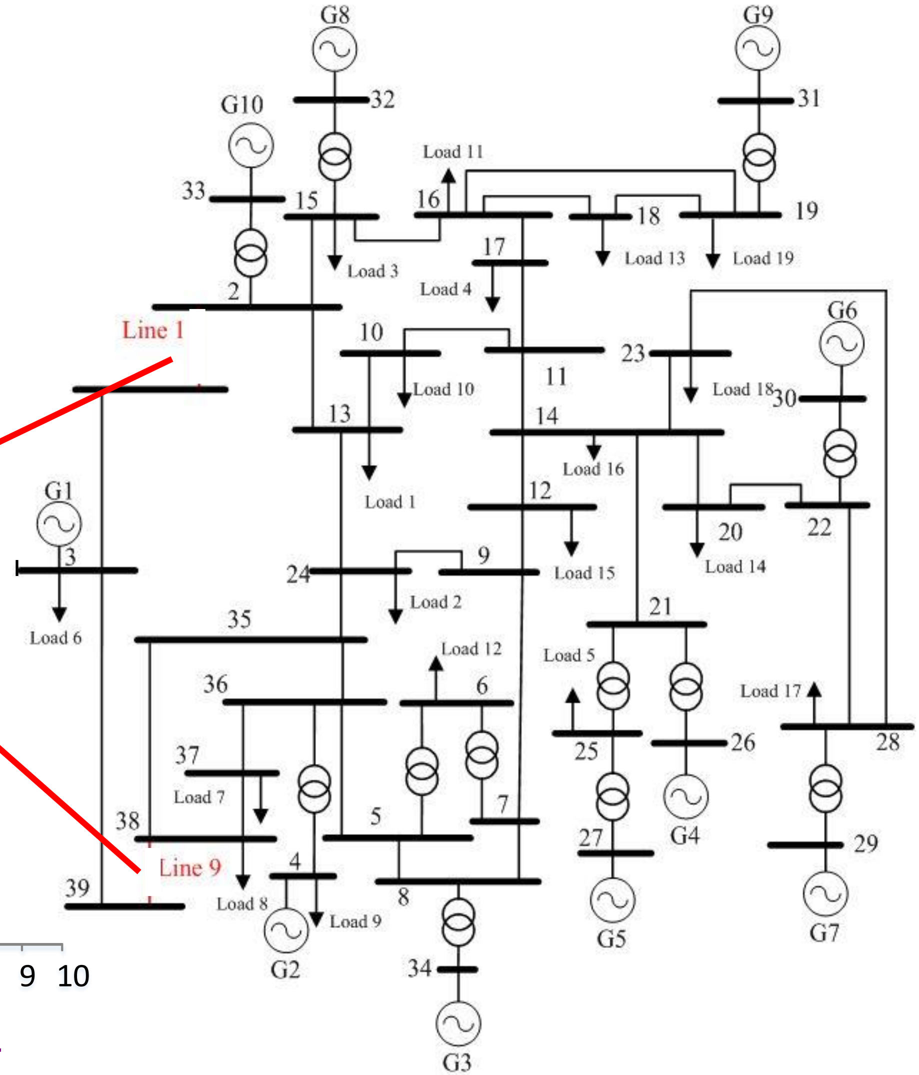


Initiating Event

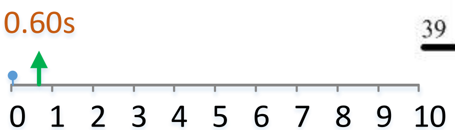
Time(s) 0 1 2 3 4 5 6 7 8 9 10

Controlled Islanding Example

2



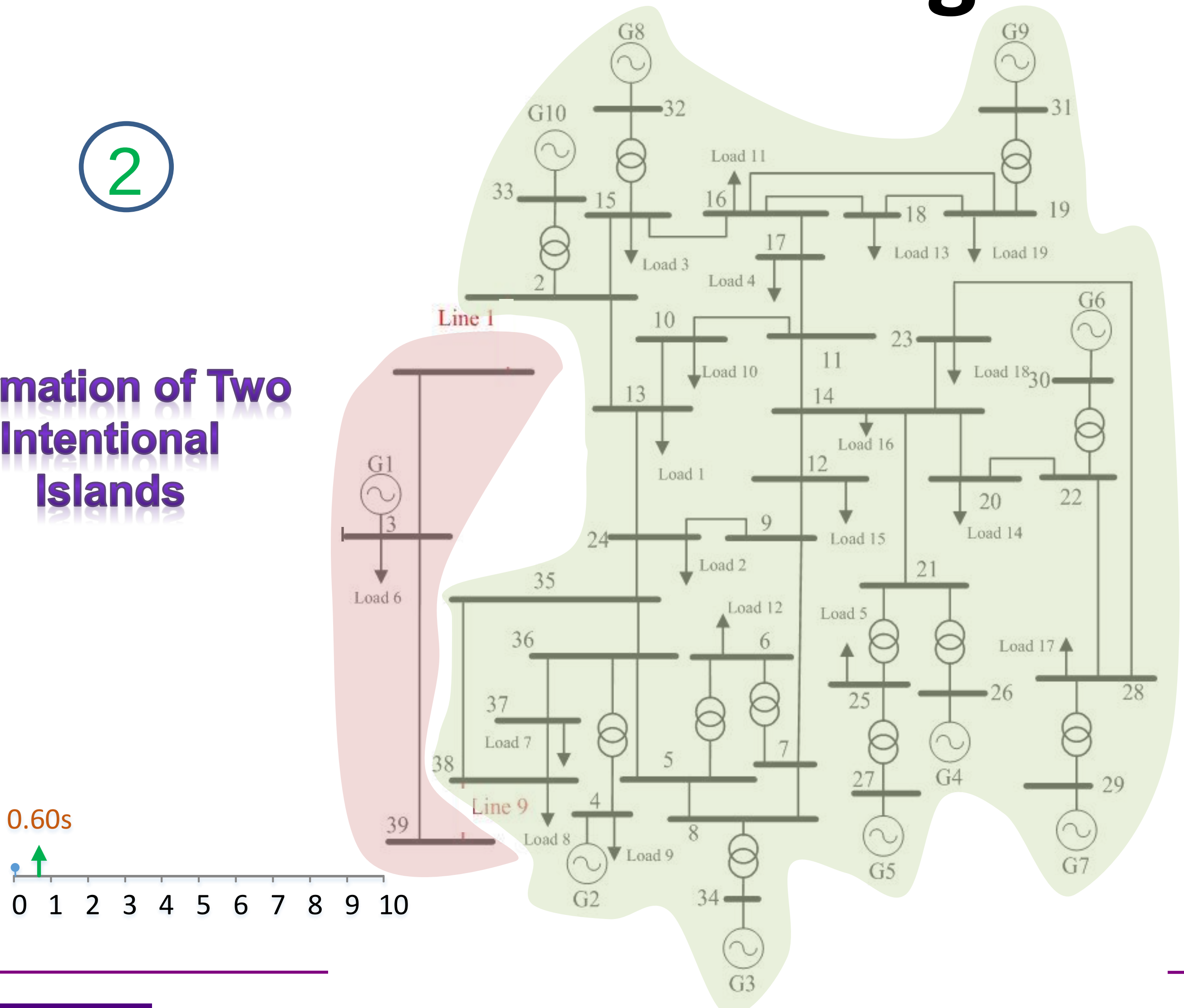
Intentional tripping of the lines



Controlled Islanding Example

2

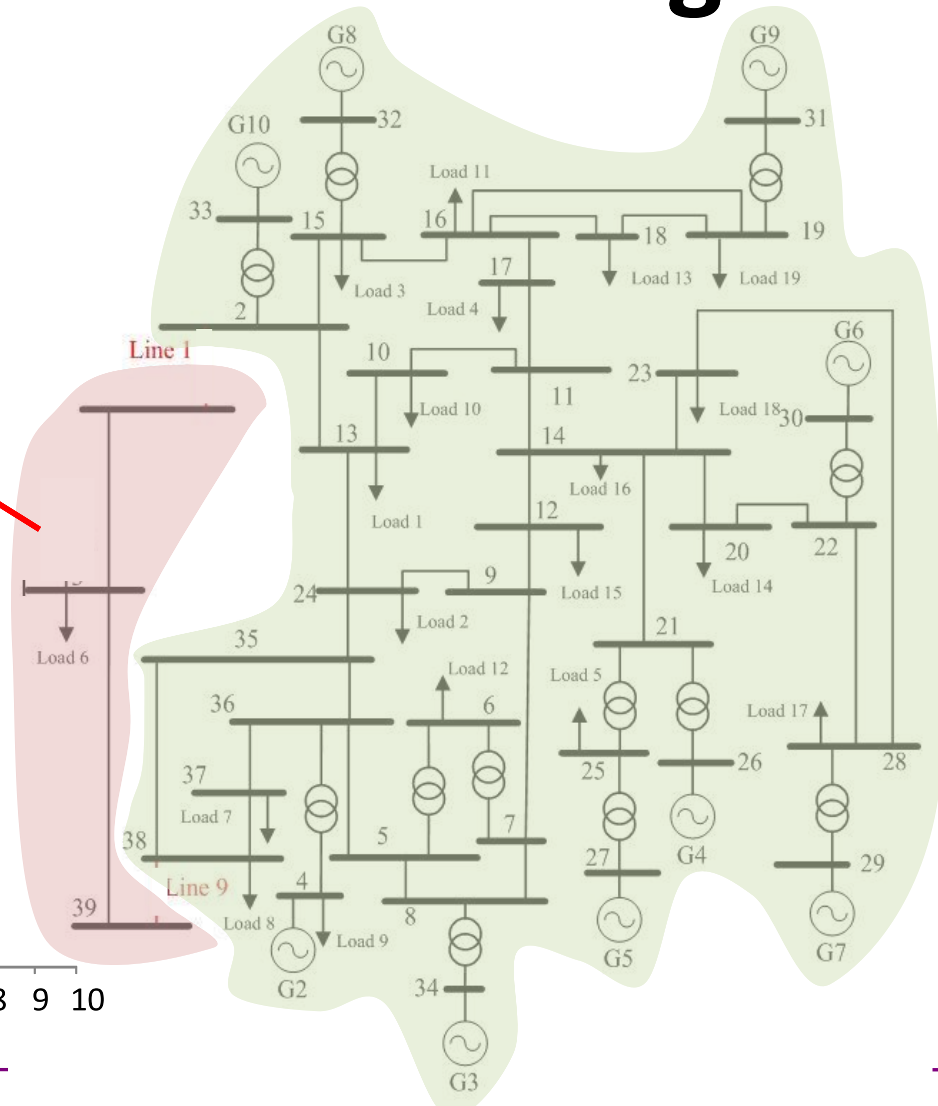
Formation of Two Intentional Islands

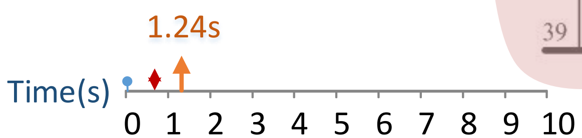


Controlled Islanding Example

3

Generator trips due to out of step operation





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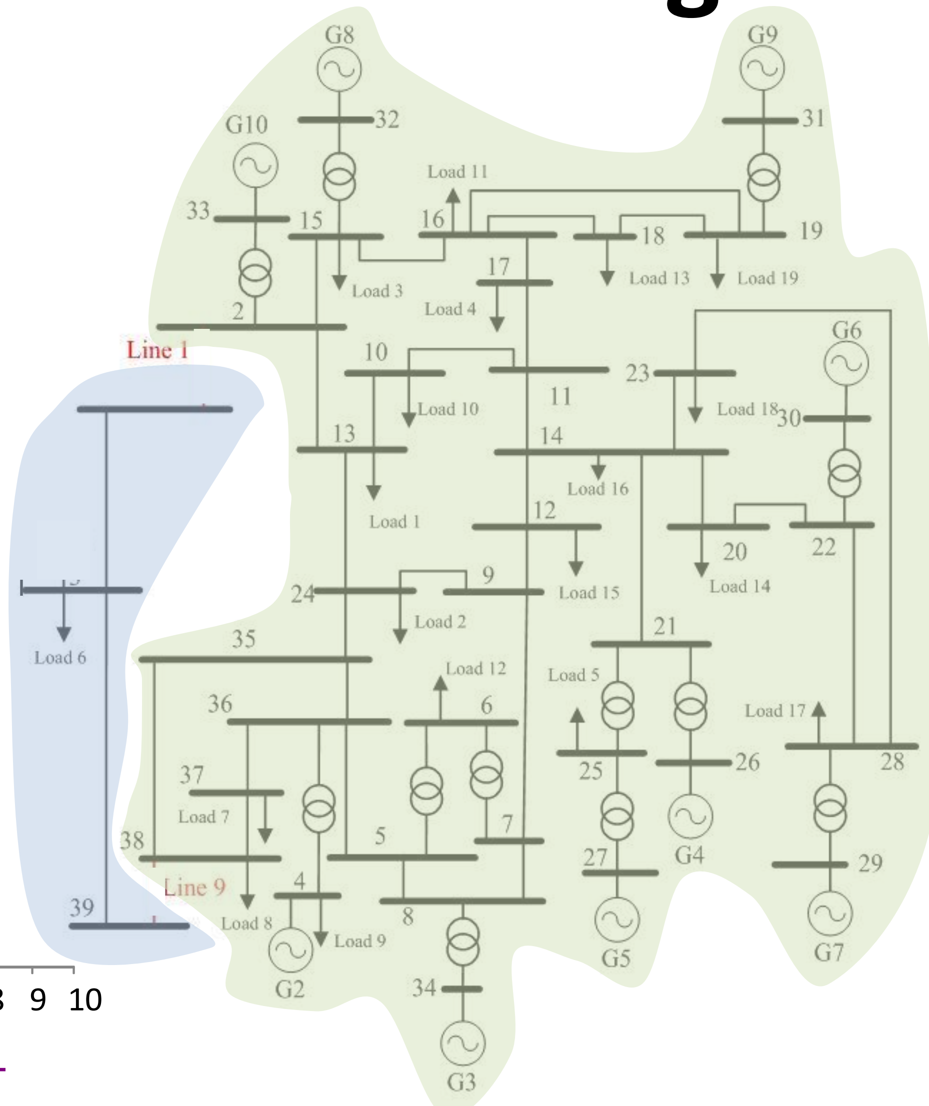
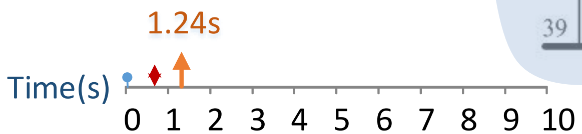
Controlled Islanding Example

3

Island 1 Collapses

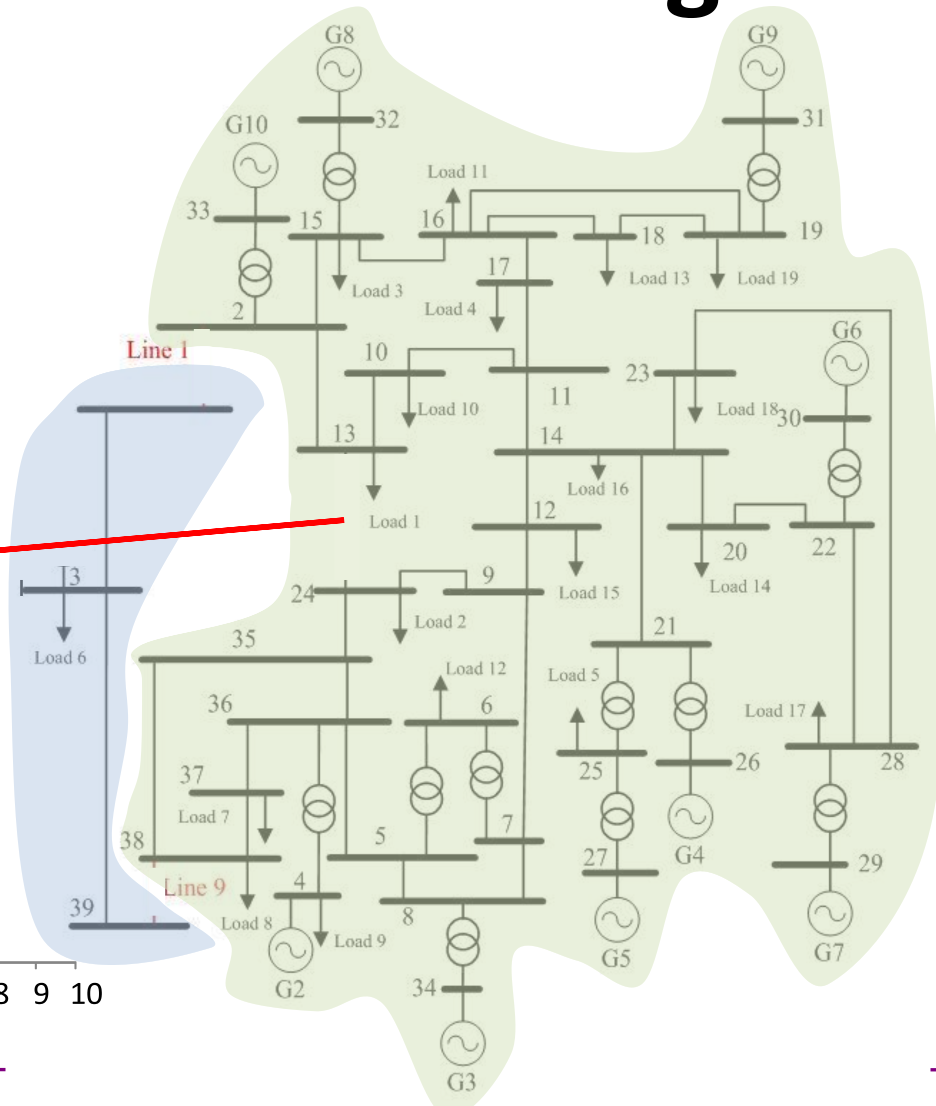


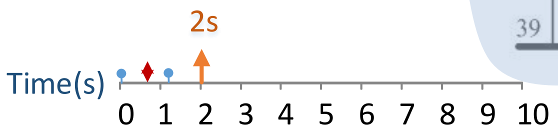


Controlled Islanding Example

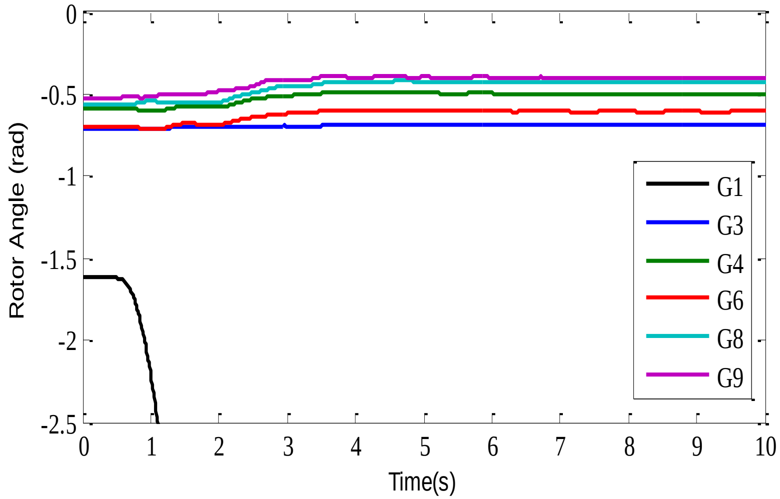
4

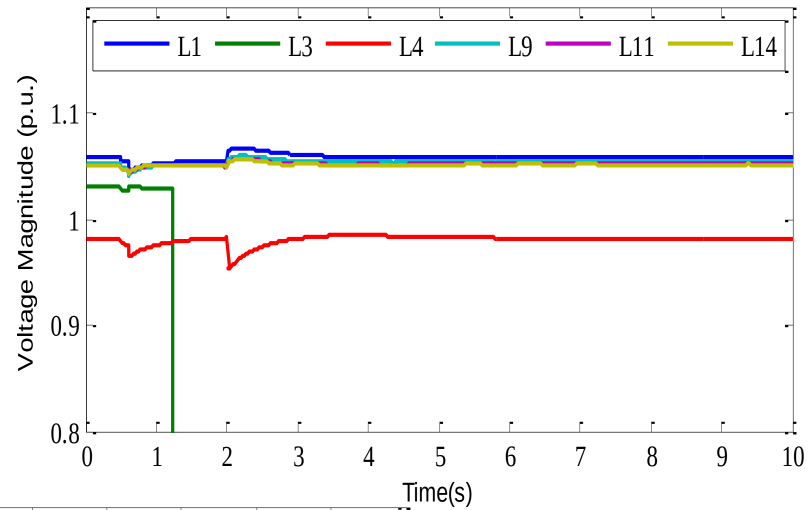
Line trips due to overload

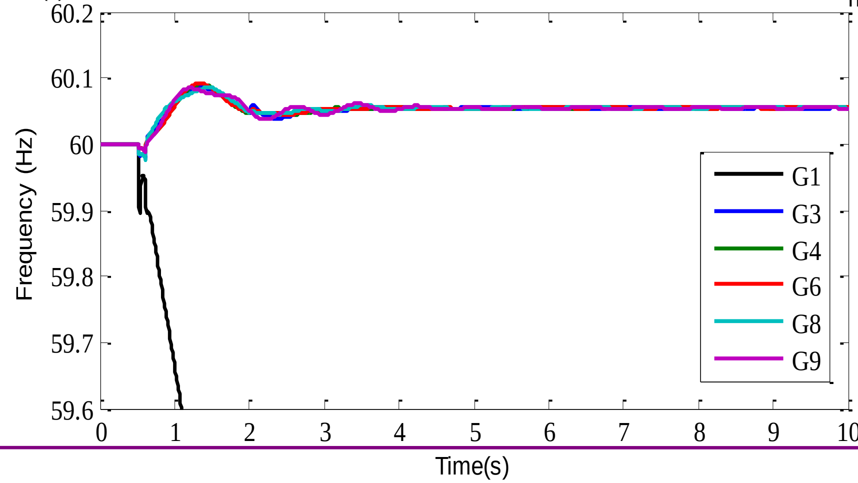




Controlled Islanding Example

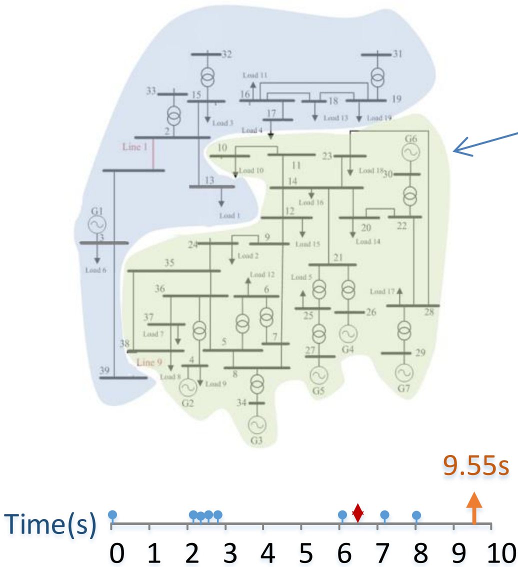






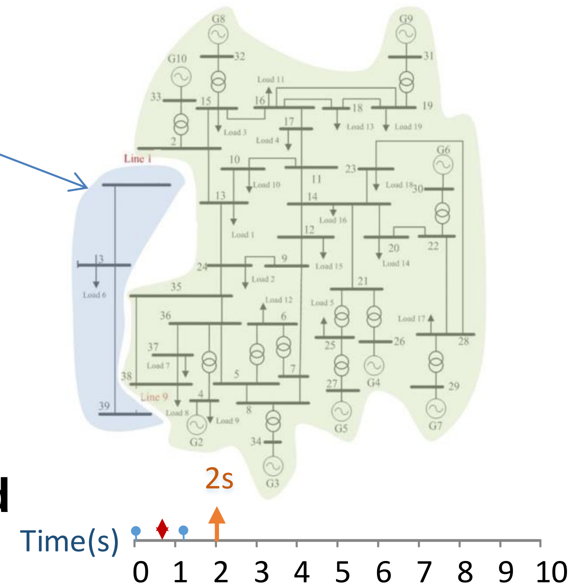
Comparison

Same Initiating Event



Without Controlled Islanding

With Controlled Islanding

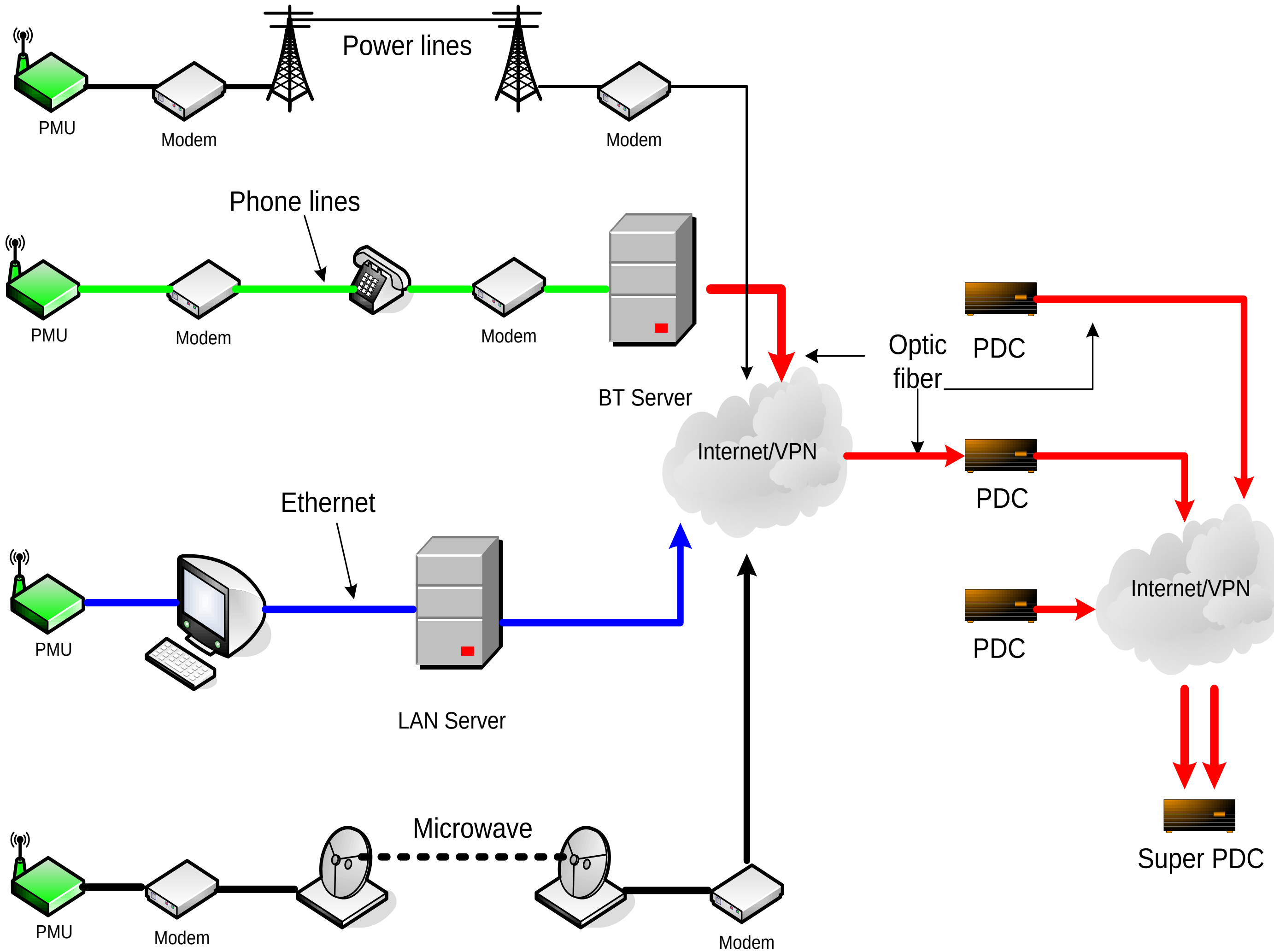


Conclusion

- **Real-time application must rely on a secure, reliable and robust communication infrastructure**

Communication in WAMPAC System

Communication Media options



Conclusion

- **Challenges related to time synchronisation are still open; solution: a PMU technology not requiring time-synchronization**
- **WAMS well established world-wide**
- **WAC and WAP under development**
- **A need for serious Hardware in the Loop testing**

Questions?

The University of Manchester

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1st International Symposium on Smart Grid Methods, Tools, and Technologies

A Journey from Wide Area Monitoring to Wide Area Protection and Control of Future Power Systems

Prof Vladimir Terzija

The University of Manchester, UK

v.terzija@manchester.ac.uk