1. INSTITUTE VISION & MISSION

Vision of the Institution:

To be a Pioneer Institute and leader in Engineering education whose primary concern would be the development of the human race and betterment of society through their knowledge, technological understanding and the spirit of progress

Mission of the Institution:

1. ***To create a conductive environment for student centric learning and Industry Institute Interaction.***
2. ***To integrate the state of the art infrastructure, facilities and cutting edge academic delivery.***
3. ***To develop and nurture socially conscious technocrats through continuing education and research.***

PRINCIPAL

2. DEPARTMENT VISION & MISSION

Vision of the Department:

To produce the professionally competent graduates in the field of Electrical and Electronics Engineering for addressing the challenges in industry and society

Mission of the Department:

1. *To develop Institute Industry Interaction for collaborative research and entrepreneurial skills among the stakeholders.*
2. *To offer high quality graduate program in Electrical and Electronics domain and to prepare students for professional Career and higherstudies.*
3. *To promote excellence in teaching, research and positive contributions to society.*

HOD/EEE

3. PEOs, PSOs & POs STATEMENTS

3.1. PROGRAMME EDUCATIONAL OBJECTIVES (PEO's):-

(i). To prepare students with excellent foundation in mathematics, basic sciences and engineering subjects to enable them to find employment or pursue higherstudies.

(ii). To inculcate problem solving capabilities in students with analysis, design and practical skills which would facilitate them to innovate modern equipment for societaldevelopment

(iii). To have an understanding in the importance of lifelong and professional development with ethicalvalues

3.2. PROGRAM SPECIFIC OUTCOMES(PSO's):-

(i). To apply science, engineering, mathematics through differential and integral calculus, complex variables and to solve Electrical Engineeringproblems

(ii). To demonstrate proficiency in the use of software and hardware which are required to practice Electrical Engineeringproblems.

3.3. PROGRAM OUTCOMES (PO's):

PO1: Engineering Knowledge: *Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.*

PO2: Problem Analysis: *Identify, formulate, research literature and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.*

PO3: Design/ Development of Solutions: *Design solutions for complex engineering problems and design system components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal and environmentalconsiderations.*

PO4: Conduct investigations of complex problems: *Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of information to provide valid conclusions.*

PO5: Modern Tool Usage: *Create, select and apply appropriate techniques, resources and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.*

PO6: The Engineer and Society: *Apply reasoning informed by contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to professional engineering practice.*

PO7: Environment and Sustainability: *Understand the impact of professional engineering solutions in societal and environmental contexts and demonstrate knowledge of and need for sustainable development.*

PO8: Ethics: *Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.*

PO9: Individual and Team Work: *Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.*

PO10: Communication: *Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.*

PO11: Project Management and Finance: *Demonstrate knowledge and understanding of engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.*

PO12:Life-long Learning: *Recognize the need for and have the preparation and ability to Engage in independent and life- long learning in the broadest context of technological Change.*

***

SIDDHARTHA INSTIUTE OF ENGINEERING & TECHNOLOGY
Vinobha Nagar, Ibrahimpatnam, Ranga Reddy Dist

Department of Electrical and Electronics Engineering

4.COURSE INFORMATION SHEET

COURSE PLAN: POWER SYSTEM OPERATION&CONTROL **CLASS: IV EEE**

Subject		**POWER SYSTEM OPERATION&CONTROL**
Faculty		**Mr. M.NAGARAJU**
	Text / Ref.	**Text Books(to be acquired by the Students)**
Book1	Text Book	Power system operation and control by Sivanagaraju
Book2	Text Book	Power system operation and control by Dr.K.Uma Rao
Book3	Text Book	Modern Power Systems Analysis by I.J. Nagarath & D.P Kothari
Book4	Text Book	Operation and control in power systems by PSR Murthy

Unit	**Topic**	**Chapters**				**No. Of the Classes**
		Book1	Book2	Book3	Book4	
I	**Economic Operation of Power Systems**	✓	✓	✓	✓	13
II	**Hydrothermal Scheduling**	✓	✓	-----	✓	9
III	**Modeling of Turbine, Governor**	✓	✓	✓	✓	23
IV	**Single Area & Two Area Load Frequency Control, Load Frequency control of 2-area system, Load Frequency Controllers**	✓	✓	✓	✓	13
V	**Reactive Power Control**	✓	✓	✓	✓	5
					Contact classes for Syllabus Coverage	**63**
					Special Descriptive tests	**2**
					Tutorial Classes	**10**
					Beyond the syllabus	**2**
					NPTEL	**2**
					Total Classes	**79**

4.1. ACADEMIC CALENDER

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY HYDERABAD
REVISED ACADEMIC CALENDAR (2018-19)
FOR NON-AUTONOMOUS CONSTITUENT& AFFILIATED COLLEGES
B. TECH. II, III & IV YEARS I & II SEMESTERS

I SEM

S. No	EVENT	DATE	Duration
12.	Commencement of Instruction	9th July 2018	--
13.	First Mid Term Examinations	4th to 6th Sept. 2018	--
14.	Submission of First Mid Term Exam Marks to University on or before	15th Sept. 2018	--
15.	Parent-Teacher Meeting	13th Oct. 2018	--
16.	Dussehra recess	15th to 20th Oct. 2018	1 week
17.	Last date of Instruction	10th Nov. 2018	16 weeks
18.	Second Mid Term Examinations	12th to 14th Nov. 2018	--
19.	Preparation Holidays and Practical Examinations	15th to 24th Nov. 2018	1 week
20.	Submission of Second Mid Term Exam Marks to University on or before	24th Nov. 2018	--
21.	End Semester / Supplementary Examinations	26th Nov. to 8th Dec. 2018	2 weeks
22.	Semester Break	10th to 15th Dec. 2018	1 week

II SEM

S. No	EVENT	DATE	Duration
11.	Commencement of Instruction	24th Dec. 2018	--
12.	First Mid Term Examinations	18th to 20th Feb. 2019	--
13.	Submission of First Mid Term Exam Marks to University on or before	27th Feb. 2019	--
14.	Parent-Teacher Meeting	9th March. 2019	--
15.	Last date of Instruction	20th April 2019	16 weeks
16.	Second Mid Term Examinations	22nd to 24th April 2019	--
17.	Preparation Holidays and Practical Examinations	25th April to 4th May 2019	1 week
18.	Submission of Second Mid Term Exam Marks to University on or before	2nd May 2019	--
19.	End Semester / Supplementary Examinations	6th to 18th May 2019	2 weeks
20.	Summer Vacation	20th May to 13th July 2019	8 weeks

17.12.18
DIRECTOR
ACADEMIC & PLANNING, JNTUH

SIDDHARTHA INSTIUTE OF ENGINEERING & TECHNOLOGY
Vinobha Nagar, Ibrahimpatnam, Ranga Reddy Dist
Department of Electrical and Electronics Engineering

4.2. TIME TABLE

NAME: Mr. M.NAGARAJU

Academic Year : 2018-19
Semester : I sem

SUB : Power System Operation & Control **Class : IV EEE**

Day/period	1	2	3	4	12.20 PM TO 1.00 PM	5	6	7
TIME	9.00am To 9.50am	9.50am To 10.40am	10.40am To 11.30am	11.30am To 12.20pm	L U N C H	1.00pm To 1.50pm	1.50pm To 2.40pm	2.40pm To 3.30pm
MON								PSOC
TUE						PSOC		
WED								
THU			PSOC					
FRI				PSOC				
SAT	PSOC							

Signature of the HOD

4.3. Course Syllabus and General Objectives

A70230: POWER SYSTEM OPERATION & CONTROL

B.Tech IV YearISem

L	T	P	C
4	1	0	4

Prerequisite: Power Systems – I & II

Course Objectives:

- To study and understand the economic operation of power systems,hydro thermal scheduling and modeling of turbines,generators and automatic controllers.
- To emphasizes on single area and two area load frequency control and reactive power control.

Course Outcomes:

- Understanding the Economic operation of power systems, hydrothermal scheduling
- Modeling of turbines, generators and automatic controllers.
- operation of load frequency controllers, reactive power control, uncompensated transmission line and compensation in transmission systems through shunt and series compensations
- Students will be able to understand and apply the conceptual things to real- world electrical and electronics problems and applications.

UNIT – I

Economic Operation of Power Systems: Optimal operation of Generators in Thermal Power Stations, – heat rate Curve — Cost Curve — Incremental fuel and Production costs, input-output characteristics, Optimum generation allocation with line losses neglected. Optimum generation allocation including the effect of transmission line losses — Loss Coefficients, General transmission line loss formula.

UNIT – II

Hydrothermal Scheduling: Optimal scheduling of Hydrothermal System: Hydroelectric power plant models, scheduling problems-Short term hydrothermal scheduling problem.

UNIT - III

Modeling: Modeling of Turbine: First order Turbine model, Block Diagram representation of Steam Turbines and Approximate Linear Models.

Modeling of Governor: Mathematical Modeling of Speed Governing System — Derivation of small signal transfer function. Modeling of Excitation System: Fundamental Characteristics of an Excitation system, Transfer function, Block Diagram Representation of IEEE Type-1 Model.

UNIT – IV

Single Area & Two Area Load Frequency Control: Necessity- of keeping frequency constant, Definitions of Control area Single area control Block diagram representation of an isolated power system — Steady state analysis Dynamic response — Uncontrolled case,

Load frequency control of area system: Uncontrolled case and controlled case, tie1ine bias control.

Load Frequency Controllers: Proportional plus Integral control of single area and its block diagram representation, steady state response — Load Frequency Control and Economic dispatch control.

UNIT - V

Reactive Power Control: Overview of Reactive Power control — Reactive Power compensation in transmission systems — advantages and disadvantages of different types of compensating equipment for transmission systems. Load compensation: Specifications of load compensator, Uncompensated and compensated transmission lines: shunt and Series Compensation. (Qualitative treatment)

TEXT BOOKS:

1. Power System Operation and Control, Dr. K. Uma Rao
2. Power system Analysis,operation and control, Abhijit Chakrabarti

REFERENCE BOOKS:

1. Operation and Control in Power Systems,PSR Murthy, BS Publications
2. Power systems stability and control, Prabha kundur, The McGraw-Hill companies
3. Power system analysis, C.L.Wadhwa, Newage International.
4. Modern Power Systems Analysis, I.J. Nagarath & D.P Kothari Tata McGraw-Hill companies

GENERAL OBJECTIVES

- To study and understand the economic operation of power systems,hydro thermal scheduling and modeling of turbines,generators and automatic controllers.
- To emphasizes on single area and two area load frequency control and reactive power control.

4.4. CourseOutcomes, Relationship of COs to POs & Relationship of COs to PSOs

Course Name: Power system Operation and Control (A70230) for academic year 2018-19 (IV-I)

Items	Course Outcomes
A702304.1	Knowledge and understanding: Understanding the Economic operation of power systems, hydrothermal scheduling
A702304.2	Modeling of turbines, generators and automatic controllers.
A702304.3	After going through this course student will get thorough knowledge on economic operation of power systems, scheduling of hydrothermal power plants.
A702304.4	operation of load frequency controllers, reactive power control, uncompensated transmission line and compensation in transmission systems through shunt and series compensations
A702304.5	Students will be able to understand and apply the conceptual things to real- world electrical and electronics problems and applications.

(i) Relationship of COs to POs

Course Name: Power system Operation and Control (A70230) for academic year 2018-19 (IV-I)

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
A702304.1	3	3	3	3	3	3	3	1	1	1	3	1
A702304.2	3	3	3	3	3	3	3	1	1	1	2	1
A702304.3	3	2	3	3	3	3	2	1	1	1	3	1
A702304.4	3	2	3	3	3	3	2	1	1	1	2	1
A702304.5	3	1	3	3	3	3	1	1	1	1	1	1
Average	3	2.2	3	3	3	3	2.2	1	1	1	2.2	1

(ii) Relationshipof COs to PSOs

CO	PSO01	PSO02
A702304.1	1	3
A702304.2	1	3
A702304.3	1	3
A702304.4	1	3
A702304.5	1	3
Average	1	3

***

4.5 . LECTURE PLAN

Date of commencement of Class / SEM: 24/12/2018
Dept : EEE
Sub : PSOC

Class / Semester : IV B.TECH I SEM
Name of the Faculty : M.NAGARAJU

Unit No	Chapter	DATE	Topics to be covered	Hours	Cumulative	Teaching Method
1	Economic Operation of Power Systems	09/07/2018	Introduction to Power generation unit	2	2	Chalk& Talk
		10/072018	State variables, problem of optimum dispatch-formulation	2	4	Chalk& Talk
		12/07/2018	Input-output characteristics	1	5	Chalk& Talk
		13/07/2018	Cost Curve characteristics, Incremental fuel Cost Curve	2	7	Chalk& Talk
		14/07/2018	Heat rate curve, incremental efficiency	2	9	Chalk& Talk
		17/07/2018	Neglecting the transmission loss **(tutorial)**	1	10	Chalk& Talk
		19/07/2018	Mathematical determination of Optimum Allocation among different units	2	12	Chalk& Talk
		20/07/2018	Optimum Generation scheduling problem-consideration of Transmission Losses . **(tutorial)**	1	13	Chalk& Talk
		21/07/2018	Determination of ITL formula-problems	1	14	Chalk& Talk
		23/07/2018	Penalty factor-problems	1	15	Chalk& Talk
2	Hydro thermal Scheduling	24/07/2018	Optimal scheduling of Hydrothermal System	1	16	Chalk& Talk
		26/07/2018	Hydro thermal coordination	1	17	Chalk& Talk
		27/07/2018	Scheduling of hydro units in a hydro thermal system	1	18	Chalk& Talk
		02/08/2018	Coordination of run-off river plant and steam plant	1	19	Chalk& Talk
		03/08/2018	Long term coordination	1	20	Chalk& Talk
		04/08/2018	Short term coordination,	2	22	Chalk& Talk
		09/08/2018	Mathematical formulation of long term hydro thermal scheduling, solution of short term hydro thermal scheduling problem	2	24	Chalk& Talk

		10/08/2018	Kirchmayer's method-problems **(tutorial)**	2	26	Chalk& Talk
3	Modeling of Turbine, Generator, Governor, Excitation system	13/08/2018	Modeling of Turbine, hydraulic turbine system	2	28	Chalk& Talk
		16/08/2018	Modeling of hydraulic turbine, calculation of water time constant	2	30	Chalk& Talk
		21/08/2018	Steam turbine modeling-non reheat & reheat type, modeling of speed governing system	2	32	Chalk& Talk
		23/08/2018	Speed governing mechanism for steam turbines; mechanical hydraulic controlled speed governing system **(tutorial)**	2	34	Chalk& Talk
		24/08/2018	Electro-hydraulic controlled speed governing system	1	35	Chalk& Talk
		27/08/2018	General model for speed governing system	1	36	Chalk& Talk
		28/08/2018	Hydro turbines: mechanical hydraulic controlled speed governing system	2	38	Chalk& Talk
		30/08/2018	General model for hydraulic turbine speed governing system	1	39	Chalk& Talk
		31/08/2018	Electro-hydraulic controlled speed governing system	1	40	Chalk& Talk
		01/09/2018	Modeling of a steam governor turbine system, reheat system unit	2	42	Chalk& Talk
		03/09/2018	Block diagram, transfer function of the steam governor turbine modeling	2	44	Chalk& Talk
		13/09/2018	Modeling of a hydro turbine speed governor **(Beyond the syllabus)**	1	45	Chalk& Talk
		14/09/2018	Modeling of excitation system, effect of varying excitation of a synchronous generator	2	47	Chalk& Talk
		18/09/2018	Methods of providing excitation, common excitation bus method	2	49	Chalk& Talk
		19/09/2018	Individual excitation method, block diagram of a general excitation system	2	51	Chalk& Talk
		20/09/2018	Excitation control scheme, excitation system classification	2	53	Chalk& Talk
		21/09/2018	IEEE Type-1 excitation system	1	54	Chalk& Talk
4	Single Area & Two-area Load Frequency Control	22/09/2018	Necessity of maintaining frequency constant	2	56	Chalk& Talk
		28/09/2018	Definitions of control area, single area control	2	58	Chalk& Talk
		29/09/2018	Generator controllers; p-f, q-v; speed governing system, Block diagram of an isolated power system	3	61	Chalk& Talk
		01/10/2018	Steady state analysis, dynamic response ,load frequency control of 2-area system	2	63	Chalk& Talk
		03/10/2018	Uncontrolled & controlled case, Tie line bias control	2	65	Chalk& Talk
		04/10/2018	Load frequency controllers, proportional plus integral control of single area **(tutorial)**	2	67	Chalk& Talk
		05/10/2018	Block diagram representation **(Beyond the syllabus)**	1	68	Chalk& Talk
		06/10/2018	Steady state response-load frequency control &economic dispatch control	2	70	Chalk& Talk
		08/10/2018	Overview of Reactive Power Control	1	71	Chalk&

						Talk
5	Reactive Power control	01/11/2018	Reactive Power Compensation in Transmission Systems, Advantages& disadvantages of Different Types Of Compensating equipment for transmission systems **(NPTEL)**	2	73	Chalk& Talk
		02/11/2018	Load compensation	1	74	Chalk& Talk
		05/11/2018	Specifications of load compensator	1	75	Chalk& Talk
		06/11/2018	Uncompensated & Compensated Transmission lines **(tutorial)**	2	77	Chalk& Talk
		08/11/2018	shunt Compensation	1	78	Chalk& Talk
		09/11/2018	Series Compensation	1	79	Chalk& Talk

HOD SIGNATURE

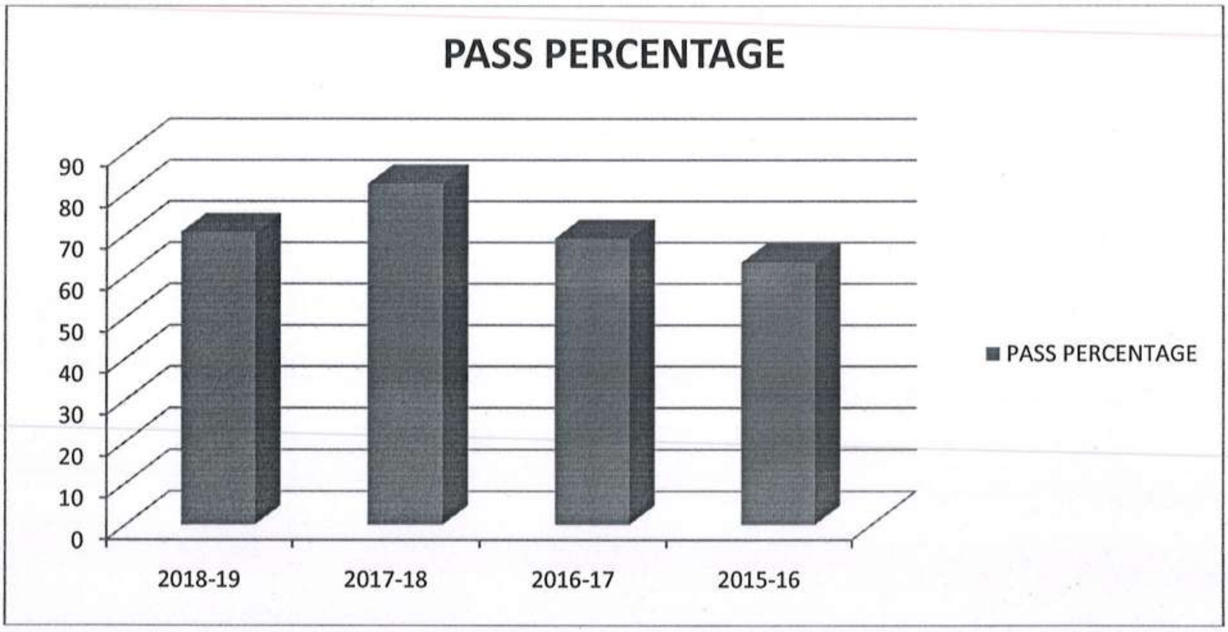
FACULTY SIGNATURE

4.6. Result Analysis of Past 4 Years with BAR Chart

4.7. (i).Result Analysis for the Past Three Years: POWER SYSTEM OPERATION&CONTROL

POWER SYSTEM OPERATION AND CONTROL			
ACADEMIC YEAR	APPEARED	PASSED	PASS PERCENTAGE
2018-19	92	65	70.65
2017-18	57	47	82.46
2016-17	81	56	69.14
2015-16	117	74	63.25

(ii) Result Analysis BAR Graph



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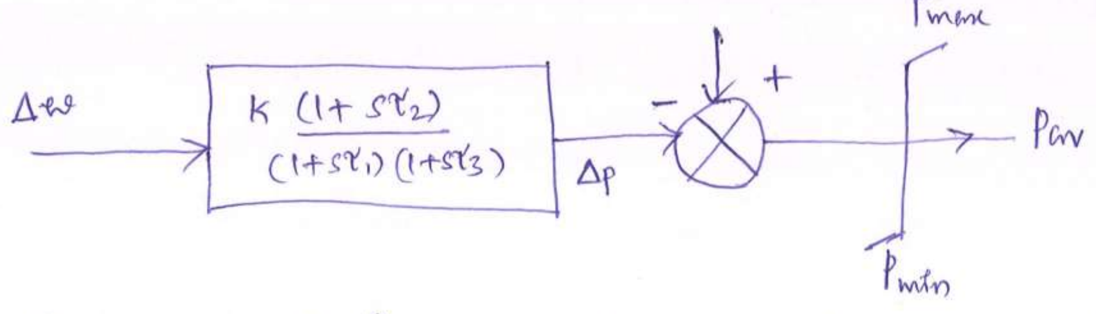
4.7. Add on Course Material

S.No	Topic	Presentation Method	Remarks
1	Modeling of a hydro turbine speed governor	**PPT Presentation**	
2	Block diagram representation	**NPTEL Video**	
3	Reactive Power Compensation in Transmission Systems, Advantages& disadvantages of Different Types Of Compensating equipment for transmission systems	**NPTEL Video**	

* Add on Course topics Notes :-

① Modelling of a hydro turbine speed Governor :-

The low-power functions associated with speed sensing and droop compensation in a modern speed governing system for hydro-turbines can be performed by an electronic apparatus, which results in the better performance and greater flexibility in both dead band and dead time. For interconnected System operation, however, the dynamic performance of the electric governor is necessarily adjusted to be essentially the same as that for the mechanical governor, so that a separate model is not needed.



General model for a speed-governing system for hydro turbines.

The general model for a hydraulic turbine speed-governing system is shown in figure.

Let $\tau_A = \left[\frac{1}{\sigma}\right] \tau_R \tau_G$

$\tau_B = \left[\frac{1}{\sigma}\right] (\sigma + \delta) \tau_R + \tau_G$

Then τ_1 and τ_3 of figure can be expressed approximately as,

$$\tau_1, \tau_3 = \frac{\tau_B}{2} \pm \sqrt{\frac{\tau_B^2}{2} - \tau_A}$$

$$K = \frac{1}{\sigma}; \quad \tau_2 = 0$$

'P_0' is the initial power

'P_{GV}' is the output of the governor

It is also to be noted that 'K' is the reciprocal of σ (steady-state SR in p.u.).

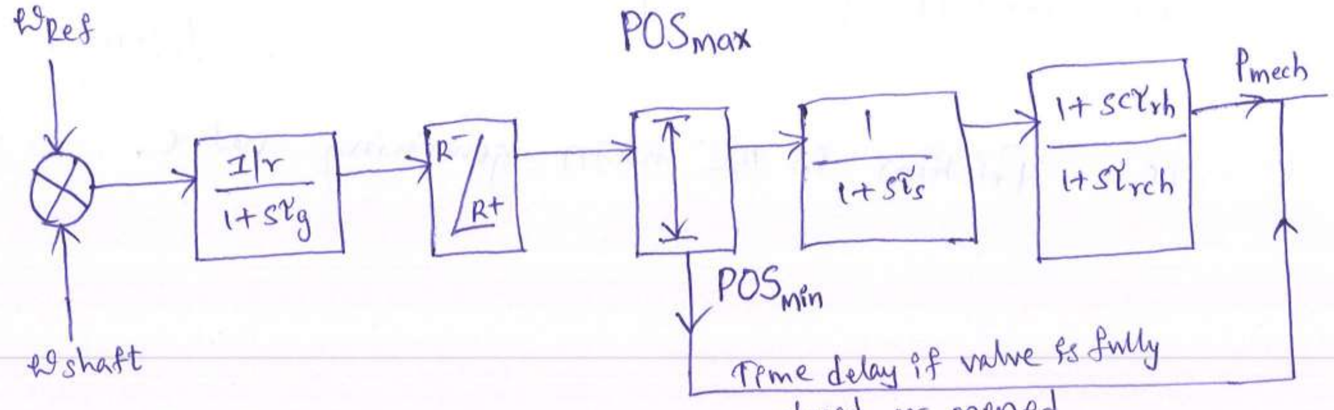
② Block diagram representation :-

The block diagram representation of modeling a reheat system unit with a reduction in-elements shown in figure.

r = Steady-state droop system setting in rad/s MW turbine power output

τ_g = Time Constant of a governing system

R^- = Maximum closing rate of a governing valve in MW/s



Block diagram representation of modeling a simple reheat steam turbine unit

R^+ = Maximum opening rate of the governing valve in MW/s

POS_{max} = maximum power output of the turbine in MW (max. governor valve opening)

POS_{min} = Minimum power output of the turbine in MW (governing valve may be closed)

τ_s = Equivalent time Constant of steam entrained in the turbine HP stage

τ_{rh} = Equivalent time Constant of the reheater and the associated piping

ω_{ref} = Reference Speed setting of the governor in rad/s

ω_{shaft} = Actual angular rotor velocity in rad/s

Delays and dead bands are present in the operations of:

(a) The speed-sensing mechanism, friction, and blacklash.

(b) Over capping of oil ports in the servosystem as well as friction

(c) friction in the main governing valve.

—o—

③ Reactive Power Requirements in Transmission Systems, Advantages & Dis-advantages of Different types of compensating equipments :

From the line voltage and the level of power transmission, the reactive power requirements can be determined. It is very important to know the reactive power requirements because they determine the reactive power ratings of the synchronous machines as well as those of any compensating equipment.

Comparison among different types of compensating equipment for transmission systems is tabulated below :

Compensating Equipment	Advantages	Disadvantages
(i) Switched shunt Reactor	Simple in principle, and construction	fixed in value.
(ii) Switched shunt Capacitor	Simple in principle & Construction	fixed in value - switching transients, Limited overload capacity.

(iii) Synchronous Condenser	Fully controllable. Low harmonics	Performance sensitive to location. Requires strong foundations.
(iv) Poly-phase - Saturated Reactor	very rugged construction, Large overload capability. No effect on fault level. Low harmonics.	Essentially fixed in value. Performance sensitive to Location & noisy.
(V) TCR	fast responce, Fully controllable, No effect on fault level. Can be rapidly repaired after - failures.	Generator harmonics performance sensitive to location
(Vi) TSC	can be ripidly repaired after failures. No harmonics.	No inherent - absorbing capability to limit overvoltages, Complex bus works and controls low - frequency resonance with system. Performance sensitive to location.

—o—

SIDDHARTHA INSTIUTE OF ENGINEERING & TECHNOLOGY
Vinobha Nagar, Ibrahimpatnam, Ranga Reddy Dist

Department of Electrical and Electronics Engineering

5. Unit Wise Lecture Notes

UNIT NO.	TITLE IN BRIEF	NO.OF PAGES
I	Economic Operation of Power Systems	
II	Hydrothermal Scheduling	
III	Modeling: Modeling of Turbine, Modeling of Governor	
IV	Single Area & Two Area Load Frequency Control, Load frequency control of area system, Load Frequency Controllers	
V	Reactive Power Control	

Unit - I (1-23)

Economic Operation of Power Systems

* Introduction :- A Power System Consists of several generating stations, where electrical energy is - generated, and several consumers for whose - use the electrical energy is generated.

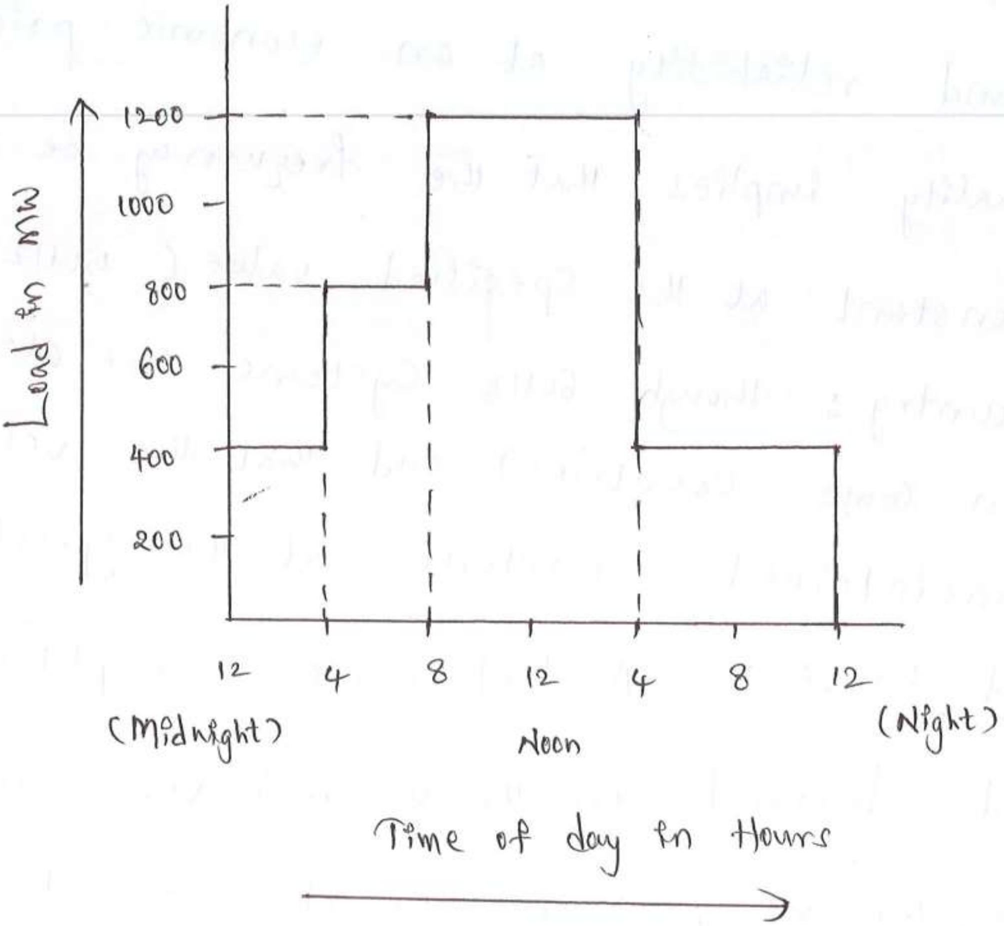
* The objective of any power system is to generate the electrical energy in sufficient quantities at the best - suited locations and to transmit it to the various load centres and then distribute it to the various consumers, maintaining the quality and reliability at an economic price.

* Quality implies that the frequency be maintained Constant at the specified value (50Hz in our - country; though 60Hz Systems are also available in some countries) and that the voltage be maintained Constant at the specified value.

Load curve :- A load curve is a plot of the load demand (on the y-axis) versus the time (on the x- axis) in the chronological order.

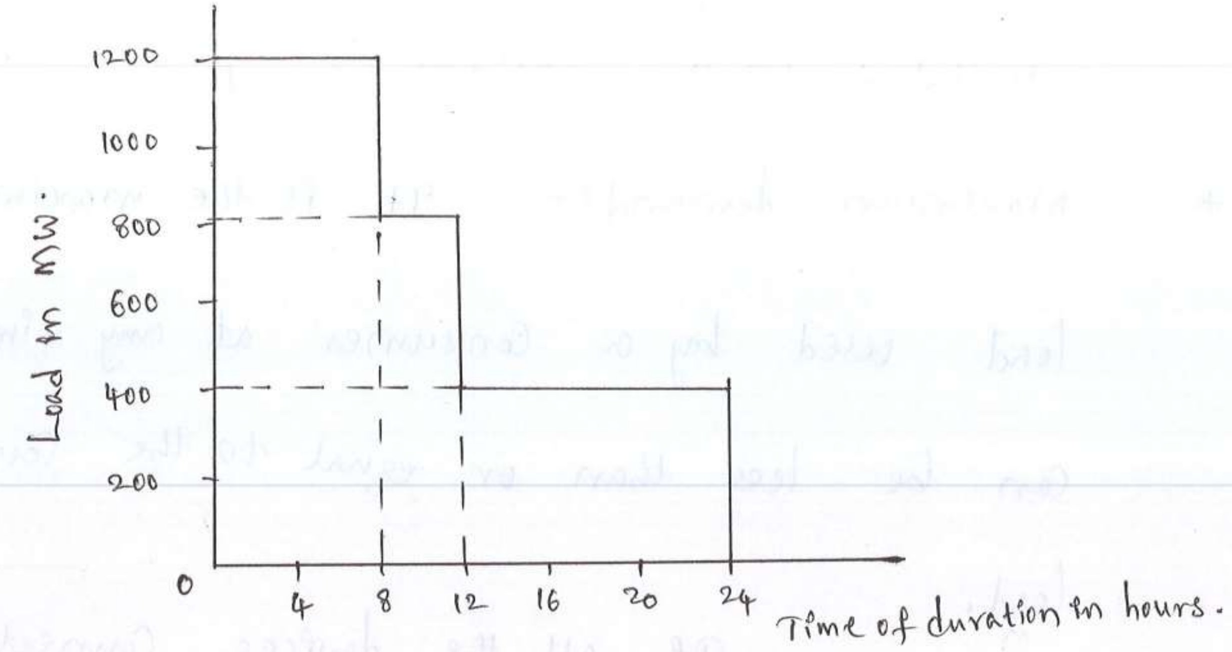
* If the load is measured (in units of power) at regular intervals of time, say, once in an hour (or half-an-hour) and recorded, we can draw a curve, known as the "load curve".

* A time period of only 24 hours is - considered, and the resulting load curve, which is called a "Daily load curve" is shown in figure.



* Load Duration curve :- The load duration curve is a plot of the load demands (in units of power) arranged in a descending order of magnitude (on the y-axis) and the time in hours (on the x-axis).

* It can be drawn as shown in the figure.



* Integrated Load Duration Curve :-

The integrated load-duration curve is a plot of the cumulative no. of units of electrical energy (on the x-axis) and the load demand (on the y-axis).

* Connected load :-

A domestic Consumer, may have several appliances rated at different wattages. The sum of these ratings is his connected load.

Connected load is the sum of the ratings (W, KW, or MW) of the apparatus installed on a Consumer's premises.

* Maximum demand :- It is the maximum load used by a Consumer at any time. It can be less than or equal to the Connected load.

If all the devices Connected in the Consumer's house, run to their fullest extent Simultaneously, then the maximum demand will be equal to the Connected load.

* Demand factor :-

The ratio of the maximum - demand to the Connected load is called the "demand factor".

$$DF = \frac{\text{maximum demand}}{\text{Connected load}}$$

* It's units are same, (W, kW, or MW).

* Average load :-

If the no. of kWh supplied by a station in one day is divided by 24 hours, then the value obtained is known as the "daily average load".

$$\text{Daily average load} = \frac{\text{kWh in one day}}{24}$$

$$\text{Monthly average load} = \frac{\text{kWh in one day}}{30 \times 24}$$

$$\text{Yearly average load} = \frac{\text{kWh in one day}}{365 \times 24}$$

* Load factor :-

The ratio of the average demand to the maximum demand is called the load factor.

$$\text{Load factor (LF)} = \frac{\text{average demand}}{\text{max demand}}$$

If the plant is in operation for a period T,

$$\text{Load factor} = \frac{\text{average demand} \times T}{\text{max demand} \times T}$$

$$= \frac{\text{Units generated in T hours}}{\text{max. demand} \times T.}$$

* Diversity factor :-

Diversity factor is the ratio of the sum of the maximum demands of a group of consumers to the simultaneous - maximum demand of the group of consumers.

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{maximum demand on the - system.}}$$

* plant capacity :-

It is the capacity or power for which a plant or station is designed.

* It is equal to the sum of the ratings of all the generators in a power station.

* plant Capacity factor:-

It is the ratio of the average demand on the station to the maximum installed capacity of the station.

$$\text{plant capacity factor} = \frac{\text{Average demand}}{\text{max. installed capacity}}$$

$$\text{(or)} \quad \text{Capacity factor} = \text{load factor} \times \text{Utilization factor}$$

$$\text{Reserve capacity} = \text{plant capacity} - \text{maximum demand.}$$

* Utilization factor (plant-use factor) :-

It is the ratio of kwh generated to the product of the plant capacity and the - no.of hours for which the plant was in operation.

$$\text{plant use factor} = \frac{\text{Station output in kwh}}{\text{plant capacity} \times \text{hours of use}}.$$

* Base Load :- It is the unvarying load that occurs almost during the whole day on the station.

* Peak Load :- It is the various peak demands of load over and above the base load of the station.

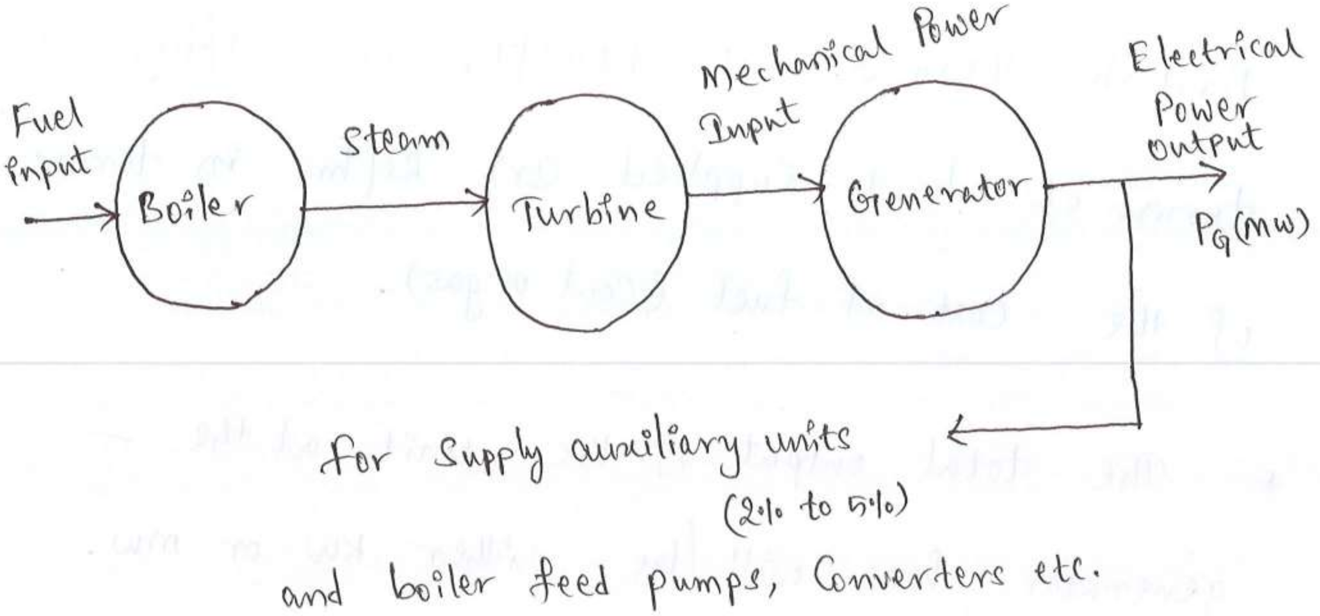
* Base load stations run at 100% capacity on a 24 hours basis. Nuclear reactors are ideally suited for this purpose.

* Peak load stations operate during the peak load hours only. Since the gas-turbine driven generators are best suited to serve as peak load stations, they can pick up the load very quickly.

* Characteristics of Power Generation (Steam) Unit :-

In analyzing the economic operation of a thermal unit, input - output modeling characteristics are significant.

* for this reason, Consider a single unit - Consisting of a boiler, a turbine, and a - generator as shown in figure.



Thermal generation system

* This unit has to supply power not only - to the load Connected to the Power system, but also to the local needs for the -

- auxiliaries in the station, which may vary from 2% to 5%.

* The Power requirements for station auxiliaries are necessary to drive boiler feed pumps, fans, and condenser circulating water pumps, etc.

* The total input to the thermal unit can be British thermal unit (Btu)/hr (or) cal/hr in terms of heat supplied (or) Rs/hr in terms of the cost of fuel (coal or gas).

* The total output of the unit at the generator bus will be either kW or MW.

* System Variables :-

To analyze the power system network, there is a need of knowing the system variables. They are,

(i) Control variables

(ii) Disturbance variables

(iii) State variables.

(i) Control variables :— (P_G and Q_G) :

The real and reactive power generations are called Control variables since they are used to Control the state of the system.

(ii) Disturbance variables (P_D and Q_D) :—

The real and reactive power demands are called demand variables, since they are beyond the system Control and are hence Considered as unControlled (or) disturbance variables.

(iii) State variables :-

The bus voltage magnitude 'v' and it's phase angle 'δ' dispatch the state of the system. These are dependent variables that are being controlled by the control variables.

* Problem of Optimum Dispatch - Formulation:-

'Scheduling' is the process of allocation of generation among different generating units.

* 'Economic scheduling' is a cost-effective mode of allocation of generation among the different units in such a way that, the overall cost of generation should be minimum.

* This can be termed as an "optimal dispatch".

* Let the total load demand on the station = P_D

and the total no.of generating units = n

* The optimization problem is to allocate the total load 'P_D' among these 'n' units in optimal, way to reduce the overall cost of generation.

* Let P_{G_1}, P_{G_2}, P_{G_3}, ----- P_{G_n} be the power - generated by each individual unit to supply a load demand of P_D.

* To formulate this problem, it is necessary to know the "input- output characteristics" of each unit.

* Input - Output characteristics :-

The idealized form of input- Output characteristics of a steam unit is - shown in figure.

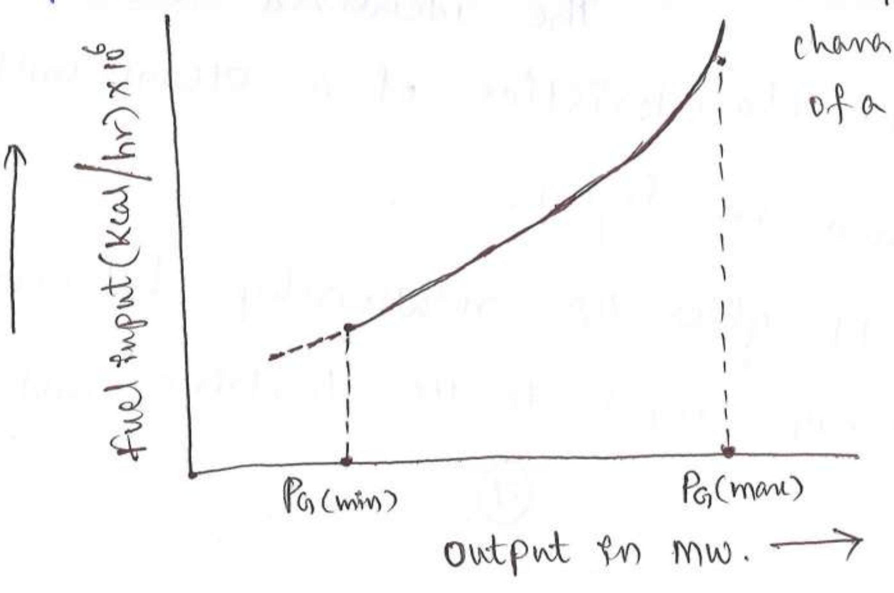
* It gives the relationship between the - energy input to the turbine and the -

- energy output from the electrical generator.

* The input to the turbine, either in terms of the heat energy, which is measured in Btu/hr or Kcal/hr (or) in terms of the cost of fuel per hour in Rs/hr.

* The output is the net electrical power of steam unit in KW (or) MW.

* The steam turbine-generating unit curve consists of minimum and maximum limits in operation, which depend upon the steam cycle, thermal characteristics of material, the operating temperature, etc.



* Input-output characteristics of a steam unit.

Units of turbine input :-

In terms of heat, the unit is 10^6 Kcal/hr (or) Btu/hr (or) in terms of the amount of fuel, the unit is tons of fuel/hr, which becomes millions of kcal/hr.

* Cost curves :-

To convert the input-output curves into cost curves, the fuel input per hour is multiplied with the cost of the fuel (expressed in Rs/million kcal)

i.e, $\frac{\text{Kcal} \times 10^6}{\text{hr}} \times \text{Rs.}/\text{million. kcal.}$

$= \text{million. kcal/hr} \times \text{Rs.}/\text{million kcal.}$

$= \text{Rs/hr.}$

* Incremental Fuel Cost Curve :-

From the input-output curves, the incremental fuel cost (IFC) curve can be obtained.

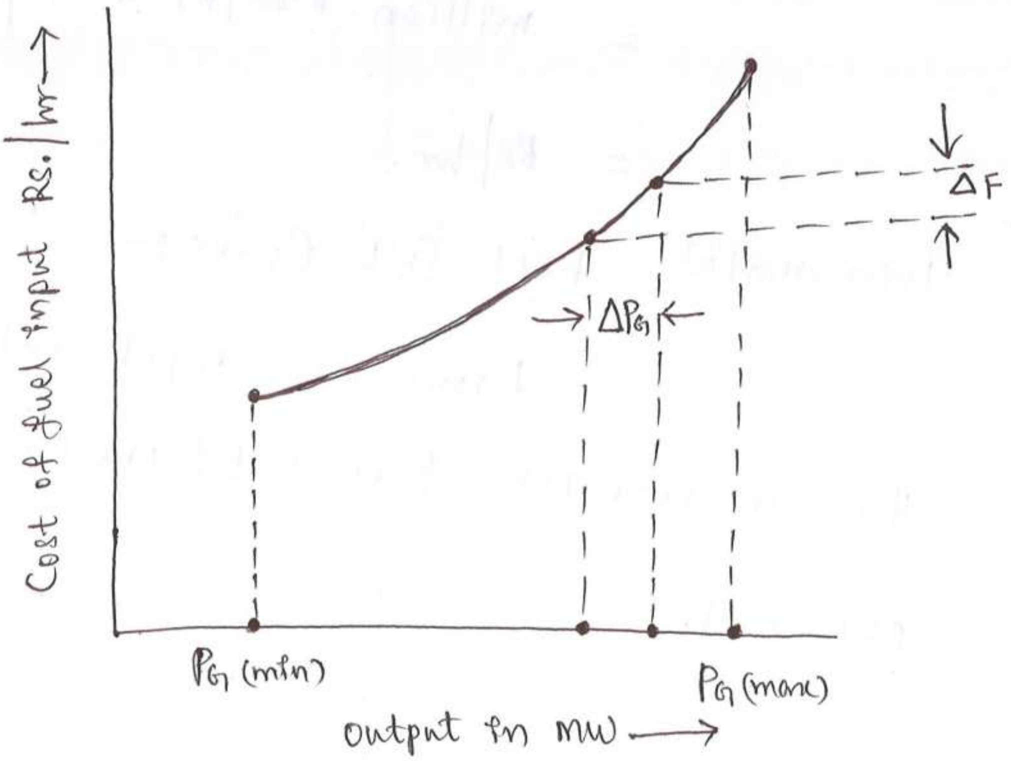
- The IFC is defined as the ratio of a small change in the input to the corresponding small change in the output.

$$\text{Incremental fuel cost} = \frac{\Delta \text{ input}}{\Delta \text{ output}} = \frac{\Delta F}{\Delta P_G}$$

where 'Δ' represents small changes.

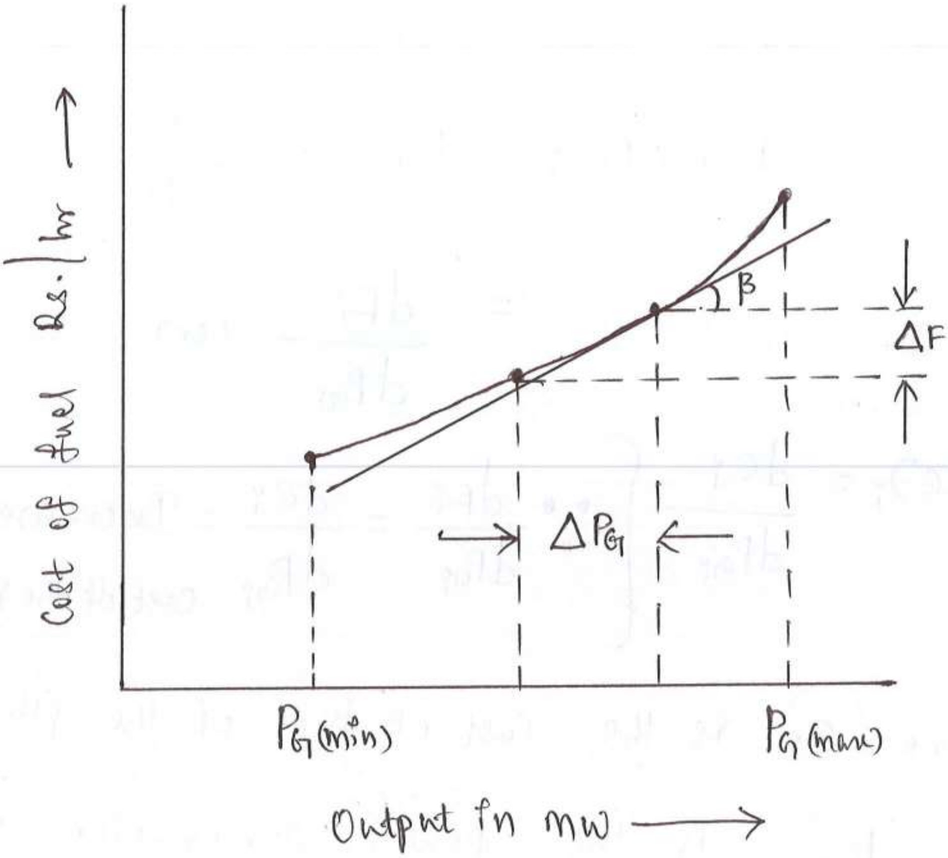
* As the 'Δ' quantities become progressively smaller, it is seen that the IFC is $\frac{d(\text{input})}{d(\text{output})}$.

* And is expressed in Rs./mwh. A typical plot of the IFC versus output power is shown in Figure. (a).



(a)

The incremental cost curve is obtained by – Considering the change in the cost of generation to the change in real-power generation at various points on the on the input-output curves, i.e, slope of the input-output curve as shown in figure (b).



(b)

(b) Incremental fuel cost characteristics in terms of the slope of the input-output curve.

The IFC is now obtained as,

$(IC)_i$ = Slope of the fuel cost curve.

① The cost function of 50 mw generator is given by $F(P_i) = 0.02 P_i^2 + 53 P_i + 225$ Rs/hr when 100% load is applied, calculate incremental fuel cost and fuel cost.

Sol:-

$$F(P_i) = 0.02 P_i^2 + 53 P_i + 225$$

$$\frac{dF}{dP_i} = 0.04 P_i + 53$$

$$= 0.04(50) + 53 = 55 \text{ Rs/MWhr}$$

$$\text{fuel cost} = 0.02(50^2) + 53(50) + 225$$

$$= 2925 \text{ Rs/hr.}$$

② The fuel cost of 2 units are as follows:

$$\left.\begin{aligned} F_1 &= 0.2 P_1^2 + 30 P_1 + 60 \\ F_2 &= 0.15 P_2^2 + 20 P_2 + 80 \end{aligned}\right\} \text{Rs/hr}$$

Calculate the generation schedule of the each unit for a Lagrangian multiplier of Rs. 120 per MWhr.

Sol:-

$$F_1 = 0.2 P_1^2 + 30 P_1 + 60$$

$$F_2 = 0.15 P_2^2 + 20 P_2 + 80$$

- of the cost curve.

- Cost curve expression,

$$C_i = \frac{1}{2} a_i P_{G_i}^2 + b_i P_{G_i} + d_i$$ (Second-degree - Polynomial)

The IFC,

$$\frac{dC_i}{dP_{G_i}} = (IC)_i = a_i P_{G_i} + b_i$$ (linear approximation)

for all $i = 1, 2, 3, \ldots, n$

- where, $\frac{dC_i}{dP_{G_i}}$ is the ratio of incremental fuel energy input in Btu to the incremental energy output in kwh, which is called "the incremental heat rate".

- The fuel cost is the major component and the IFC is very significant in the - economic loading of a generating unit.

* Heat Rate Curve :-

The heat rate characteristics obtained from the plot of the net heat rate in Btu/kwh (or) kcal/kwh versus power output in kw is shown in figure.

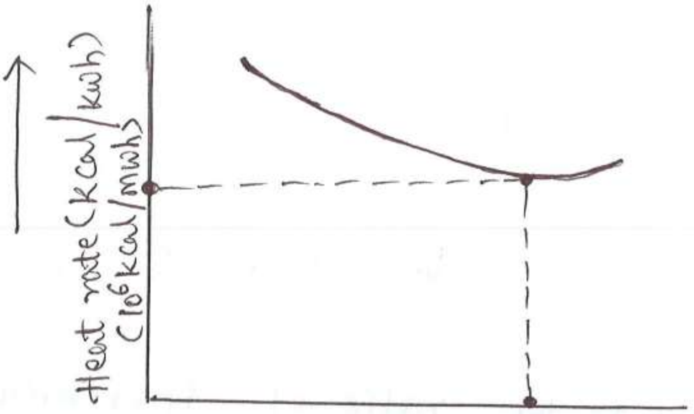


Figure. Heat rate curve.

- * The thermal unit is most efficient at a min. heat rate, which corresponds to a particular generation P_G.
- * The curve indicates an increase in heat rate at low and high power limits.

* Incremental Efficiency :- The reciprocal of the — incremental fuel rate (or) heat rate, which is defined as the ratio of output energy to input energy, gives a measure of fuel efficiency for the input.

i.e, $\text{Incremental efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{dP_G}{dC}$

The problem of economic operation of the power system involves two sub-problems, namely, unit Commitment (UC) and economic dispatch (ED).

* While UC is an off-line problem, ED is an area of online concern. The result ~~of UC~~ is an initial solution of the ED problem.

* Unit Commitment Problem :-

Generally the load curve of a plant, where there is a variation of load, vs time in a season. follows a particular trend or pattern.

* Hence these curves can be predicted with minimum degree of error.

* Let 'N' be the no. of generating units available in a plant.

* The problem of UC is to forecast, how the plant load should be allocated amongst the 'N' units in such a way that, the overall cost of generation of the plant is minimum.

* In other words, the solution of UC for 'N' available units is a schedule of the units that must be kept in 'ON' (Committed) condition or in 'off' (decommitted) condition.

* The problem of 'UC' is complex, since a large no.of constaints such as, start-up and shut-down costs and times, fuel cost per kwh, minimum and maximum generating capacities need to be addressed.

* Economic Despatch Problem:-

In contrast to the UC problem, ED assumes that, 'N' no.of units in the different generating stations are already -

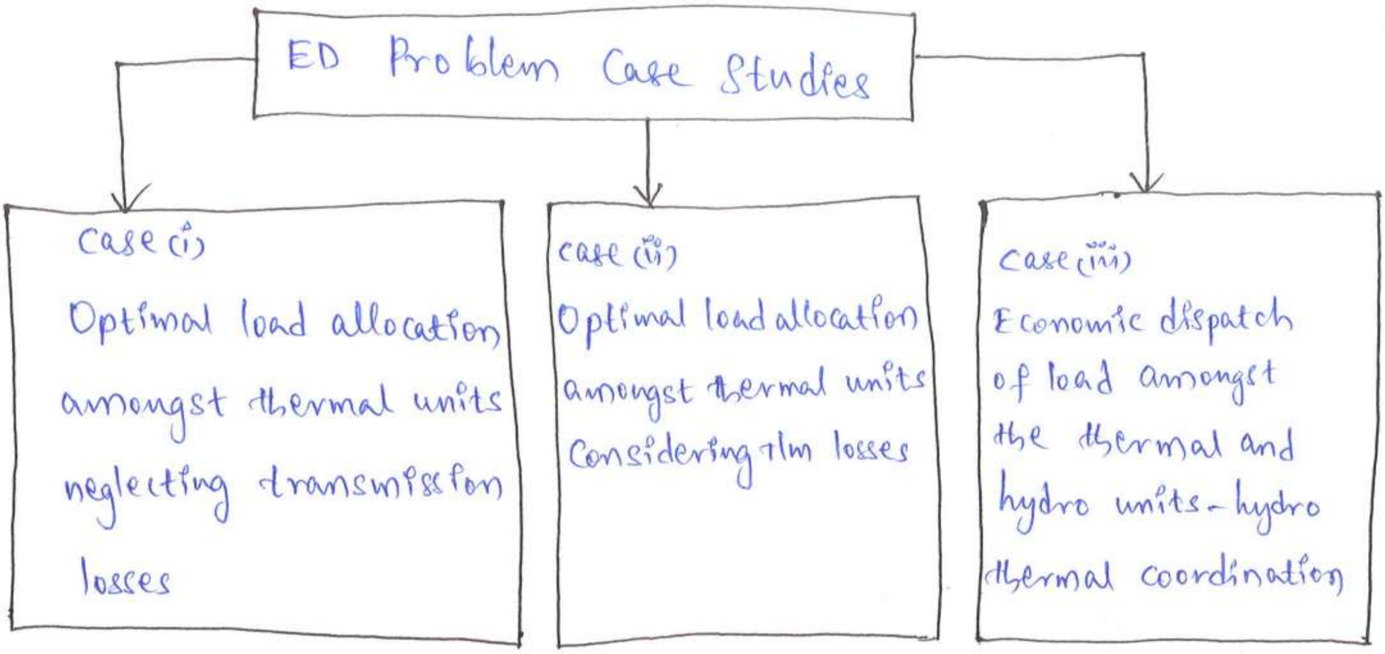
- Committed or in 'ON' condition.

* The problem here is to forecast, how the load should be shared amongst them in such a way that the overall cost of generation is minimum.

* The solution to UC is the starting point of the 'ED' problem.

* That is, once a decision on the units that are to be committed is taken, then, 'ED' resolves the distribution of load amongst the committed units.

* If all the units are in 'ON' condition, UC does not exist and we have to take up only the ED problem.


ED Problem Case Studies
Case (i)
Optimal load allocation amongst thermal units neglecting transmission losses
case (ii)
Optimal load allocation amongst thermal units Considering T/m losses
Case (iii)
Economic dispatch of load amongst the thermal and hydro units - hydro thermal coordination

* Optimization Problem - Mathematical formulation (Neglecting The Transmission Losses)

An optimization problem consists of:

1. Objective function
2. Constraint equations

* Objective function :- The objective function is to minimize the overall cost of production of Power generation.

* Cost in thermal and nuclear stations is nothing but the cost of fuel. Let 'n' be the no. of units in the system and 'C_i' the cost of power generation of unit 'i':

$$\therefore \text{Total cost} = C = C_1 + C_2 + C_3 + \dots + C_n$$

$$\text{i.e.,} \quad C = \sum_{i=1}^{n} C_i$$

* The cost of generation of each unit in thermal power plants is mainly a fuel cost.

* The generation cost depends on the amount of

- real power generated, since the real-power-generation is increased by increasing the - fuel input.

* The generation of reactive power has negligible influence on the cost of generation, since it is controlled by the field current.

* ∴ the generation cost of ith unit is a function of real-power generation of that unit and hence the total cost is expressed as,

$$C = \sum_{i=1}^{n} C_i(P_{Gi}) \quad — ①$$

$$\text{i.e,} \quad C = C_1(P_{G1}) + C_2(P_{G2}) + C_3(P_{G3}) + \cdots + C_n(P_{Gn})$$

* This objective function consists of the - summation of the terms in which each term is a function of separate independent variables. This type of objective function is called a "separable objective function".

The optimization problem is to allocate the total load demand (P_D) among the various generating units, such that the cost of generation is minimized and satisfies the following constraints.

* Constraint equations :-

The economic power system - operation needs to satisfy the following types of constraints.

① Equality Constraints :-

The sum of real-power generation of all the various units must always be equal to the total real-power demand on the system.

$$\text{i.e,} \quad P_D = \sum_{i=1}^{n} P_{Gi}$$

(or)

$$\sum_{i=1}^{n} P_{Gi} - P_D = 0 \quad \text{——} ②$$

where, $\sum_{i=1}^{n} P_{Gi}$ = total real-power generation and 'P_D' is the total real power demand.

— Equation ② is known as the real-power — balance equation when losses are neglected.

② Inequality Constraints :—

These constraints are considered in an economic power system operation due to the physical and operational limitations of the units and components.

* Output power constraints :—

Each generating unit should not operate above it's rating or below some minimum generation. This minimum value of real-power generation is determined from the technical feasibility.

$$P_{Gi(min)} \leq P_{Gi} \leq P_{Gi(max)}$$

Similarly, the limits also have to be considered — over the range of reactive power capabilities of the generator unit requiring that,

$$Q_{Gi(min)} \leq Q_{Gi} \leq Q_{Gi(max)} \text{ for } i = 1, 2, 3, \ldots, n.$$

* Economic Dispatch Neglecting losses and including Generator Limits :-

The output power of any generator should either exceed its rating or should it be below that necessary for the stable operation of a boiler.

- Thus, the generations are restricted to lie within given minimum and maximum limits.
- The problem is to find the active power generation of each plant, such that the objective function (i.e, total production cost) is minimum, subject to the equality constraint, and the inequality constraints are,

$$\sum_{i=1}^{n} P_{G_i} = P_D \quad \text{and} \quad P_{G_i(min)} \leq P_{G_i} \leq P_{G_i(max)},$$

respectively.

- If any generating unit violates the above inequality constraints, set its generation at its respective limit as given below.

- In addition, the balance of the load is then shared between the remaining units on the basis of equal incremental cost.

- The necessary conditions for optimal dispatch when losses are neglected.

$$\frac{dC_i}{dP_{Gi}} = \lambda \quad \text{for} \quad P_{Gi(min)} \leq P_{Gi} \leq P_{Gi(max)}$$

$$\frac{dC_i}{dP_{Gi}} \leq \lambda \quad \text{for} \quad P_{Gi} = P_{Gi(max)}$$

$$\frac{dC_i}{dP_{Gi}} \geq \lambda \quad \text{for} \quad P_{Gi} = P_{Gi(min)}$$

* Mathematical Determination of optimal Allocation of total Load Among Different Units :-

Consider a power station having 'n' number of units. Let us assume that each unit does not violate the inequality constraints and let the transmission losses be neglected.

The cost of production of electrical energy

$$C = \sum_{i=1}^{n} C_i(P_{G_i}) \quad \text{——} \quad ①$$

Where 'C_i' is the cost function of the ith unit

This cost is to be minimized subject to the equality constraint given by

$$P_D = \sum_{i=1}^{n} P_{G_i} \quad (\text{or})$$

$$\sum_{i=1}^{n} P_{G_i} - P_D = 0 \quad \text{——} \quad ②$$

Where 'P_{G_i}' is the real-power generation of the 'ith' unit.

This is a constrained optimization problem.

To get the solution for the optimization problem, we will define an objective function by augmenting -

equation ① with an equality constraint (equation ②) through the Lagrangian multiplier (λ) as,

$$C' = C - \lambda\left[\sum_{i=1}^{n} P_{Gi} - P_D\right]$$

$$\min\left[C'\right] = \min\left\{C - \lambda\left[\sum_{i=1}^{n} P_{Gi} - P_D\right]\right\} \longrightarrow \text{③}$$

The condition for optimality of such an augmented objective function is,

$$\frac{dC'}{dP_{Gi}} = 0$$

From equation ③,

$$\frac{dC'}{dP_{Gi}} = \frac{dC}{dP_{Gi}} - \frac{d}{dP_{Gi}}\left\{\lambda\left[\sum_{i=1}^{n} P_{Gi} - P_D\right]\right\} = 0$$

i.e,

$$\frac{dC'}{dP_{Gi}} = \frac{dC}{dP_{Gi}} - \lambda(1-0) = 0$$

Since P_D is a constant and is an uncontrolled variable,

$$\frac{dP_D}{dP_{Gi}} = 0$$

$$\therefore \quad \frac{dc'}{dP_{G_i}} = \frac{dc}{dP_{G_i}} - \lambda = 0 \quad \text{(or)}$$

$$\frac{dc}{dP_{G_i}} - \lambda = 0$$

$$\frac{dc}{dP_{G_2}} - \lambda = 0$$

$$\frac{dc}{dP_{G_3}} - \lambda = 0$$

$$\vdots$$

$$\frac{dc}{dP_{G_n}} - \lambda = 0$$

$$\therefore \quad \frac{dc}{dP_{G_1}} = \frac{dc}{dP_{G_2}} = \frac{dc}{dP_{G_3}} = \cdots = \frac{dc}{dP_{G_n}} = \lambda. \quad \text{④}$$

Since the expression of 'c' is in a variable separable form. i.e, the overall cost is the summation of cost of each generating unit, which is a function of real- power generation of that unit only:

$$\text{i.e,} \quad \frac{dc}{dP_{G_1}} = \frac{dc_1}{dP_{G_1}}$$

$$\frac{dc}{dP_{G_2}} = \frac{dc_2}{dP_{G_2}}$$

$$\vdots$$

* → In the case of thermal plants, the optimal scheduling problem can be completely solved at any desired instant without referring to the operation at other times. It is a "static optimization problem".

* → The operation of a system having both hydro and thermal plants is more complex as, hydro plants have a negligible operating cost, but are required to run under the constraint of availability of water for hydro generation during a given period of time. This problem is the "dynamic optimization problem". Where the time factor is to be considered.

* → The optimal scheduling problem in a hydro-thermal system can be stated as, to minimize the fuel cost of thermal plants under the constraint of water availability for hydro-generation over a given period of operation.

* Optimal Generation Scheduling problem : Consideration of Transmission Losses :-

In a practical system, a large amount of power is being transmitted through the transmission network, which causes power losses in the network (P_L) as shown in figure.

* In finding an optimal solution for economic scheduling problem (allocation of total load among the generating units.), it is more realistic to consider the transmission line losses, which are about 5-15% of the total generation.

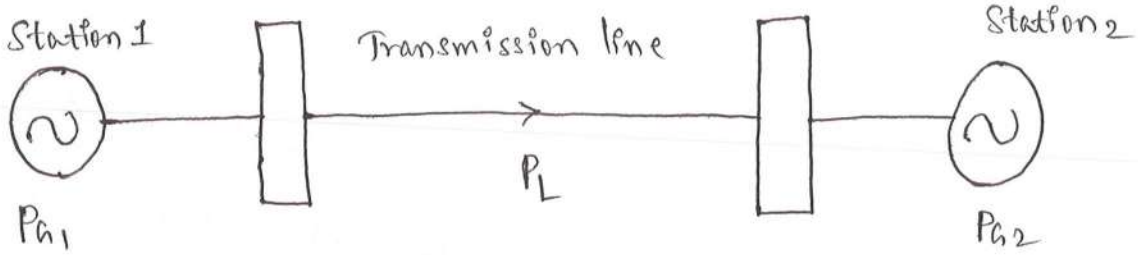
* In general, the condition for optimality, when losses are considered, is different. Equal incremental fuel costs (IFCs) for all generating units, will not give an optimal solution.

* Mathematical modeling :-

Consider the objective function:

$$C = \sum_{i=1}^{n} C_i(P_{G_i}) \quad \text{——} \; ①$$

Minimize Equation ① Subject to the following equality and inequality constraints.



Transmission network

*(i) Equality Constraints :-

The real power balance equation, i.e, total real power generations minus the total losses should be equal to the real-power demand.

$$\text{i.e,} \quad \sum_{i=1}^{n} P_{G_i} - P_L = P_D$$

(or)

$$\sum_{i=1}^{n} P_{G_i} - P_D - P_L = 0 \quad \text{——} \; ②$$

where 'P_L' is the total transmission losses (MW), 'P_D' is the total real-power demand (MW), and 'P_{Gi}' is the real-power generation at the ith unit (MW).

(ii) Inequality Constraints :-

Always there will be upper and lower limits for real and reactive-power-generation at each of the stations. The inequality constraints are represented:

(a) In terms of real-power generation as,

$$P_{Gi(min)} \leq P_{Gi} \leq P_{Gi(max)} \quad — ③$$

(b) In terms of reactive-Power generation as,

$$Q_{Gi(min)} \leq Q_{Gi} \leq Q_{Gi(max)} \quad — ④$$

The reactive power constraints are to be considered, since the transmission line loss is a function of real and reactive power generations and also the voltage at the station bus.

(c) In addition, the voltage at each of the stations should be maintained within certain limits: i.e, $V_{i(min)} \leq V_i \leq V_{i(max)}$ — ⑤

The optimal solution should be obtained by minimizing the cost function satisfying constraint equations :

② - ⑤

* Mathematical determination of optimum - Allocation of Total Load when Transmission Losses are Taken into Consideration :-

Consider a power station having 'n' no. of units. Let us assume that each unit does not violate the inequality constraints and let the transmission losses be considered.

Assuming that the inequality constraint is satisfied, the objective function is - redefined by augmenting Equation ① with equality constraint equation ② using - "Lagrangian multiplier (λ)" and is given by,

$$C' = \sum_{i=1}^{n} C_i(P_{Gi}) - \lambda \left[\sum_{i=1}^{n} P_{Gi} - P_D - P_L(P_{Gi}) \right] \quad ⑥$$

This augmented objective function is called - Constrained objective function.

In the above objective function, the real power generations are the control variables, and the condition for optimality becomes $\frac{\partial c'}{\partial P_{Gi}} = 0$, $i = 1, 2, ----, n$:

i.e, $$\frac{\partial c'}{\partial P_{Gi}} = \frac{\partial c_i}{\partial P_{Gi}} - \lambda \left[1 - 0 - \frac{\partial P_L}{\partial P_{Gi}} \right] = 0 \quad \text{—⑦}$$

(or)

$$\frac{\partial c_i}{\partial P_{Gi}} = \lambda \left[1 - 0 - \frac{\partial P_L}{\partial P_{Gi}} \right]$$

$$\therefore \frac{\partial c_i}{\partial P_{Gi}} = \lambda \left[1 - \frac{\partial P_L}{\partial P_{Gi}} \right] \quad \text{—⑧}$$

(or)

$$\lambda = \frac{\frac{\partial c_i}{\partial P_{Gi}}}{\left[1 - \frac{\partial P_L}{\partial P_{Gi}} \right]} \quad \text{—⑨}$$

where, $\frac{\partial P_L}{\partial P_{Gi}}$ represents the variation of total transmission loss with respect to real-power generation of the i^{th} station and is called incremental transmission loss (ITL) of the i^{th} station.

Equation ⑨ can be written as,

$$\therefore \quad \lambda = \frac{\dfrac{dC_i}{dP_{Gi}}}{\left[1-(ITL)_i\right]}$$

(or)

$$\lambda = L_i \frac{dC_i}{dP_{Gi}} \quad \text{—} ⑩$$

where $L_i = \dfrac{1}{\left[1-\dfrac{dP_L}{dP_{Gi}}\right]}$ and is called the penalty factor of the ith station. Equation ⑩ can be utilized to obtain the optimal cost of operation.

- The condition for optimality, when the Tm losses are considered is that the IFC of each plant multiplied by it's penalty factor must be the same for all the plants.

$$\text{i.e,} \quad \frac{dC_1}{dP_{G_1}} L_1 = \frac{dC_2}{dP_{G_2}} L_2 = \cdots = \frac{dC_n}{dP_{G_n}} L_n = \lambda \quad \text{—} ⑪$$

Equation ⑦ is a set of 'n' equations with (n+1) unknowns. Here, the powers of 'n' generators are unknown and 'λ' is also unknown. These equations are known as, "exact co-ordination equations" because they "co-ordinate the ITL with IFC"

—o—

* Determination of ITL formula :-

$$\boxed{P_L = B_{11} P_{G_1}^2 + B_{22} P_{G_2}^2 + 2B_{12} P_{G_1} P_{G_2}} \quad — ①$$

→ Equation ① expresses the total loss as a function of real power generations, P_{G_1} and P_{G_2}.

→ The coefficients B_{11}, B_{22}, and B_{12} are called loss coefficients (or) B- coefficients and the unit is $(MW)^{-1}$

→ The same procedure can be extended for systems having more no. of stations. If the system have 'n' no. of stations, supplying the total load through transmission lines, the transmission line loss is given by

$$P_L = \sum_{p=1}^{n} \sum_{q=1}^{n} P_{G_p} B_{pq} P_{G_q} \quad — ②$$

When n=2,

$$P_L = \sum_{p=1}^{2} \sum_{q=1}^{2} P_{G_p} B_{pq} P_{G_q}$$

$$= P_{G_1} B_{11} P_{G_1} + P_{G_1} B_{12} P_{G_2} + P_{G_2} B_{21} P_{G_1} + P_{G_2} B_{22} P_{G_2}$$

$$= B_{11} P_{G_1}^2 + B_{22} P_{G_2}^2 + 2B_{12} P_{G_1} P_{G_2}$$

Similarly n=3,

$$P_L = \sum_{p=1}^{3} \sum_{q=1}^{3} P_{G_p} B_{pq} P_{G_q}$$

$$= B_{11}P_{G_1}^2 + B_{22}P_{G_2}^2 + B_{33}P_{G_3}^2 + 2B_{12}P_{G_1}P_{G_2} + 2B_{23}P_{G_2}P_{G_3} + 2B_{31}P_{G_3}P_{G_1} \quad ③$$

Since the transmission lines are Symmetrical, loss-coefficients B_{pq} and B_{qp} are equal, i.e, $B_{pq} = B_{qp}$.

→ The B_{pq} coefficients are loss coefficients and can be represented in matrix form of an n-generator System as,

$$B_{pq} = \begin{bmatrix} B_{11} & B_{12} & \cdots & Bm \\ B_{21} & B_{22} & \cdots & B_{2n} \\ \vdots & & & \\ B_{n1} & B_{n2} & \cdots & B_{nn} \end{bmatrix}_{n\times n}$$

ITL formula:-

when a system Consists of three generating units, i.e, n=3, the transmission loss is

$$P_L = \sum_{p=1}^{3}\sum_{q=1}^{3} P_{Gp} B_{pq} P_{Gq}$$

$$= B_{11}P_{G_1}^2 + B_{22}P_{G_2}^2 + B_{33}P_{G_3}^2 + 2B_{12}P_{G_1}P_{G_2} + 2B_{23}P_{G_2}P_{G_3} + 2B_{31}P_{G_3}P_{G_1}$$

$(\because B_{pq} = B_{qp})$

ITL of Generator-1 is obtained as,

$$\frac{\partial P_L}{\partial P_{G_1}} = 2B_{11}P_{G_1} + 2B_{12}P_{G_2} + 2B_{13}P_{G_3}$$

(1-Terms)

$$= 2\left(B_{11}P_{G_1} + B_{12}P_{G_2} + B_{13}P_{G_3}\right)$$

$$= \sum_{i=1}^{n} 2B_{1i}P_{Gi}$$

In general,

$$\frac{dP_L}{dP_{Gi}} = \sum_{j=1}^{n} 2B_{ij} P_{Gj} \quad — ④$$

We know that the IFC of the i^{th} unit is,

$$\frac{dC_i}{dP_{Gi}} = (IC)_i = a_i P_{Gi} + b_i \quad — ⑤$$

Substitute equations ④ and ⑤ in equation ⑦

$$\boxed{\frac{dc'}{dP_{Gi}} = \frac{dC_i}{dP_{Gi}} - \lambda\left[1 - 0 - \frac{dP_L}{dP_{Gi}}\right] = 0}$$

$$\therefore \frac{dc'}{dP_{Gi}} = (a_i P_{Gi} + b_i) - \lambda.\left[1 - 2\sum_{j=1}^{n} B_{ij} P_{Gj}\right] = 0$$

$$a_i P_{Gi} + b_i - \lambda + 2\lambda\left[\sum_{\substack{j=1 \\ j\neq i}}^{n} (B_{ij} P_{Gj} + B_{ii} P_{Gi})\right] = 0$$

$$[a_i + 2\lambda B_{ii}] P_{Gi} = \lambda - 2\lambda \sum_{\substack{j=1 \\ j\neq i}}^{n} (B_{ij} P_{Gj}) - b_i$$

Dividing the above equation by λ, we get,

$$\left[\frac{a_i}{\lambda} + 2B_{ii}\right] P_{Gi} = 1 - 2\sum_{\substack{j=1 \\ j\neq i}}^{n} (B_{ij} P_{Gj}) - \frac{b_i}{\lambda}$$

$$\therefore \boxed{P_{Gi} = \frac{1 - 2\sum_{\substack{j=1 \\ j\neq i}}^{n} (B_{ij} P_{Gj}) - \frac{b_i}{\lambda}}{\left[\frac{a_i}{\lambda} + 2B_{ii}\right]}}$$

* Penalty factor :-

Consider Equation ⑦

$$\boxed{\frac{dc'}{dP_{Gi}} = \frac{dc_i}{dP_{Gi}} - \lambda\left[1-0-\frac{dP_L}{dP_{Gi}}\right] = 0}$$ (or)

$$\frac{dc_i}{dP_{Gi}} = \lambda\left[1-0-\frac{dP_L}{dP_{Gi}}\right]$$

$$\therefore \frac{dc_i}{dP_{Gi}} = \lambda\left[1-\frac{dP_L}{dP_{Gi}}\right] \text{ (or) } \lambda = \frac{\frac{dc_i}{dP_{Gi}}}{\left[1-\frac{dP_L}{dP_{Gi}}\right]}$$

The above expression can be written as,

$$\therefore \lambda = \frac{\frac{dc_i}{dP_{Gi}}}{\left[1-(ITL)_i\right]} = \frac{\text{Incremental fuel cost}}{\left[1-\text{Increment transmission loss}\right]}$$

(or) $\lambda = L_i \frac{dc_i}{dP_{Gi}}$ where, $L_i = \frac{1}{\left[1-\frac{dP_L}{dP_{Gi}}\right]}$

is called the penalty factor of the ith station.

$$\boxed{L_i = \frac{1}{\left[1-\frac{dP_L}{dP_{Gi}}\right]} = \frac{1}{\left[1-(ITL)_i\right]}}$$

Defination :- The penalty factor of any unit is defined as, the ratio of a small change in power at that unit to the small change in received power when only that unit supplies this small change in received power.

—0—

① The cost function of 50 MW generator is given by $F(P_i) = 0.02 P_i^2 + 53 P_i + 225$ Rs/hr when 100% load is applied, calculate incremental fuel cost and fuel cost.

Sol :-

$$F(P_i) = 0.02 P_i^2 + 53 P_i + 225$$

$$\frac{dF}{dP_i} = 0.04 P_i + 53$$

$$= 0.04(50) + 53 = 55 \text{ Rs/MWhr}$$

$$\text{fuel cost} = 0.02(50^2) + 53(50) + 225$$

$$= 2925 \text{ Rs/hr.}$$

② The fuel cost of 2 units are as follows:

$$\left.\begin{aligned} F_1 &= 0.2 P_1^2 + 30 P_1 + 60 \\ F_2 &= 0.15 P_2^2 + 20 P_2 + 80 \end{aligned}\right\} \text{Rs/hr}$$

Calculate the generation schedule of the each unit for a Lagrangian multiplier of Rs. 120 per MWhr.

Sol :-

$$F_1 = 0.2 P_1^2 + 30 P_1 + 60$$

$$F_2 = 0.15 P_2^2 + 20 P_2 + 80$$

④ The Power generated by two plants are $P_1 = 50 MW$, $P_2 = 40 MW$. If the loss coefficients are $B_{11} = 0.001$, $B_{22} = 0.0025$ and $B_{12} = -0.0005$, then power loss will be :

Sol :-

$$\text{Power loss} = \sum_{m=1}^{n} \sum_{n=1}^{n} P_m B_{mn} P_n$$

$$= B_{11} P_1^2 + B_{22} P_2^2 + P_1 B_{12} P_2 + P_2 B_{21} P_1$$

$$= (0.001) \times (50)^2 + (0.0025) \times (40)^2 + 50 \times 40 \times -0.0005 + 40 \times 50 \times (-0.0005)$$

$$= 2.5 + 4 - 1 - 1 = 4.5 MW.$$

⑤ The fuel cost of two units are given by

$$C_1 = C_1(P_{G1}) = 1.0 + 25 P_{G1} + 0.2 P_{G1}^2 \text{ Rs/hr}$$

$$C_2 = C_2(P_{G2}) = 1.5 + 35 P_{G2} + 0.2 P_{G2}^2 \text{ Rs/hr}$$

If the total demand on the generator is 200MW, find the economic load scheduling of the two units.

Sol :- The condition for economic load scheduling when neglecting the transmission losses is,

$$\frac{dC_i}{dP_{Gi}} = \lambda \quad \text{for } i = 1, 2, ---, n$$

i.e, $\frac{dc_1}{dP_{G_1}} = \frac{dc_2}{dP_{G_2}} \cdots \frac{dc_n}{dP_{G_n}} = \lambda$

$$C_1 = 1.0 + 25 P_{G_1} + 0.2 P_{G_1}^2$$

$$\frac{dc_1}{dP_{G_1}} = 25 + 0.4 P_{G_1} \quad Rs/mwh$$

$$C_2 = 1.5 + 35 P_{G_2} + 0.2 P_{G_2}^2$$

$$\frac{dc_2}{dP_{G_2}} = 35 + 0.4 P_{G_2}$$

for economical load dispatch,

$$\frac{dc_1}{dP_{G_1}} = \frac{dc_2}{dP_{G_2}} = \lambda$$

$$25 + 0.4 P_{G_1} = 35 + 0.4 P_{G_2} \quad (or)$$

$$0.4 P_{G_1} - 0.4 P_{G_2} = 35 - 25$$

$$0.4 P_{G_1} - 0.4 P_{G_2} = 10 \text{ mw} \longleftarrow ①$$

and $P_{G_1} + P_{G_2} = 200 \text{ mw} \longleftarrow ②$

$$0.4 P_{G_1} - 0.4 P_{G_2} = 10$$

multiplying both sides of Equation ② by 0.4, we get,

$$0.4 P_{G_1} + 0.4 P_{G_2} = 80 \longleftarrow ③$$

By adding Equations ① and ③, we get,

$$\begin{array}{l} 0.4P_{G_1} - \cancel{0.4P_{G_2}} = 10 \\ 0.4P_{G_1} + \cancel{0.4P_{G_2}} = 80 \\ \hline 0.8P_{G_1} = 90 \end{array}$$

(or) $\therefore P_{G_1} = \frac{90}{0.8} = 112.5 \text{ MW}.$

Substituting $P_{G_1} = 112.5 \text{ MW}$ in equation ②

$$112.5 + P_{G_2} = 200$$

$$\therefore P_{G_2} = 87.5 \text{ MW}.$$

—o—

Unit-II (1-17)

Hydrothermal Scheduling

* Introduction:- No state (or) country is endowed with plenty of water sources or abundant coal and nuclear fuel. For minimum environmental pollution, thermal generation should be minimum. Hence, a mix of hydro and thermal power generation is necessary.

→ The states that have a large hydro potential can supply excess hydro-power during periods of high water run-off to other states. and can receive thermal power during periods of low water run-off from other states.

→ The whole or a part of the base load can be supplied by the run-off river hydro-plants.

→ And the peak load is then met by a proper mix of reservoir-type hydro plants and thermal plants.

* Hydro - Thermal Co-ordination :-

Initially, there were mostly thermal power plants to generate electrical power. There is a need for the development of hydro-Power plants. due to the following reasons.

(i) Due to the increment of power in the load-demand from all sides, such as, industrial, agricultural, Commercial and domestic.

(ii) Due to the high cost of fuel (Coal).

(iii) Due to the limited range of fuel.

- → The hydro plants can be started easily and can be assigned a load in very short time.

- → In the case of thermal plants, it requires several hours to make the boilers, super-heater, and turbine system ready to take the load.

*→ for this reason, the hydro plants can handle fast changing loads effectively. The thermal plants in contrast are slow in responce.

*→ Hence, due to this, the thermal plants are more Suitable to operate as, base load plants, hydro- plants to operate as peak load plants.

*→ In a hydro-thermal system, the whole part of the base load can be supplied by the run-off river hydro- plants and the peak load is then met by a proper co-ordination of reservoir type hydro-plants and thermal plants.

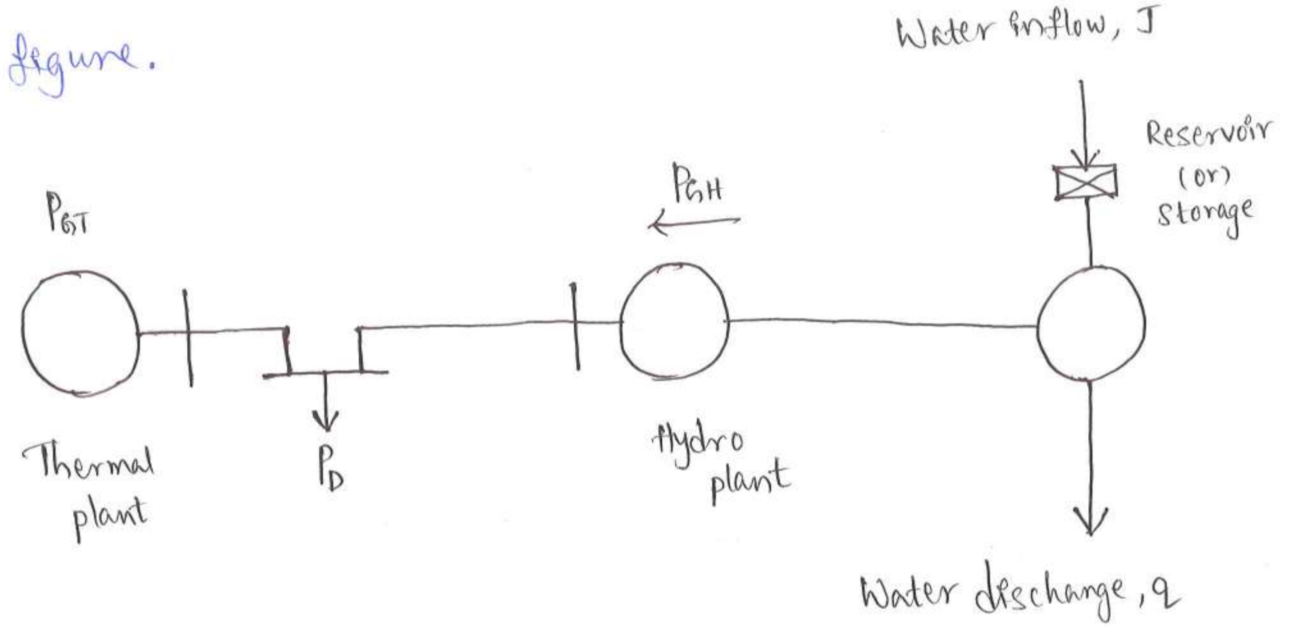
→* The operating cost of thermal plants is very high, and at the same time its capital cost is low and the operating cost of a hydro-electric plant is low, and its capital cost is high such that it has become economical & convenient to run both thermal as well as hydro-plants hydro-plants, in the same grid.

* → In the case of thermal plants, the optimal scheduling problem can be completely solved at any desired instant without referring to the operation at other times. It is a "Static optimization problem".

* → The operation of a system having both hydro and thermal plants is more complex as, hydro plants have a negligible operating cost, but are required to run under the constraint of availability of water for hydro generation during a given period of time. This problem is the "dynamic optimization problem". where the time factor is to be considered.

* → The optimal scheduling problem in a hydro-thermal system can be stated as, to minimize the fuel cost of thermal plants under the constraint of water availability for hydro-generation over a given period of operation.

→ Consider a simple hydro-thermal system, shown in figure.



Fundamental hydro-thermal system.

*→ which consists of one hydro and one thermal-plant supplying power to load connected at the centre in between the plants and is referred to as the fundamental system.

*→ To solve the optimization problem in this system, consider the real power generations of two plants $P_{G\,\text{Thermal}}$ and $P_{G\,\text{Hydro}}$ as control variables. The transmission power loss is expressed in terms of the 'B' coefficient as,

$$\boxed{P_L = \sum_{p=1}^{n} \sum_{q=1}^{n} P_{Gp} B_{pq} P_{Gq}}$$

→ This type of Co-ordination of a run-off river hydro-plant with a thermal plant results in a greater utilization factor of the river-flow and a saving in the amount of fuel, Consumed in the thermal plant.

* Long Term Co-ordination :-

Typical long term co-ordination - may be extended from one week to one year or several years.

→ The co-ordination of the operation of reservoir type hydro-power plants and steam plants involves the best utilization of water interms of the - scheduling of water released.

→ In other words, the operating costs of hydro-plants are very low, hydro power can be generated at very little incremental cost.

→ In a combined operational system, the generation of thermal power should be displaced by available hydro power, so that maximum decrement - production costs will be realized at the steam plant.

→ The long term scheduling problem involves the long-term forecasting of water availability and the scheduling of reservoir water releases for an interval of time that depends on the - reservoir capacities and the chronological load -

2.5

- curve of the system.

→ Based on these factors during different times of the year, the hydro and steam plants can be operated as base load plants and peak load plants and vice-versa.

→ Long term scheduling is made based on an optimizing policy in view of statistically treated unknowns such as, load, hydraulic inflows and unit availability i.e, steam and hydro-plants.

→ The useful techniques employed for this type of scheduling problems include:

(i) The simulation of an entire long term operational time period for a given set of operating conditions by using the dynamic programming method.

(ii) Composite hydraulic simulation models, and

(iii) statistical production cost models.

* Short term co-ordination :-

The economic scheduling of combined hydro-thermal systems depends on the conditions existing over the entire operating period.

This type of hydro-thermal scheduling is required for one day or one week, which involves the hour-by-hour scheduling of all available generations on a system to get the minimum production cost for the given time.

→ Such type of scheduling problems, the load, hydraulic inflows, and unit availabilities are to be known.

→ The problem is how to supply load, as per the load cycle during the period of operation so that generation by thermal plants will be minimum.

→ This condition will be satisfied, when the value of hydro-power generation, rather than its amount is a maximum over a certain period.

→ The factors on which the economic operation of a combined hydro-thermal system depends are as follows:

- * Load cycle.
- * Incremental fuel costs of thermal power stations.

* General Mathematical Formulation of Long-Term - Hydro-Thermal Scheduling :-

To mathematically formulate the optimal scheduling problem in a hydro-thermal system, the following assumptions are to be made for a certain period of operation 'T' (a day, a week, or a year):

(i) The storage of a hydro-reservoir at the beginning and at the end of period of operation 'T' are specified.

(ii) After accounting for the irrigation purpose, water-inflow to the reservoir & load demand on the system are known deterministically as functions of time.

→ The optimization problem is to determine the water discharge rate q(t), so as to minimize the cost of thermal generation.

Objective function is,

$$\min C_T = \int_0^t C' (P_{GT}(t))dt \quad \text{— ①}$$

Subject to the following constraints :

(i) The real power balance equation :

$$P_{GT}(t) + P_{GH}(t) = P_L(t) + P_D(t)$$

i.e, $P_{GT}(t) + P_{GH}(t) - P_L(t) - P_D(t) = 0$ for $t \in (0,T)$ — ②

where, $P_{GT}(t)$ — is the real power thermal generation at time 't',

$P_{GH}(t)$ — is the real power hydro generation at time 't',

$P_L(t)$ — is the real power loss at time 't', and

$P_D(t)$ — is the real power demand at time 't'.

(ii) Water availability equation :-

$$x'(t) - x'(0) - \int_0^T J(t)\,dt + \int_0^T q(t)\,dt = 0 \quad \text{③}$$

where, $x'(t)$ is the water storage at time 't',

$x'(0)$ is the water storage at the beginning of operation time, T,

$x'(T)$ is the water storage at the end of operation time, T,

$J(t)$ is the water inflow rate, and

$q(t)$ is the water discharge rate.

(iii) Real-power hydro generation :-

The real power hydro-generation $P_{GH}(t)$ is a function of water storage $x'(t)$ and water discharge rate $q(t)$.

i.e, $P_{GH}(t) = f(x'(t), q(t))$ — ④

* Solution of Problem- discretization principle:-

By the discretization principle, the above problem can be conveniently solved. The optimization interval 'T' is sub-divided into 'N' equal sub-intervals of Δt time length and over each sub-interval, it is assumed that all the variables remain fixed in value.

→ The same problem can be reformulated as,

$$\min_{q^K (K=1,2,---,N)} \Delta t \sum_{K=1}^{N} c' (P_{GT}^K) = \min_{q^K (K=1,2,---,N)} \sum_{K=1}^{N} C(P_{GT}^K) \quad \text{——— ⑤}$$

subject to the following constraints:

(i) Power balance equation

$$P_{GT}^K + P_{GH}^K - P_L^K - P_D^K = 0 \quad \text{——— ⑥}$$

where, P_{GT}^K is the thermal generation in K^{th} interval

P_{GH}^K is the hydro generation in K^{th} interval

P_L^K is the transmission power loss in K^{th} interval

and is expressed as,

$$P_L^K = B_{TT} (P_{GT}^K)^2 + 2B_{TH} P_{GT}^K P_{GH}^K + B_{HH} (P_{GH}^K)^2, \text{ and}$$

P_D^K is the load demand in the K^{th} interval.

(ii) Water availability equation :-

$$x'^{K} - x'^{(K-1)} - j^{K}\Delta t + q^{K}\Delta t = 0 \quad \text{———} ⑦$$

where x'^{K} is the water storage at the end of interval K, j^{K} is the water inflow rate in interval 'K' and q^{K} is the water discharge rate in interval 'K'.

Dividing Equation ⑦ by Δt, it becomes,

$$x^{K} - x^{K-1} - j^{K} + q^{K} = 0 \quad \text{for } K = 1, 2, ----, N \longrightarrow ⑧$$

where $x^{K} = \frac{x'^{K}}{\Delta t}$ is the water storage in - discharge units.

x^{0} and x^{N} are specified as water storage rates at the beginning and at the end of the optimization interval, respectively.

(iii) The real power hydro-generation in any sub-interval - can be written as,

$$P_{GH}^{K} = h_0 \left\{1 + 0.5\,e\,(x^{K} + x^{K-1})\right\}(q^{K} - \rho) \longrightarrow ⑨$$

where $h_0 = 9.81 \times 10^{-3} h_0'$

h_0' is the basic water head, which is corresponding to dead - storage.

'e' is the water head correction factor for the - variation in head with storage.

i.e, $x^1 - x^0 - j^1 + q^1 = 0$ for $K=1$

$x^2 - x^1 - j^2 + q^2 = 0$ for $K=2$

$x^N - x^{(N-1)} - j^N + q^N = 0$ for $K = N^{th}$ interval.

By adding the above set of equations, we get,

$$x^N - x^0 - (j^1 + j^2 - - - + j^N) + (q^1 + q^2 - - - + q^N) = 0$$

(or)

$$x^N - x^0 - \sum_{K=1}^{N} j^k + \sum_{k=1}^{N} q^k = 0 \quad \text{———} \quad ⑩$$

Equation ⑩ is known as the "water availability equation".

→ For $K = 2, 3, - - -, N$, there are $(N-1)$ no.of water discharges (q's), which can be specified as independent variables and the remaining one, i.e, q^1, is specified as a dependent variable and it can be determined from Equation ⑩ as

$$q^1 = x^0 - x^N + \sum_{K=1}^{N} j^k - \sum_{K=2}^{N} q^K \quad \text{———} \quad ⑪$$

* Solution of Short-Term Hydro-Thermal Scheduling Problems.

- Kirchmayer's method :-

In this method, the co-ordination equations are derived in terms of penalty factors of both plants for obtaining the optimum scheduling of a hydro-thermal system and hence it is also known as the "penalty factor method" of solution of short-term hydro-thermal scheduling problems.

Let,

P_{GT_i} - be the power generation of i^{th} thermal plant in MW.

P_{GH_j} - be the power generation of j^{th} hydro-plant in MW.

$\frac{dC_i}{dP_{GT_i}}$ - be the incremental fuel cost of i^{th} thermal plant in Rs./MWh

W_j - be the quantity of water used for power generation at j^{th} hydro-plant in m^3/s

$\frac{dW_j}{dP_{GH_j}}$ - be the incremental water rate of j^{th} hydro-plant in $m^3/s/MW$.

$\frac{dP_L}{dP_{GT_i}}$ - be the incremental transmission loss of i^{th} thermal plant.

→ The coefficient 'γ' must be selected so as to use the Specified amount of water during the operating period.

Now, the objective function becomes,

$$\min C = \sum_{i=1}^{\alpha} \int_0^T C_i \, dt + \sum_{j=\alpha+1}^{n} \gamma_j K_j$$

Substituting 'K_j' from equation ③ in the above equation,

we get,

$$\min C = \sum_{i=1}^{\alpha} \int_0^T C_i \, dt + \sum_{j=\alpha+1}^{n} \gamma_j \int_0^T w_j \, dt \quad — ④$$

For a particular load demand 'P_D', Equation ② results as

$$\sum_{i=1}^{\alpha} \Delta P_{GT_i} + \sum_{j=\alpha+1}^{n} \Delta P_{GH_j} - \sum_{i=1}^{\alpha} \frac{\partial P_L}{\partial P_{GT_i}} \Delta P_{GT_i} - \sum_{j=\alpha+1}^{n} \frac{\partial P_L}{\partial P_{GH_j}} \Delta P_{GH_j} = 0 \quad — ⑤$$

For a particular hydro-plant 'x', Equation ⑤ can be rewritten as,

$$\Delta P_{GHx} - \frac{\partial P_L}{\partial P_{GHx}} \Delta P_{GHx} = -\sum_{i=1}^{\alpha} \Delta P_{GT_i} - \sum_{\substack{j=\alpha+1 \\ j \neq x}}^{n} \Delta P_{GH_j} + \sum_{i=1}^{\alpha} \frac{\partial P_L}{\partial P_{GT_i}} \Delta P_{GT_i} + \sum_{\substack{j=\alpha+1 \\ j \neq x}}^{n} \frac{\partial P_L}{\partial P_{GH_j}} \Delta P_{GH_j} = 0$$

By rearranging the above equation, we get,

$$\left[1-\frac{\partial P_L}{\partial P_{GH_x}}\right]\Delta P_{GH_x} = -\sum_{i=1}^{\alpha}\left[1-\frac{\partial P_L}{\partial P_{GT_i}}\right]\Delta P_{GT_i} - \sum_{j=\alpha+1}^{n}\left[1-\frac{\partial P_L}{\partial P_{GH_j}}\right]\Delta P_{GH_j} \quad — ⑥$$

From equation ④, the condition for minimization is,

$$\Delta\left[\sum_{i=1}^{\alpha}\int_0^T C_i\,dt + \sum_{j=\alpha+1}^{n}\gamma_j\int_0^T w_j\,dt\right] = 0 \quad — ⑦$$

The above equation can be written as,

$$\sum_{i=1}^{\alpha}\frac{dc_i}{dP_{GT_i}}\Delta P_{GT_i} + \sum_{j=\alpha+1}^{n}\gamma_j\frac{dw_j}{dP_{GH_j}}\Delta P_{GH_j} = 0 \quad — ⑧$$

for hydro-plant x,

$$\gamma_x\frac{dw_x}{dP_{GH_x}}\Delta P_{GH_x} = -\sum_{i=1}^{\alpha}\frac{dc_i}{dP_{GT_i}}\Delta P_{GT_i} - \sum_{\substack{j=\alpha+1\\ j\neq x}}^{n}\gamma_j\frac{dw_j}{dP_{GH_j}}\Delta P_{GH_j}$$

Multiplying the above equation by $\left[1-\frac{\partial P_L}{\partial P_{GH_x}}\right]$,

$$\left[1-\frac{\partial P_L}{\partial P_{GH_x}}\right]\gamma_x\frac{dw_x}{dP_{GH_x}}\Delta P_{GH_x} = \left[1-\frac{\partial P_L}{\partial P_{GH_x}}\right]\left[-\sum_{i=1}^{\alpha}\frac{dc_i}{dP_{GT_i}}\Delta P_{GT_i} - \sum_{\substack{j=\alpha+1\\ j\neq x}}^{n}\gamma_j\frac{dw_j}{dP_{GH_j}}\Delta P_{GH_j}\right] \quad — ⑨$$

Substitute for $\left[1-\frac{\partial P_L}{\partial P_{GH_x}}\right]\Delta P_{GH_x}$ from Equation ⑥ in Equation ⑨, we get

$$\gamma_x\frac{dw_x}{dP_{GH_x}}\left[-\sum_{i=1}^{\alpha}\left[1-\frac{\partial P_L}{\partial P_{GT_i}}\right]\Delta P_{GT_i} - \sum_{\substack{j=\alpha+1\\ j\neq x}}^{n}\left[1-\frac{\partial P_L}{\partial P_{GH_j}}\right]\Delta P_{GH_j}\right] =$$

$$\left[1-\frac{\partial P_L}{\partial P_{GH_x}}\right]\left[-\sum_{i=1}^{\alpha}\frac{dc_i}{dP_{GT_i}}\Delta P_{GT_i} - \sum_{\substack{j=\alpha+1\\ j\neq x}}^{n}\gamma_j\frac{dw_j}{dP_{GH_j}}\Delta P_{GH_j}\right]$$

Equations ⑯ and ⑰ are the co-ordinate equations, which are used to obtain the optimal scheduling of the hydro-thermal system when considering the transmission losses.

→ In the above equations, the transmission loss 'P_L' is expressed as,

$$P_L = \sum_{i=1}^{\alpha} \sum_{k=1}^{\alpha} P_{GT_i} B_{ik} P_{GT_k} + \sum_{g=\alpha+1}^{n} \sum_{j=\alpha+1}^{n} P_{GH_g} B_{gj} P_{GH_j} + 2 \sum_{i=1}^{\alpha} \sum_{j=\alpha+1}^{n} P_{GT_i} B_{ij} P_{GH_j} \quad \text{—} ⑳$$

→ The power generation of a hydro-plant P_{GH_j} is directly proportional to it's head and discharge rate w_j.

→ when neglecting the transmission losses, the co-ordination equations become,

$$\frac{dC_i}{dP_{GT_i}} = \lambda \; ; \quad \gamma_j \frac{dw_j}{dP_{GH_j}} = \lambda$$

—o—

① A two-plant System that has a thermal station near-the load Centre and a hydro-power Station at a remote location is shown in figure. The characteristics of both stations are,

$(26 P_{GT} + 0.045 P_{GT}^2)$

$C_1 = (26 + 0.045 P_{GT}) P_{GT}$ Rs/hr.

$W_2 = (7 + 0.004 P_{GH}) P_{GH}$ m³/s

$(7 P_{GH} + 0.004 P_{GH}^2)$

and $\gamma_2 =$ Rs. 4×10^{-4}/m³, The transmission loss Coefficient, $B_{22} = 0.0025$ MW⁻¹. Determine the power generation at each station and the power received by the load when $\lambda = 65$ Rs/MWh.

Sol :- Here, $n = 2$

Transmission loss, $P_L = \sum_{p=1}^{n} \sum_{q=1}^{n} P_{Gp} B_{pq} P_{Gq}$

$$= B_{11} P_{G1}^2 + B_{22} P_{G2}^2 + 2 B_{12} P_{G1} P_{G2}$$

Since, the load is near the thermal station, the power flow is from the hydro-station only;

$\therefore B_{12} = B_{11} = 0$;

$\therefore P_L = B_{22} P_{GH}^2 = 0.0025 P_{GH}^2$ (Since $B_{22} = B_{HH}$)

$\Rightarrow \dfrac{dP_L}{dP_{GT}} = 0$ and $\dfrac{dP_L}{dP_{GH}} = 2 B_{HH} P_{GH} = 0.005 P_{GH}$.

$= 2 \times 0.0025 P_{GH} = \uparrow$

and $(0.000216 P_{GH} + 0.675) \times \frac{1}{1 - 0.003 P_{GH}} = 45$

(or)

$(0.000216 P_{GH} + 0.675) = (1 - 0.003 P_{GH}) 45$

$0.135216 P_{GH} = 44.325$

$\therefore P_{GH} = 327.809$ mw.

Transmission loss, $P_L = B_{22} P_{GH}^2 = 0.0015(327.809)^2$

$= 161.188$ mw.

The load Connected, $P_D = P_{GT} + P_{GH} - P_L$

$= 187.5 + 327.809 - 161.188$

$= 354.121$ MW.

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE FILE CONTENTS

ACADEMIC YEAR/SEMESTER 2018-19

SUBJECT : POWER SYSTEM OPERATION&CONTROL (A70230)

1. **InstituteVision& Mission**
2. **Department Vision& Mission**
3. **PEOs, PSOs & POs STATEMENTS**
    - **3.1.PROGRAMME EDUCATIONAL OBJECTIVES (PEO's)**
    - **3.2.PROGRAM SPECIFIC OUTCOMES(PSO's)**
    - **3.3.PROGRAM OUTCOMES (POs)**
4. **Course Information Sheet**
    - **4.1.Academic Calender**
    - **4.2.Subject Time Table**
    - **4.3.Course Syllabusand General Objectives**
    - **4.4.Course Outcomes , Relationshipof COs to POs &Relationshipof COs to PSOs**
    - **4.5.Lecture Plan**
    - **4.6.Result Analysisof Past 3 Yearswith BAR Chart**
    - **4.7.Add on Course Material**
5. **Unit Wise Lecture Notes**
6. **Question Bank**
    - **6.1. Unit Wise Question Bank**
    - **6.2. University Question Paperwith Key for one Year**
    - **6.3. Previous Question Papers**
7. **MID-I & MID –II Test Papers**
    - **7.1. MID Question Paperwith Key**
        - **7.1.1. Sample Answer Scripts**
    - **7.2. Unit Wise Assignment Questionswith Key**
        - **7.2.1. Sample Assignments**
8. **Continuous Evaluation**
    - **8.1. Identifying Weak Students from MID-I & II Test Marks**
    - **8.2. Identifying Weak Students from Class Attendance**
9. **Copy of Attendance Register**
10. **CD / DVD (AllCourse Information – likeNPTEL,Lectures, Unit Wise PPT'S)**