Lecture #2

Introduction to Power System Operation and Control

using ARISTO

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Outline

Power system basics

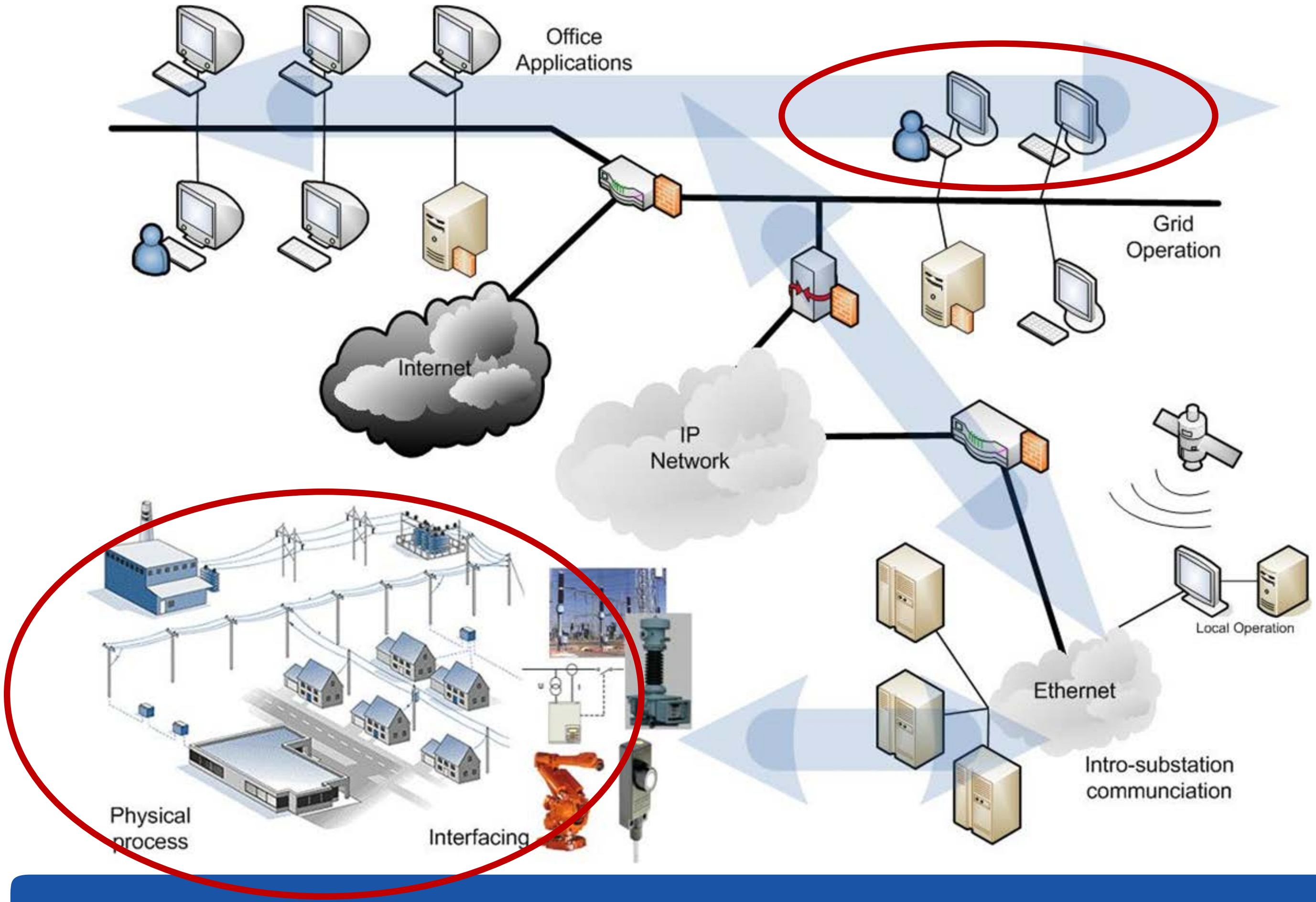
Operational states

Power system control

- Active power and frequency
- Reactive power and voltage

Lab session

Course road map



Transport of electric power

Apparent power (Complex power) (S) [VA]

- **S=VI*=P+jQ**
- Electric power P [W]
- Reactive Power Q [VAR]

Two ways to increase the transported power

- Increase current *I*
  - Larger conductor cross-section
- Increase voltage *U*
  - More insulation

Two ways to transport electricity

- Alternating current (AC)
- Direct current (DC)

Power network structure

Transmission system

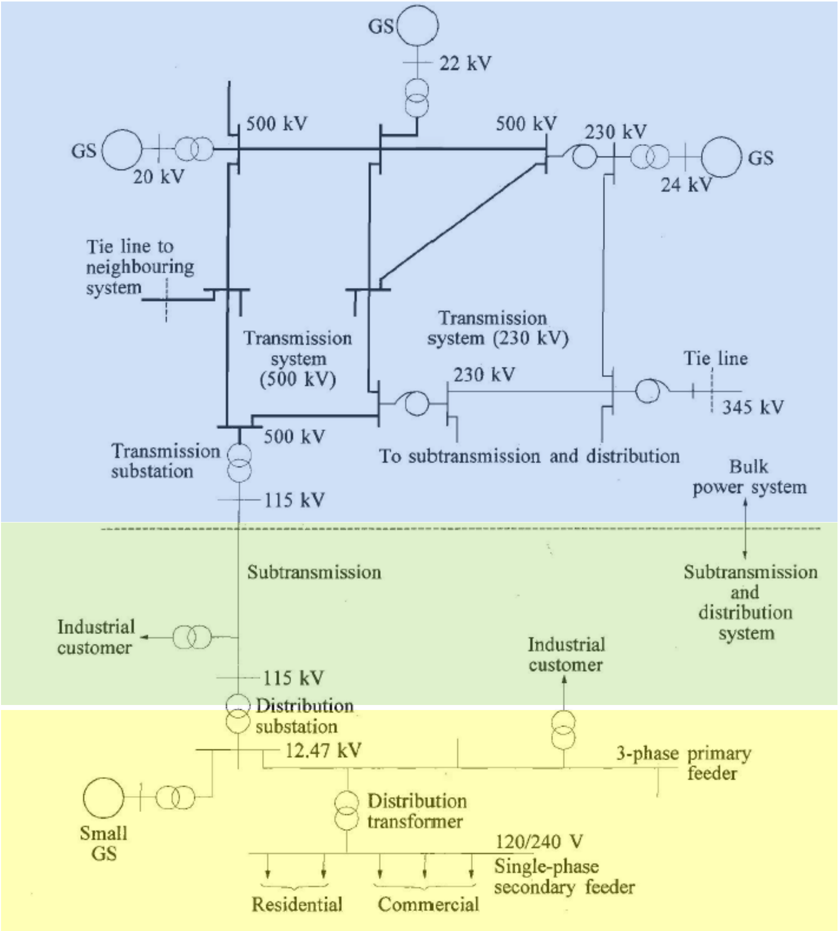
- all major generating stations and main load centers
- voltage levels (typically, 230 kV and above).

Sub-transmission system

- transmits the transmission substations to the distribution substations.
- Large industrial customers

Distribution system

- power to the individual customers
- between 4.0 kV and 34.5 kV



Operational states

Normal state, all system variables are within the normal range

Alert state, security level falls below a certain limit of adequacy because of a disturbance

- generation shifting (security dispatch) , Increased reserve

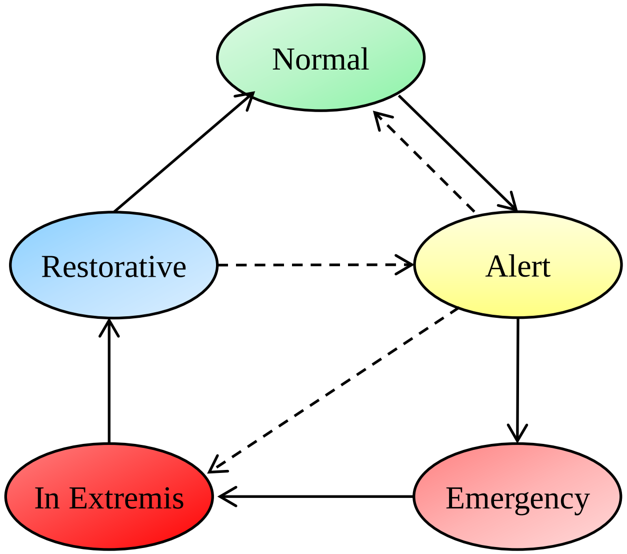
Emergency state, *severe disturbance*

- fault clearing, generation tripping, load curtailment

In extremis, *cascading outages*

- load shedding and controlled system separation

Restorative state, *control action is being taken to reconnect all the facilities and to restore system load.*



Operational requirement

Follow the change in the load demands

Supply energy at minimum cost and environmental impact.

Power quality

- Frequency
- Voltage
- Level of reliability.

Why constant frequency

Frequency fluctuations are harmful to electrical appliances.

- Speed of three phase ac motors proportional to the frequency. (N=120f/p)
- The blades of steam and water turbines are designed to operate at a particular speed. Frequency variation leads to speed variation and results in mechanical vibration

Why constant voltage

Over voltage and under voltage

- Electric motors will tend to run on over speed when they are fed with higher voltages resulting vibration and mechanical damage.
- Over voltage may also cause insulation failure.
- For a specified power rating, lower voltage results in more current and this results in heating problems. (P=VI)

Control parameters

Active Power and Frequency

- Balance of load and generation
- Load-Frequency Control

Reactive Power and Voltage

- Automatic voltage regulator
- capacitors and reactors
- Tap-changing transformers

Load & generation balance

Match between electric load and generation

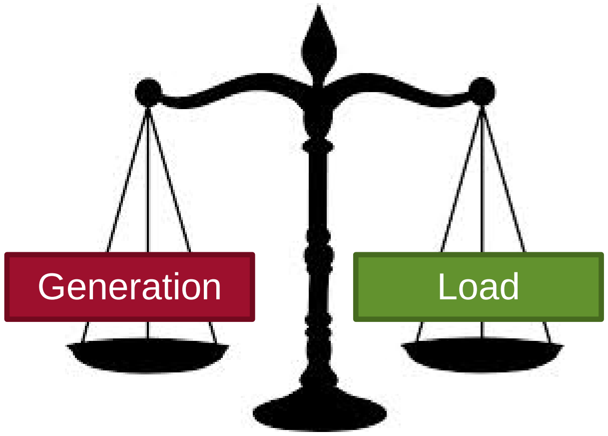
Frequency is an indication

Balanced system, 50/60 Hz

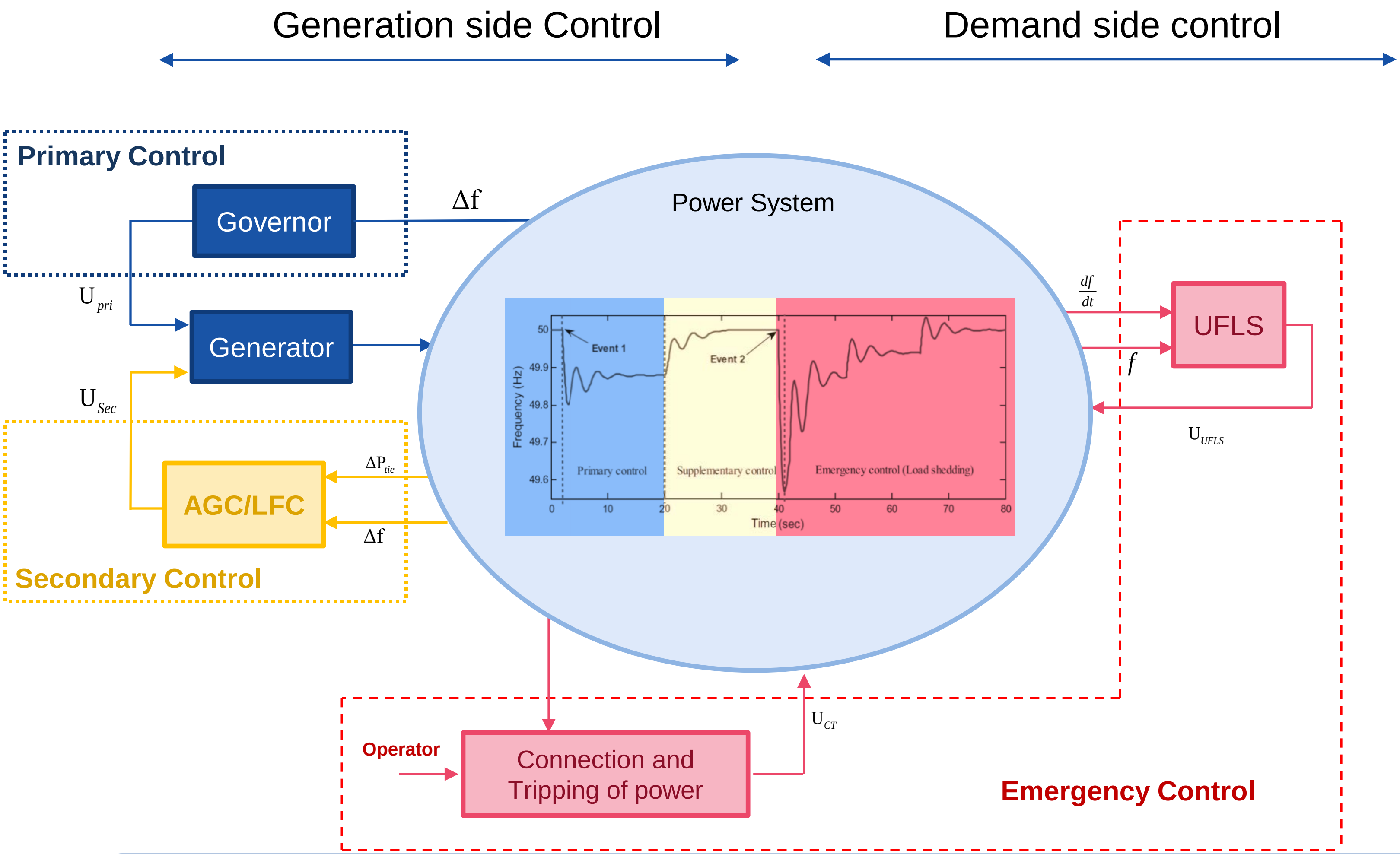
Net power surplus , frequency increases

Net power shortage, frequency decreases

$$\Delta P \longrightarrow \Delta f$$

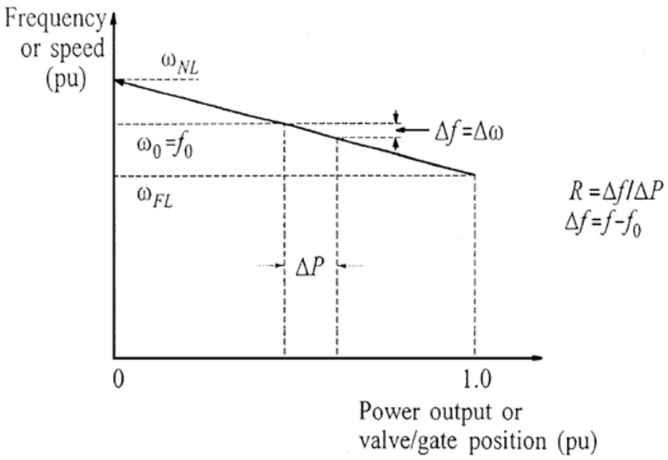


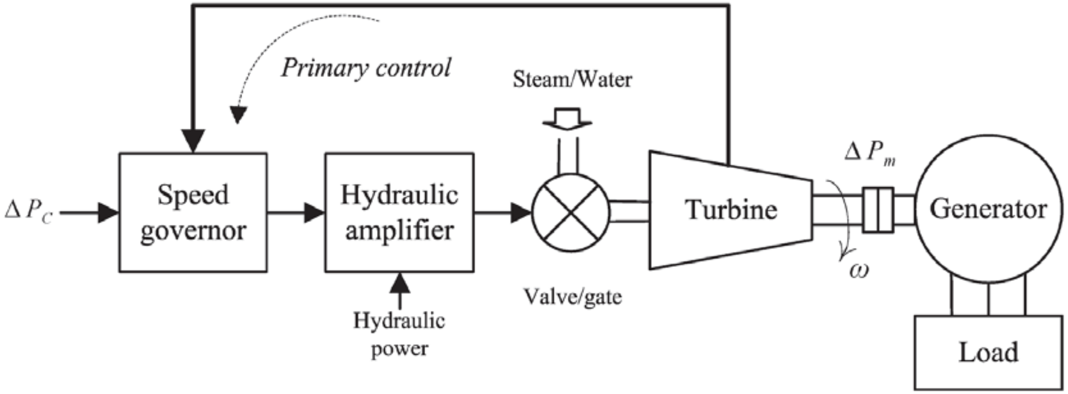
Frequency control actions



Primary Frequency Control

- Generation is controlled by mechanical output of the prime mover
- The *speed governor* senses the change in speed (frequency)
- Actions taken within 5 – 30 seconds by generator droop control





Need of primary control reserves

UCTE 3000 MW (Continental Europe)

- 3000 MW or equivalent of two 1500 MW nuclear plants or lines trip at the same time

Eastern Interconnection (USA)

- 3000 MW = largest interconnection

NORDEL (North Europe)

- Continuous control = 600 MW/0.1 Hz
- Frequency response = 1000 MW, if frequency drop to 49,5 – 49,9 Hz

Secondary control reserves

Should reset the primary control reserves in 5 – 15 minutes to be ready for next disturbance

Should correct the frequency deviation within allowable limit

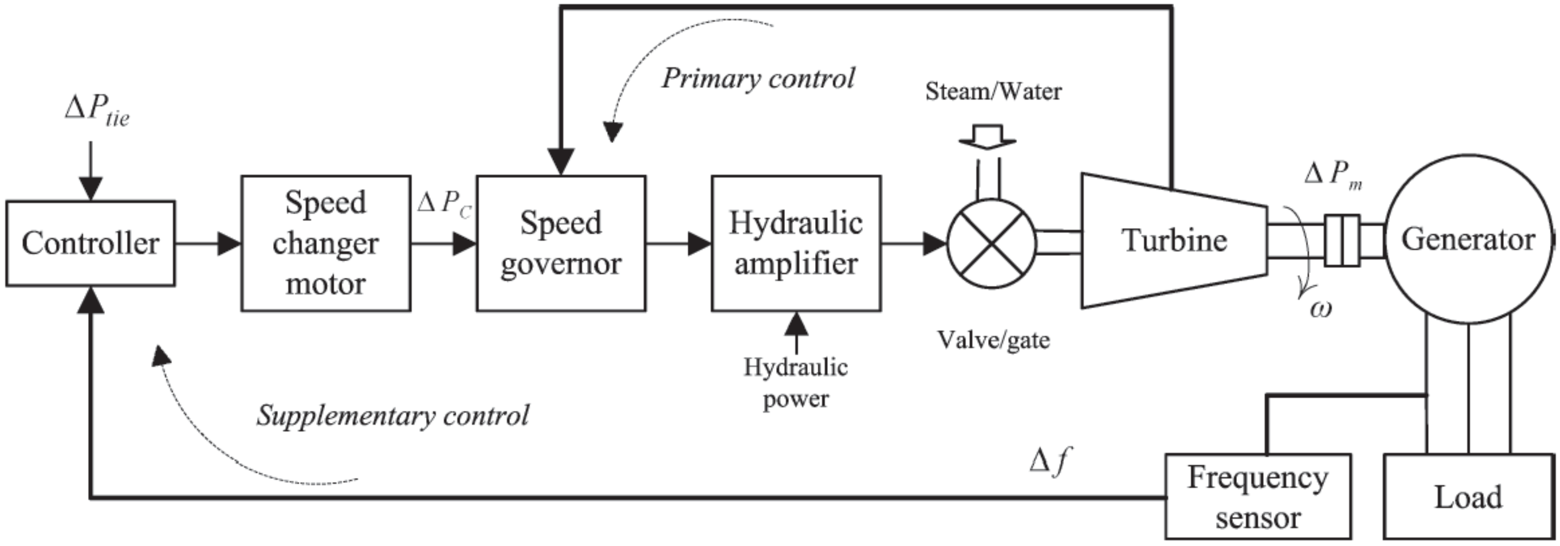
- +/- 0.1 Hz in Nordel
- +/- 0.2 Hz in UCTE

Supplementary/Secondary Control

Frequency deviation feedback

PI or I controller

Connected to economic dispatch system



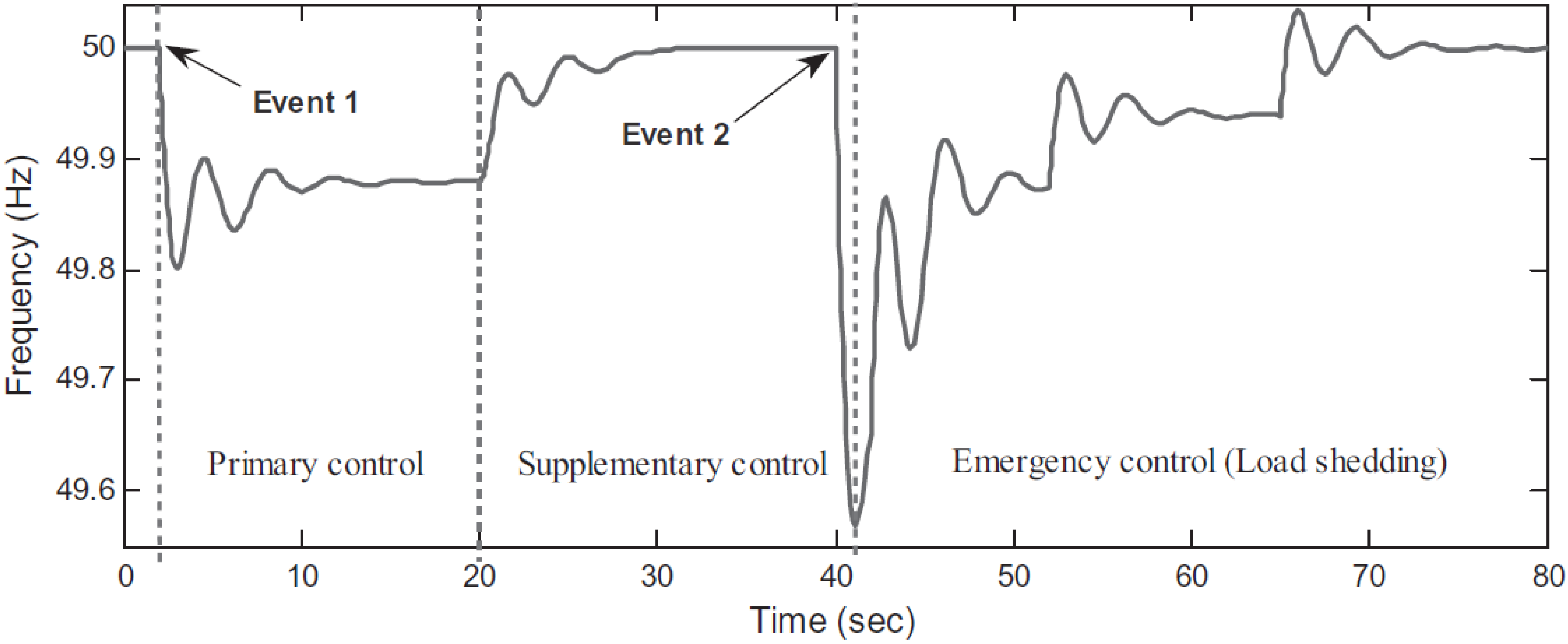
Under frequency Load Shedding (UFLS)

To prevent extended operation of separated areas at low frequency, load shedding schemes are employed.

A typical scheme for USA:

- 10% load shed when frequency drops to 59.2 Hz
- 15% additional load shed when frequency drops to 58.8 Hz
- 20% additional load shed when frequency reaches 58.0 Hz

Example



Event 1
Event 2
Primary control
Supplementary control
Emergency control (Load shedding)
Frequency (Hz)
50
49.9
49.8
49.7
49.6
0
10
20
30
40
50
60
70
80
Time (sec)

Voltage Control

Control of voltage levels is carried out by controlling the production, absorption, and flow of reactive power

Generating units provide the basic means of voltage control. synchronous generators

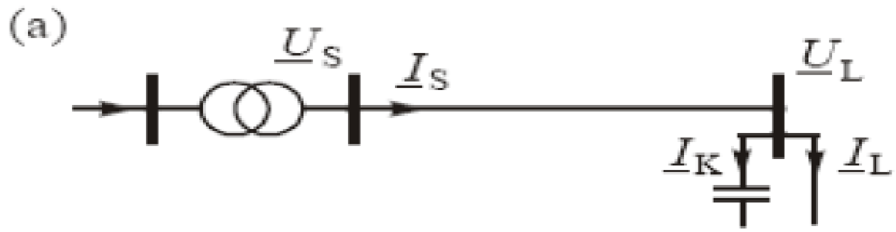
- can generate or absorb Q depending on excitation
- automatic voltage regulator continuously adjusts excitation to control armature voltage
- primary source of voltage support

Voltage Control

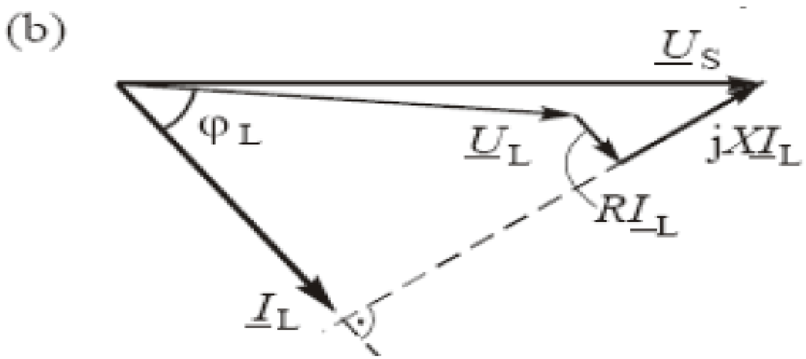
Additional means are usually required to control voltage throughout the system:

- sources or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers, and static var compensators (SVCs)
- line reactance compensators, such as series capacitors
- regulating transformers, such as tap-changing transformers and boosters

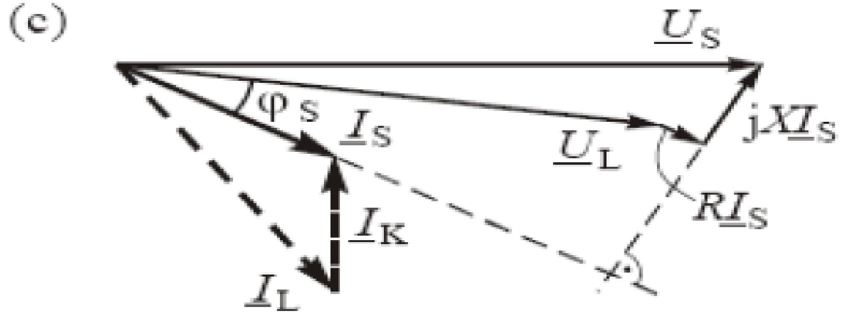
Example: Shunt Compensation



a) shunt compensation



b) phasor diagram without compensation



c) phasor diagram with compensation

Introduction to LAB 1

Using ARISTO

Aim of Lab1

To introduce

- Basic operational phenomena in a typical power system
- Corresponding countermeasures
- Real time simulations
- Dynamic behaviour of power system

What is ARISTO

The *ARISTO* system is a fast, interactive power system dynamics simulator for learning and analysis.

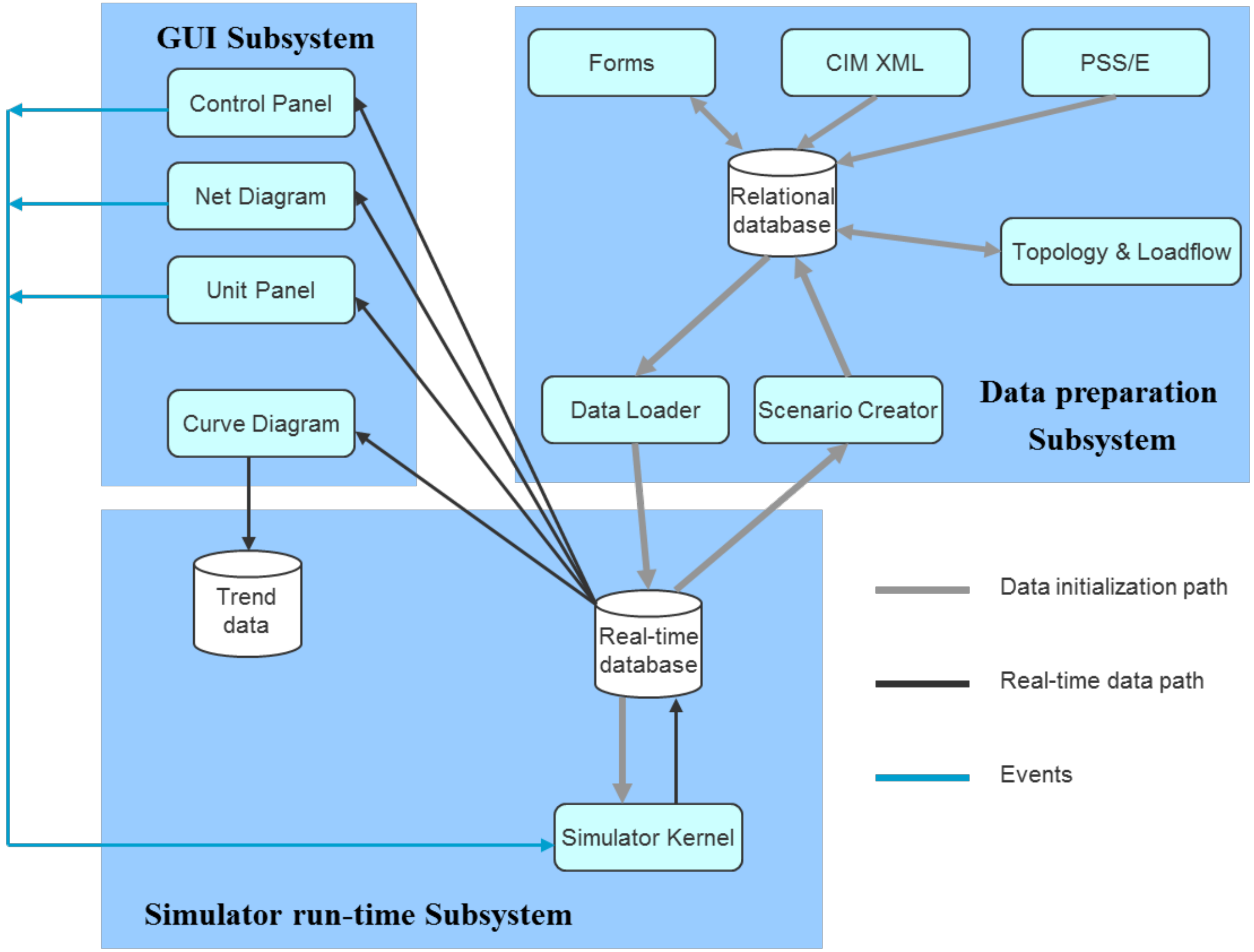
The simulator is capable of real-time simulation of large systems.

Simulation of very large systems is possible with a slower simulation speed.

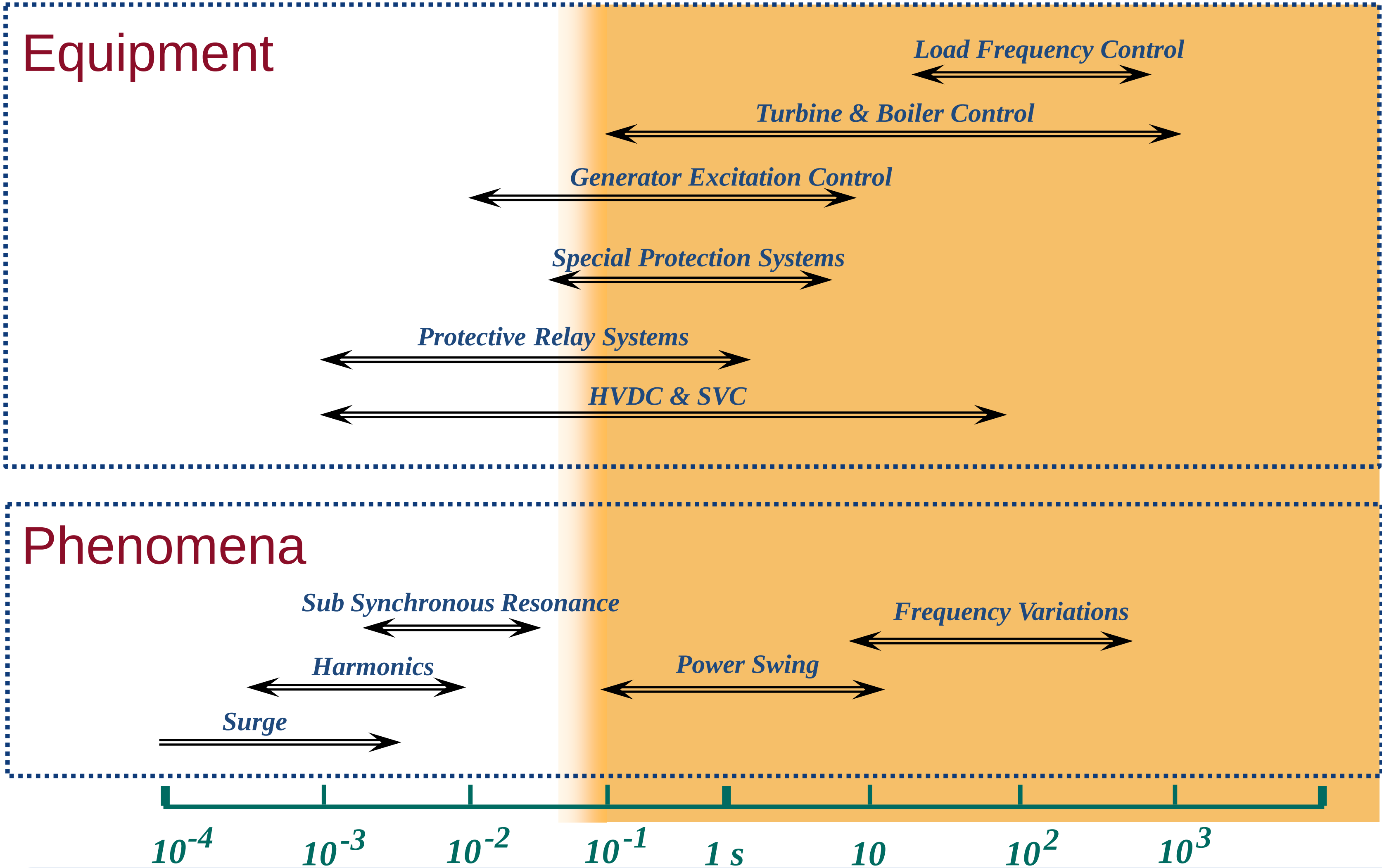
The phenomena to be simulated are:

- Transient stability.
- Long term dynamics.
- Voltage stability.

System Overview



What can be modeled?



Exercises - Scenarios

Task 1: Voltage Support

- Injection / Consumption of reactive power

Task 2: Voltage Collapse in a power system (N-1 Operation)

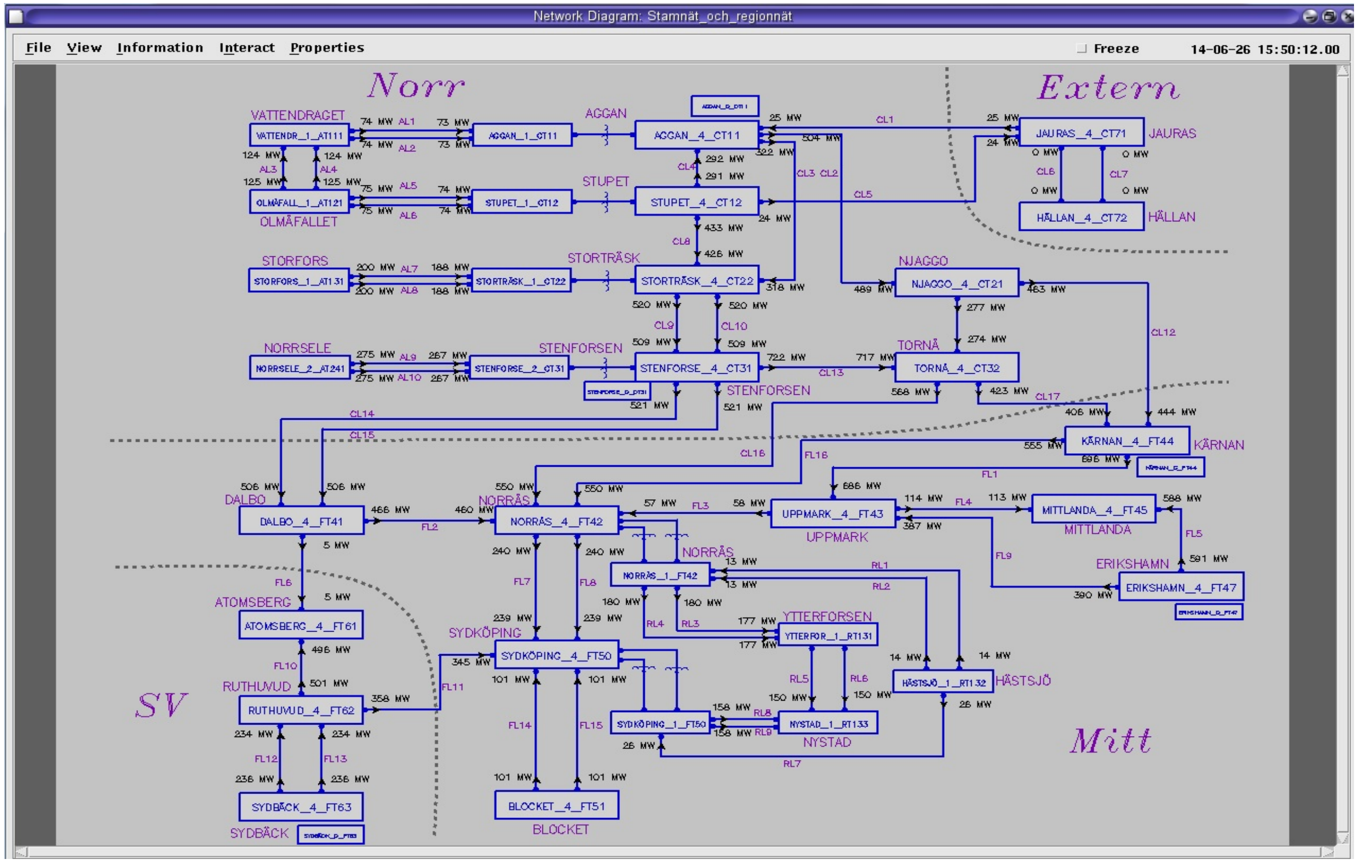
- Operation of Line Distance Protection (LDP) relays
- Islanding of power system due to voltage instability

Task 3: Frequency control along with load shedding

- Primary Frequency Control (Governor Droop Characteristics)
- Secondary Frequency Control (Manual)
- Under Frequency Load Shedding

Exercises - Model

- Simulations are performed with NORDIC 32 test system



Nordic 32 system description

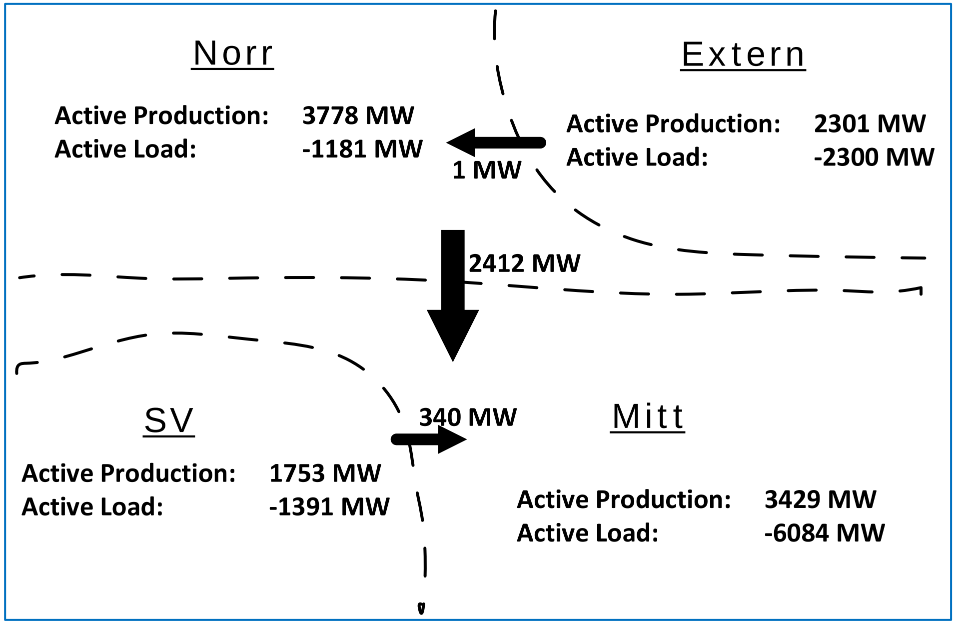
Buses
32 Buses
21 PV buses, 10 PQ buses, 1 Slack bus
19 buses 400kV, 11 buses 135kV, 2 buses 220kV

Transmission lines
52 Lines
33 Lines in 400kV, 17 Lines in 135kV
and 2 Lines in 220kV

Loads
21 buses have loads connected to them

Generators
39 Generators
23 Hydro stations, 15 Thermal Stations and 1 Synchronous compensator
21 buses have generators

Shunts
22 buses have shunts connected
3 buses have both shunt reactors and shunt capacitors
11 buses have shunt reactors alone, 8 buses have shunt capacitors alone



Exercises - Outcome

- Getting started with ARISTO real time simulator
- Operation and control of a typical power system
- Voltage stability
- Operation of Line Distance Protection (LDP) relays
- Primary and Secondary Frequency control

Question?