Lecture 4 – Fundamentals of Power System Operation
Barış Sanlı
Review

- Remember the hand dynamo?
  - More load -> slower return
  - More generation -> faster return
- Reactive (balancing of bicycle)
- History
  - Electric and magnetic understanding
Question

If there is no storage, how system matched load and supply?
Resource

Explaining Power System Operation to Nonengineers,
Lennart Soder
The Grid

Active Power Balance

- All sprockets are connected with chains, they rotate at the same speed
- Bike rpm -> system frequency
- Some pedalling (generation)
- Some braking (loads)
- To keep constant speed
  - Total force

System frequency

- Some continuously look at the speed of the bike
- When speed decreases
  - They stoke to pedals
- When speed increases
  - They lose their strokes
Reactive Power Balance

- Midpoint

*Figure 1. Forces on the tandem bike*

*Figure 2. Forces on a four-person tandem bike*

System operation

Power system

- Power system measurements
  - Status information
    - e.g., Circuit breaker position
  - Analogue values
    - e.g., MW, MVar, voltages, frequency

Supervisory Control and Data Acquisition (SCADA)

SCADA direct control actions

Power system view
  - Alarms and messages

Operator control actions
Acceptable operating conditions

G_1 Rating = 500 MW
G_2 Rating = 700 MW
G_3 Rating = 900 MW

Transient stability limit:
- 1800 MW no line tripping
- 900 MW one line tripping
Generation planning & control
**Inertia**

- Tendency to stay at rest or remain in motion
- The larger the object the more inertia
- Rotating machines not generator
- Power System Stabilizers (PSS)
  - Installed on gens
  - Governors control (the amount of steam/water to turbines)
System Stability/Instability
Generator Dispatch Factors

- Availability of Sources
- Incremental Efficiency of each Source
- Transmission Losses
- Startup – Shutdown Costs & Constraints
- Fuel Costs
- Desired Generation for each Source
- Reserve Requirements
- Load Rate of Change
- High & Low Limit of Each Source
- Transmission Line Constraints
- Source Rate of Change

Evaluation and Calculation
Three uncertainty

- Capacity
- Ramp rate
- Ramp duration
31 July 2012 – India Blackout

Frequency profile as captured by IIT Bombay

Legend:
- Mumbai
- Kapur
- Bangalore
- Chennai
- Punjab
- Delhi
- Kerala
- Gujarat
- Maharashtra
- Rajasthan
- Andhra Pradesh
- Bihar
- Tamil Nadu
- Karnataka
- Telangana
- West Bengal
- Uttar Pradesh
- Assam
- Jammu and Kashmir
- Himachal Pradesh
- Odisha
- Madhya Pradesh
- Jharkhand
- NCR

Initiating Network Disturbance

Line Trippings due to large angular separation. Probably system separated at this point.
Power system stability

- Angular stability
  - Small-signal stability
  - Transient stability
- Voltage stability
  - Steady state
  - Large disturbance

Mid-term/long-term stability
Ancillary Services

1. **Energy**
2. Regulation & Load Following Services – AGC/Real time maintenance of system’s phase angle and balancing of supply/demand variations.
3. Synchronised Reserve – 10 min Spinning up and down
4. Non-Synchronised Reserve – 10 min up and down
5. Operating Reserve – 30 min response time
6. Voltage Support – RPS, Locational Specific
7. Black Start – (Service Contracts)
CAISO - balancing functions
Integrated Operation
Multi-settlement market design
Duck Curve

Net load—March 31

- Overgeneration risk
- Ramp need ~13,000 MW in 3 hours
Germany's eclipse is poised to cause a rapid decrease in solar power supply, followed by a rapid increase.

Expected solar electric output (gigawatts) in Germany on March 20, 2014

Steep decrease in solar power supply

Steep increase in solar power supply

Modeled values assume clear-sky (i.e. cloudless) conditions. Adapted from source: Hochschule für Technik und Wirtschaft Berlin (October 2014).
How regulation works
ACE (Area control error)

- Certain types of generating units can move up and down in 4s. (regulation units)
- AGC (Automatic generation control)
  - Output of regulation units adjusted (secondary)
- Governors are primary frequency controls
In Europe

- Primary freq reserves
  - 30 seconds
- Secondary freq reserves
  - 15 minutes
- Tertiary freq reserves
  - Slower, take primary & secondary back to reserve
Network Security

• Contingency
  – N-1

• Facility Thermal Limitation
  – Can cause conductors to sag or stretch
Thank you

• For more info

www.barissanli.com