System Operation and Control

Generation Technologies and Generation Facilities in Pakistan

EMP @ LUMS
July 17-22, 2018

Presentation Sequence

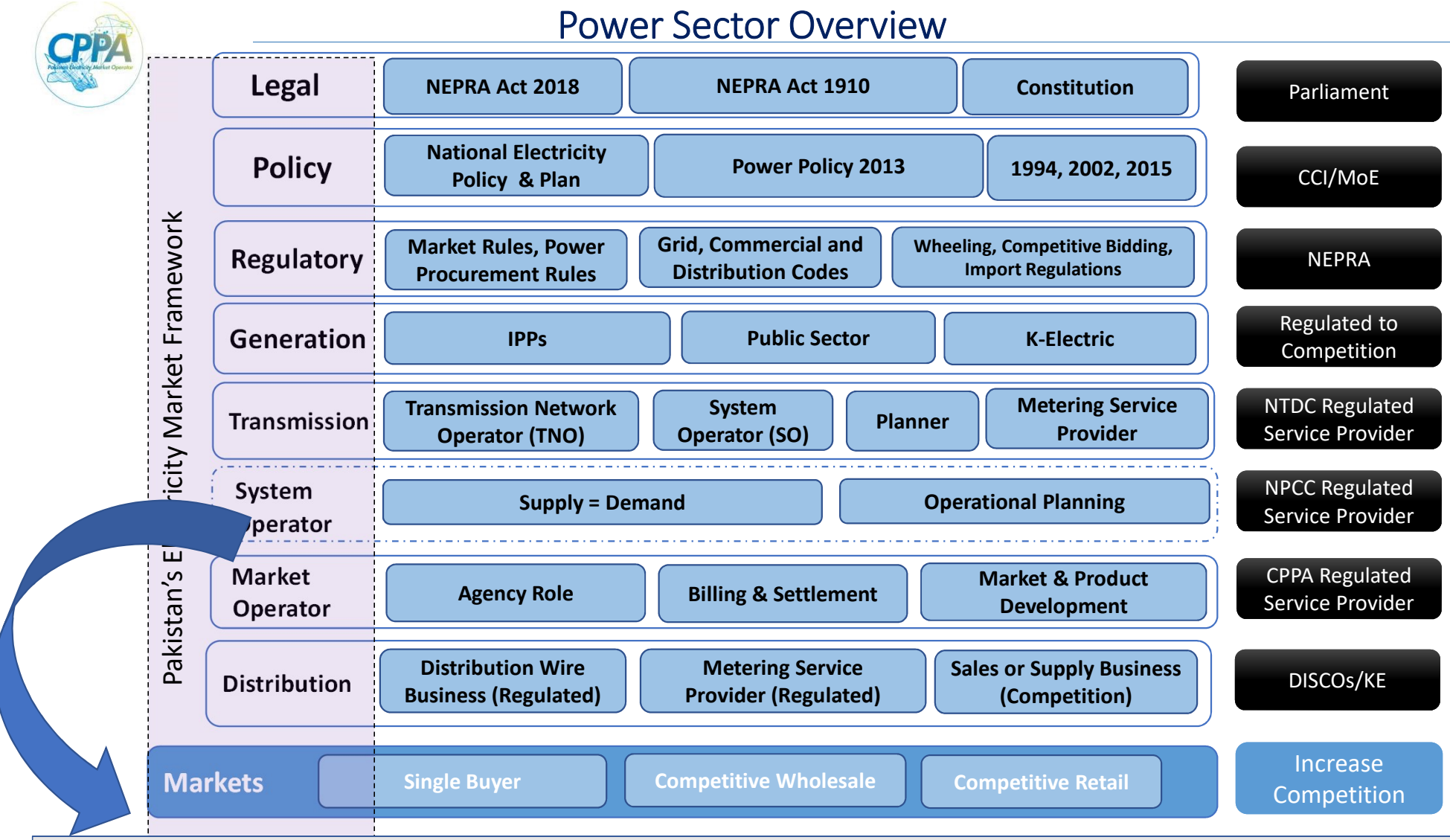
- Power Sector of Pakistan
- Introduction to NPCC
- Regulatory framework
- System Operation, Control and Planning
- Generation Technologies and Mix in Pakistan
- Generation Demand Balance and Dispatch
- Forecasting and its Horizons
- Operational Planning and Expansion Planning

Power System of Pakistan

- Pakistan's electricity sector is a single buyer model

- Government through its administratively controlled companies is responsible for the purchase and distribution of electric power throughout the country.

Power Sector Overview



'Vital link' between Service Providers, & Regulators on one end and physical system and market players on the other

Introduction to NPCC

- National Power Control Center (NPCC) - Power System Operator of Pakistan is part of National Transmission and Despatch Company (NTDC)
- NTDC constructs, operates, maintains 500/220 kV lines/grid stations, provides transmission facility to DISCOs for purchase of power from generators and selling to consumers
- DISCOs construct, operate, maintain 132/66 kV lines & grid stations and 11/0.4 kV distribution system
- NPCC being system operator is responsible for safe and reliable operation of the grid

Regulatory Framework of System Operations

- Operation of power system regulated under NEPRA's Grid Code
  - OC-1 : General operating principles
  - OC-2 : Demand Forecast
    - Input from all stakeholders for different time horizons consolidated by NPCC
  - OC-3 : Demand Management
  - OC-4: Operational Planning
    - Network operation and outage planning / coordination
    - Generation dispatch and outage coordination
    - Insufficient power operating margin
    - Frequency and voltage control and operating margins

Major Functions of the System Operator

1. Maintaining balance between Supply & Demand.
2. Frequency and voltage control.
3. Operational Control of Power Network.
4. Maintaining security & stability of network.
5. Month-wise Annual Energy Estimation.
6. Economic Dispatch.
7. Maintenance outages administration on power plants & Transmission network elements
8. Short to medium term operational planning.
9. Advance notifications to thermal plants for fuel arrangement.
10. Collection of system data and preparation of reports

Power System Structure

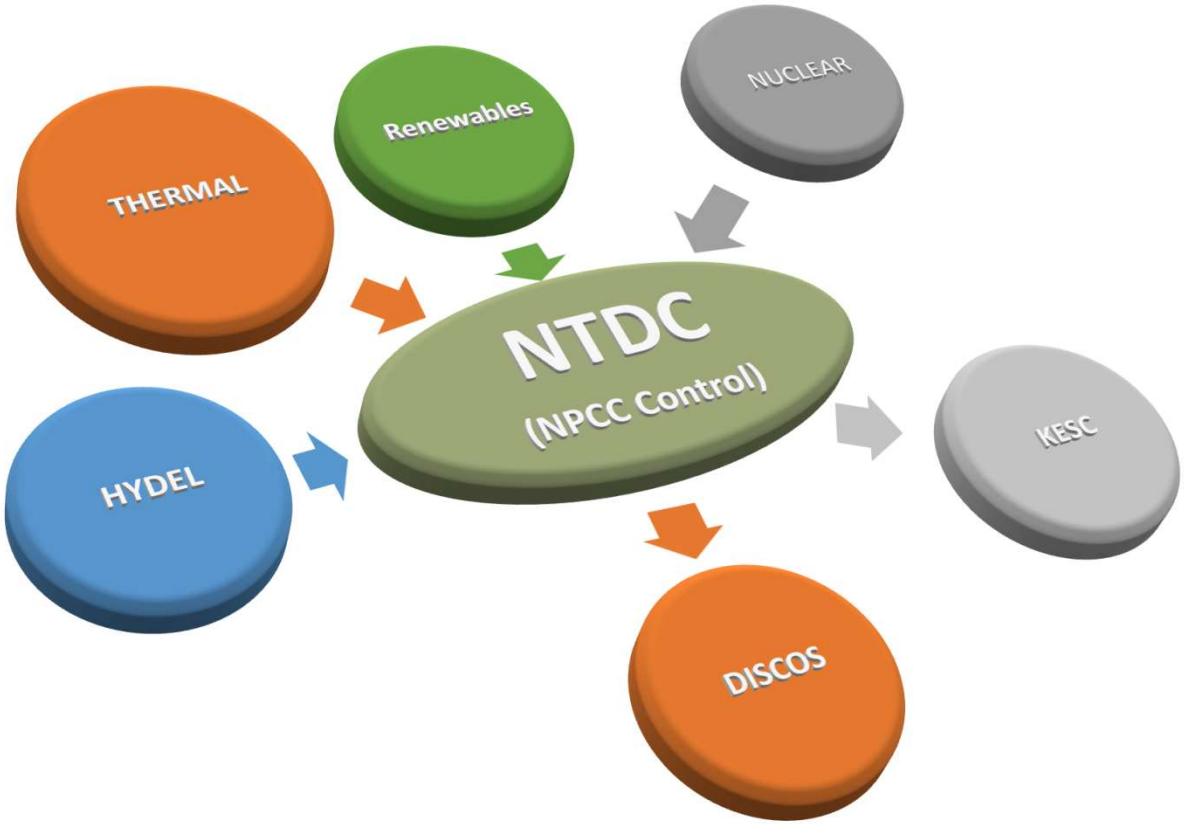
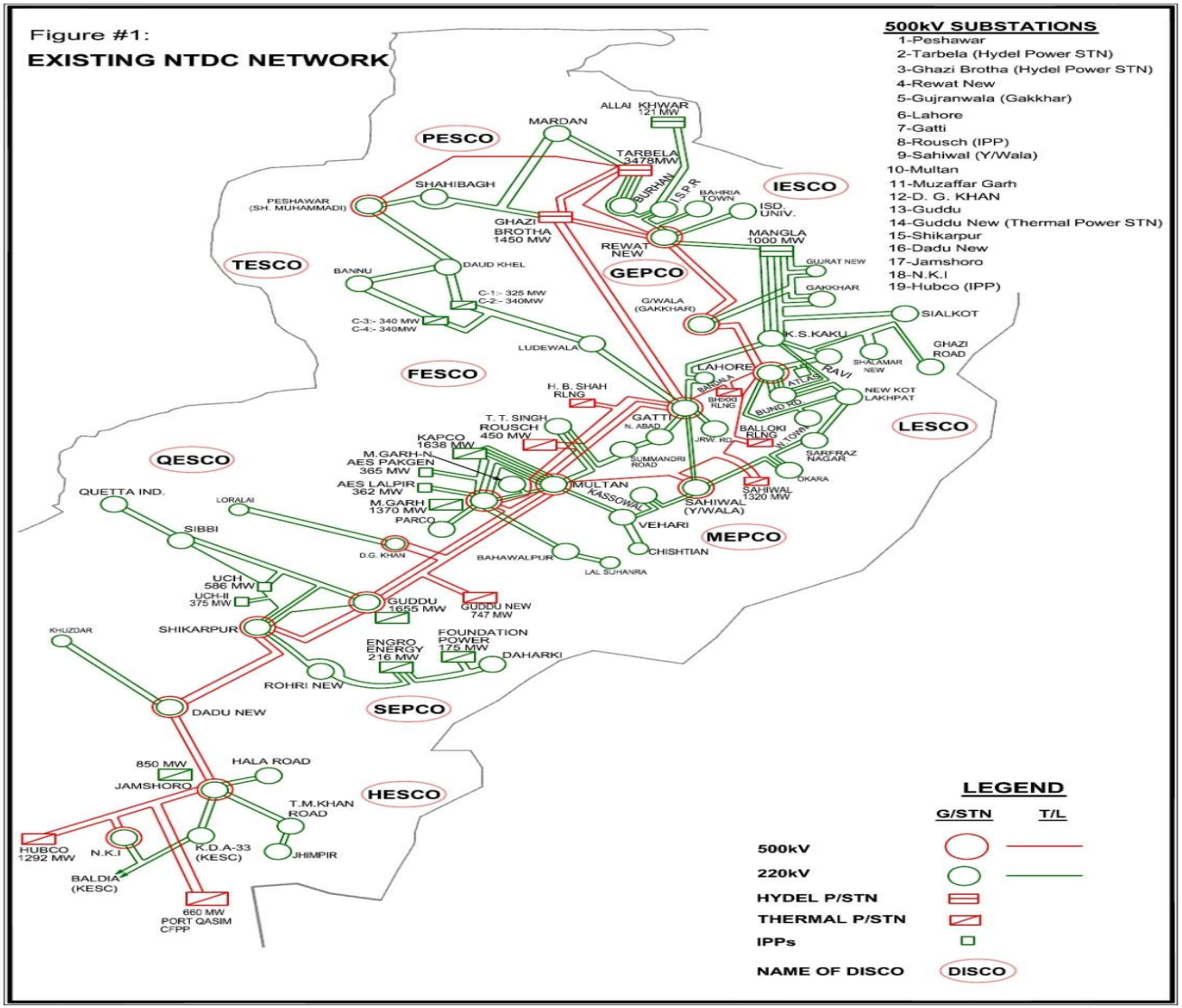
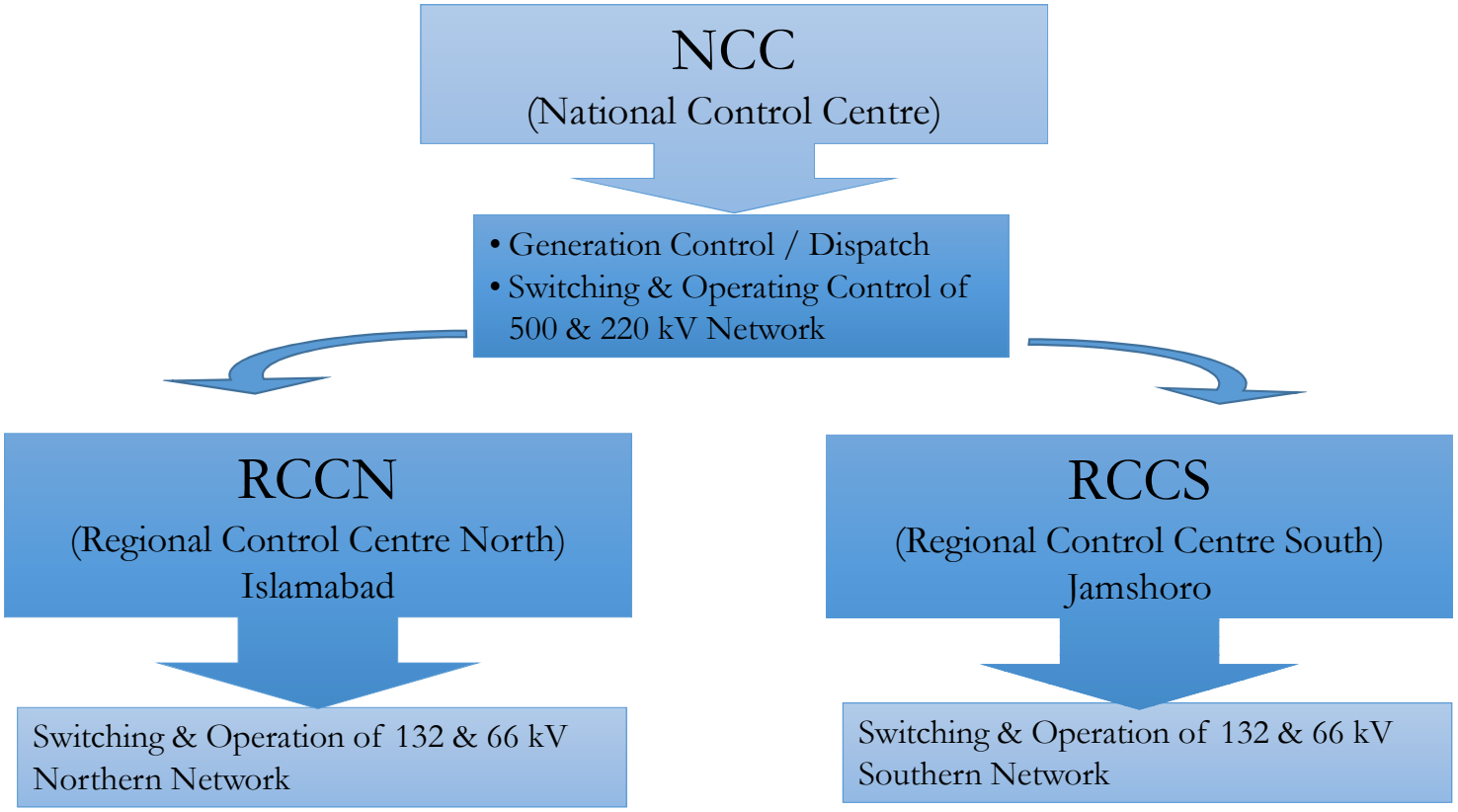


Figure #1:

EXISTING NTDC NETWORK



System Operations Hierarchy



Generation Planning & Dispatch

Procedure and steps.

- Generation forecasting/estimation on daily, weekly, monthly, quarterly, yearly basis keeping in view:
    - Irrigation indents of Hydel stations
    - Schedule outages
    - Forced outages
    - Constraints if any
- Demand forecasting/estimation on historical trends
- Dispatch of available generation in merit order.

Transmission Operation and Control

Objectives:

- Keeping stable voltages over primary network
- Monitoring of transmission & transformer parameters

Operations:

- Planned shutdowns for maintenance, cleaning and washing activities
- Emergent shutdowns in case of abnormal situations.
- Transmission lines and transformers tripping.

Generation Technologies and Generation Mix

Existing and Committed Generators Fleet In Pakistan

Sequence

- Generator Types
- Fuel for power generation
- Operation of a Steam turbine
- Operation of a Gas turbine (Simple Cycle)
- Operation of a Gas turbine (Combined Cycle)
- Power Generation Facilities in Pakistan

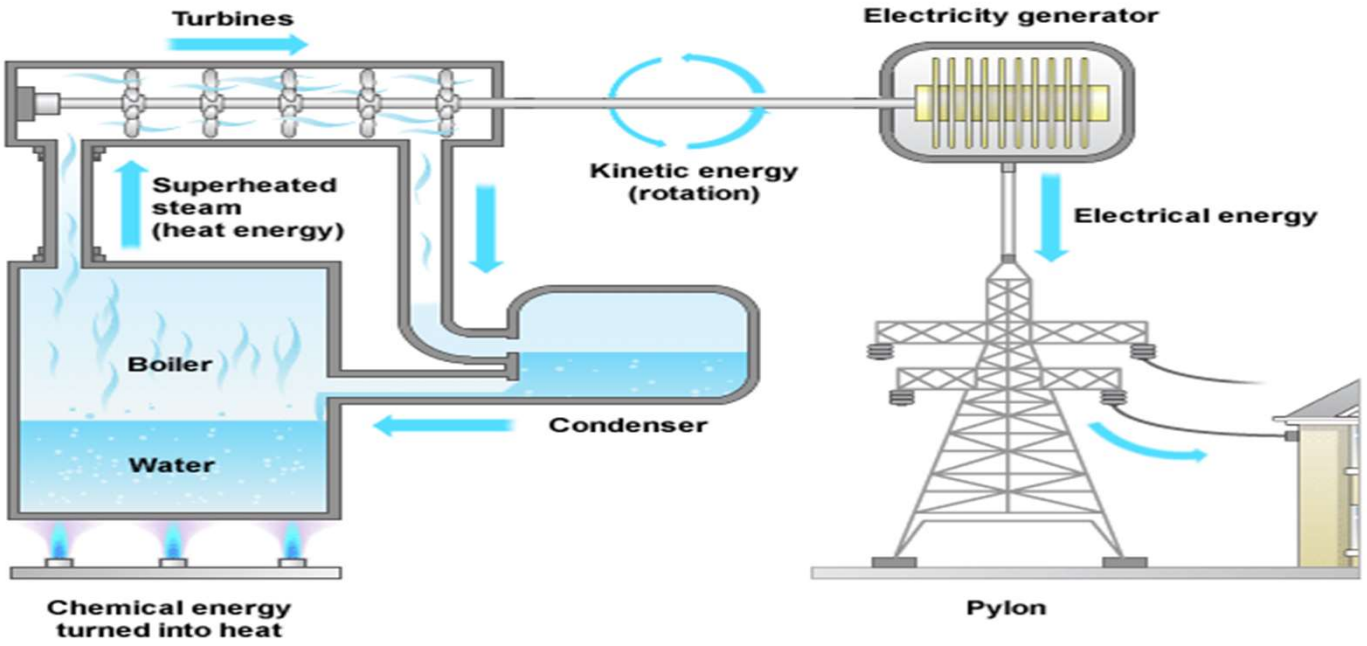
Generator Types

- Broadly, generators can be classified as
  - Hydro Generators
  - Steam Turbines
  - Gas Turbines
  - Diesel Generator Sets
  - Wind Generators
  - PV Cells

Power Generation based on Fuel type

- Based on Fuel type, electricity generation technologies can be broadly classified as
  - Hydro generation
    - Reservoir based, run-of-river, tidal energy
  - Thermal generation
    - Gas fired, Coal fired, Bagasse, Nuclear, Fuel Oil
  - Renewable generation
    - Wind, solar

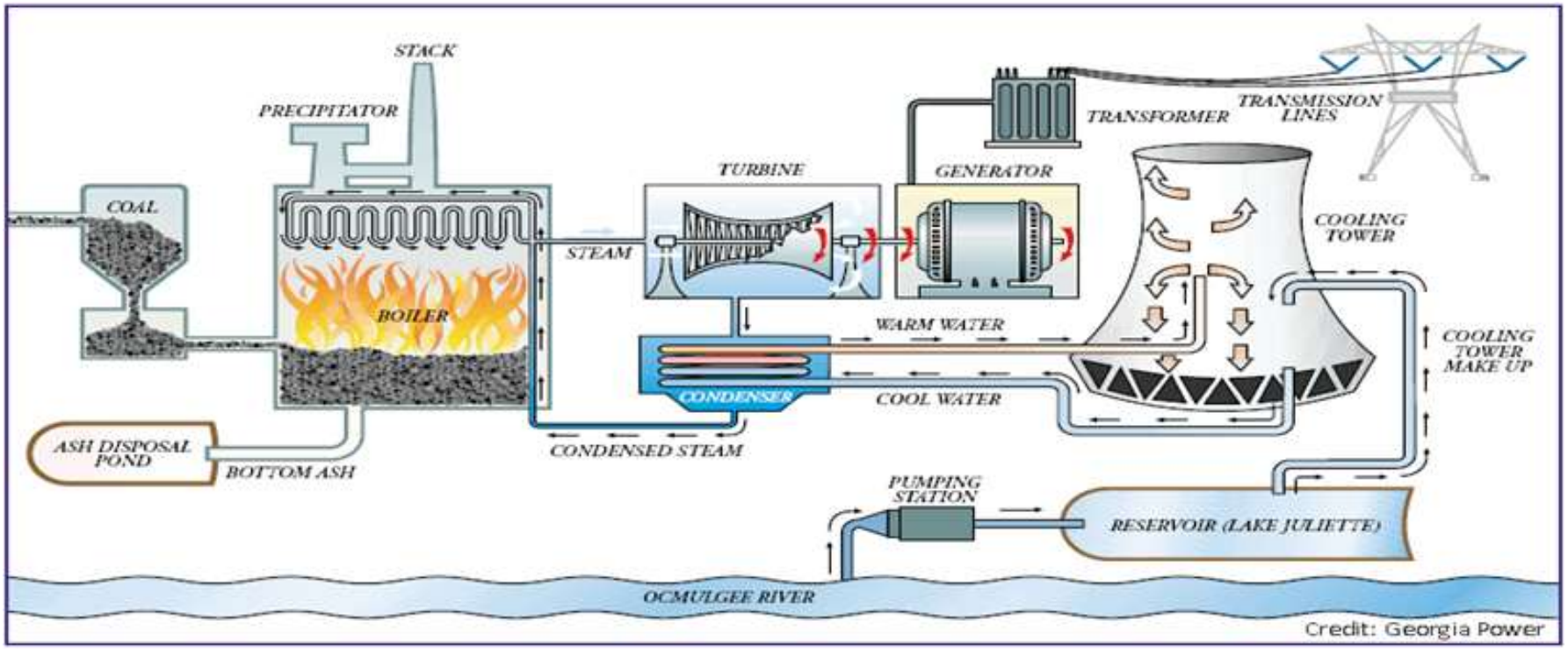
Operation of a Steam Turbine



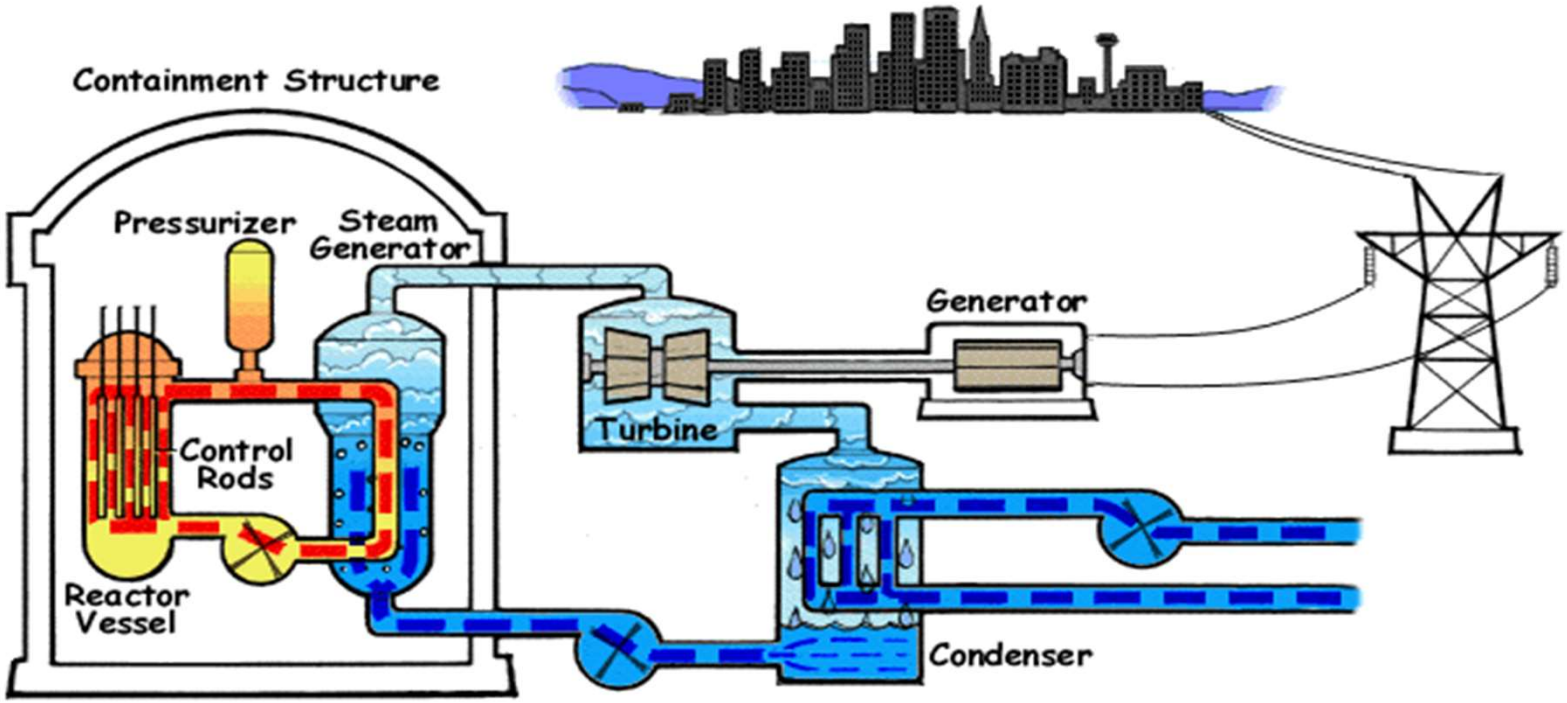
Furnace can be ignited with:

Coal
Uranium
Gas
Furnace Oil
Bagasse
HSD

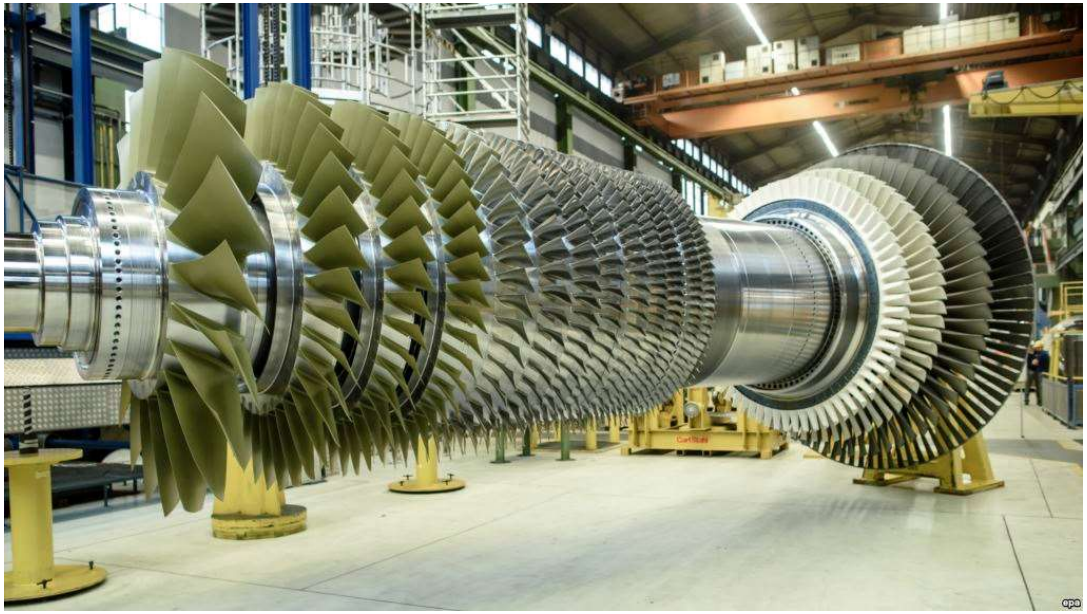
Coal Fired Steam Turbine



Nuclear Fueled Steam Turbine



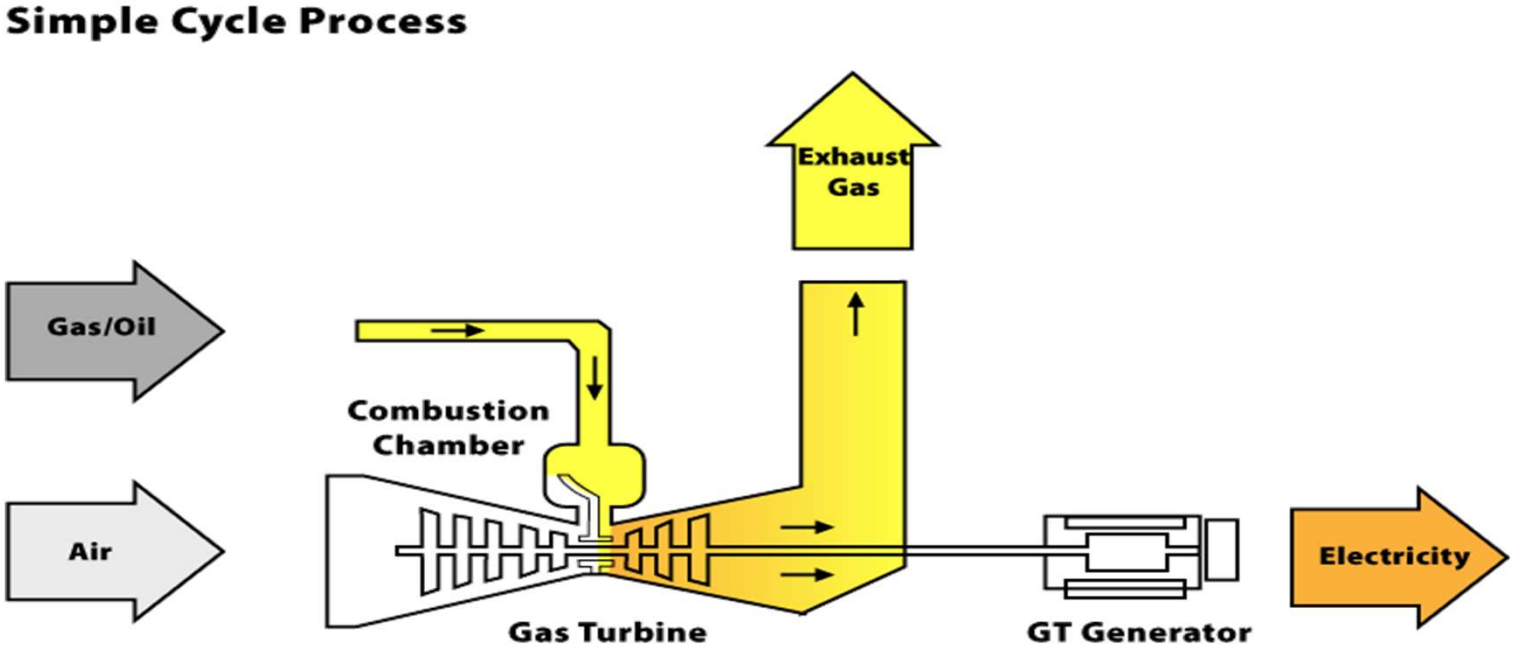
Steam Turbine Blades



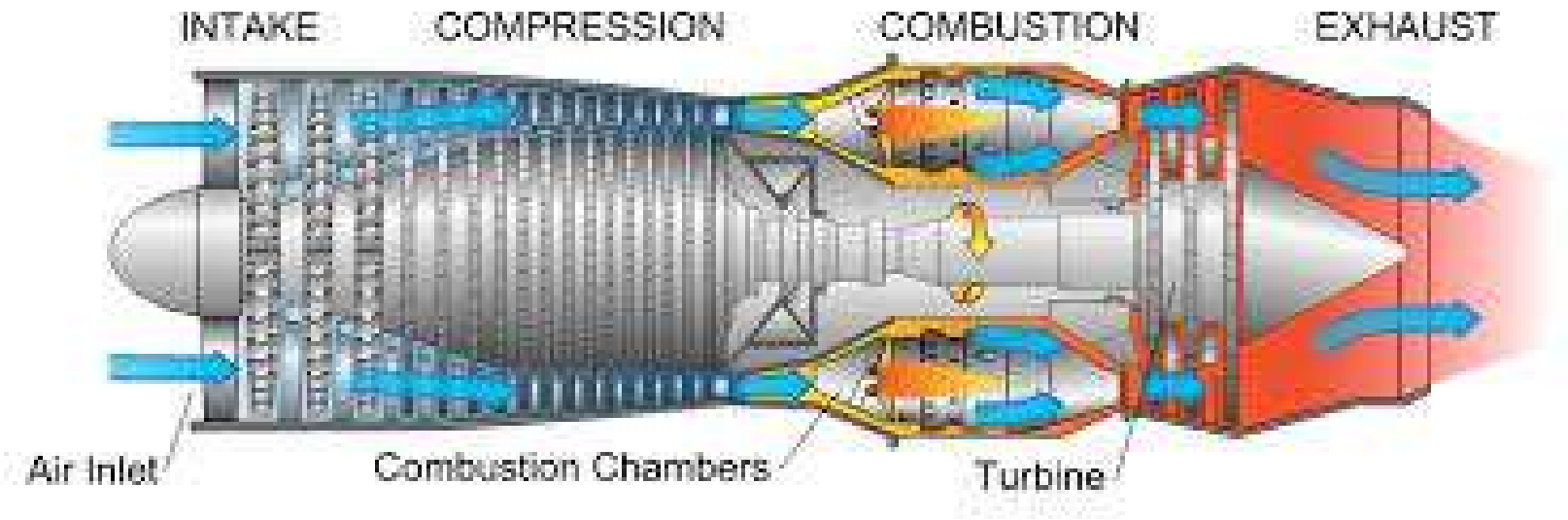
Steam Generator (Typical Startup Time and Ramping Rates)

State / Time Since Shut Down (hrs)	Startup Time (minutes)	Loading Range	Ramp rate (%)/min
Hot / Up to 2 hrs	30	0 – 25 % 25 – 50 % 50 – 100 %	1% 2% 3%
Warm I/ 2 – 32 hrs	100 – 130		
Warm II / 32 – 150 hrs	300		
Cold / >150 hrs	400	0 – 25 % 25 – 50 % 50 – 100 %	1% 1% 1%

Operation of a Gas Turbine



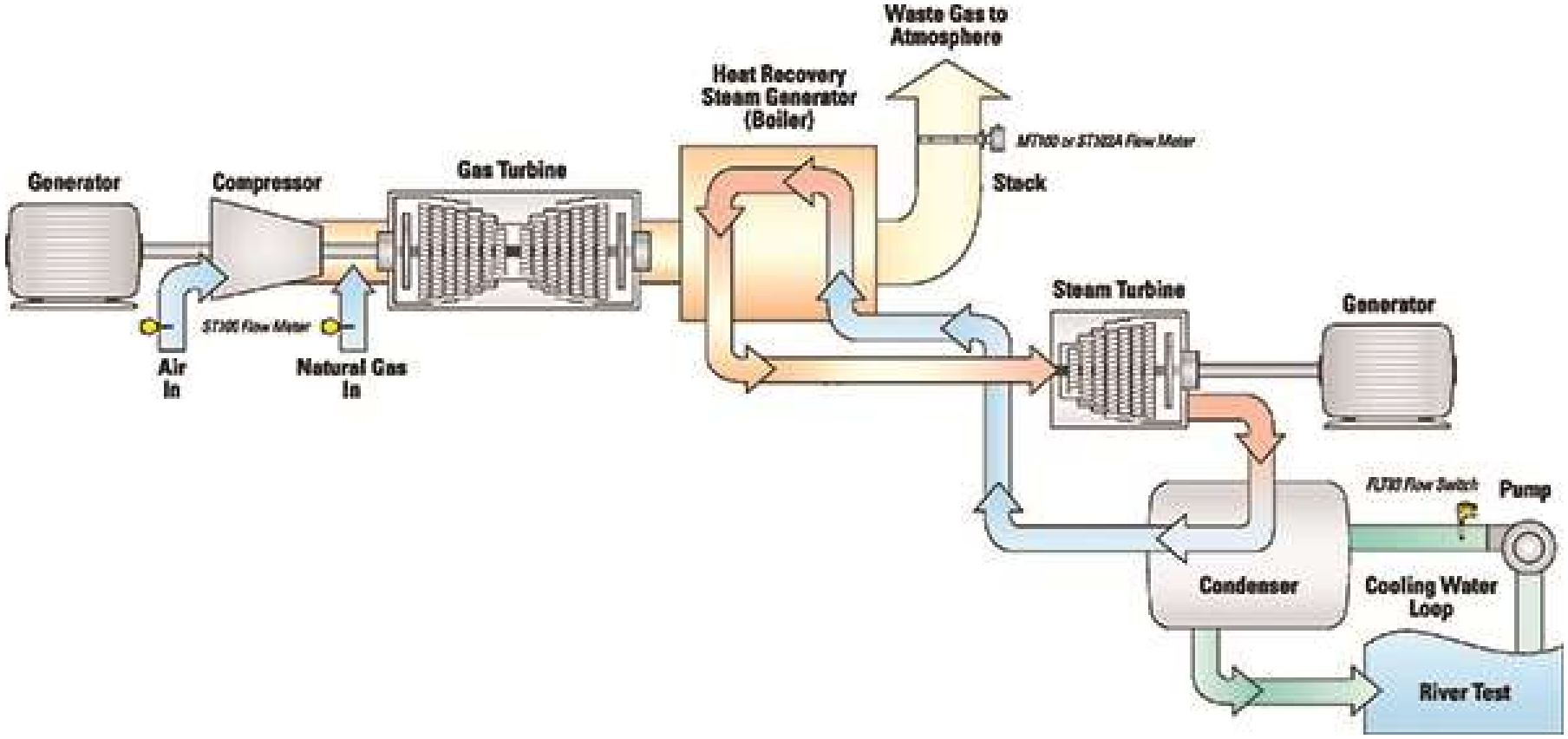
Cross Sectional View and Operation of a Gas Turbine



Combined Cycle Power Plant

- A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra power.

Combined Cycle Power Plant



Some important operating constraints and Concepts

- **Startup Cost**
- Part Load Adjustment Charges (**PLAC**)
- **Heat Rate**: A common measure of efficiency of a thermal power plant. It is defined as the ratio of energy input to a system (typically BTU) to the electrical energy generated (KW) form that system. Mathematically given as

$$Heat\ Rate\ \left(\frac{BTU}{kWh}\right) = \frac{Energy\ Input\ (\frac{BTU}{hr})}{Energy\ output\ (kW)}$$

- **Efficiency** is the ratio of useful energy output to the energy input, mathematically given as

$$Efficiency\ = \frac{Useful\ energy\ output}{Energy\ input}$$

- Efficiency ⟷ Heat Rate

$$\boldsymbol{\eta} = \frac{3.412}{HeatRate}$$

* 1 MWh of electricity has the same amount of energy as 3.412 mmBTU

Power Generation Facilities in Pakistan

Hydel	Type	Capacity	Units
Tarbela	Reservoir	3478	175 MW x 10 + 432 MW x 4
Tarbel 4th Ext*	Reservoir	1410	470 MW x 3
Mangla	Reservoir	1000	100 MW x 10 **
Ghazi Brotha	Small Reservoir	1,450	290 MW x 5
Warsak	Run of River	243	40 MW x 6
Chashma	Run of River	184	23 MW x 8
Jinnah	Run of River	96	12 MW x 8
Allai Khwar	Run of River	121	60.5 MW x 2
Khan Khwar	Run of River	72	34 MW x 2 + 4 MW x 1
Dubair Khwar	Run of River	130	65 MW x 2
Small Hydel	Run of River	128	-
Jagran	Run of River	28	6.08 MW x 5
Malakand III	Run of River	81	27 MW x 3
New Bong Escape	Run of River	84	21 MW x 4
Patrind	Run of River	147	49 MW x 3
Neelum Jehlum	Small Reservoir	969	242 MW x 4 ***

* Under testing phase, COD not achieved yet
** Rehabilitation of units after upraising in progress
*** Under testing, COD not achieved yet

Power Generation Facilities in Pakistan (CCGTs)

Plant	Fuel	Capacity (MW)	Structure (GTs + ST)
KOTRI	Gas, HSD	120	4 + 1
GUDDU	Gas, FO	550	(2 + 1) x 2
GUDDU 747	Gas	747	2 + 1
GTPS F/ABAD	Gas, HSD	120	4 + 1
NANDI PUR	Gas, FO, HSD	425	3 + 1
KAPCO	Gas, FO, HSD	1345	(2 + 1) x 5
HCPC QUETTA	Gas	124	3 + 1
UCH	Gas	550	3 + 1
ROUSCH	Gas	395	2 + 1
FKPCL	Gas	150	1 + 1
LIBERTY POWER	Gas	210	1 + 1
ENGRO ENERGY	Gas, HSD	210	1 + 1
FOUNDATION POWER	Gas	168	1 + 1
SAIF	Gas, HSD	200	2 + 1
ORIENT	Gas, HSD	200	2 + 1
SAPPHIRE	Gas, HSD	200	2 + 1
HALMORE	Gas, HSD	200	2 + 1
UCH-II	Gas	375	2 + 1
BHIKI POWER	Gas, HSD	1156	2 + 1
HB Shah	Gas, HSD	1207	2 + 1
Balloki	Gas, HSD	1198	2 + 1

Power Generation Facilities in Pakistan (STs)

Plant	Fuel	Capacity (MW)	Units
Jamshoro	Gas, FO	650	4 *
Muzaffar Garh	Gas, FO	1130	6
Lakhra	Coal	30	1
Quetta	Gas	25	1
Guddu	Gas	350	3
HUBCO	FO	1200	4
Lalpir	FO	350	1
Pakgen	FO	350	1
Saba	FO	125	1
Sahiwal	Coal	1250	2
Port Qasim	Coal	1250	2
Chashnupp I	Nuclear	301	1
Chashnupp II	Nuclear	310	1
Chashnupp III	Nuclear	315	1
Chashnupp IV	Nuclear	315	1

Power Generation Facilities in Pakistan (STs)

Plant	Fuel	Capacity (MW)	Units
JDW (II)	Bagasse	24	1
JDW (III)	Bagasse	24	1
RYKML	Bagasse	24	1
CHINIOT	Bagasse	63	2
FATIMA	Bagasse, Coal	108	2
HAMZA Sugar	Bagasse	15	1
Thall Power	Bagasse	40	1

Power Generation Facilities in Pakistan (DG Sets)

Plant	Fuel	Capacity (MW)	Structure (DG + ST)
KEL	FO	124	8 + 1
AGL	FO	156	8 + 1
ATLAS	FO	210	11 + 1
NISHAT POWER	FO	195	11 + 1
NISHAT CHUNIA	FO	195	11 + 1
LIBERTY TECH	FO	196	11 + 1
HUBCO NAROWAL	FO	213	11 + 1
RESHMA	FO	96	
GULF	FO	84	

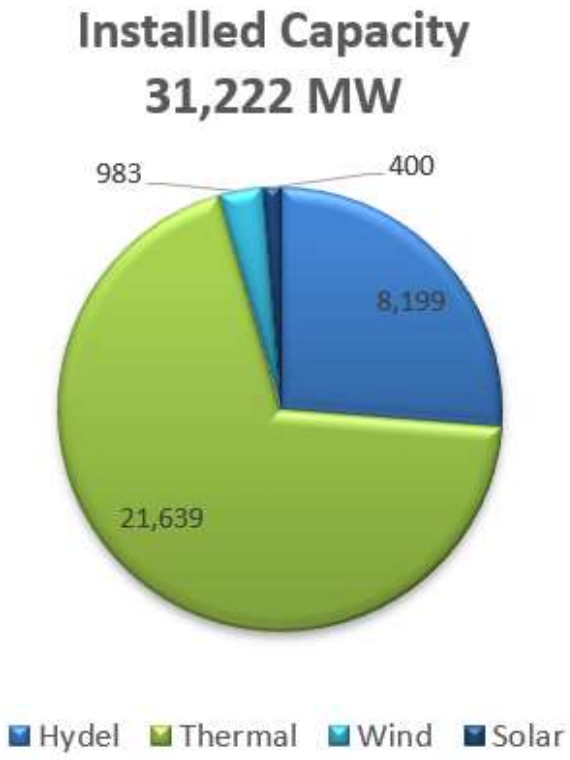
Power Generation Facilities in Pakistan (REs)

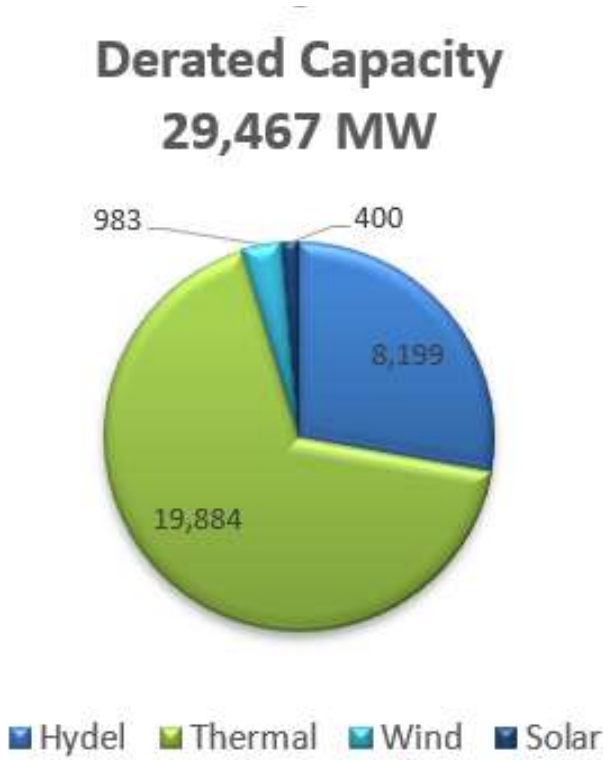
Plant	Fuel	Capacity (MW)
QA Solar	Solar	100
APPOLO Solar	Solar	100
Best Green Solar	Solar	100
Crest Energy Solar	Solar	100
FFCEL WIND	Wind	49.5
ZEPL WIND	Wind	56.4
TGF WIND	Wind	49.5
FWEL-I WIND	Wind	49.5
FWEL-II WIND	Wind	49.5
SAPPHIRE WIND	Wind	49.5
METRO WIND	Wind	49.5
YOUNIS WIND	Wind	49.5
TAPAL WIND	Wind	30
MASTER WIND	Wind	53
TENANGA WIND	Wind	49.5

Power Generation Facilities in Pakistan (REs)

Plant	Fuel	Capacity (MW)
GUL AHMED WIND	Wind	49.5
DAWOOD WIND	Wind	49.5
SACHAL WIND	Wind	49.5
UEP	Wind	99
ARTISTIC WIND	Wind	49.5
JHIMPIR POWER	Wind	49.5
HAWA WIND	Wind	49.5
TGT Wind	Wind	49.5

Generation Mix





Generation Demand Balance and Dispatch of Electric Power

Unit Commitment, Scheduling and Dispatch

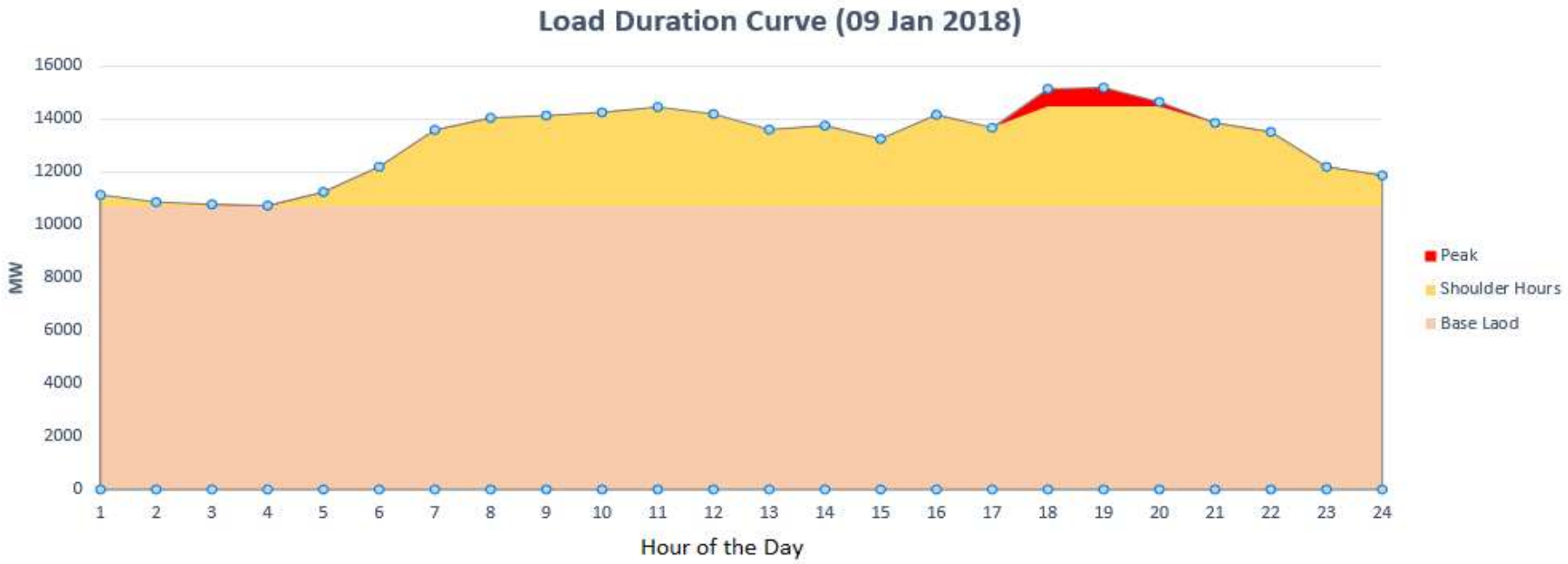
- The process of continuously adjusting the output of power plants to meet electricity demand is known as dispatch of power plants.

- There are actually two stages to the dispatch process, and they occur over different time horizons.
  - Scheduling / Commitment: occurs a day or more in advance of the need to meet real-time electricity demand
  - Dispatch: where the scheduled plants are selected to run at a given level to meet total electricity demand

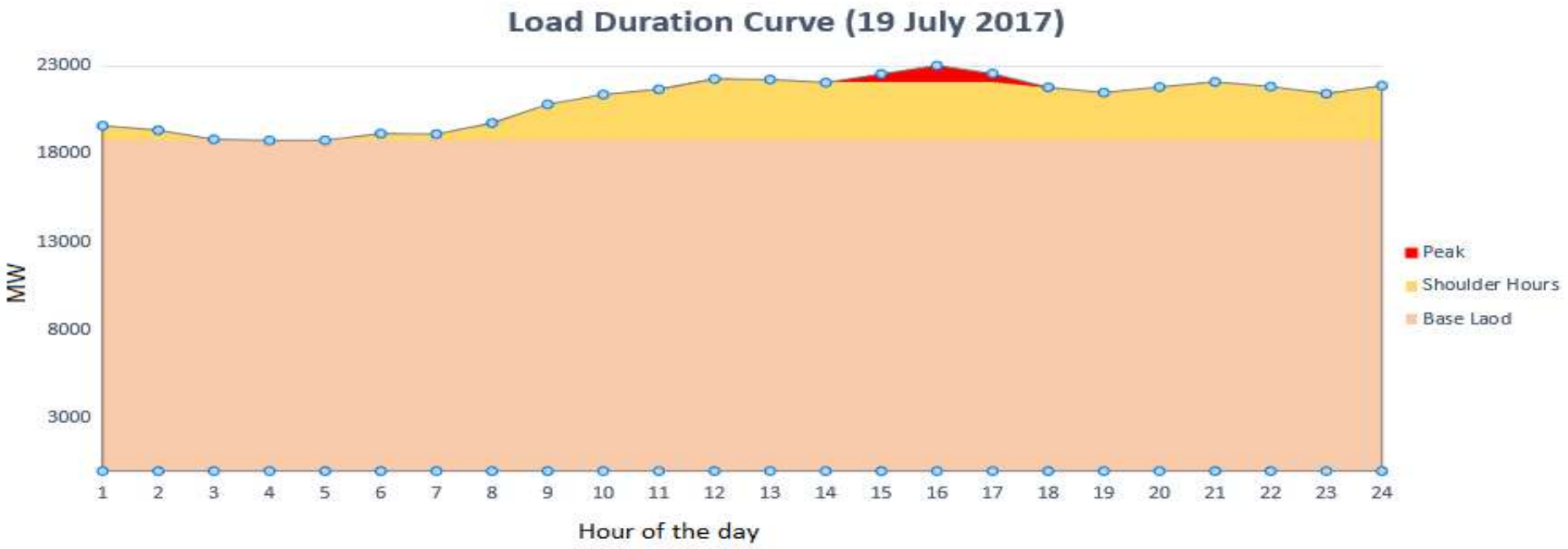
- The dispatch decision is driven primarily by economic factors, but other types of operational considerations such as ramp rates and minimum run times are also considered in the dispatch decision

Unit Wise EMO

Load Duration Curve of a Typical Winter Day



Load Duration Curve of a Typical Summer Day



Scheduling Process

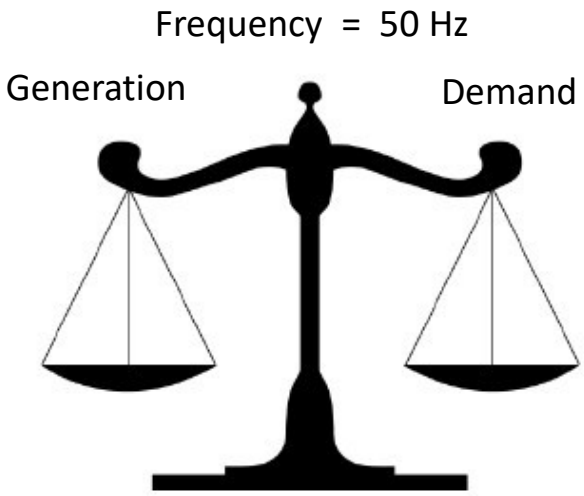
- Hourly Generation availability notice by Power Producers for scheduled day
- Day ahead energy assessment of hydro plants based on allowed indents and hourly scheduling of hydro resources
- Hourly Demand Forecast by SO for scheduled day
- Hourly notice of generation required from each generator by SO (indicative) based on forecasted demand

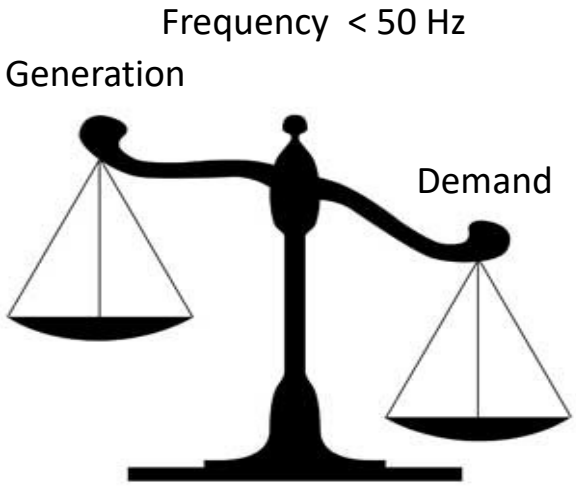
Scheduling Process

	Plant / Hour of the day	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
Generator Availability	Plant A (Nuc 1/kwh)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
	Plant B (Hydel)	5600	5300	5100	5100	5200	5200	5200	5200	5200	5200	5500	5600	5700	5500	5700	5700	5700	5000	5200	5600	5600	5500	5500	5500
	Plant C (RE)	70	70	70	70	70	80	110	160	360	420	410	440	400	390	120	90	150	220	300	110	80	170	160	150
	Plant D (Coal Rs 6/kwh)	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600
	Plant E (Gas Rs 7.5/kwh)	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
	Plant F Oil (Rs 12.5/kwh)	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100	4,100
	Total	22070	21770	21570	21570	21670	21680	21710	21760	21960	22020	22310	22940	23000	22790	22720	22690	22750	22120	22400	22610	22580	22570	22560	22550
Demand (forecast)		19600	19300	18800	18800	18800	19200	19100	19800	20800	21400	21700	22300	22200	22000	22500	23000	22600	21800	21500	21800	22100	21800	21400	21900
Surplus (+) / Deficit (-)		2470	2470	2770	2770	2870	2480	2610	1960	1160	620	610	640	800	790	220	-310	150	320	900	810	480	770	1160	650
Generator Schedule	Plant A (Nuc 1/kwh)	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
	Plant B (Hydel)	5600	5300	5100	5100	5200	5200	5200	5200	5200	5200	5500	5600	5800	5500	5800	5700	5100	5000	5200	5600	5900	5700	5700	5900
	Plant C (RE)	70	70	70	70	70	80	110	160	360	420	410	440	400	390	120	90	290	220	300	110	80	170	160	150
	Plant D (Coal Rs 6/kwh)	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600	2,600
	Plant E (Gas Rs 7.5/kwh)	8,500	8,500	8,500	8,500	8,500	8,500	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
	Plant F Oil (Rs 12.5/kwh)	1,630	1,630	1,330	1,330	1,230	1,620	990	1,640	2,440	2,980	2,990	3,460	3,200	3,310	3,780	4,100	4,100	3,780	3,200	3,290	3,320	3,130	2,740	3,050
	Total	19600	19300	18800	18800	18800	19200	19100	19800	20800	21400	21700	22300	22200	22000	22500	22690	22290	21800	21500	21800	22100	21800	21400	21900

Real Time Dispatch

- Demand is continuously varying in time
- Every MW of power required at any point in time must be supplied at the same instance
- Indication to SO – System Frequency





Real Time Dispatch

	Plant / Hour of the day	0700	1300	1600	2000
Plant Availability		21710	23000	22690	22610
Generator Schedule	Plant A (Nuc 1/kwh)	1200	1200	1200	1200
	Plant B (Hydel)	5200	5800	5700	5600
	Plant C (RE)	110	400	90	110
	Plant D (Coal Rs 6/kwh)	2,600	2,600	2,600	2,600
	Plant E (Gas Rs 7.5/kwh)	9,000	9,000	9,000	9,000
	Plant F Oil (Rs 12.5/kwh)	990	3,200	4,100	3,290
	Total	19100	22200	22690	21800
Demand (Real Time)		18000	21900	23150	21950
Dispatch	Plant A (Nuc 1/kwh)	1200	1200	1200	1200
	Plant B (Hydel)	5200	5800	5700	5600
	Plant C (RE)	90	450	90	110
	Plant D (Coal Rs 6/kwh)	2,600	2,600	2,600	2,600
	Plant E (Gas Rs 7.5/kwh)	8,910	9,000	9,000	9,000
	Plant F Oil (Rs 12.5/kwh)	0	2,850	4,100	3,440
	Total	18000	21900	22690	21950
Surplus (+) / Deficit (-)		3710	1100	-460	660

Generation Demand Balance

- Load is continuously varying in time and so the generation has to be varied in order to keep frequency in permissible limits
- Variation in generation
  - Hydel (Fastest ramping rates)
  - Thermal
    - Steam Turbines
    - Gas Turbines
    - DG Sets

Forecasting and its Horizons

Forecasting and its Horizons

- Electricity demand forecast has a critical role in the operation of a power sector
  - Short term and medium term demand forecast is crucial in order to optimally utilize the available resources
  - Long term forecasts are the basis for planning and investing in new capacity procurements
- The costs of over- or under contracting electricity resources are typically so high that they can lead to huge financial losses; and bankruptcy in the extreme case, besides causing social unrest in the shape of unnecessary deficits and surpluses.

Forecasting and its Horizons

Forecast Type	Purpose	Typical Time Horizon	Grid Code Reference	Target outcomes
Short Term	Operational	From hour ahead up to few days ahead	OC 2	Generation schedule / unit commitment Marginal pricing
Medium Term	Operational Planning	From weeks ahead up to few years (typically 3-5) ahead	OC 2,4	Maintenance outage planning Energy estimates Fuel arrangements Cash flows Balance sheets Risk management
Long Term	Expansion Planning	Few years ahead up to 40 years ahead	OC 4	Transmission and generation expansion planning Investment analysis Determination of future sites and fuel resources for power plants

AH9 Minimum 20 years ahead

Abrar Hussain, 7/13/2018

POWER TO THE PEOPLE

SAVE ON ELECTRICITY

Thank You

Questions???