MANCHESTER 1824

The University of Manchester

A Centralized Underfrequency Load Shedding Controller based on State Estimator for Microgrids Applications

Mazaher Karimi, Peter Wall, Hazlie Mokhlis, Vladimir Terzija

Relay Protection and Automation for Electric Power Systems 2017, Saint-Petersburg, Russia

MANCHESTER 1824
The University of Manchester

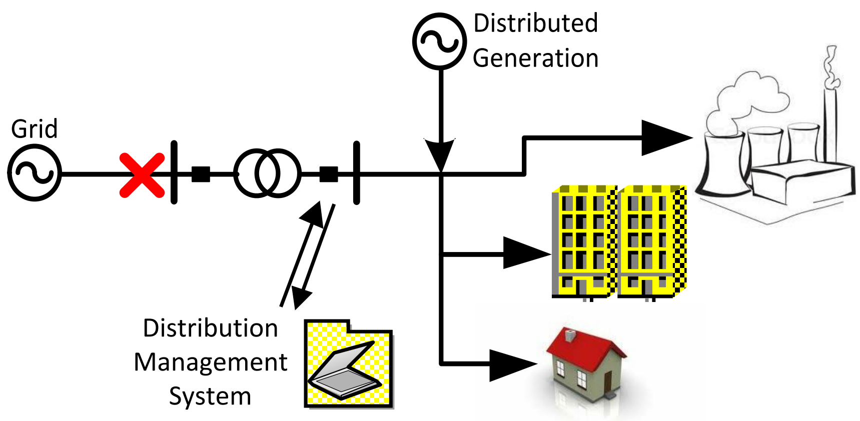
Presentation Outline

- Introduction
- Problem Statement
- The proposed centralized frequency controller
- Test system and testing scenarios
- Case studies and simulation results
- Conclusions

MANCHESTER 1824
The University of Manchester

Introduction

- Islanding occurs when:
  - A section of the distribution network is separated from the grid.
  - The supply to the separated section is maintained by distributed generation.
- Implementing an intentional islanding operation of RES will establish continuity of supply and helps to improve reliability of supply to customers.



Problem Statement

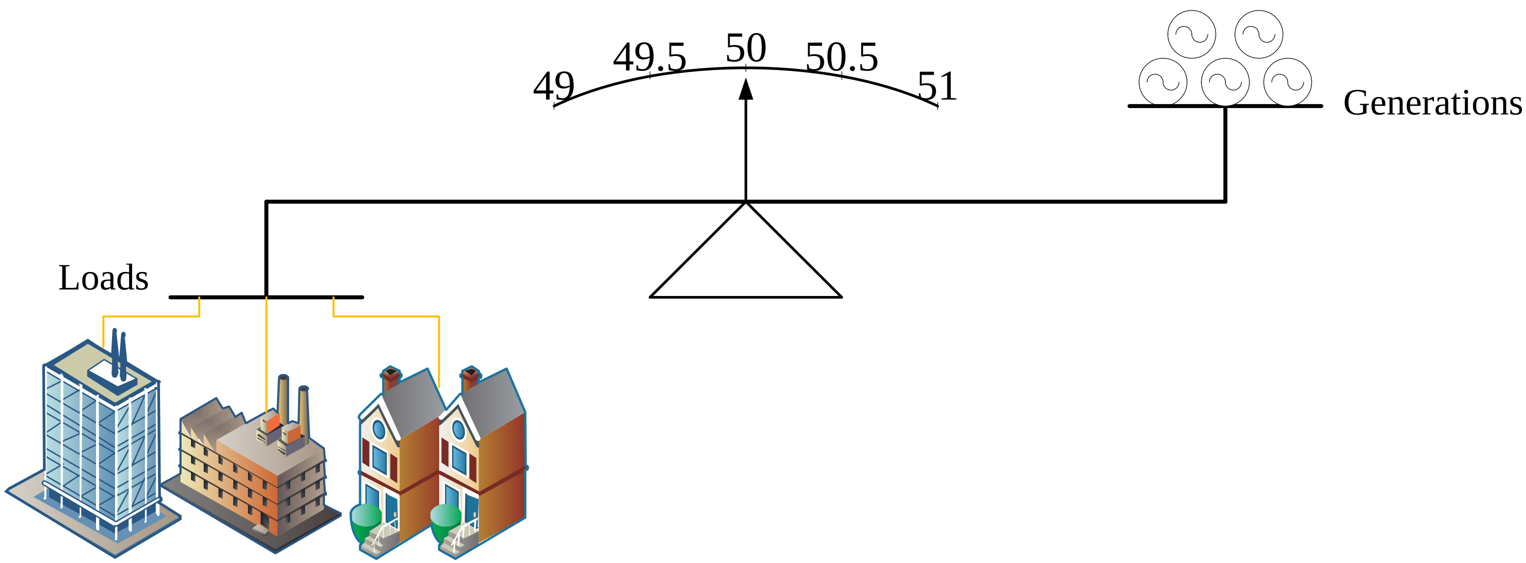
- The success of RES operation in islanded mode depends on resolving the following technical issues:
  - Voltage and frequency control
  - Coordinating the protection scheme and modifications
  - Load shedding scheme

- RESs such as mini-hydro with small system inertia experience rapidly dropping system frequency

- The main obstacle in implementing effective load shedding is the lack of sufficient data from online monitoring such as PMU as compare to transmission system which is automated with Wide-Area Monitoring System (WAMS)

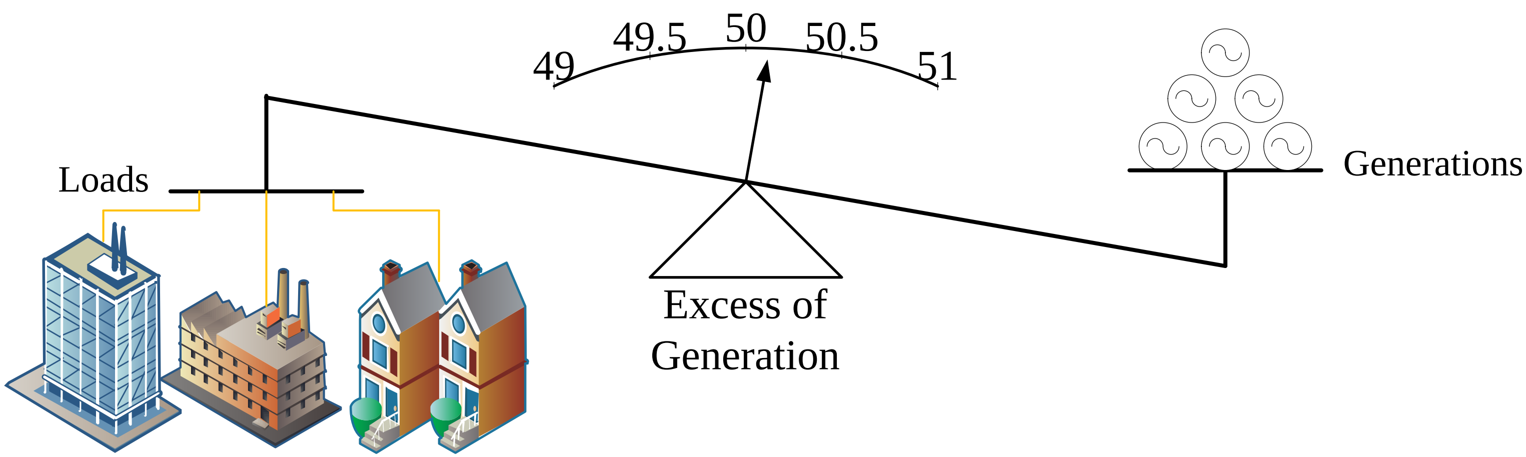
System frequency balance

- Frequency of the system will vary as load and generation change
- For instance, National Grid (UK) is needed to maintain the frequency within statutory limit (49.5Hz - 50.5Hz) and operational limits (49.8Hz - 50.2Hz)



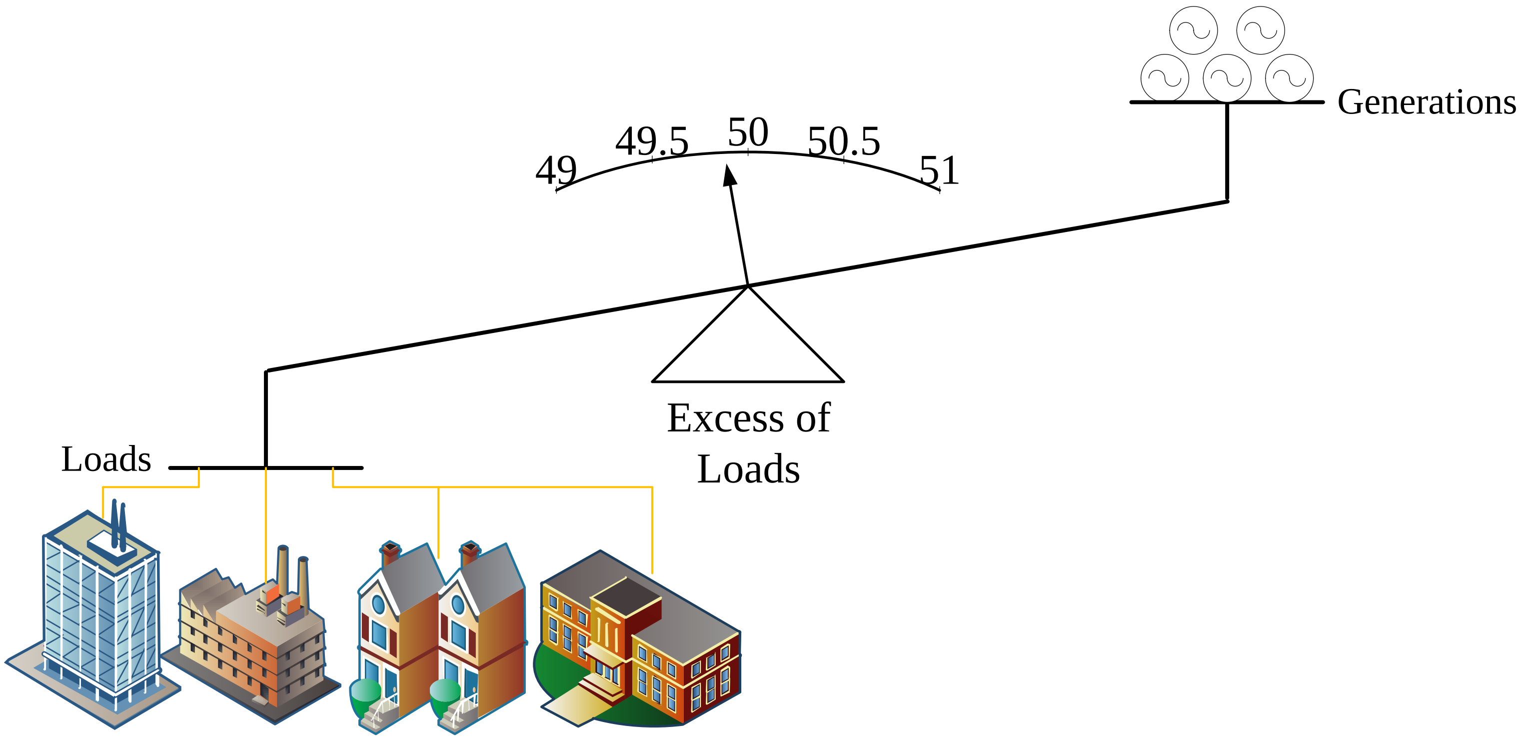
System frequency balance

- If generation is greater than demand, the frequency rises



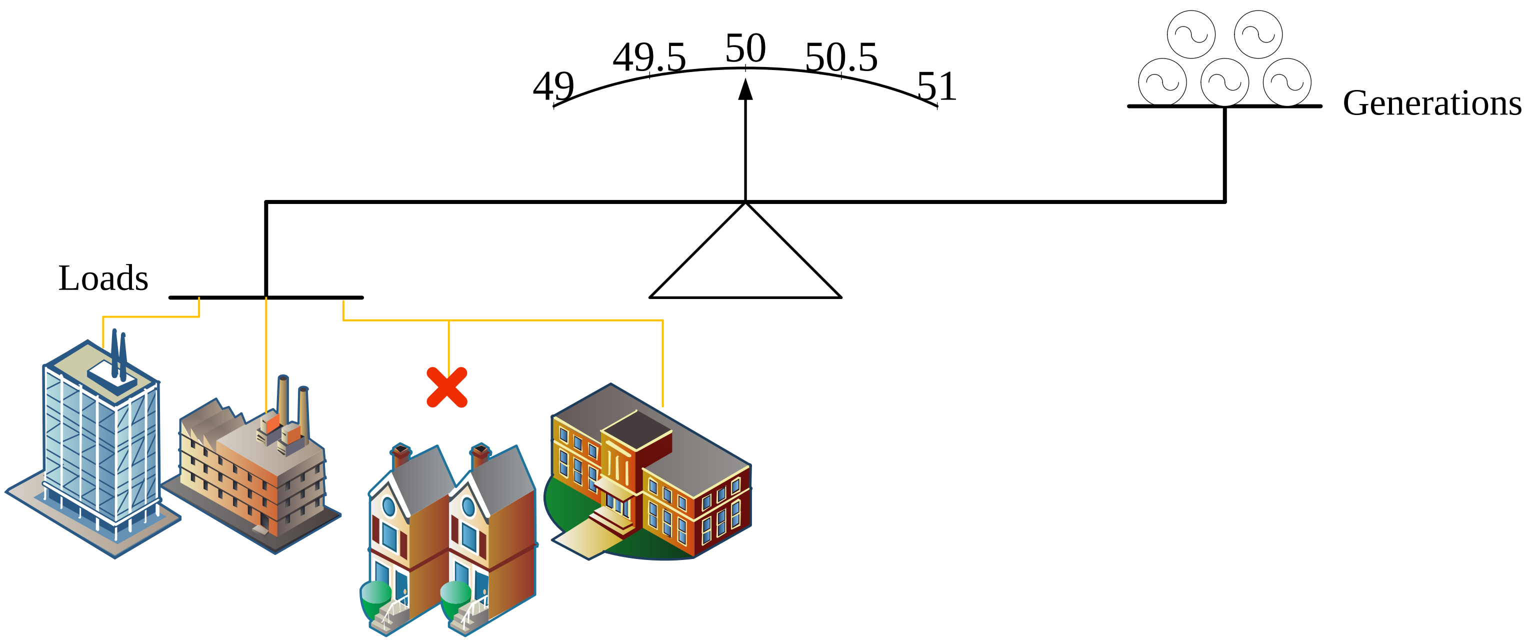
System frequency balance

- During a severe overload caused by tripping or failure of generators or interconnector lines, the power system frequency will decline, due to an imbalance of load versus generation



System frequency balance

- To prevent system frequency collapse, load shedding scheme is widely used to shed loads with low priority to rebalance the supply and demand



The proposed centralized frequency controller

- The proposed controller is formed by combination of **adaptive under frequency load shedding scheme** with **Distribution State Estimation (DSE)** method
- It starts with obtaining system parameters such as **voltage, frequency and power flow** from the available PMU devices
- DSE task is to estimate the ***real time power values*** (active and reactive power) of the loads at each bus

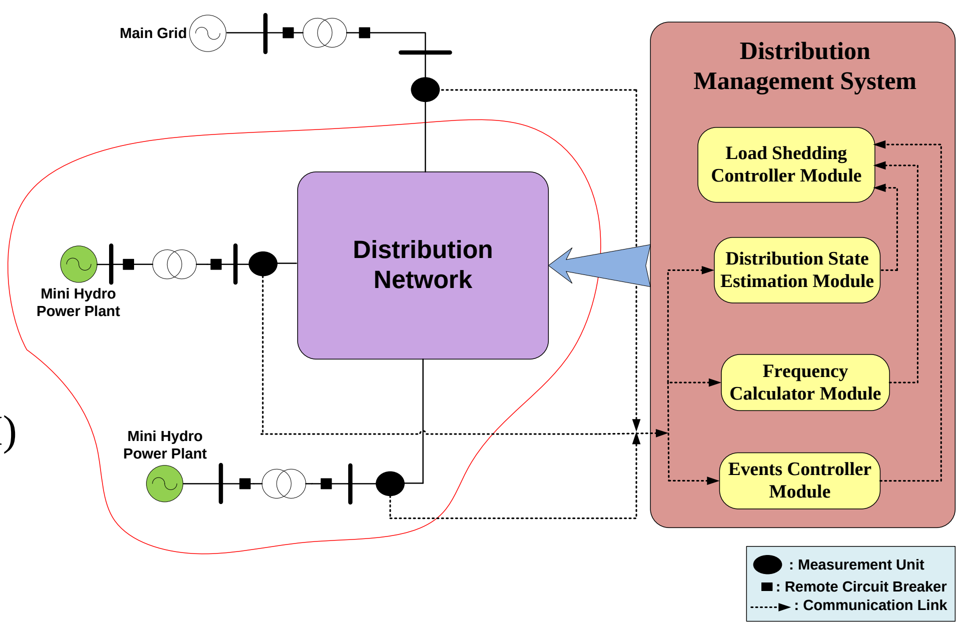
The proposed centralized controller is consist of:

a. Event Calculator Module (ECM)

b. Frequency Calculator Module (FCM)

c. Distribution State Estimation Module (DSEM)

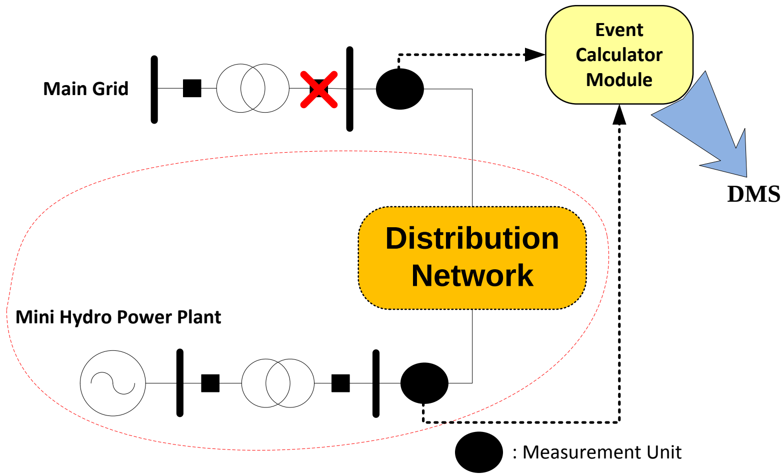
d. Load Shedding Controller Module (LSCM)

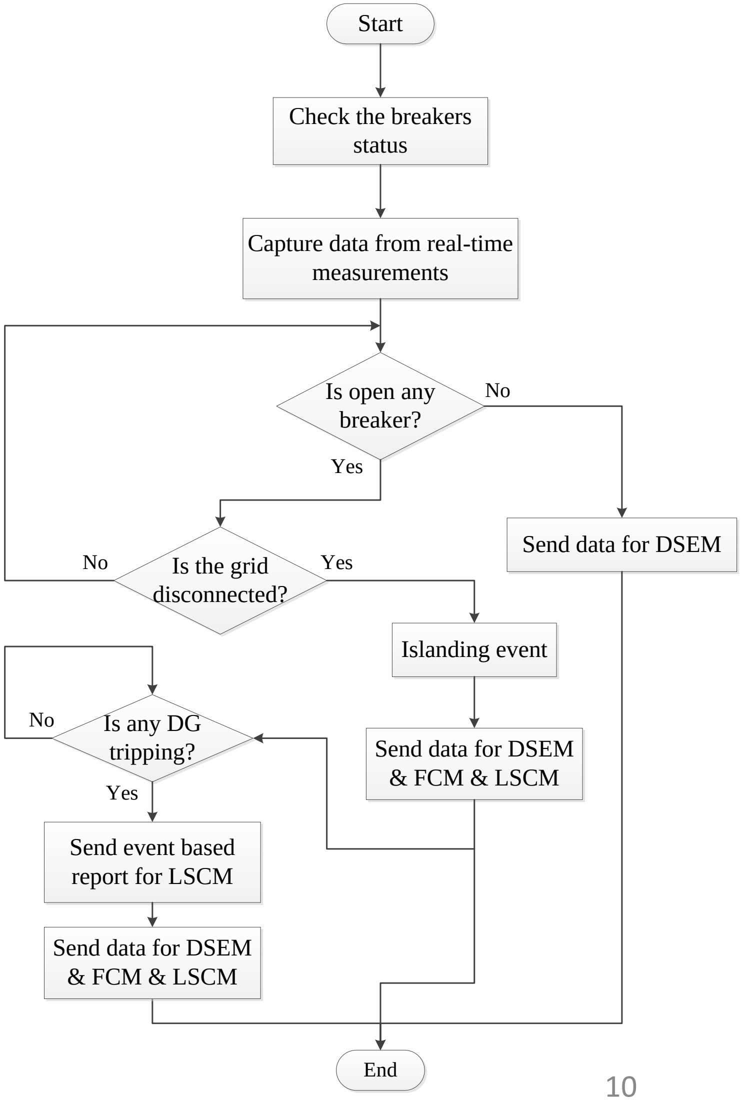


The proposed centralized frequency controller

a. Event Calculator Module (ECM)

- The module is designed to monitor the real-time measurements such as Phasor Measurement Unit (PMU) which is installed in the main substations of microgrid; *monitoring of islanding, or disconnection of generators in the microgrid.*
- By implementing the ECM, it is possible to capture all events in distribution network





The proposed centralized frequency controller

b. Frequency Calculator Module (FCM)

- While the system is connected to the grid, the grid's frequency is calculated. However, the frequency of the Center of Inertia (f_{COI}) is calculated during islanding operation
- f_{COI} is calculated by using the inertia constant and frequency of each generator of islanded distribution network

$$f_c = \frac{\sum_{i=1}^{N} H_i \times f_i}{\sum_{i=1}^{N} H_i}$$

- Then, f_{COI} will use to calculate the Rate of Change of Frequency (RoCoF)

The University of Manchester

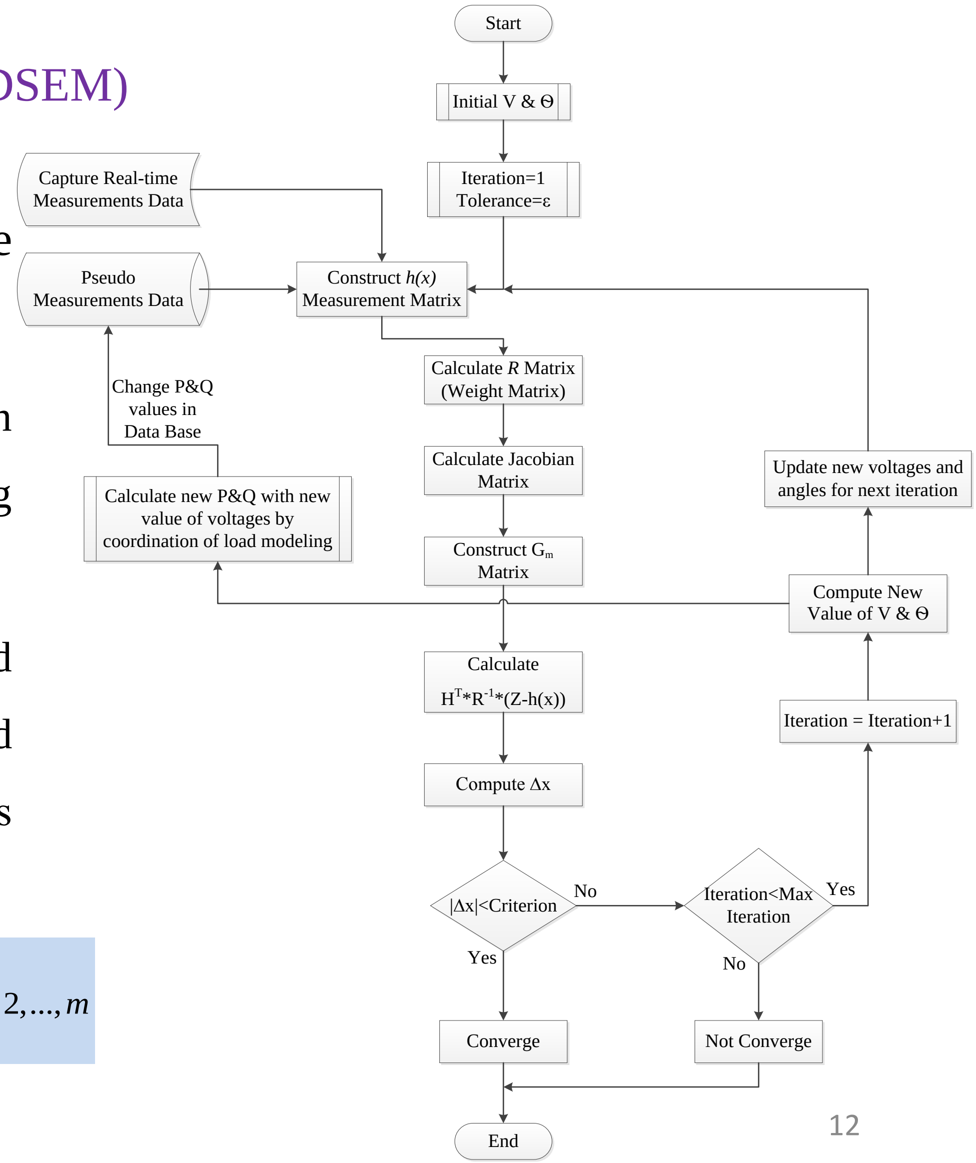
The proposed centralized frequency controller

c. Distribution State Estimation Module (DSEM)

- DSE algorithm based on nodal voltage is improved as follow:
  - The sparsity problem of the Jacobian matrix is solved by implementing *pseudo measurements*
  - It incorporates *load modelling* to find the correct amount of active and reactive power related to the system's voltage

$$P_i = P_{i0}\left(\frac{|V_i|}{|V_{i0}|}\right)^a , \quad i = 1, 2, \ldots, m$$

$$Q_i = Q_{i0}\left(\frac{|V_i|}{|V_{i0}|}\right)^b , \quad i = 1, 2, \ldots, m$$



The proposed centralized frequency controller

d. Load Shedding Controller Module (LSCM)

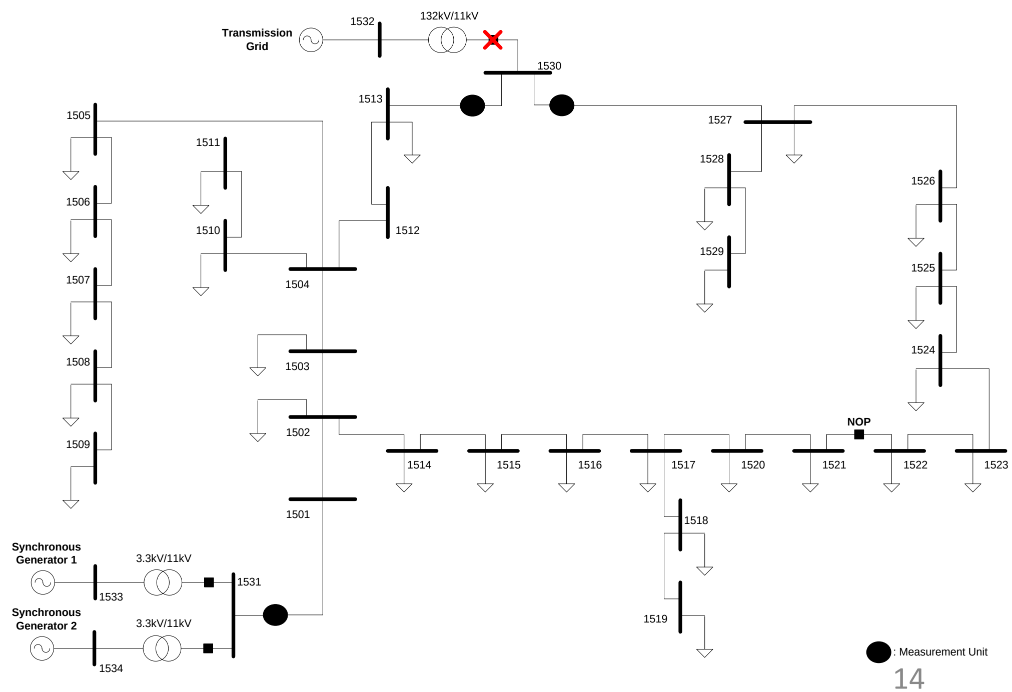
- In *response based strategy*, the LSCM estimates the power imbalance, ΔP, by using RoCoF and simplest expression of the swing equation

$$\Delta P = \frac{2 \times \sum_{i=1}^{N} H_i}{f_n} \times \frac{df_c}{dt}$$

- The RoCoF magnitude is valid immediately after the disturbance occurs due to the dynamic response of the control elements such as turbine, governor, load and generator
- Hence, a minimum RoCoF value is captured and saved by the LSCM after the disturbance happens and then power imbalanced, ΔP, will be calculated
- f_{COI} is calculated by using the inertia constant and frequency of each generator from FCM
- The power imbalance will be shed according to the load priority and load estimated value as provided by DSEM

Test system and testing scenarios

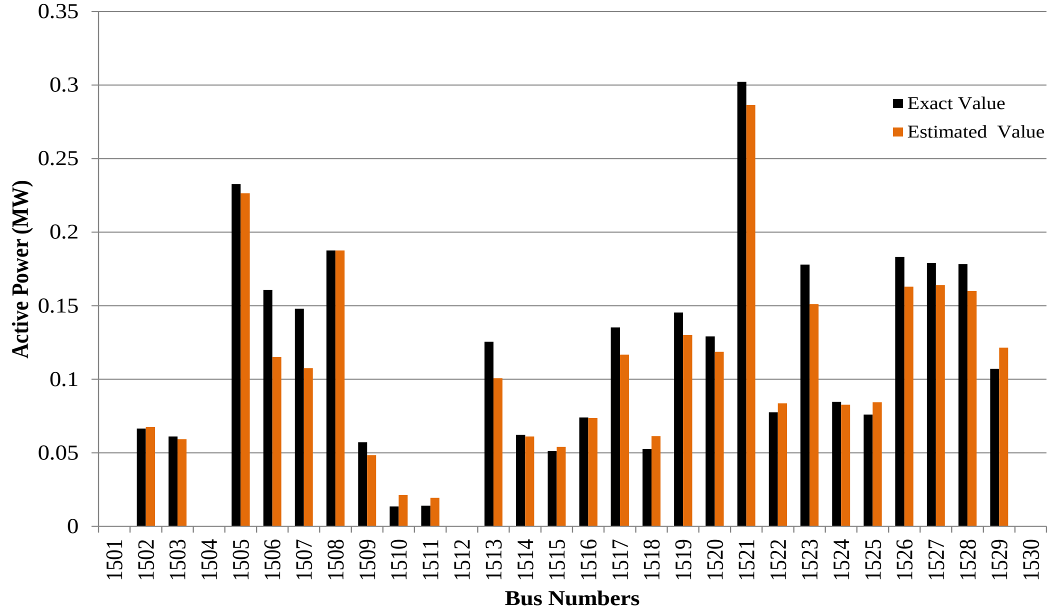
- 2 mini-hydro generators unit (2 MVA rating power, operating at 3.3 kV with 2.5 s inertia constant) utilized as RES in test system
- The mini-hydro generators are connected to the distribution network through two parallel 2 MVA transformer units that step-up the voltage level to 11 kV
- Distribution network is connected to the grid via a 132 kV/11 kV step down transformer
- PMUs are installed at buses 1530 and 1501 to monitor all connected feeders to these buses
- Based load demand is 2.329 MW (excluding network losses)
- Peak load demand is 3.083 MW (excluding network losses)



Case studies and simulation results

- Following scenarios are tested for validation of proposed controller:
  a. Islanding operation at t_1 = 5 s followed by generator tripping at t_2 = 65 s
  b. Islanding operation at t_1 = 5 s followed by load increments at t_2 = 65 s

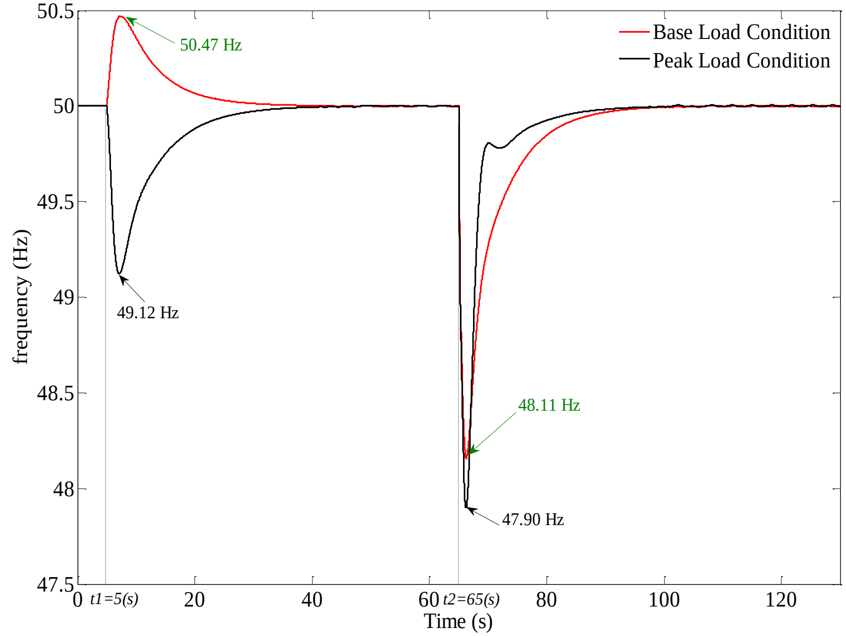
- The result of DSEM for peak load condition is presented in this figure
- Real-time measurement accuracy is assumed 1% according to practical data and 25% for pseudo measurement data
- An estimated active power loads at all buses are also compared with actual active power in this figure



Case studies and simulation results

a. Islanding operation followed by generator tripping

System frequency response and the active power generation of DG units for base and peak load are illustrated (<f threshold 49.5 Hz)



Load Cases	Islanding event at t_1 = 5 (s)	
	Imbalance Power	Load Shedding Amount
Base Load	0 MW	0 MW
Peak Load	0.25 MW	0.061 MW (1)

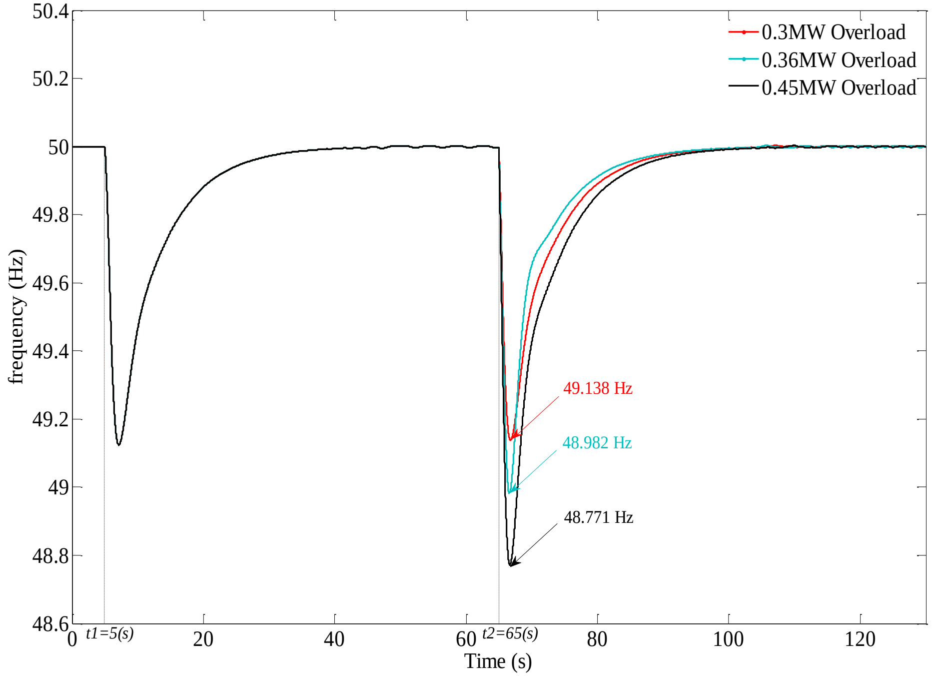
Load priority number

Load Cases	DG Tripping at t_2 = 65 (s)	
	Imbalance Power	Load Shed Amount
Base Load	1.209 MW	1.009 MW (1-15)
Peak Load	1.555 MW	1.407 MW (2-16)

Case studies and simulation results

b. Islanding operation followed by load increment

In order to demonstrate the effectiveness of the centralized controller for response based strategy, sudden load increment at t2=65s of 0.30 MW, 0.36 MW and 0.45 MW is simulated



Load Case	Load increment at t_2 = 65 (s)	
	Imbalance Power	Load Shedding Amount
Peak Load	0.3 MW	0.118 MW (2-3)
	0.36 MW	0.195 MW (2-4)
	0.45 MW	0.206 MW (2-5)

MANCHESTER 1824
The University of Manchester

Conclusions

The proposed centralized underfrequency load shedding controller based on state estimator has been successfully modelled and developed

- It uses an adaptive under frequency load shedding scheme to improve the estimation of power imbalance in the system
- Distribution state estimation has been improved by incorporating a load modelling and pseudo measurements
- The proposed UFLS with the improved DSE method has been combined to improve reliability of islanded distribution system
- The developed scheme manages to immediately perform load shedding in order to maintain the system frequency and voltage

The University of Manchester

Q & A