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Lecture 15
EMS Application II
Automatic Generation Contol

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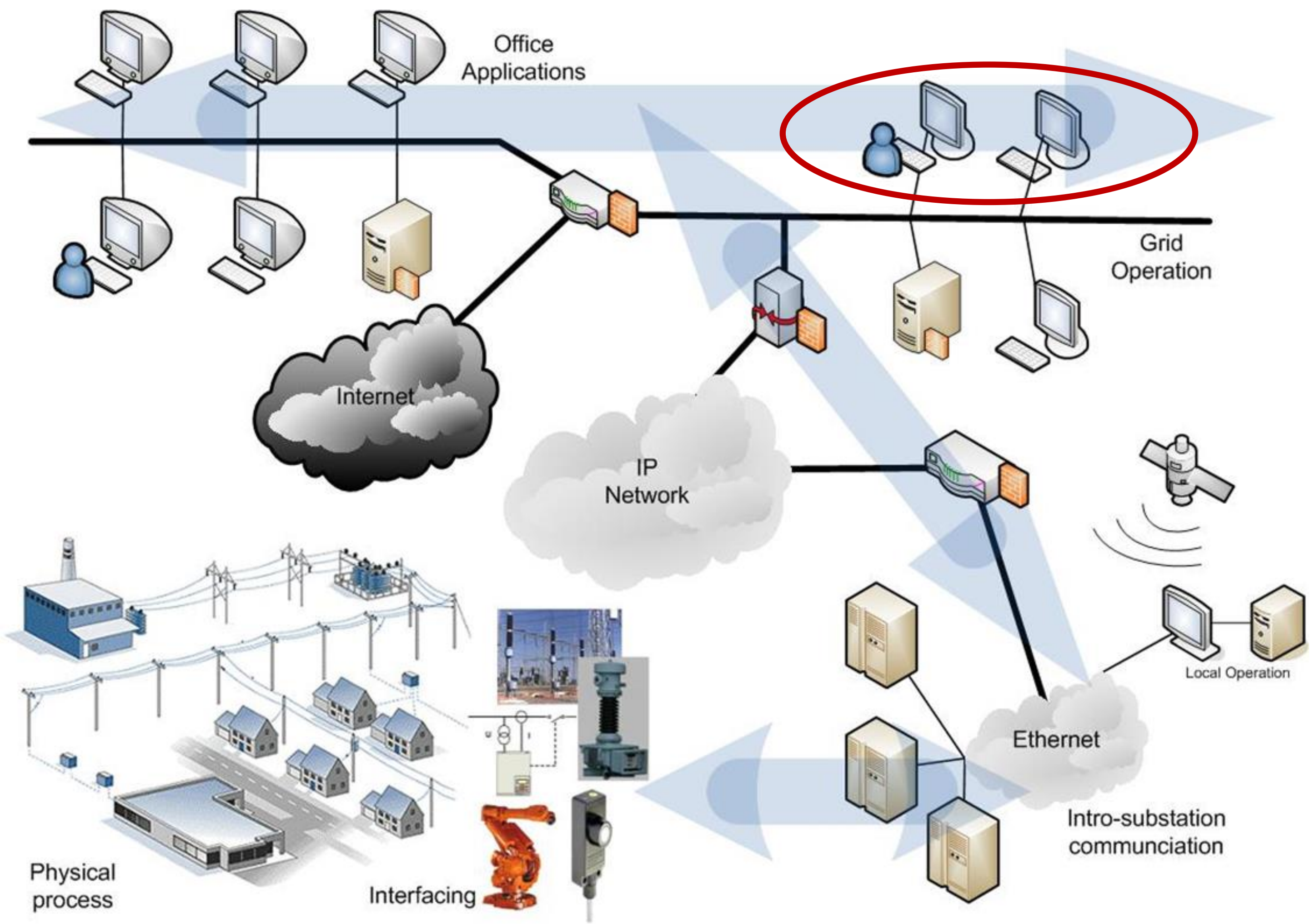
2015-12-03

Outline

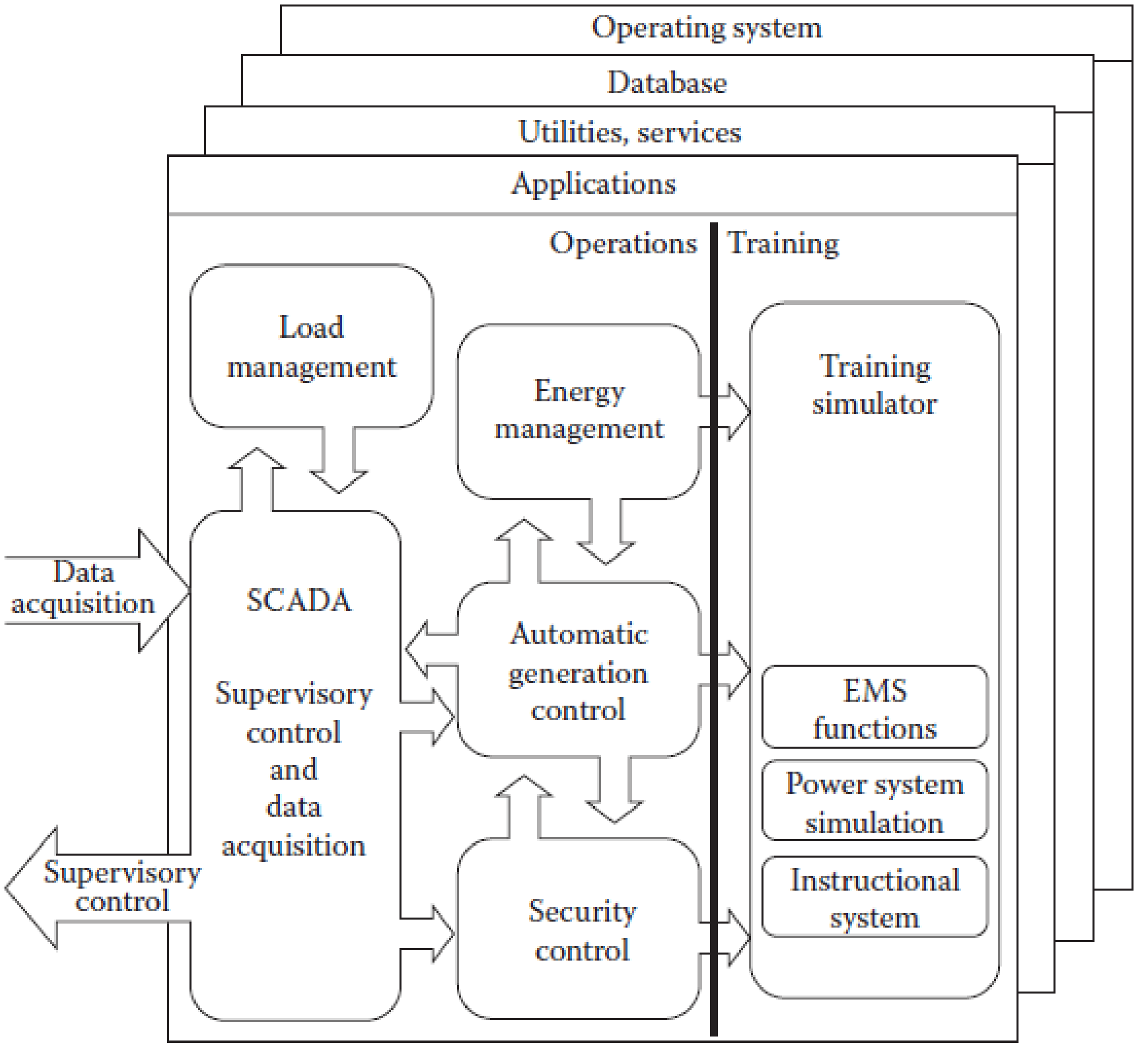
- Generation Control
  - Why
  - How
- AGC design
  - Area Control Error
  - Parameter Calculation

Course road map



Recall!

SCADA / EMS (Energy Management System)



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Introduction to Generation Control

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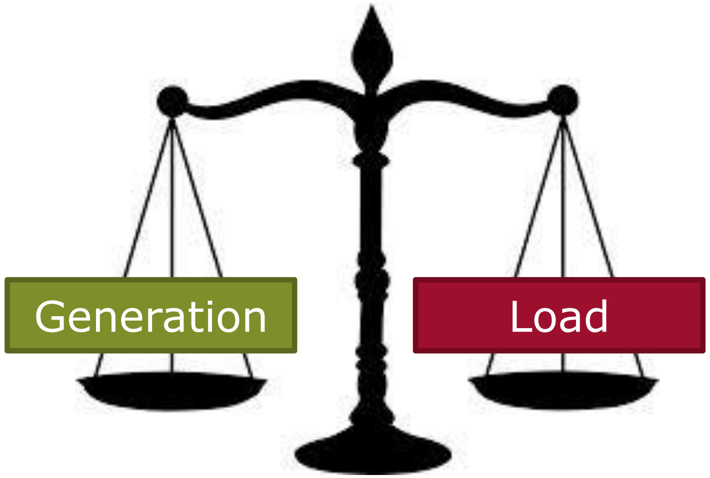
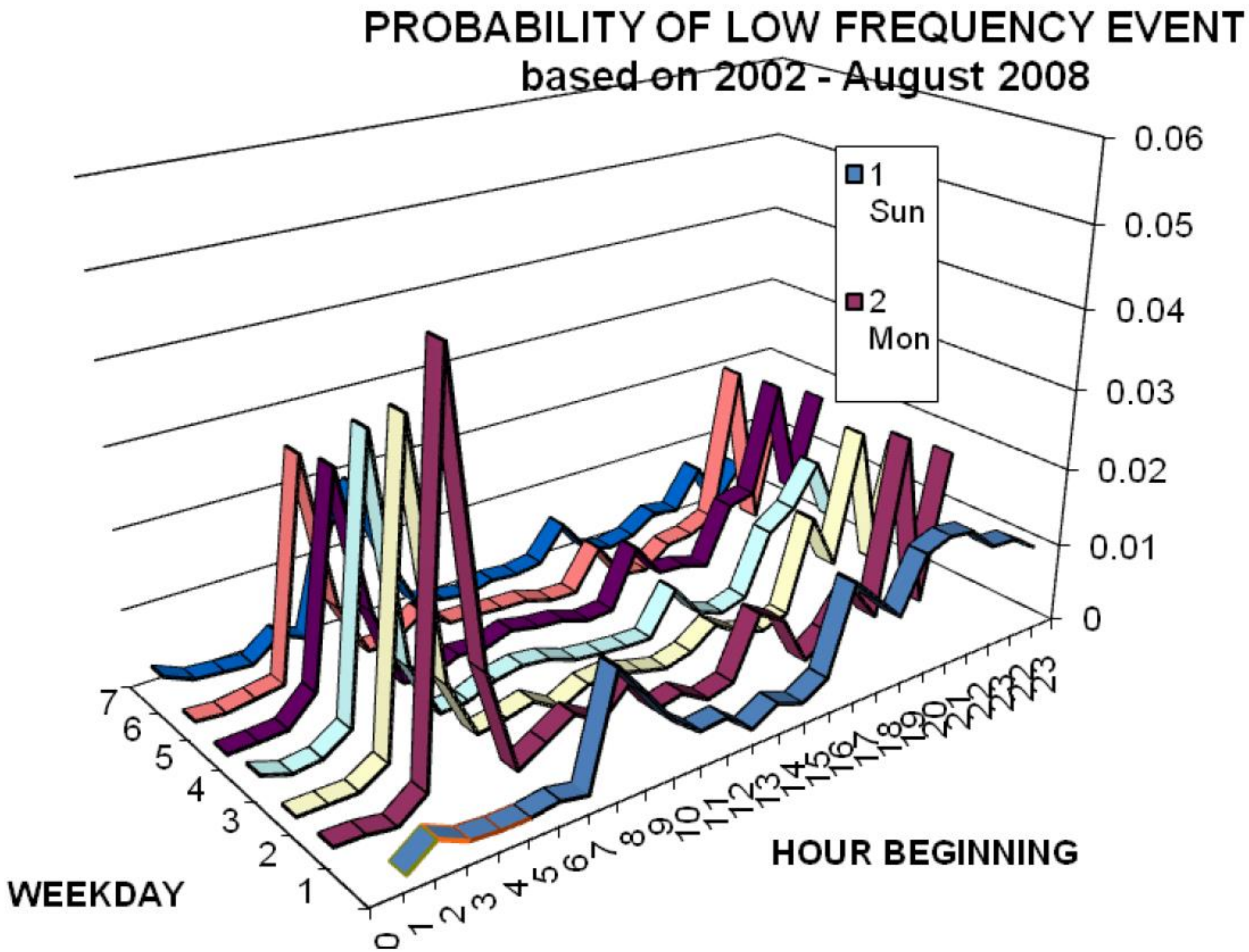
Load & Generation Balance

- 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

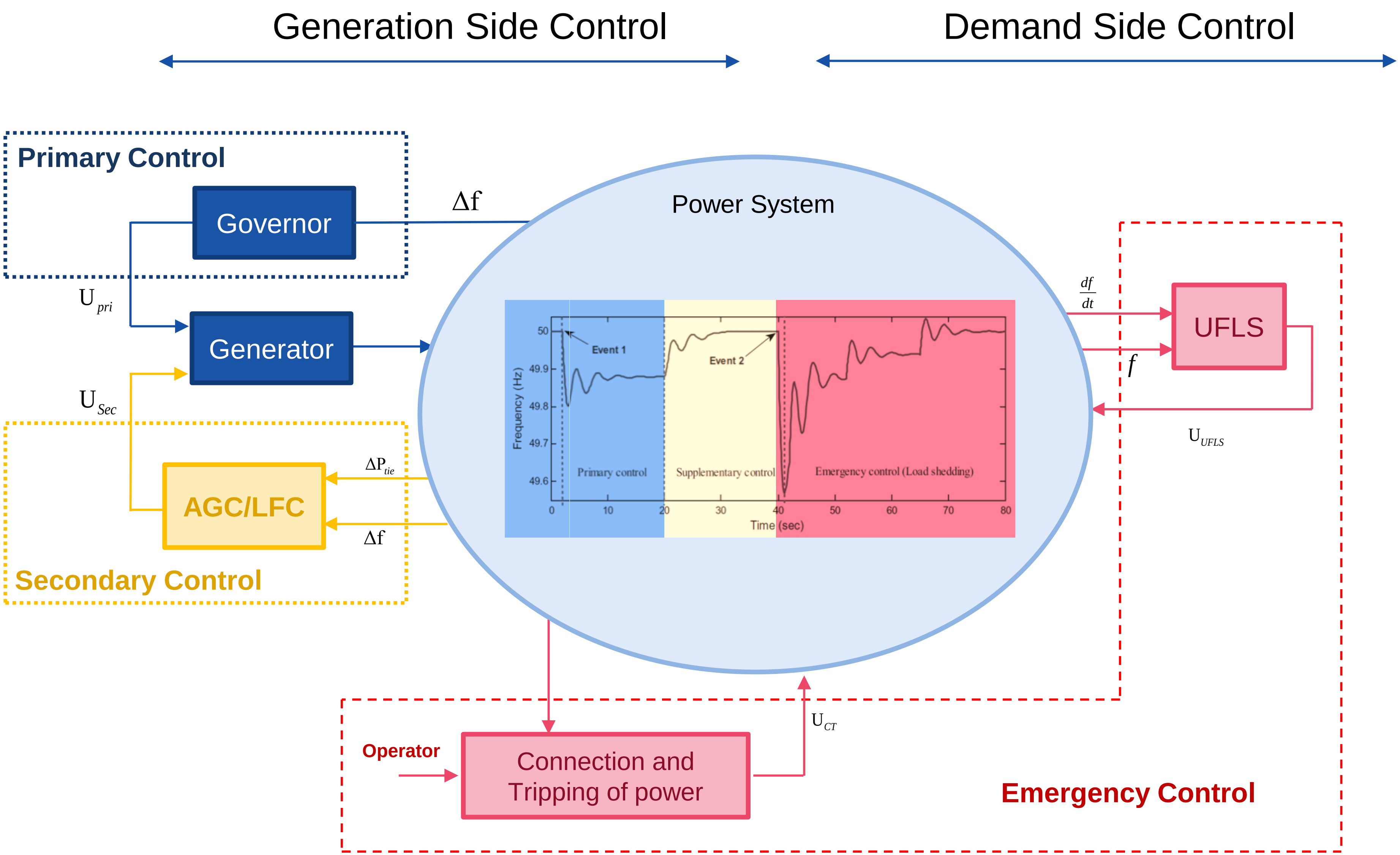
$$\Delta P \longrightarrow \Delta f$$



Frequency disturbances

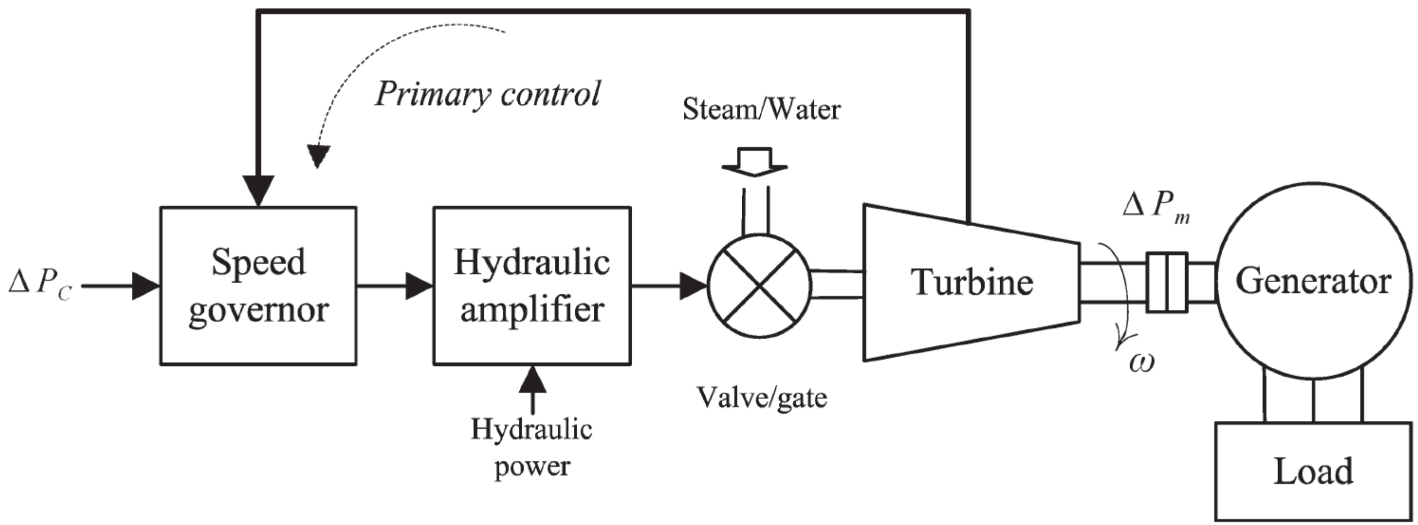


Frequency Control Actions



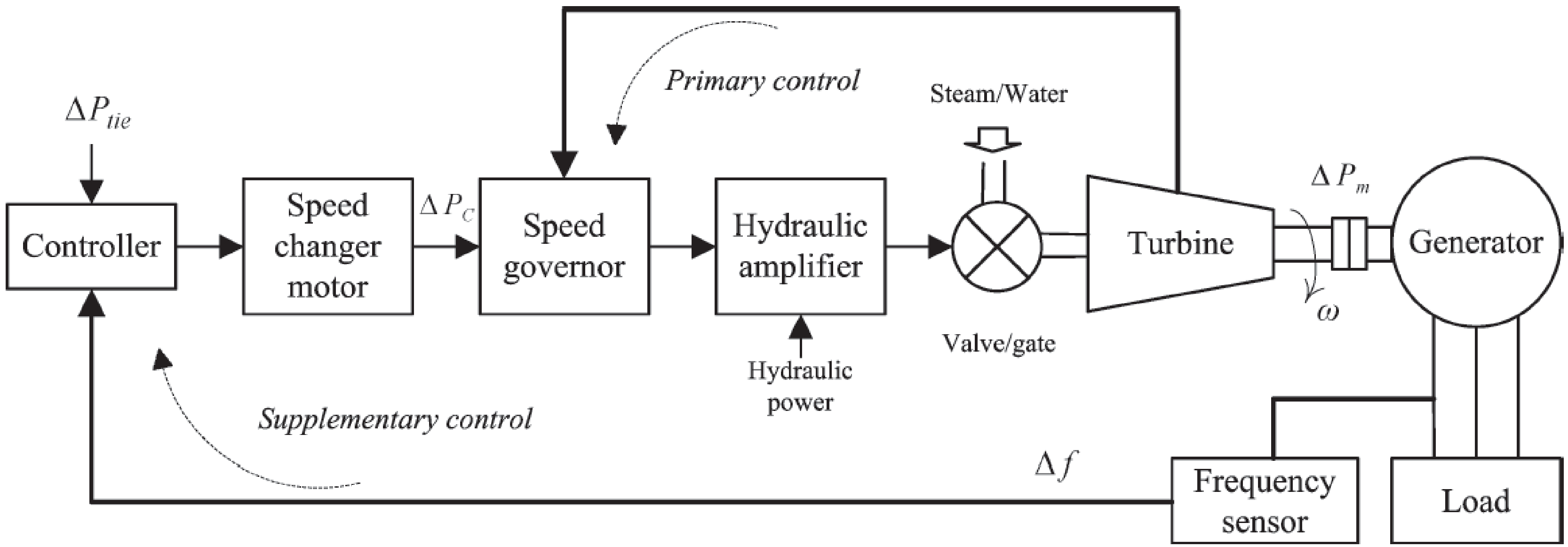
Primary Control / Frequency Response

- Generation is controlled by mechanical output of the prime mover
- The *speed governor* senses the change in speed (frequency)



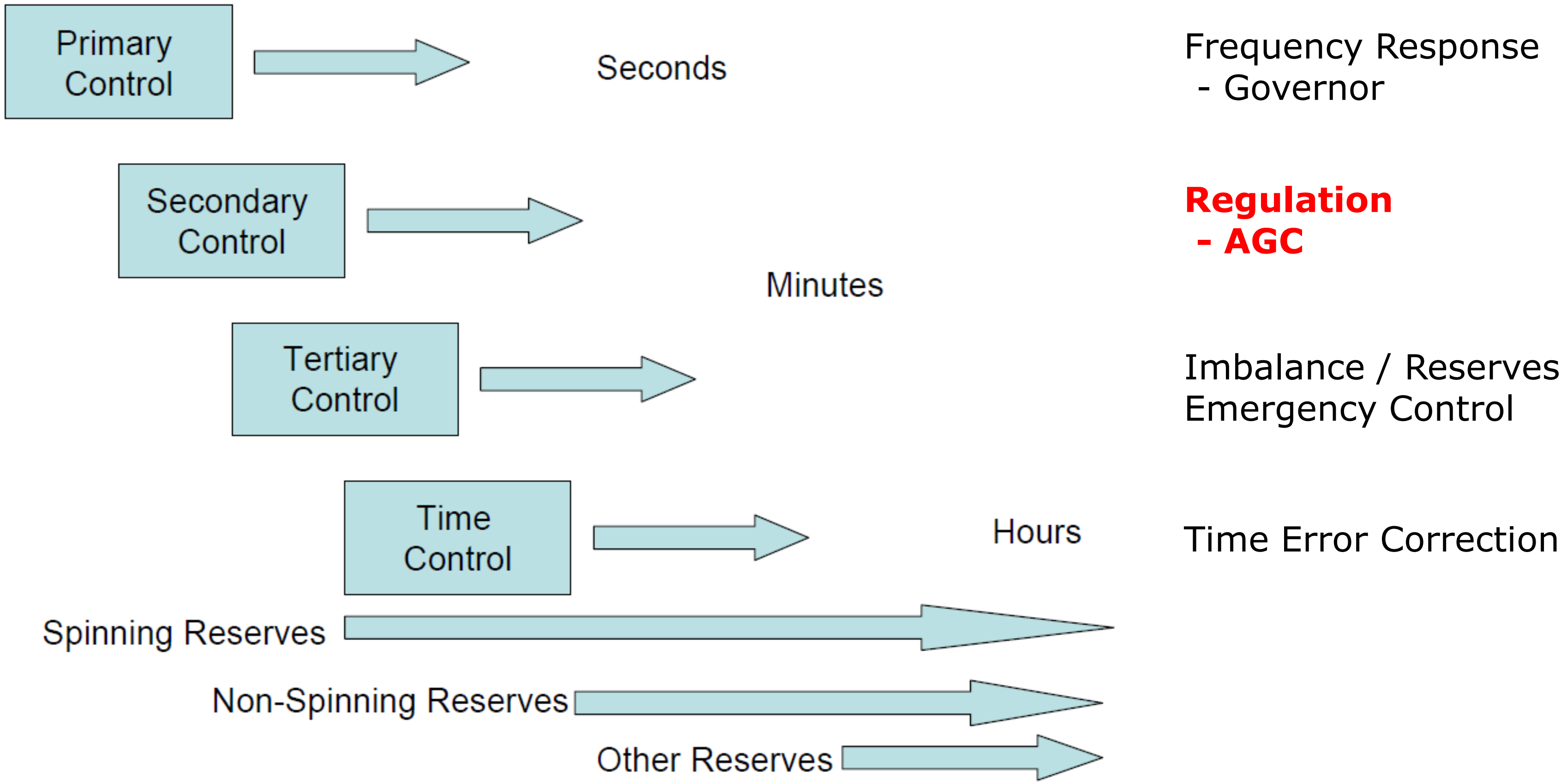
Supplementary/Secondary Control

- Frequency deviation feedback
- PI or I controller
- Part of AGC



Frequency control time frame

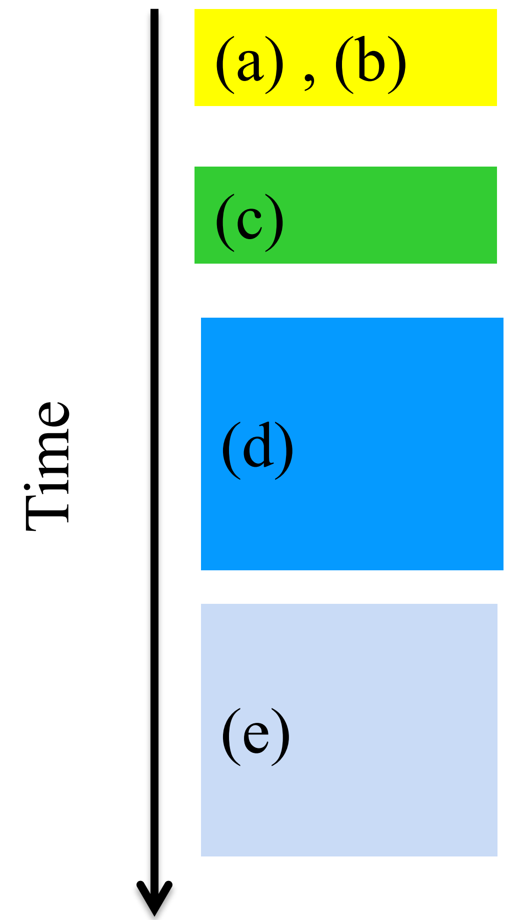
- Balancing and frequency control occur over a continuum of time using different resources



NERC technical report, 2011

Operating Reserves

Operating Reserves		
On-Line	**Regulating Reserve (a)** **Spinning Reserve (b)**	**Other On-Line Reserve (d)**
Off-Line	**Non-Spinning Reserve (c) such as Interruptible Load Fast-Start Generation**	**Other Off-Line Reserve (e) such as Curtailable Load Off-Line Units**
	<= 10 min	**10-60 min**



Operating reserves

- Spinning Reserve
  - the on-line reserve capacity that is synchronized to the grid system and ready to meet electric demand within 10 minutes of a dispatch instruction by the System Operator.
  - to maintain system frequency stability during emergency operating conditions and unforeseen load swings.
- Non-Spinning Reserve
  - off-line generation capacity that can be ramped to capacity and synchronized to the grid within 10 minutes of a dispatch instruction by the System Operator
  - and that is capable of maintaining that output for at least two hours. Non-Spinning Reserve is needed to maintain system frequency stability during emergency conditions.

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Automatic Generation Control

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Generation Control System

- The Generation Control system contains real-time processes that regulate the generation of power in accordance with operational and economic constraints

- maintains system frequency and control area net interchange at their scheduled values.

- divided into the following sections:
  - Automatic Generation Control (AGC)
  - Economic Dispatch (ED)

Automatic Generation Control (AGC)

- The Automatic Generation Control (AGC) regulates the output of electric generating units in order to maintain the power system frequency and/or control area net interchange to their scheduled values.

- AGC can also regulate the power output of electric generating units to ensure compliance with the current system production schedule.

Economic Dispatch (ED)

- The Economic Dispatch (ED) function calculates the optimum basepoints for in-service economically dispatchable generating units
- The economically dispatchable generating units are controlled generating units that can be modeled as thermal units or hydro units.

Generation Control Functions

Generation Control Applications

Automatic Generation Control

- Regulates the generating unit MW outputs

Reserve Monitoring

- Calculates and monitors system reserves to meet reliability requirements

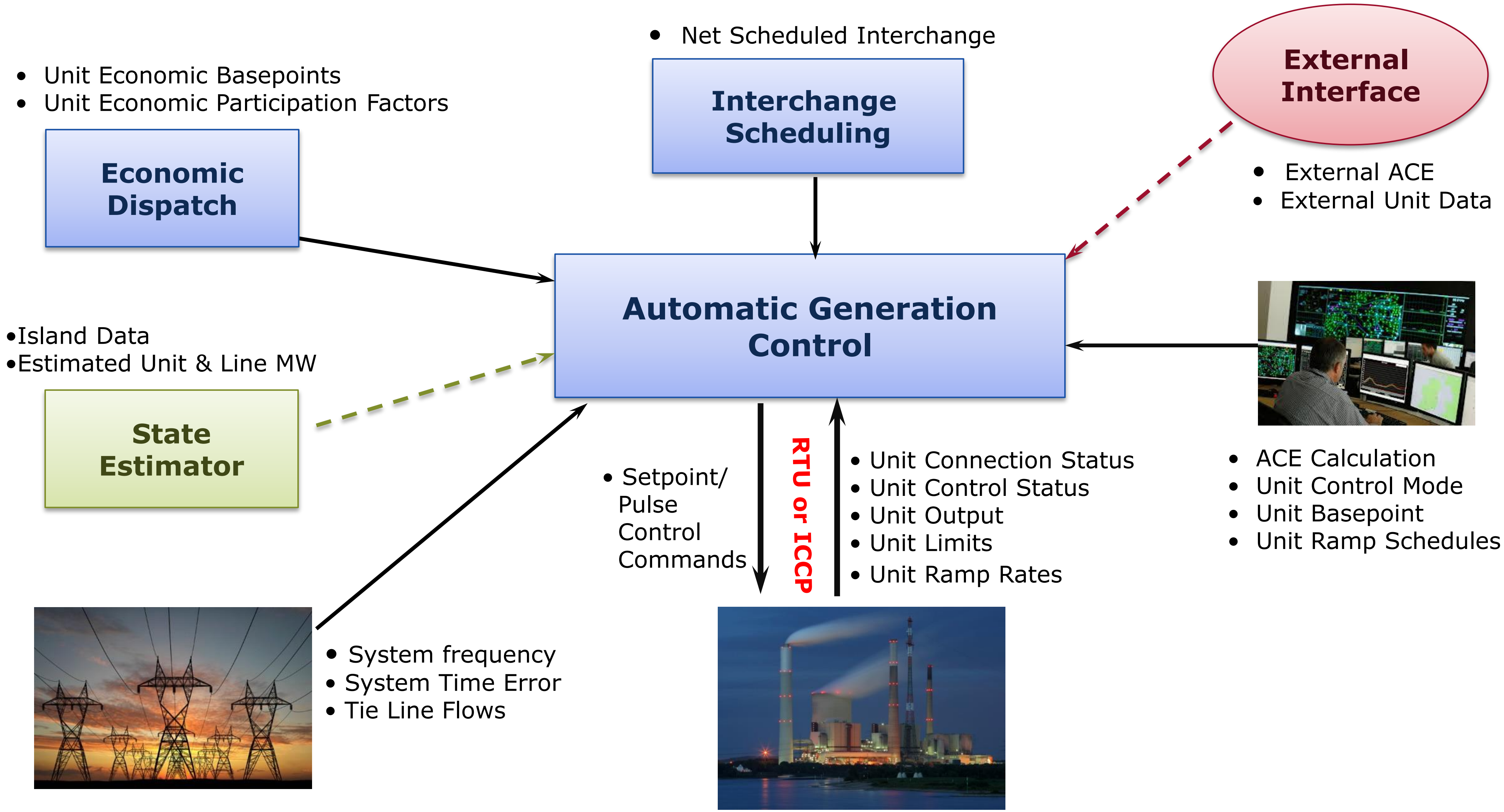
Economic Dispatch

- Provides economic basepoints and participation factors
- Optional Hydro Calculation function

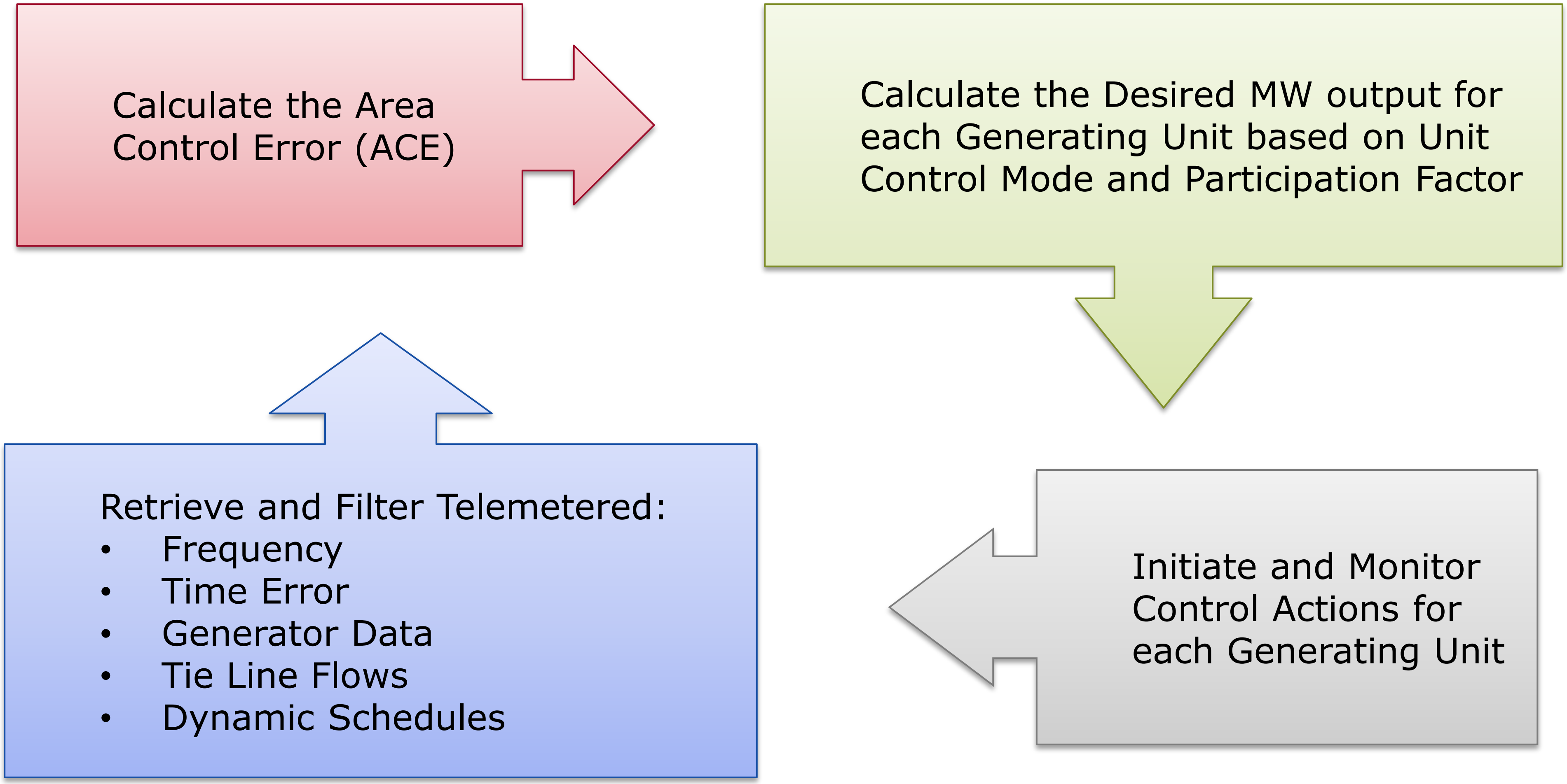
Production Cost Calculation

- Calculates fuel usage and production costs

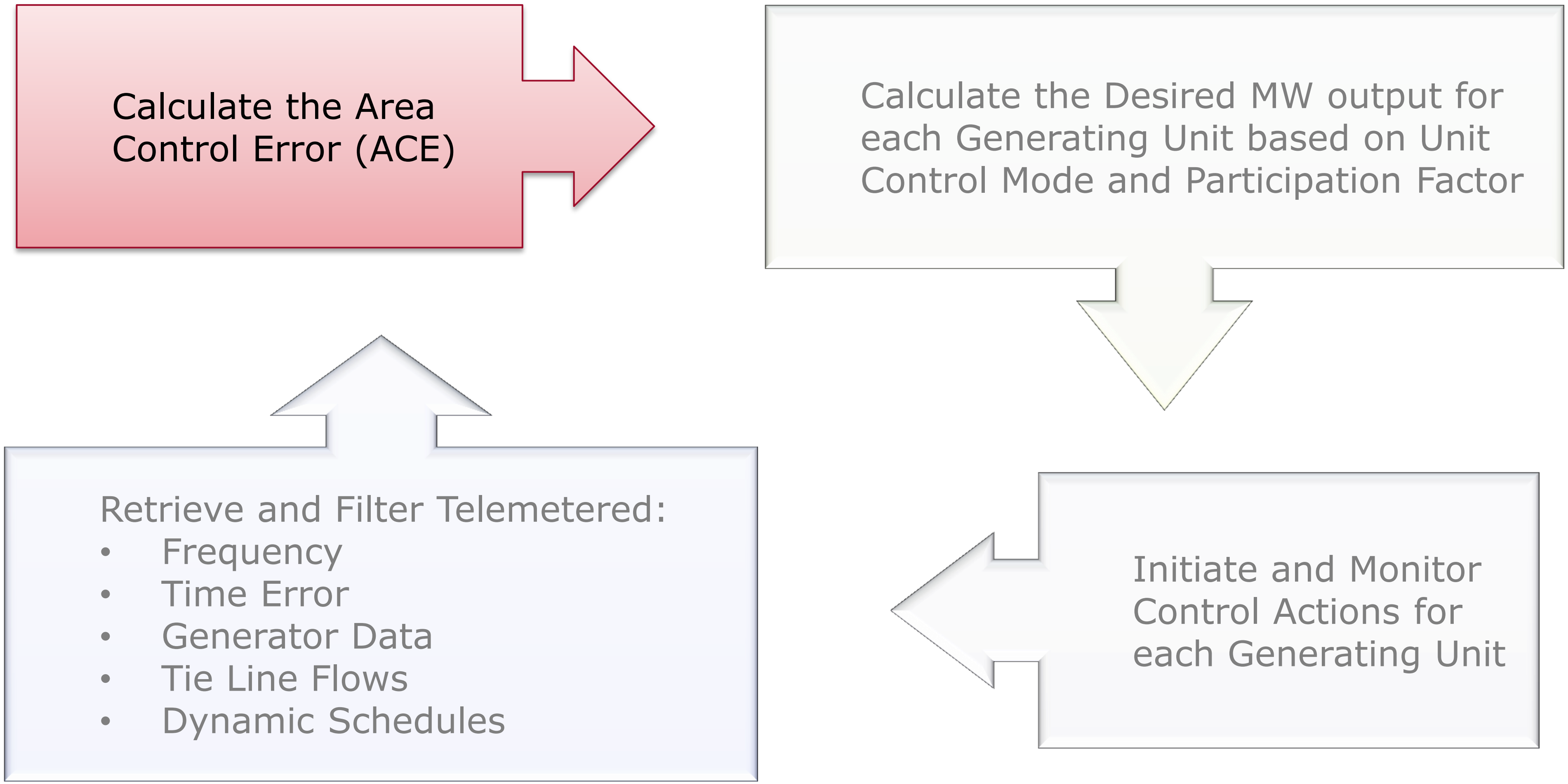
Automatic Generation Control Interfaces



AGC closed Loop Control

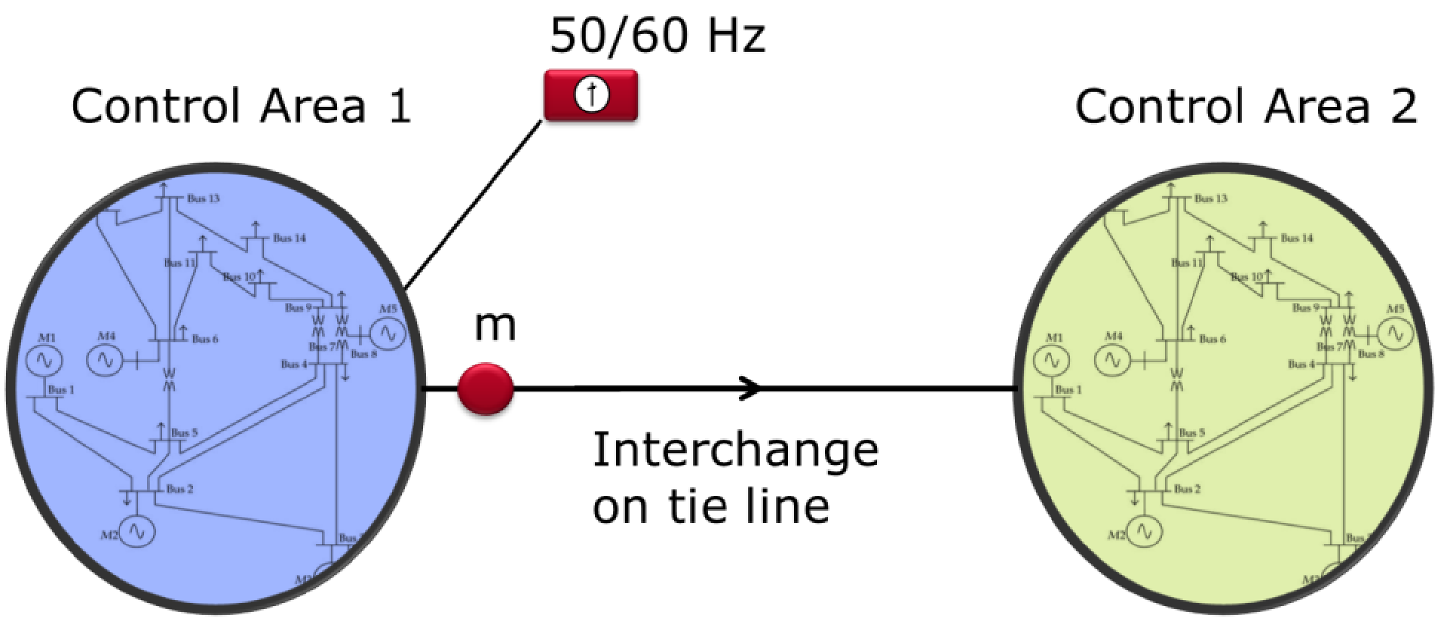


AGC closed Loop Control



AGC Control Area

- A coherent area consisting of a group of generators and loads, where all the generators respond to changes in load or speed changes settings, in unison.
- Frequency is assumed to be same in CA.



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Area Control Error

- Demand and generation are constantly changing within all Control Areas.

- This means Balancing Authorities will usually have some unintentional outflow or inflow at any given instant.

- This mismatch is represented via a real-time value called **Area Control Error** (ACE), estimated in MW.

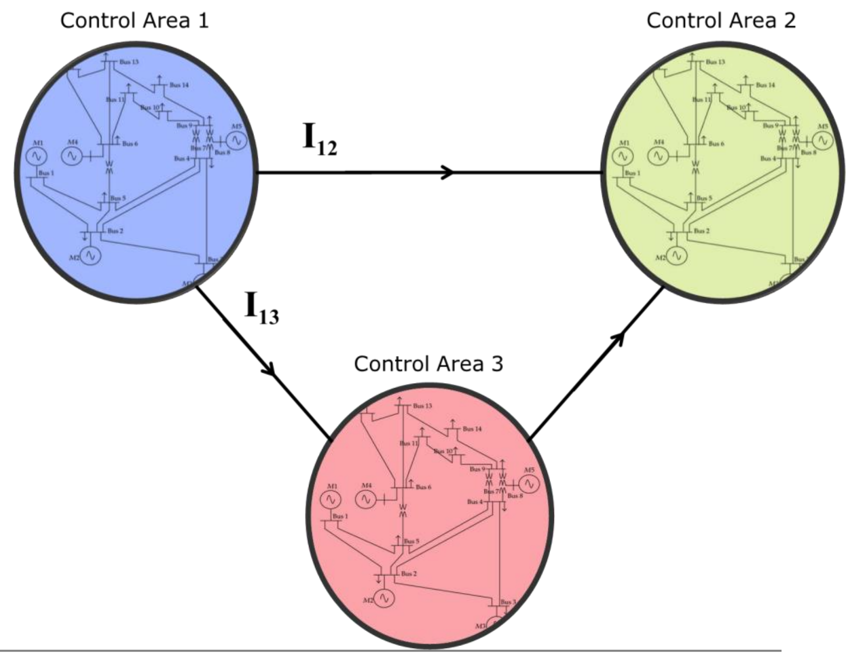
AGC Tie-Line

- A tie-line is a transmission line connecting two different Control Areas
- All tie-lines in a system must be specified
- Updated measurements of active power must be available for all tie-lines
- There may be more than one tie-line connecting two Control Areas
- Only net interchange is controlled, individual tie-lines are not controlled.

Interchange on tie lines

- Actual Net Interchange (NI_A)
  - the algebraic sum of tie line flows of a Control Area.
- Scheduled Net Interchange (NI_S)
  - the net of all scheduled transactions with other Control areas.
- Usually, flow into a Control Area is defined as negative. Flow out is positive.

$$NI_{A1}=I_{12}+I_{13}$$



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ACE Calculation Methods

- Flat Frequency Control
  - Calculated based on minus the frequency bias
- Flat Tie Line Control
  - Calculated based on the net interchange
- Tie Line Bias Control
  - calculated as the net interchange deviation minus the frequency bias

Flat Frequency Control

- ACE is calculated as minus the frequency bias.
- This term is the balancing authority's obligation to support frequency

$$ACE = -10B\,(f_a - f_s)$$

f_a = Actual frequency (Hz)

f_s = Scheduled frequency (Hz)

B = Balancing authority's frequency bias constant (MW/0.1Hz)

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Flat Tie Line Control

- ACE is calculated as the net interchange deviation, that is, the deviation of actual net interchange from the scheduled net interchange.

$$ACE = (NI_A - NI_S) - I_{ME}$$

NI_A = Net Interchange, Actual

NI_S = Net Interchange, Scheduled

I_{ME} = Meter error correction

Tie Line Control

- ACE is calculated as the net interchange deviation, that is, the deviation of actual net interchange from the scheduled net interchange.

$$ACE = (NI_A - NI_S) - 10B\,(f_a - f_s) - I_{ME}$$

f_a = Actual frequency (Hz)

f_s = Scheduled frequency (Hz)

NI_A = Net Interchange, Actual

NI_S = Net Interchange, Scheduled

I_{ME} = Meter error correction

Meter error correction

- The meters that measure instantaneous flow are not always as accurate as the hourly meters on tie lines.
- check the error between the integrated instantaneous and the hourly meter readings.
- If there is a metering error, a value should be added to compensate for the estimated error. This value is I_{ME}. This term should normally be very small or zero.

ACE example

- Assume a Balancing Authority with a Bias of -50 MW / 0.1 Hz is purchasing 300 MW.
- The actual flow into the Balancing Authority is 310 MW.
- Frequency is 60.01 Hz.
- Assume no time correction or metering error.
- Tie Line Control Mode

ACE example (Cont')

$$ACE = (NI_A - NI_S) - 10B\,(f_a - f_s) - I_{ME}$$

$$ACE = (-310 - - 300) – 10 * (-50) * (60.01 – 60.00)$$
$$= (-10) – (-5) = -5 \text{ MW.}$$

- The Balancing Authority should be generating 5 MW more to meet its obligation to the Interconnection.
- Even though it may appear counterintuitive to increase generation when frequency is high, the reason is that this Balancing Area is more energy-deficient at this moment (-10 MW) than its bias obligation to reduce frequency (-5 MW).

Calculated Frequency Bias Constant

$$B = D + \sum_{i=1}^{n} \frac{1}{R_i}$$

D Area load bias contribution (Mw/01.Hz) due to the almost linear response of the system load to frequency deviation

$1/R_i$ frequency bias contribution (Mw/01.Hz) due to ***n*** online generating units

Load Bias Contribution

- linear response of the system load to frequency deviation

$$B = D + \sum_{i=1}^{n} \frac{1}{R_i}$$

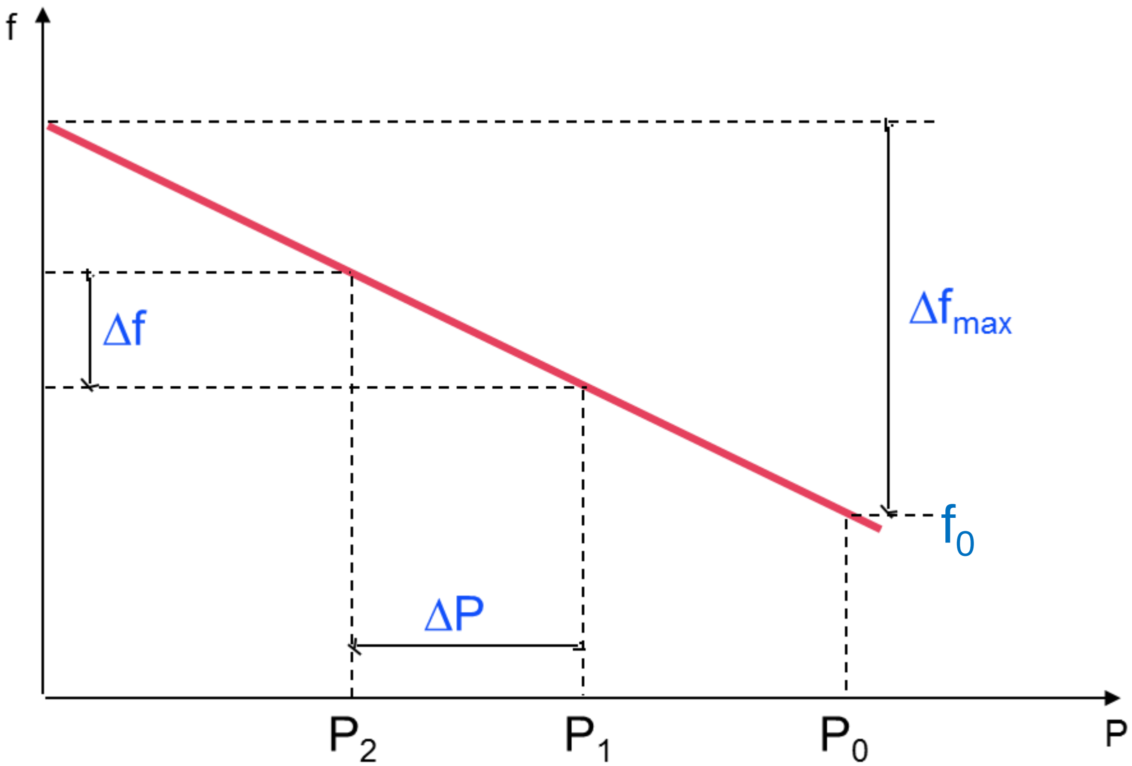
$$\mathbf{D = L_{damp} \ x \ L_n}$$

L_{damp} ⮝ area load damping factor (1/0.1Hz)

L_n ⮝ area total load (MW)

Estimation of Speed Droop

$$B = D + \sum_{i=1}^{n} \frac{1}{R_i}$$



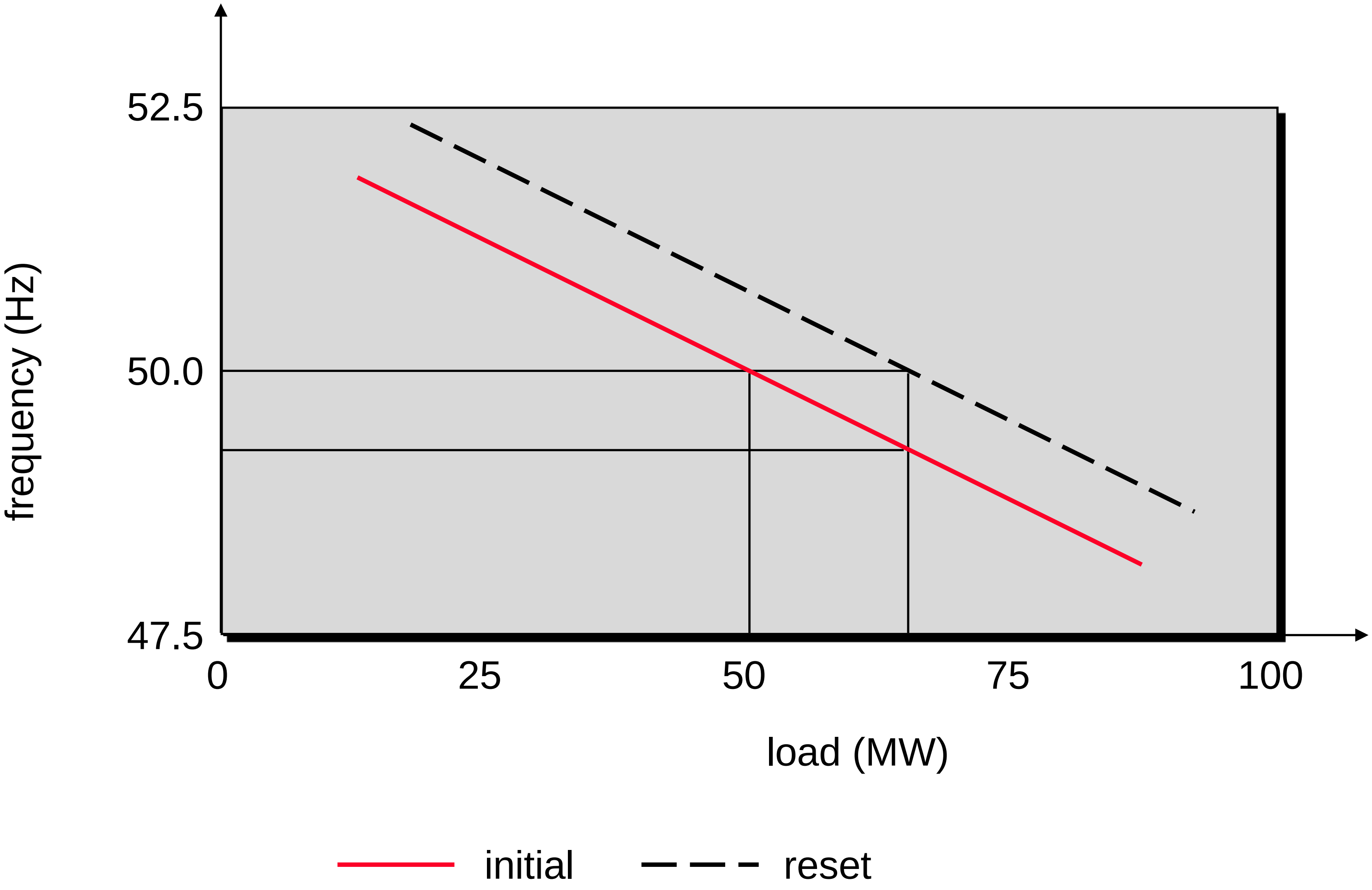
- Speed droop of the unit

$R_i = \Delta f / \Delta P$ (Hz/MW)

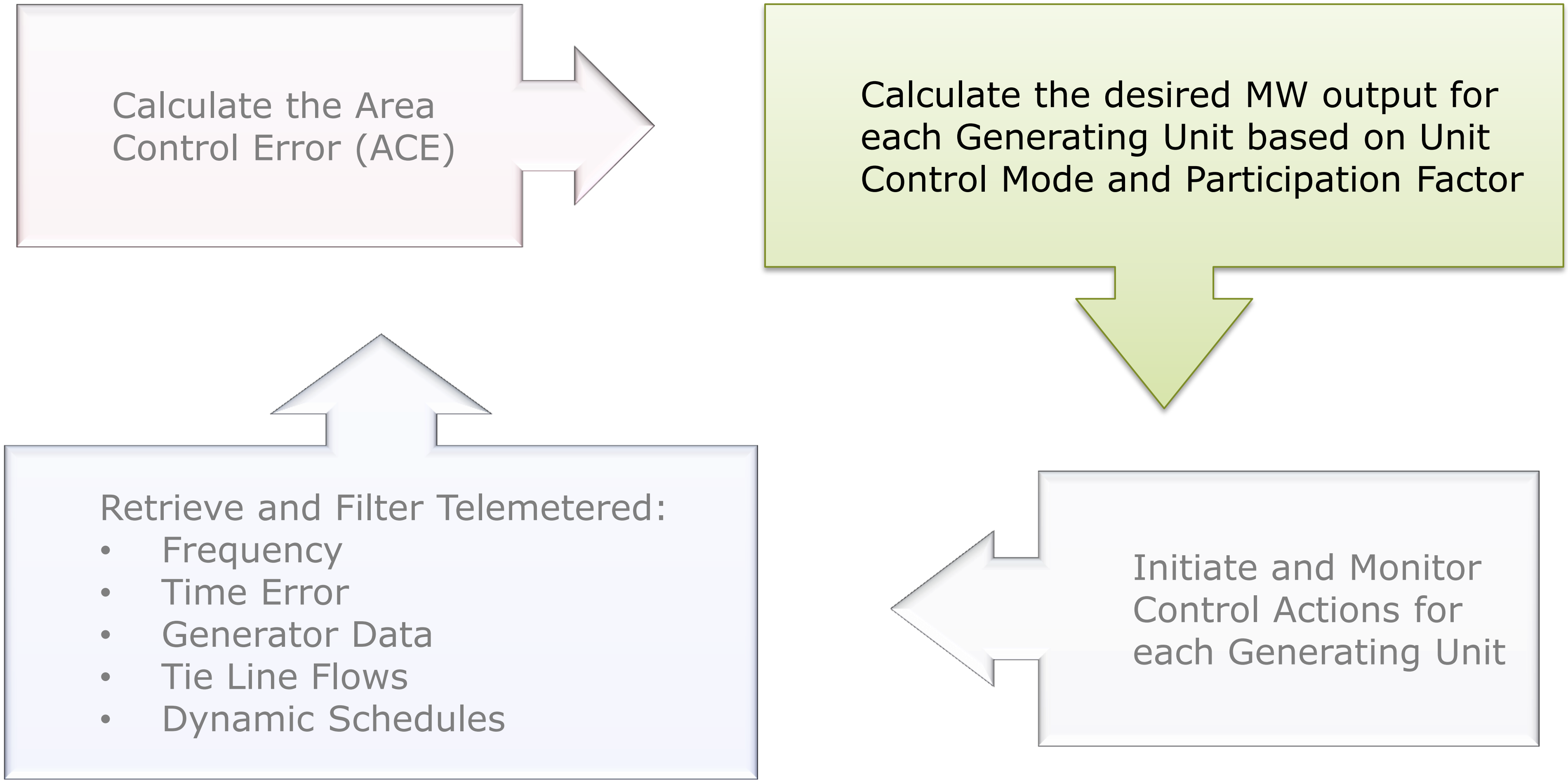
- Speed droop design

$$R_i = \frac{\Delta f_{max}}{P_0}$$

Governor Speed Regulation



AGC closed Loop Control



Participation Factor

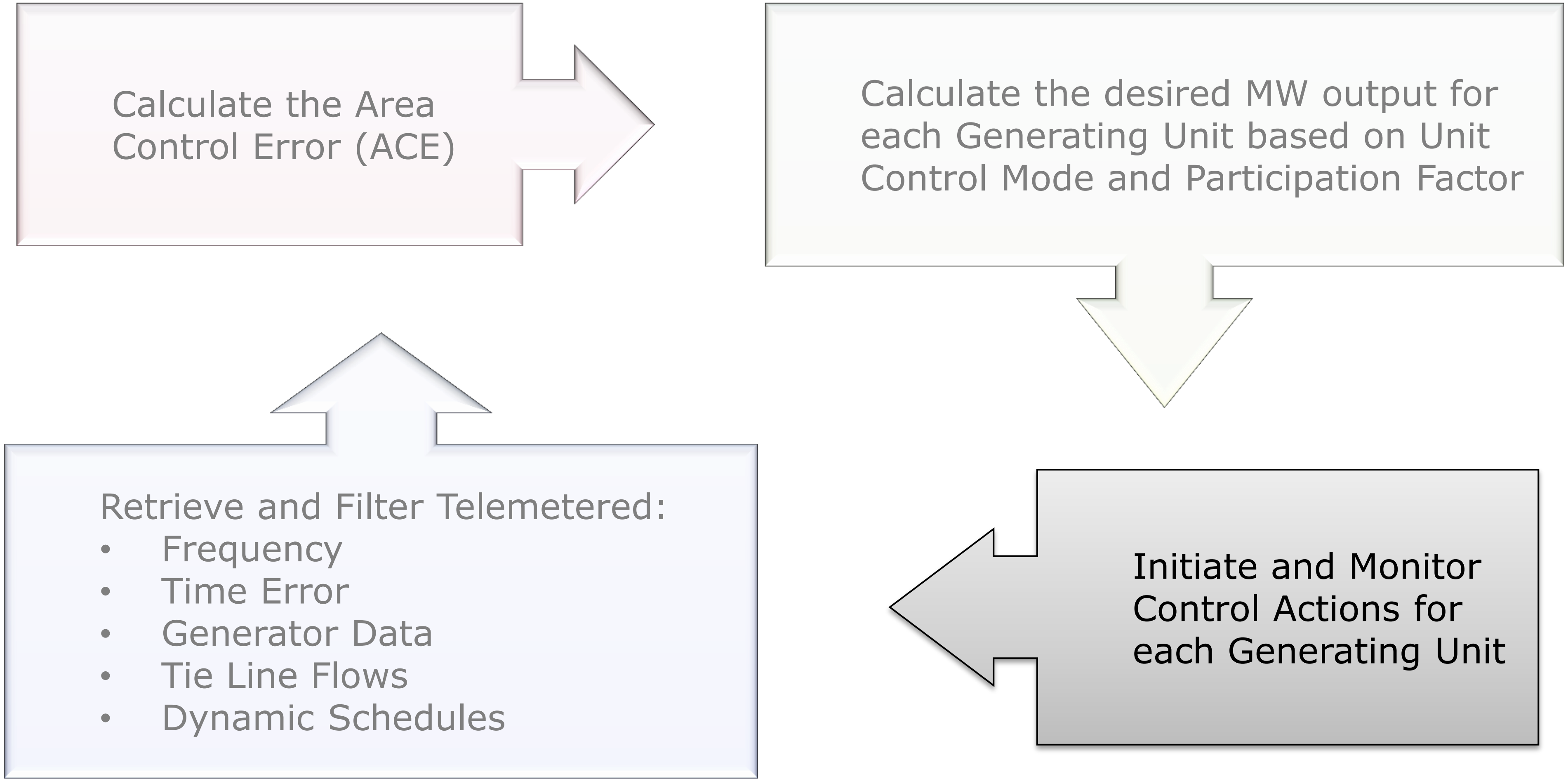
- ACE is calculated.
- The contribution of each generator within a Control Area is determined by a participation factor.

$$ACE_i = (NI_A - NI_S) - 10B\,(f_a - f_s) - I_{ME}$$

$$\Delta P_{G_k} = \alpha_k^i \times ACE_i$$

$$\sum_{k=1}^{n} \alpha_k^i = 1, \qquad 0 \le \alpha_k^i \le 1$$

AGC closed Loop Control



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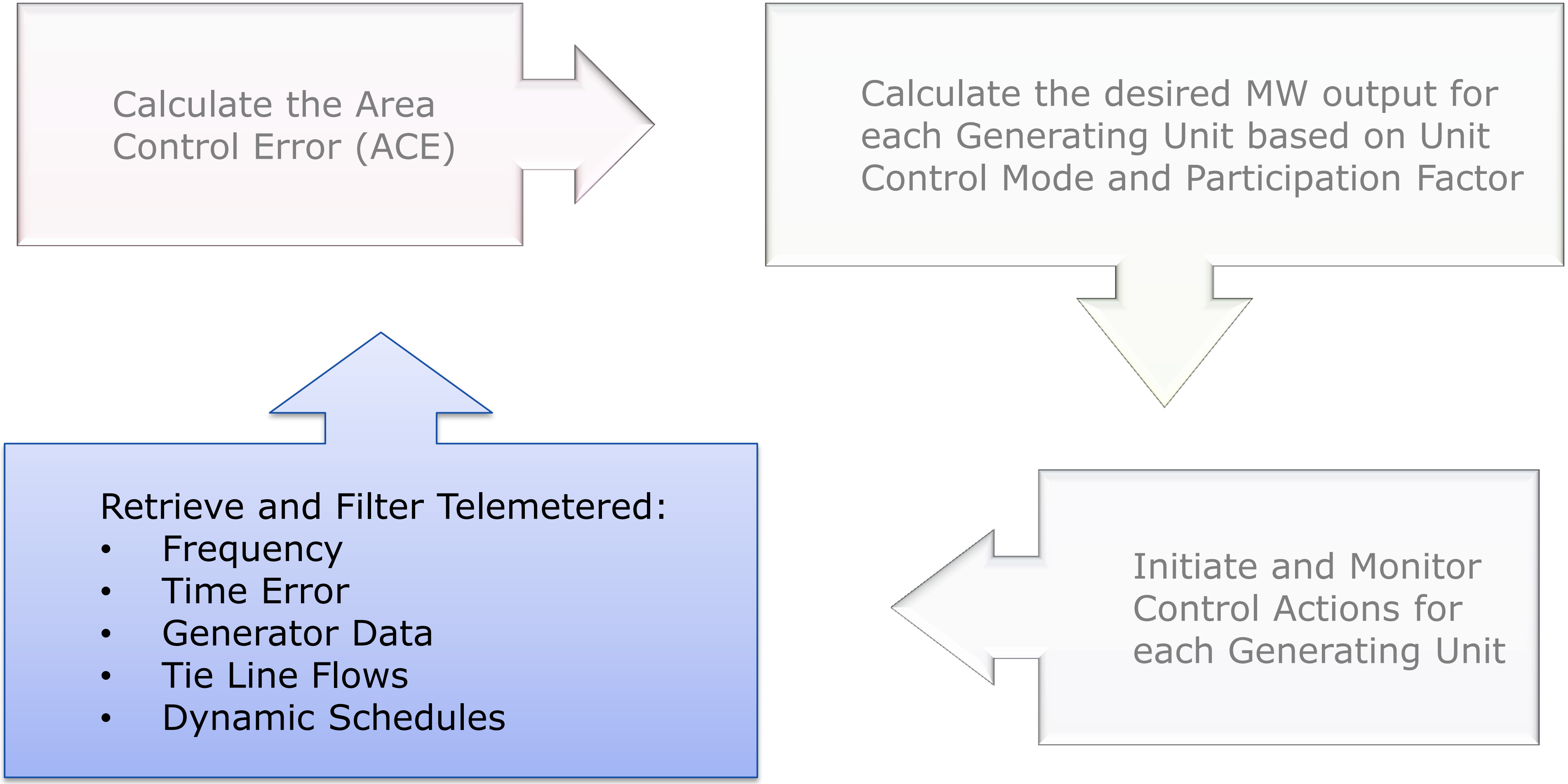
Initiate and Monitor Control Actions

- Pulse Control
  - A pulse time corresponding to a MW change is sent out.
  - A pulse direction (increase/decrease) is also sent
  - The local control equipment handles the actual pulsing of the unit
- Set-point Control
  - An absolute MW value sent out
  - The local control equipment handles the actual change of unit generation
- The AGC monitors the unit response

AGC closed Loop Control



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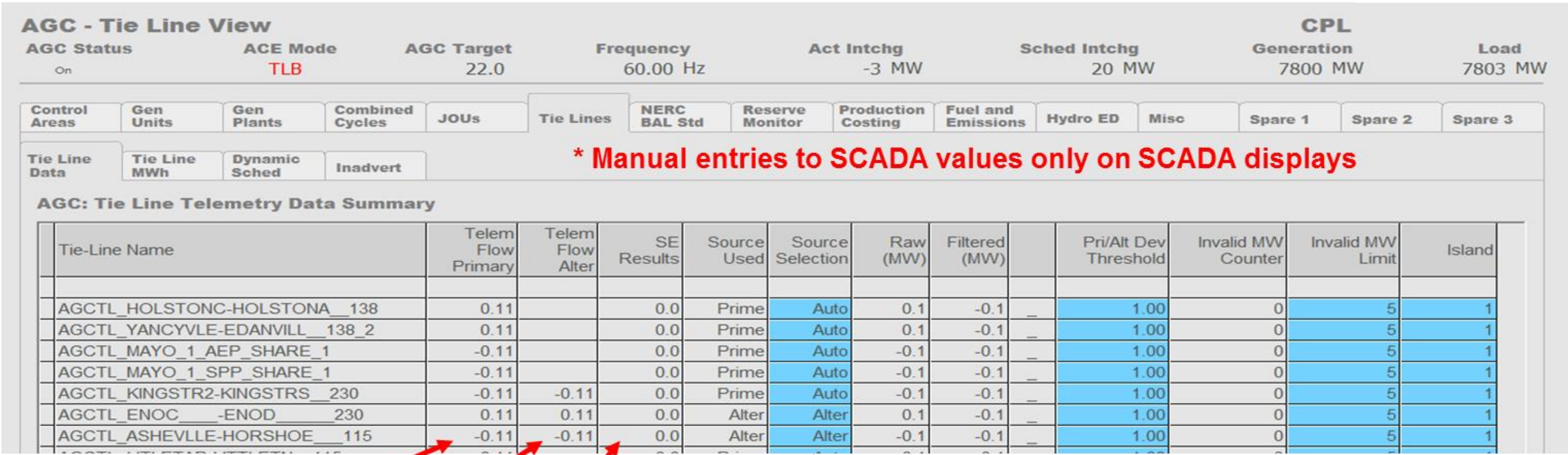
Telemetered Data Inputs

- Tie line MW flows
- Dynamic Schedules
- System frequency signals
- System time error
- Generating unit MW outputs
- Generating unit breaker or connectivity status
- Generating unit control status (Local/Remote)
- Generating unit high and low regulating limits
- Generating unit raise and lower ramp rates
- Generating unit MVAR measurement (for SYNC state)

Example of Application Outline

- Tie Line MW Flow Telemetered Data



Tie-Line Name	Telem Flow Primary	Telem Flow Alter	SE Results	Source Used	Source Selection	Raw (MW)	Filtered (MW)		Pri/Alt Dev Threshold	Invalid MW Counter	Invalid MW Limit	Island
AGCTL_HOLSTONC-HOLSTONA__138	0.11		0.0	Prime	Auto	0.1	-0.1	_	1.00	0	5	1
AGCTL_YANCYVLE-EDANVILL__138_2	0.11		0.0	Prime	Auto	0.1	-0.1	_	1.00	0	5	1
AGCTL_MAYO_1_AEP_SHARE_1	-0.11		0.0	Prime	Auto	-0.1	-0.1	_	1.00	0	5	1
AGCTL_MAYO_1_SPP_SHARE_1	-0.11		0.0	Prime	Auto	-0.1	-0.1	_	1.00	0	5	1
AGCTL_KINGSTR2-KINGSTRS__230	-0.11	-0.11	0.0	Prime	Auto	-0.1	-0.1	_	1.00	0	5	1
AGCTL_ENOC____-ENOD______230	0.11	0.11	0.0	Alter	Alter	0.1	-0.1	_	1.00	0	5	1
AGCTL_ASHEVLLE-HORSHOE___115	-0.11	-0.11	0.0	Alter	Alter	-0.1	-0.1	_	1.00	0	5	1

If primary source has failed, the alternate source or State Estimator result may be used by AGC

User may force the source for measurement
Auto = AGC auto decide: Prim, Alter, Estim

Counter in 'AGC Cycles' allow for 'shaky' SCADA communications

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AGC Dashboard Display

Use the Dashboard Display to quickly achieve situational awareness of the system.

Analog dials indicate Frequency, ACE, etc...

Indicators highlight red to show cause of AGC Timeout / Suspend status.

Compliance Levels (shown in percent) are also highlighted in color

Bar charts indicate available reserves in relation to requirements.

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AGC in Islanding Situation

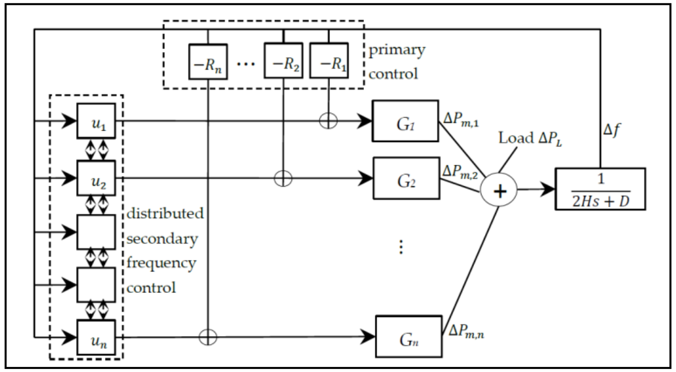
AGC Operation with Multiple Islands

The AGC is designed to work with one island or multiple islands. When islanding occurs or the number of islands changes:

- The ACE Calculation Method for all islands is automatically changed to Flat Frequency Control.
- The manual schedule status is automatically changed from Automatic to Manual, indicating that the Net Scheduled Interchange received is no longer used by AGC.
- The Islanding Data Display is updated with the latest frequency, interchange, and ACE data for each island.
- The operator can enter net interchange schedule overrides, change the frequency bias calculation, and change the ACE calculation method for each in-service island as desired.

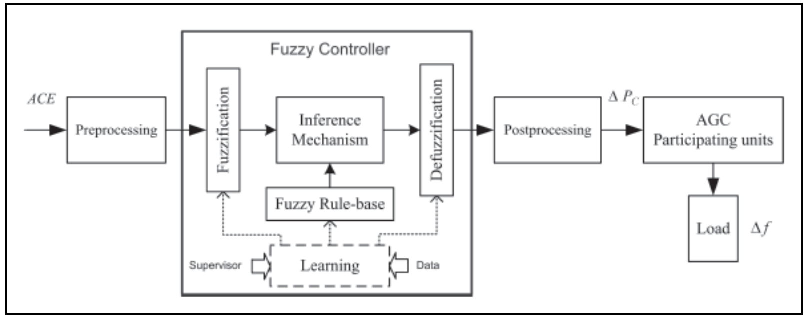
Advanced topics!

- Control Architecture
  - Centralized
  - Distributed



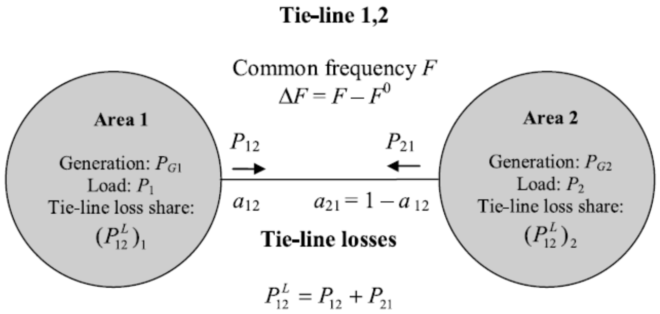
Control Strategies

- Fuzzy Control
- Multi-agent
- ANN



Advanced Computations

- Tie-line loss compensation



Summary (AGC)

- Regulates System Frequency and Area Net Interchange to the Scheduled Values
- Calculates Area Control Error
- Calculates Desired MW output of the Generating Units placed under AGC control
- Performs Closed-Loop Control of the selected Generating Units
- Reduces excessive duty, unit maintenance and repair cost by monitoring unit response and applying operational constraints
- Performs Reserve Monitoring