CONTROL CENTRE OPERATION OF POWER SYSTEMS

Syllabus:
Introduction to SCADA, control centre, digital computer configuration, automatic generation control, area control error, operation without central computers, expression for tie-line flow and frequency deviation, parallel operation of generators, area lumped dynamic model.

General

Electrical Technology was founded on the remarkable discovery by Faraday that a changing magnetic flux creates an electric field. Out of that discovery, grew the largest and most complex engineering achievement of man: the electric power system. Indeed, life without electricity is now unimaginable. Electric power systems form the basic infrastructure of a country. Even as we read this, electrical energy is being produced at rates in excess of hundreds of giga-watts (1 GW = 1,000,000,000 W). Giant rotors spinning at speeds up to 3000 rotations per minute bring us the energy stored in the potential energy of water, or in fossil fuels. Yet we notice electricity only when the lights go out!

While the basic features of the electrical power system have remained practically unchanged in the past century, but there are some significant milestones in the evolution of electrical power systems.
• Introduction to SCADA
• Control Centre
• Digital Computer Configuration
• Automatic Generation Control
• Area Control Error
• Operation Without Central Computers
• Expression for Tie Line Flow
• Parallel Operation of Generators
• Area Lumped Dynamic Model

1.0 Introduction

Electrical energy is an essential ingredient for the industrial and all round development of any country. It is generated centrally in bulk and transmitted economically over long distances. Electrical energy is conserved at every step in the process of Generation, Transmission, Distribution and utilization of electrical energy. The electrical utility industry is probably the largest and most complex industry in the world and hence very complex and challenging problems to be handled by power engineering particularly, in designing future power system to deliver increasing amounts of electrical energy. This calls for perfect understanding, analysis and decision making of the system. This power system operation and its control play a very important task in the world of Electrical Power Engineering.

Power Quality

Power quality is characterized by –

a. Stable AC voltages at near nominal values and at near rated frequency subject to acceptable minor variations, free from annoying voltage flicker, voltage sags and frequency fluctuations.

b. Near sinusoidal current and voltage wave forms free from higher order harmonics
All electrical equipments are rated to operate at near rated voltage and rated frequency.

Effects of Poor Power Quality
- Maloperation of control devices, relays etc.
- Extra losses in capacitors, transformers and rotating machines
- Fast ageing of equipments
- Loss of production due to service interruptions
- Electro-magnetic interference due to transients
- power fluctuation not tolerated by power electronic parts

Major causes of Poor Power Quality
- Nonlinear Loads
- Adjustable speed drives
- Traction Drives
- Start of large motor loads
- Arc furnaces
- Intermittent load transients
- Lightning
- Switching Operations
- Fault Occurrences

Steps to address Power Quality issues
- Detailed field measurements
- Monitor electrical parameters at various places to assess the operating conditions in terms of power quality.
- Detailed studies using a computer model. The accuracy of computer model is first built to the degree where the observed simulation values matches with those of the field measurement values. This provides us with a reliable computer model using which we workout remedial measures.
For the purpose of the analysis we may use load flow studies, dynamic simulations, EMTP simulations, harmonic analysis depending on the objectives of the studies.

We also evaluate the effectiveness of harmonic filters through the computer model built, paying due attention to any reactive power compensation that these filters may provide at fundamental frequency for normal system operating conditions.

The equipment ratings will also be addressed to account for harmonic current flows and consequent overheating.

**Power Quality Solutions:**

Poor power quality in the form of harmonic distortion or low power factor increases stress on a facility’s electrical system. Over time this increased electrical stress will shorten the life expectancy of electrical equipment. In addition to system degradation, poor power quality can cause nuisance tripping and unplanned shutdowns within electrical system.

In an increasingly automated electrical world, it is important for a facility to evaluate power quality. Harmonic distortion, low power factor, and the presence of other transients can cause severe damage to electrical system equipment. PSE provides system analysis and evaluation of power quality issues and makes recommendations for system design solutions.

1.1 **Structure of Power Systems**

Generating Stations, transmission lines and the distribution systems are the main components of an electric power system. Generating stations and distribution systems are connected through transmission lines, which also connect one power system (grid, area) to another. A distribution system connects all the loads in a particular area to the transmission lines.
For economical technical reasons, individual power systems are organized in the form of electrically connected areas or regional grids. As power systems increased in size, so did the number of lines, substations, transformers, switchgear etc. Their operation and interactions became more complex and hence it is necessary to monitor this information simultaneously for the total system at a focal point called as Energy Control Centre. The fundamental design feature is increase in system reliability and economic feasibility.

**Major Concerns of Power System Design and Operation**

- **Quality**: Continuous at desired frequency and voltage level
- **Reliability**: Minimum failure rate of components and systems
- **Security**: Robustness - normal state even after disturbances
- **Stability**: Maintain synchronism under disturbances
- **Economy**: Minimize Capital, running and maintenance Costs

**1.2 Need for Power System Management**

- Demand for Power Increasing every day
  - No of transmission line, Sub-stations, Transformers, switchgear etc.,
- Operation and Interaction is more and more complex
- Essential to monitor simultaneously for the total system at a focal point – ENERGY LOAD CENTRE

**Components of power system operation and control**
• Information gathering and processing
• Decision and control
• System integration

**Energy Load Centre**

The function of energy load centre is to control the function of coordinating the response in both normal and emergency conditions. Digital Computers are very effectively used for the purpose. Their function is to process the data, detect abnormalities, alarm the human operator by lights, buzzers, screens etc., depending on the severity of the problem.

**Control Centre of a Power System**

• Human Machine Interface – equipped with
• CRT presentations
• Keyboards – change parameters
• Special function keyboards- alter transformer taps, switch line capacitors etc.,
• Light-Pen cursor – open or close circuit breakers
• Alarm lights, alarms, dedicated telephone communications with generating stations and transmission substations, neighboring power utilities

**Control Features – Control Centre**

• System Commands – Mode of control
• Units – base / peak load
• AGC – Automatic Generation Control
• Data Entry
• Alarms – To find source of alarm and necessary action
• Plant/Substation selection
• Special Functions - To send/retrieve data etc.,
• Readout control – Output to CRT/printers etc.,
• CPU control – Selection for the computer
**Functions of Control Centre**

- Short, Medium and Long-term Load Forecasting
- System Planning
- Unit Commitment and maintenance Scheduling
- Security Monitoring
- State Estimation
- Economic Dispatch
- Load Frequency Control

**1.3 SCADA – Supervisory Control and Data Acquisition**

One of key processes of SCADA is the ability to monitor an entire system **in real time**. This is facilitated by data acquisitions including meter reading, checking statuses of sensors, etc that are communicated at regular intervals depending on the system.

A well planned and implemented SCADA system not only helps utilities deliver power reliably and safely to their customers but it also helps to lower the costs and achieve higher customer satisfaction and retention.

**SCADA – Why do we need it?**

- If we did not have SCADA, we would have very inefficient use of human resources and this would cost us (Rs,Rs,Rs)
- In today’s restructured environment SCADA is critical in handling the volume of data needed in a timely fashion
- Service restoration would involve travel time and would be significantly higher
- It is essential to maintain reliability

**SCADA - Architecture**

- Basic elements are sensors which measure the desired quantities
- Current Transformers CTs – measure currents and Potential Transformers PTs- measure voltages.
Today there is a whole new breed of Intelligent electronic devices (IEDs)
This data is fed to a remote terminal unit (RTU)
The master computer or unit resides at the control center EMS

**SCADA - Process**
- Master unit scan RTUs for reports, if reports exist, RTU sends back the data and the master computer places it in memory
- In some new substation architectures there could be significant local processing of data which could then be sent to the control center.
- The data is then displayed on CRTs and printed

**SCADA - Logging**
- The SCADA provides a complete log of the system
- The log could be provided for the entire system or part of the system
- Type of information provided
  - Time of event
  - Circuit breaker status
  - Current measurements, voltage measurements, calculated flows, energy, etc.
  - Line and equipment ratings

**SCADA as a System**

There are many parts of a working SCADA system. A SCADA system usually includes signal hardware (input and output), controllers, networks, user interface (HMI), communications equipment and software. All together, the term SCADA refers to the entire central system. The central system usually monitors data from various sensors that are either in close proximity or off site (sometimes miles away).

For the most part, the brains of a SCADA system are performed by the Remote Terminal Units (sometimes referred to as the RTU). The Remote Terminal Units consists
of a programmable logic converter. The RTU are usually set to specific requirements, however, most RTU allow human intervention, for instance, in a factory setting, the RTU might control the setting of a conveyer belt, and the speed can be changed or overridden at any time by human intervention. In addition, any changes or errors are usually automatically logged for and/or displayed. Most often, a SCADA system will monitor and make slight changes to function optimally; SCADA systems are considered closed loop systems and run with relatively little human intervention.

SCADA can be seen as a system with many data elements called points. Usually each point is a monitor or sensor. Usually points can be either hard or soft. A hard data point can be an actual monitor; a soft point can be seen as an application or software calculation. Data elements from hard and soft points are usually always recorded and logged to create a time stamp or history.

**User Interface – Human Machine Interface (HMI)**

A SCADA system includes a user interface, usually called Human Machine Interface (HMI). The HMI of a SCADA system is where data is processed and presented to be viewed and monitored by a human operator. This interface usually includes controls where the individual can interface with the SCADA system.

HMI's are an easy way to standardize the facilitation of monitoring multiple RTU's or PLC's (programmable logic controllers). Usually RTU's or PLC's will run a pre programmed process, but monitoring each of them individually can be difficult, usually because they are spread out over the system. Because RTU's and PLC's historically had no standardized method to display or present data to an operator, the SCADA system communicates with PLC's throughout the system network and processes information that is easily disseminated by the HMI.

HMI's can also be linked to a database, which can use data gathered from PLC's or RTU's to provide graphs on trends, logistic info, schematics for a specific sensor or
machine or even make troubleshooting guides accessible. In the last decade, practically all SCADA systems include an integrated HMI and PLC device making it extremely easy to run and monitor a SCADA system.

Today’s SCADA systems, in response to changing business needs, have added new functionalities and are aiding strategic advancements towards interactive, self healing smart grids of the future. A modern SCADA system is also a strategic investment which is a must-have for utilities of all sizes facing the challenges of the competitive market and increased levels of real time data exchange that comes with it (Independent Market Operator, Regional Transmission Operator, Major C&I establishments etc). A well planned and implemented SCADA system not only helps utilities deliver power reliably and safely to their customers but it also helps to lower the costs and achieve higher customer satisfaction and retention. Modern SCADA systems are already contributing and playing a key role at many utilities towards achieving:

- New levels in electric grid reliability – increased revenue.
- Proactive problem detection and resolution – higher reliability.
- Meeting the mandated power quality requirements – increased customer satisfaction.
- Real time strategic decision making – cost reductions and increased revenue

**Critical Functions of SCADA**

Following functions are carried out every 2 seconds:

- Switchgear Position, Transformer taps, Capacitor banks
- Tie line flows and interchange schedules
- Generator loads, voltage etc.,
- Verification on links between computer and remote equipment

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• Real time strategic decision making – cost reductions and increased revenue.

1.4 Digital Computer Configuration

Major functions
- Data acquisition control
- Energy Management
- System Security

For best/secured operation 100% redundancy is used – Dual Digital Computers
  i) on-line computer – monitors and controls the system
  ii) Backup computer – load forecasting or hydro thermal allocations

The digital computers are usually employed in a fixed-cycle operating mode with priority interrupts wherein the computer periodically performs a list of operation. The most critical functions have the fastest scan cycle. Typically the following categories are scanned every 2 seconds:
  • All status points such as switchgear position (open or closed), substation loads and voltages, transformer tap positions, and capacitor banks etc.,
  • Tie line flows and interchange schedules
  • Generator loads, voltage, operating limits and boiler capacity
  • Telemetry verification to detect failures and errors in the bilateral communication links between the digital computer and the remote equipment.

1.5 Important Areas of Concern in power System

- Automatic Generation Control (AGC)
On-line Computer Control that maintains overall system frequency and net tie-line load exchange through interconnection

- **Economic Load Dispatch**
  - On-line computer control to supply load demand using all interconnected system’s power in the most economical manner

AGC is the name given to a control system having three major objectives:

a. To hold system frequency at or very close to a specified nominal value (50 or 60Hz)
b. To maintain the correct value of interchange power between control areas
c. To maintain each unit’s generation at the most economic value.

To implement an AGC system, the following information is required:

- Unit megawatt output of each committed unit
- Megawatt flow over each tie line to neighboring systems
- System frequency

Usually, neighboring power companies are interconnected by one or more transmission lines called **Tie Lines**. The objective is to buy or sell power with neighboring systems whose operating costs make such transactions profitable. Also, even if no power is being transmitted over ties to neighboring system, if one system has a sudden loss of a generating unit, the units throught all the interconnection will experience a frequency change and can help in restoring frequency.

**Advantages of interconnected system**

- Reduces Reserve Capacity – thus reduces installed capacity
- Capital Cost/kW is less for larger Unit
  - in India single unit can support >500MW because of interconnection
- Effective Use of Generators
- Optimization of Generation – installed capacity is reduced
- Reliability
Disadvantages of interconnected system

- Fault get Propagated – calls for fast switchgear
- CB rating increases
- Proper management required – EMS and it must be automated – Economic load dispatch - Base load and Peak Load

National Regional Electricity Boards

- Northern Regional Electricity Board
- Western Regional Electricity Board
- Southern Regional Electricity Board
- Eastern Regional Electricity Board
- North-east Regional Electricity Board

Goal – To have National Grid to improve efficiency of the whole National Power Grid

Control Area Concept

All generators are tightly coupled together to form – Coherent Group
- all generators respond to changes in load or speed changer setting

Control Area – frequency is assumed to be constant throughout in static and dynamic conditions

For the purpose of analysis, a control area can be reduced to a single speed governor, turbo generator and load system

Interconnected Power System
Functions
- Exchange or sale of power
- Disturbed areas taking other area’s help
- Long distance sale and transfer of power

1.6 Area Control Error – ACE
To maintain a net interchange of power with its area neighbors, an AGC uses real power flow measurements of all tie lines emanating from the area and subtracts the scheduled interchange to calculate an error value. The net power interchange, together with a gain, B (MW/0.1Hz), called the frequency bias, as a multiplier on the frequency deviation is called the **Area Control Error (ACE)** given by,

\[ \sum_{k=1}^{k} P_k - P_s + B(f_{act} - f_0) \text{ MW} \]

- \( P_k \) = Power in Tie Line - +ve – out of the area
- \( P_s \) – Scheduled Power Interchange
- \( f_0 \) – Base frequency, \( f_{act} \) – Actual frequency
+ve ACE indicates flow out of the area.

**ACE – Input to AGC**
The real power summation of ACE loses information as to the flow of individual tie lines but is concerned with area net generation. The tie lines transfer power through the area from one neighbor to the next, called 'Wheeling Power'. The wheeling power cancels algebraically in the ACE. Thus one area purchases or sells blocks of power (MWh) with non-neighbor utilities.

**Power Sale from A to C**

- A – selling a power ‘p’ to C, then ACE for A = p
• Power export starts until its AGC forces ACE to become zero
• Area C introduces ‘-p’ into its ACE
• Power flows in to area C until its ACE becomes zero
• Areas B & C must be aware of the power exchange as they are also interconnected

The minimum requirements of AGC on controlling the interchange of power and frequency have been established by NERC – North American Electric Reliability Council, which is comprised of representatives of the major operating power pools. This committee specifies the following criteria as minimum performance expected by AGC.

A. Normal System Conditions
   - ACE = 0 at least once in 10 min period
   - Deviation of ACE from zero must be within allowable limits

B. Disturbances Conditions
   - ACE must return to zero within 10 min
   - Corrective action from AGC must be within a minimum disturbance

**Daily Load Cycle**

The allowable limit, $L_d$ of the average deviation on power systems (averaged over 10 minutes) is:

$$L_d = 0.025\Delta L + 5.0 \text{ MW}$$
\[ \Delta L = \Delta P / \Delta t \text{ MW/hr} \]
The value of \( \Delta L \) is determined annually and is taken from the daily load cycle. A power system is said to be in a disturbance condition if the ACE signal exceeds 3Ld.

### 1.7 Operation without Central Computers or AGC

Power Systems are capable of functioning even without Central Computer and/or AGC
- Due to a result of Turbine Generator speed controls in the generating station and natural load regulation
- Thus generators within an area are forced to share load and cause interconnected areas to share load

1.7.1 Generation Frequency Characteristic Curve

Let there be two independent areas A and B without tie line flow as the circuit breaker is open. Let there be a sudden change in load occurs in the area D. Area A is considered as a single operating area representing the remainder of the interconnection. It is further assumed that the areas share the disturbance in proportion to their generating capacity and operating characteristics. Let the area generation-frequency characteristics be represented by the curve GG which is a composite response curve from all the generators in area A. The characteristic curve has a negative slope with frequency.
The area connected load is defined by the curve LL as shown. As there is increase in load the rotating machinery in the area is forced to increase the speed.

**Basic Equations**

\[ G_A = G_0 + 10 \beta_1 (f_{act} - f_0) \text{ MW} \quad L_A = L_0 + 10 \beta_2 (f_{act} - f_0) \text{ MW} \]

- \( G_A \) = Total Generation, \( G_0 \) = Base generation
- \( L_A \) = Total Load, \( L_0 \) = Base load, \( f_{act} \) = System frequency, \( f_0 \) = Base frequency
- \( \beta_1 \) = Cotangent of generation-frequency characteristic, MW/0.1 Hz < 0
- \( \beta_2 \) = Cotangent of load-frequency characteristic, MW/0.1 Hz > 0

**1.7.2 Isolated Operation in A – response to load change**
For Steady State Frequency – Total generation = Total effective load
This is defined by the intersection of GG and LL curves as shown – Io.
Combined characteristic of GG and LL is CC. The composite generation load frequency characteristics is given by,

\[ G_A = G_0 + 10\beta_1 (f_{act} - f_0), \quad L_A = L_0 + 10\beta_2 (f_{act} - f_0) \]

\[ G_A - L_A = G_0 + 10\beta_1 (f_{act} - f_0) - L_0 - 10\beta_2 (f_{act} - f_0) \]

Increase in load in ‘A’ moves the load frequency curve to position L’L’. The new system frequency will now be defined by the intersection labeled as I_1 at 49.9Hz. Then it is desired to return the system frequency to 50.0Hz i.e., point I_2.
Setting AGC in ‘A’- shifting of GG to G’G’ takes place to meet frequency demand of 50.0Hz – I_2
Resulting combined characteristic is C’C’ In terms of increments,

\[ \Delta_A = G_A - G_0 + L_0 - L_A = 10\beta_1 (f_{act} - f_0) - 10\beta_2 (f_{act} - f_0) \]

\[ = 10B_A X_A \Delta f \quad \text{MW} \]

\[ \Delta_A = G_A - G_0 + L_0 - L_A = 10\beta_1 (f_{act} - f_0) - 10\beta_2 (f_{act} - f_0) \]

\[ = 10B_A X_A \Delta f \quad \text{MW} \]

\[ B_A \] - Natural regulation characteristic - % gen for 0.1Hz
\[ X_A \] - Generating Capacity of A, MW

Frequency deviation = \[ \Delta f = \Delta_A / 10B_A X_A \] Hz
Considering Tie line flow, Frequency deviation
\[ \Delta f = (\Delta_A + \Delta_T_L) / (10B_A X_A) \] Hz
\[ \Delta_A + \Delta_T_L \] - Net Megawatt change
\[ \Delta_T_L = \Delta G_A - \Delta L_A \]

1.7.3 Effect of Tie Line Flow - Interconnected operation
Let two areas A and B are interconnected through a Tie Line. Thus both Generation and Load frequency are equal to 50.0 Hz. There is no initial Tie Line Power Flow.

- Disturbance occur at B causing frequency to drop to 49.9Hz
- Area generation does not match with effective load in A
- Difference between I1 and I2 – difference between generation and load – net excess power in the area – flows out of A towards B
- Contributory effects in A are decrease in load power $\Delta L$ and increase in generation $\Delta G$

- Tie Line Flow from A to B = $\Delta T_L = (\Delta G_A - \Delta L_A)$ MW
- If area A has AGC, tie line flows increases – $\Delta T_L'$ and $\Delta T_L''$ representing increased amounts of bias due to AGC.

Frequency change due to disturbance $\Delta_B$ for a tie line power flow from A to B is

$$\Delta f = \Delta_B - \Delta T_L / (10B_B X_B) \text{ Hz}$$

$$\Delta T_L = (10B_A X_A) \Delta AB / (10B_A X_A + 10B_B X_B) \text{ MW}$$

Net power change in B is

$$\Delta AB = (10B_A X_A + 10B_B X_B) \Delta f$$

Hence, $\Delta f / \Delta AB = 1/(10B_A X_A + 10B_B X_B)$
Example

Two areas A and B are interconnected. Generating capacity of A is 36,000Mw with regulating characteristic of 1.5%/0.1Hz. B has 4000MW with 1%/0.1Hz. Find each area’s share of +400MW disturbance (load increase) occurring in B and resulting tie line flow.

\[ \Delta f = \Delta_{AB} / (10B_A X_A + 10B_B X_B) = 400 / -10(0.015)(36,000) - 10(0.01)(4000) \]

\[ = -0.06896 \text{ Hz} \]

Tie Line flow = \( \Delta T_L = (10B_A X_A) \Delta_{AB} / (10B_A X_A +10B_B X_B) \) = 5400*400/4800

\[ = 372.4 \text{MW} \]

Smaller system need only 27.6 MW

Frequency regulation is much better

1.8 Parallel Operation of Generators

Tie line flows and frequency droop described for interconnected power areas are composite characteristics based on parallel operation of generators. Each area could maintain its speed \( w = 2\pi f \), then a load common to both areas, by superposition have the terminal voltage,

\[ V_{load} = V_1 \sin w_1 t + V_2 \sin w_2 t, \]

Where, 1&2 represents areas and ‘t’ time in secs. Generator speed versus load characteristics is a function of the type of the governor used on the prime mover- type 0 – for a speed droop system and type 1 – for constant speed system.

Parallel operation of generator with infinite bus

![Graph showing speed vs frequency with infinite bus](image-url)
The generator characteristic is such that it is loaded to 50% of its capacity when paralleled to the bus. Therefore, Unit speed regulation = \( R = \frac{\Delta f(\text{pu})}{\Delta P(\text{pu})} \)

\[ = \frac{\Delta f(\text{Hz})/50(\text{Hz})}{\Delta P(\text{MW})/P_{\text{rate}}(\text{MW})} \]

If it is desired to increase the load on the generator, the prime mover torque is increased, which results in a shift of the speed-droop curve as shown below. The real power flow is given by, \( P = V_1 V_2 \sin(\theta_1 - \theta_2) / X \), where \( X = \) synchronous reactance

**Parallel operation of two identical units**

**Diagram:**
- Load
- Area A
- Area B
- Regulation, \( R \)
- Unit 1
- Unit 2

**Graph:**
- Speed or frequency (per unit)
- Load, \( P \) (per unit)
Two generators paralleled have different governor-speed-droop characteristics. Because they are in parallel, power exchange between them forces them to synchronize at a common frequency. Since the two units are of equal capacity having equal regulation are initially operating at 1.0 base speed as shown above.

If unit is operated at point A₁ satisfies 25% of the total load and unit 2 at point A₂ supplies 75%. If the total load is increased to 150%, the frequency decreases to f₁. Since the droop curves are linear, unit 1 will increase its load to 50% of rating and unit 2 to be overloaded.

**Parallel operation of two units with different capacity and regulation**

The case when two units of different frequency and regulation characteristics are operated in parallel is as shown below. The regulation characteristics are

\[ R_1 = \frac{\Delta f (pu)}{\Delta P_1 (pu)}, \quad R_2 = \frac{\Delta f (pu)}{\Delta P_2 (pu)} \]

\[ \frac{\Delta P_1}{\Delta P_2} = \frac{R_2}{R_1} \frac{P_1 \text{ rate}}{P_2 \text{ rate}} \]

Initial Loads - P₁ and P₂, change in load

\[ \Delta L = \Delta P_1 + \Delta P_2 = \frac{\Delta f}{R_2} + \frac{\Delta f}{R_2} \]

Equivalent System Regulation = \[ \frac{1}{\frac{R_1}{R_1} + \frac{R_2}{R_2}} \]
Example:

Two parallel operating generators – 1pu, 60Hz
Unit 1 = 337 MW with 0.03 pu droop, Unit2 – 420MW with 0.05 pu droop
Find each unit’s share for 0.1pu increase in load and new frequency?

Both Gen must share an increase load of $0.1(337+420) = 75.7$ MW

Equivalent System regulation - $R_{\text{system}} = \frac{1}{\frac{R_1}{R_{\text{rate}1}} + \frac{R_2}{R_{\text{rate}2}}} = -0.0386$

New System frequency due to increase in load = $\Delta f(\text{pu}) = R_{\text{system}} \Delta L(\text{pu}) = -0.00386 \text{ pu}$

Hence there is a decrease of $0.00386 \times 60 = 0.231$ Hz

$\Delta P_1 = \frac{\Delta f}{R_1} = -0.00386/-0.03 = 0.129$ pu = 43.3 MW

$\Delta P_2 = \frac{\Delta f}{R_2} = -0.00386/-0.05 = 0.0771$ pu = 32.4 MW

The total increase in load of 75.7 MW is met by increase in generation
- 43.3 MW by Unit 1 and 32.4 MW by Unit 2

1.9 Area Lumped Dynamic Model

The model discussed so far is one macroscopic behavior because there is no effort made to indicate instantaneous power flow within the system due to a tie line disturbance, magnitudes of the internal line flows, the time history of generator phase angles and so on. The power system macro model may be described by means of a block diagram as shown in the block diagram.
**H_A** = Effective Inertia of rotating machinery loads

**B_2** = Load frequency characteristics, MW/0.1Hz

**P_{irate}** = Rated power output of Gen 'i'

**ΔP_i** = Power Increment for gen 'i'

**1/R_i** = Droop characteristic of gen 'i', Hz/MW

**Analysis – Isolated Power Area without Tie Lines**

Steady State value of Frequency deviation \( \Delta f \) for a load change \( \Delta L \)

\[
= \frac{\Delta A}{S}
\]

Hence,

\[
\frac{\Delta f}{\Delta A} = \frac{1}{10\beta_1 - 10\beta_2}
\]

Combining droop characteristics of M gen,
\[-10\beta_1 = \frac{P_{1\text{rate}}}{R_1} + \frac{P_{2\text{rate}}}{R_2} + \ldots + \frac{P_{M\text{rate}}}{R_M}\]

**Analysis - Isolated Power Area with AGC**

- Area with AGC sensing only frequency – **Flat Frequency**
- To determine frequency error by AGC - equivalent transfer function and gain of all generators is considered
  \[
  \frac{\Delta f(s)}{\Delta L(s)} = \frac{-1}{(2H_A s + 10\beta_2) + \sum_{i=1}^{N} \left[ \frac{G_i(s)}{R_i} \right] + 10B \sum_{i=1}^{N} G_i'(s)G_i(s)}
  \]
- AGC sensing frequency error contributes to natural regulation
- Contribution of AGC is often **“Supplement Control”** - effect depends on transfer function
Topics studied

- Present Power scenario
- Requirement for Quality Power
- Tie Lines
  - Sale of Power
  - System Stability
  - Long distance power transmission
- Necessity of AGC
- Area Control Error
- Parallel Operation of Generators
- Area Lumped Dynamic Model