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Workshop on

Renewable Energy Integration and Procurement

March 18 -19, 2024

South Asia Regional Energy Partnership (SAREP) and Sri Lanka Energy Program

Session 1A : Sharing India Experience on Power Sector Reforms

Sharing India Experience on Power Sector Reforms

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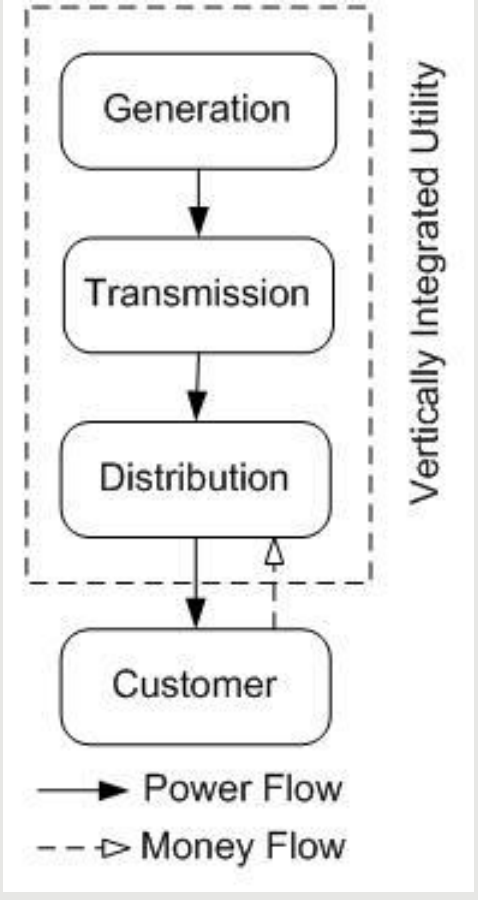
FIEEE, FINAE, LFIE(I) ,Member NAE US, Retired CPES GOI

Distinguished Member CIGRE, Distinguished Alumnus IIT KGP

Brief History…Vertically Integrated Utility

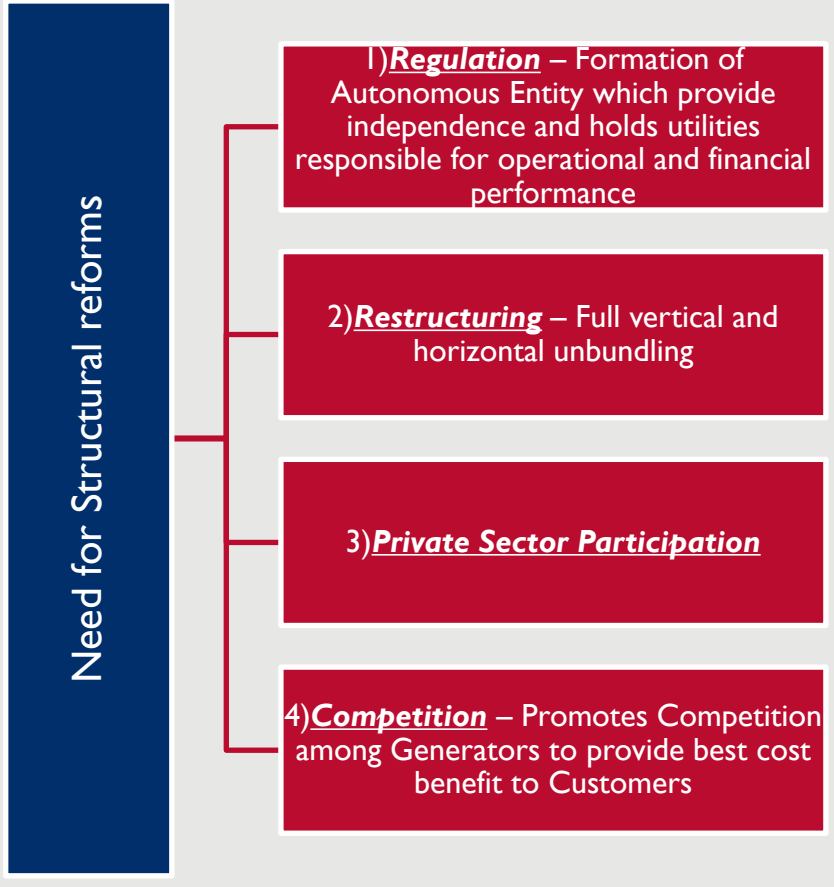
- Vertically Integrated Utility
  - Traditional model until ~ late 80s – early 90s…
- Single entity owns and operates
  - generation, transmission, distribution, retail
- Why? because building a complete power system is expensive
  - didn't make sense to have competing distribution and transmission networks
  - premium on reliable, uninterrupted power supply
- Geographic separation

Erstwhile State Electricity Boards in India till 1990s !
Unbundling started in late 1990s …



Motivation towards 'De-Regulation' & 'Competition'

- Monolith
  - No competition
  - utility earns more if it invests more
  - costs are passed on to rate-payer
  - Limited oversight on investment choices & costs
  - Costs on account of financial distress
  - Retail rates may be "higher than they should be"

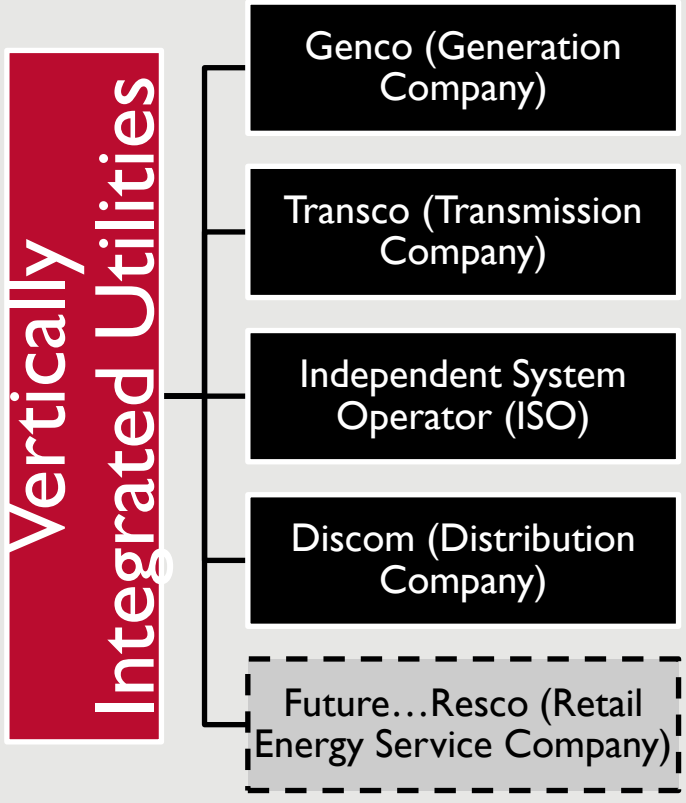


Restructuring and Regulation

- Regulation on power utilities
  - utility gets the license/rights
  - agrees to controls on its tariff

- Regulatory Commission sets tariffs so that (in medium and long-run)
  - utility recovers operating costs
  - utility recovers capital costs
  - utility can pay its investors a "fair" rate-of-return

In India, post Electricity Regulatory Commissions Act, 1998, Central Electricity Regulatory Commission (CERC) and State Electricity Regulatory Commission (SERC) were formed



Indian Power Sector Reform Timeline

- 1991- Opening up of Power Sector for IPPs

Private Opening up of Power Sector for IPPs (Private Power Policy & Mega)

- 8 Fast Track Projects ; Unbundling & Privatisation of Orissa SEB;

Followed by regulatory reforms in Haryana AP

- 1998 – Elec. Reform Act; setting up of CERC & SERCs
- 2001 Conference of Chief Ministers / Power Ministers
- 2001 - Electricity Bill Introduced
- 2001 - Ahluwalia Committee report on SEB dues
- 2002 - Privatisation of DVB (Delhi) Privatisation of DVB (Delhi)
- 2003 – Electricity Act 2003 Electricity Act 2003
- 2005 – National Electricity Policy National Electricity Policy
- 2006 – National Tariff Policy National Tariff Policy

Electricity Act 2003

After a number of draft in Lok Sabha and Rajya Sabha,
Electricity Act 2003 came into effect from 10th June 2003
It replaced the existing three legislations governing the power sector,

- Indian Electricity Act, 1910
- Electricity (Supply) Act, 1948
- Electricity Regulatory Commissions Act, 1998.

Electricity Act 2003

Objective: Competition, Protection of consumers interest & Power for all areas

- Creates liberal framework for power development
- Creates competitive environment
- Facilitates private investment
- Delicense generation
- Multiple Licensing in Distribution
- Rural Areas: Stand alone generation distribution delicenced

Need for the new legislation

- Requirement of harmonizing and rationalizing the existing laws
- Create competitive environment for benchmark competition
- Enhancing quality and reliability of service to consumer.
- Distancing regulatory responsibilities of Govt.
- Reform legislation by several States separately.
- Obviating need for individual States to enact their own reform laws.
- Requirement of introducing newer concepts like

  Power trading, Open access, Appellate Tribunal etc.
- Special provision for the Rural areas.

Electricity Act 2003

- Stringent provision for controlling theft of energy
- Obligates states to restructure SEBs
- Mandates creation of Regulatory Commissions
- Tariff to be determined by Regulatory Commissions
- Open access in Transmission
- Open access in Distribution to be allowed by SERCs in phases
- Gradual phasing out of cross subsidies
- Trading a distinct licensed activity
- Promote development of Electricity market
- Appellate Tribunal for appeals against orders of CERC/SERCs

Electricity Act 2003

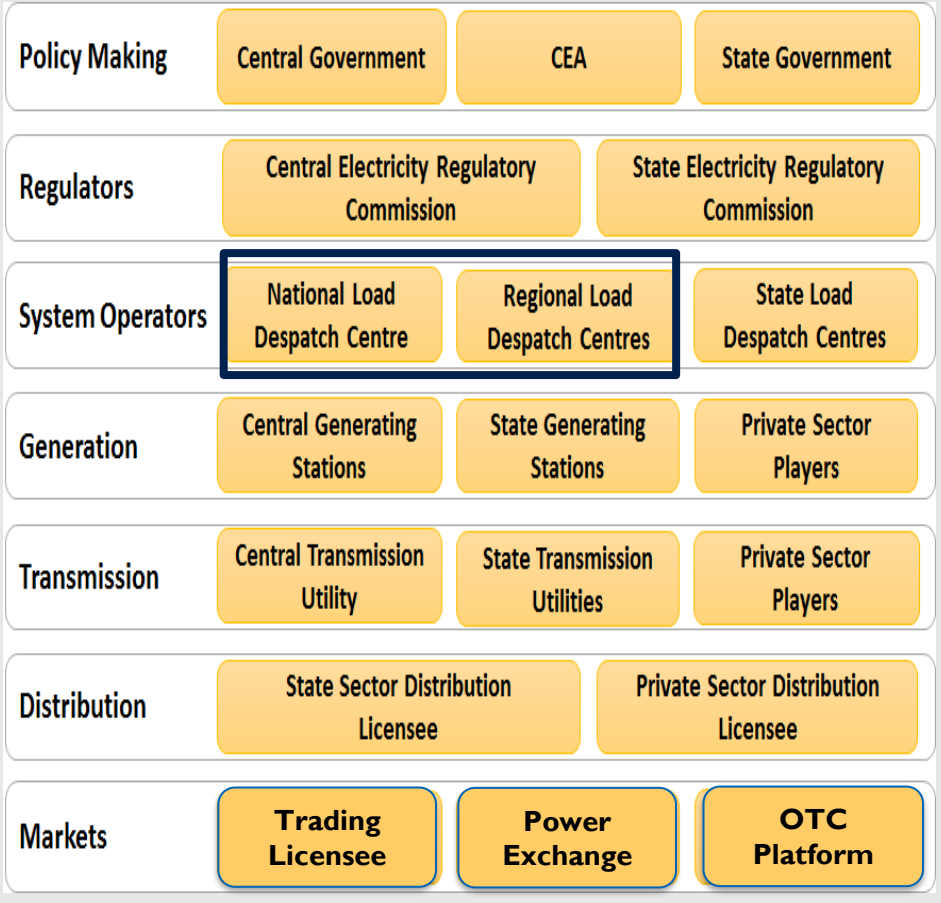
Rural Electrification: Relevant provisions of Electricity Act 2003

Section 4. The Central Govt. shall, after consultation with the State Govts. prepare and notify a national policy, permitting standalone systems(including those based on renewable source of energy and non-conventional sources of energy for rural areas

Section 2(63). “stand alone system ” means the electricity system set up to generate power and distribute electricity in a specified area without connection to Grid

Restructured Model

- Objective: Introduce competition
- Unbundle different functions
- Treat electricity as a commodity
- Create markets for trading elctricity
- ‘System operation’ as ‘neutral’ operator
- Generators compete against each other
- Retail choice



Restructuring of SEBs

- Orissa – 1 Genco 1 Transco and 3 Discoms
- Haryana – 1 Genco, 1 Transco and 3 Discoms
- AP – 1 Genco, 1 Transco and 3 Discoms
- UP – 2 Genco, 1 Transco and 4 Discoms KESCO,KESCO NPCL
- Maharashtra – 1 Genco, 1 Transco and 1 Discoms (BSES, REL)

India State Reform Acts- Common features

- Orissa (1995)
- Haryana (1997)
- Andhra Pradesh (1998)
- Uttar Pradesh (1999)
- Karnataka (1999)
- Rajasthan (1999)
- Delhi (2000)
- Madhya Pradesh (2000)
- Gujarat (2003)
- Kerala, Punjab, Tamil Nadu
- Smaller North Eastern states

Independent Regulatory Mechanism

- Constitution of SERC
- Powers of tariff fixation,
- Licensing, regulation or working of licensees,
- Performance standards etc. to SERC

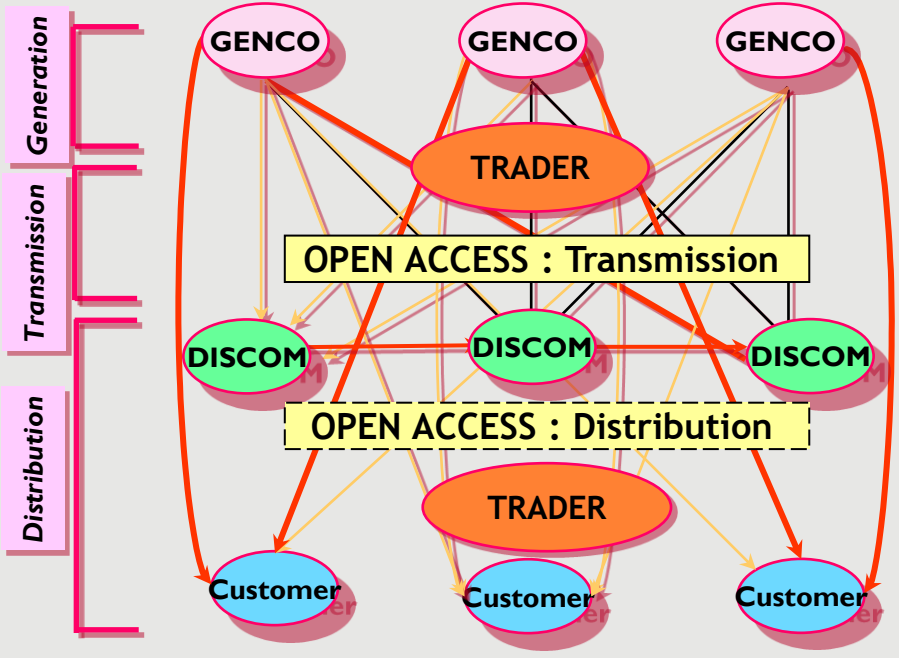
Reorganisation of SEB

- TRANSCO as successor entity
- Single buyer/ Multi buyer model
- Separation of generation, transmission & distribution

Powers of State Governments to give policy directions to SERCs.

- Policy directions also on subsidy
- State Governments to compensate licensee affected by direction regarding subsidy

Indian Electricity Market (Post Deregulation)



2003-08

- Unbundling of State Utilities
- Wholesale competition model
- Large no. of transactions – Bilateral/OTC market
- Trading on Day-ahead and ToD

2008 onwards

- Power Exchanges commence
- Multilateral transactions
- Different products for portfolio management
- 24x7 - Intra-day – Real Time transactions

Electricity Act, 2003

- De-licensing of generation
- Multi-buyer multi-seller electricity market
- Trading – licensed activity.
- Non Discriminatory Open Access
- Development of Power Market

Overarching Regulatory Framework

CERC - 21 Regulations

- Open Access in Inter-State Transmission
- Connectivity and General Network Access to the inter-State Transmission System
- Measures to relieve Congestion
- Grant of trading licence
- Renewable Energy Certificate
- Indian Electricity Grid Code
- Sharing of ISTS Charges & Losses
- Intervening Transmission Facilities
- Standards of Performance
- Planning, Coordination and Development of Economic and Efficient ISTS by CTU
- Power Market
- Terms and Conditions of Tariff
- Power System Development Fund
- Deviation Settlement Mechanism
- Fees and Charges of RLDC
- Ancillary Services Operations
- Energy Savings Certificates
- Communication in Power Sector
- Planning of Transmission System
- Cross Border Trade of Electricity
- Terms and Conditions for Tariff determination from RE Sources

CEA - 8 Standards

- Grid Standards;
- Connectivity to the Grid
- Installation and Operation of Meters
- Technical Standards for Connectivity of the Distributed Generation Resources
- Safety and Electricity Supply
- Transaction of Business
- Furnishing of Statistics, Returns & Information
- Technical Standards for Communication System in Power System Operation

Grid Development in India

1947-1964
- **State Grids**
- **Isolated Nature**

Monolithic (SEBs)

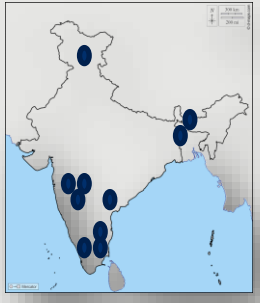
SEB – State Electricity Board

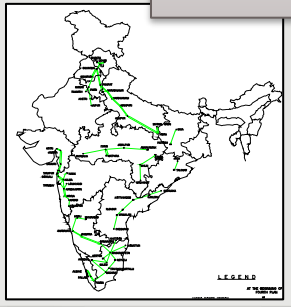
1964-2003
- **Regional Grids**
- **Inter-state connections**

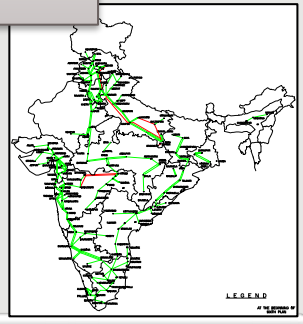
Competition (PSUs & Private)

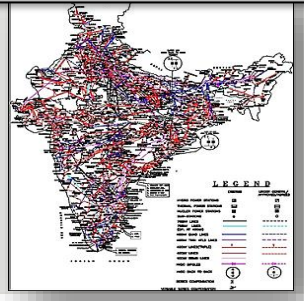
PSU – Public Sector Undertaking

2003 – Present
- **National Grid**
- **International connections**









Till 1960s → 1960s – 1980s → 1980s – 2000s → 2000s and beyond

Electricity Act, 1910

Electricity Supply Act, 1948

Electricity Act, 2003

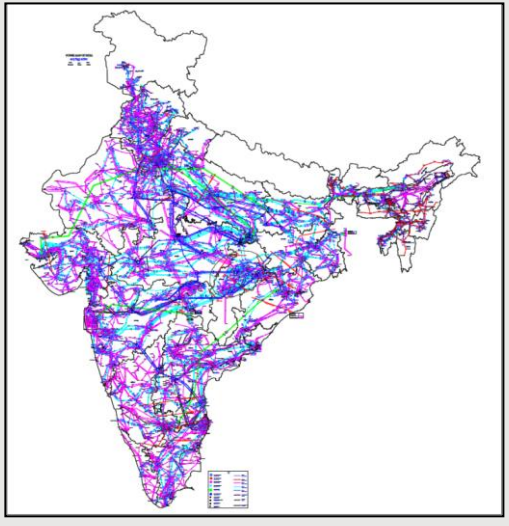
21st Century Indian Grid

Pan India Market:
All India Economy & Efficiency

Optimal utilization of resources

Well Meshed Network

400 kV Backbone (~140,000 ckt kms)

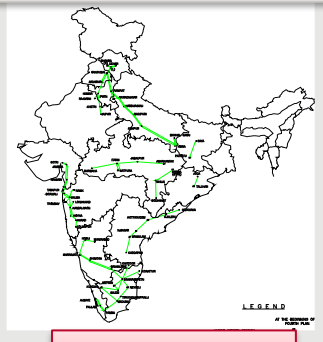


765 kV network

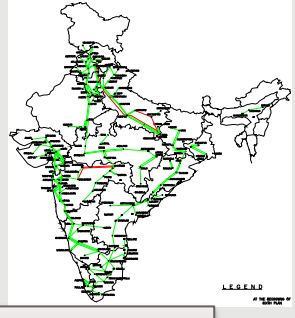
Bulk transfer through HVDCs

Robust Transmission Pricing

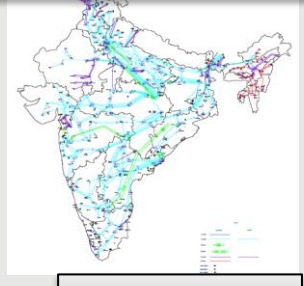
High Capacity Corridors under construction



1970s



1980s



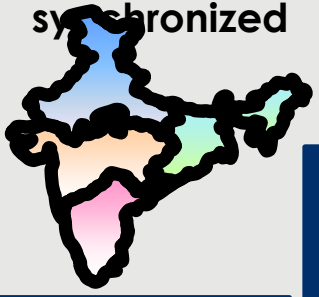
1990s

Evolution

Pre 1991:

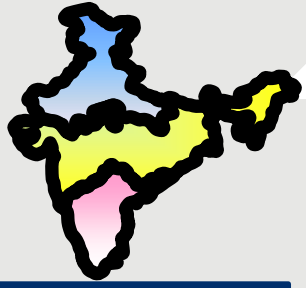
Five Regional Grids - Five Frequencies

October 1991: East and Northeast synchronized



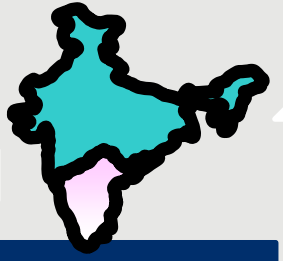
Merchant Power

March 2003: West synchronized with East & Northeast



Electricity Act, 2003, Open Access

August 2006: North synchronized with Central Grid



Merging of Markets, Power Exchanges

Dec 2013:

All India Synchronized Grid

Addition of large 500 MW & above gen. units and 765 kV trans. Lines, Ultra Mega Power Projects

Overarching Regulatory Framework

Ministry of Power Rules

- Electricity Rules
- Electricity (Promoting Renewable Energy Through Green Energy Open Access) Rules
- Electricity (Late Payment Surcharge & related matters) Rules
- Electricity (Promotion of Generation of Electricity from Must-Run Power Plant) Rules
- Electricity (Transmission System Planning, Development and Recovery of Inter-State Trans. Charges) Rules

CEA Standards

- Grid Standards
- Connectivity to the Grid
- Installation and Operation of Meters
- Technical Standards for Connectivity of the Distributed Generation Resources
- Technical Standards for Communication System in Power System Operation
- Safety and Electricity Supply
- Technical Standards for Construction of Electrical Plants and Electric Lines

CERC Regulations

- Open Access in Inter-State Transmission
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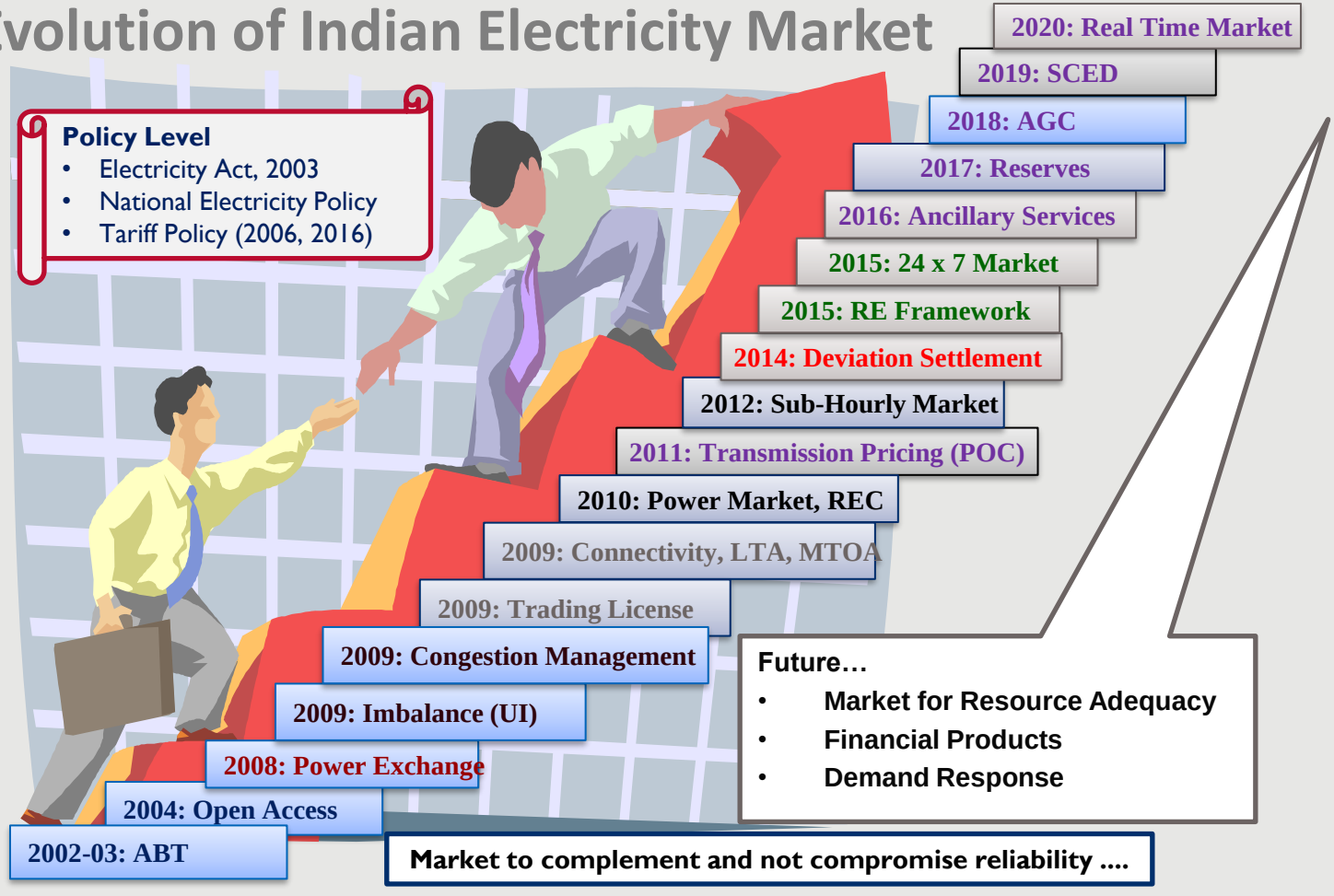
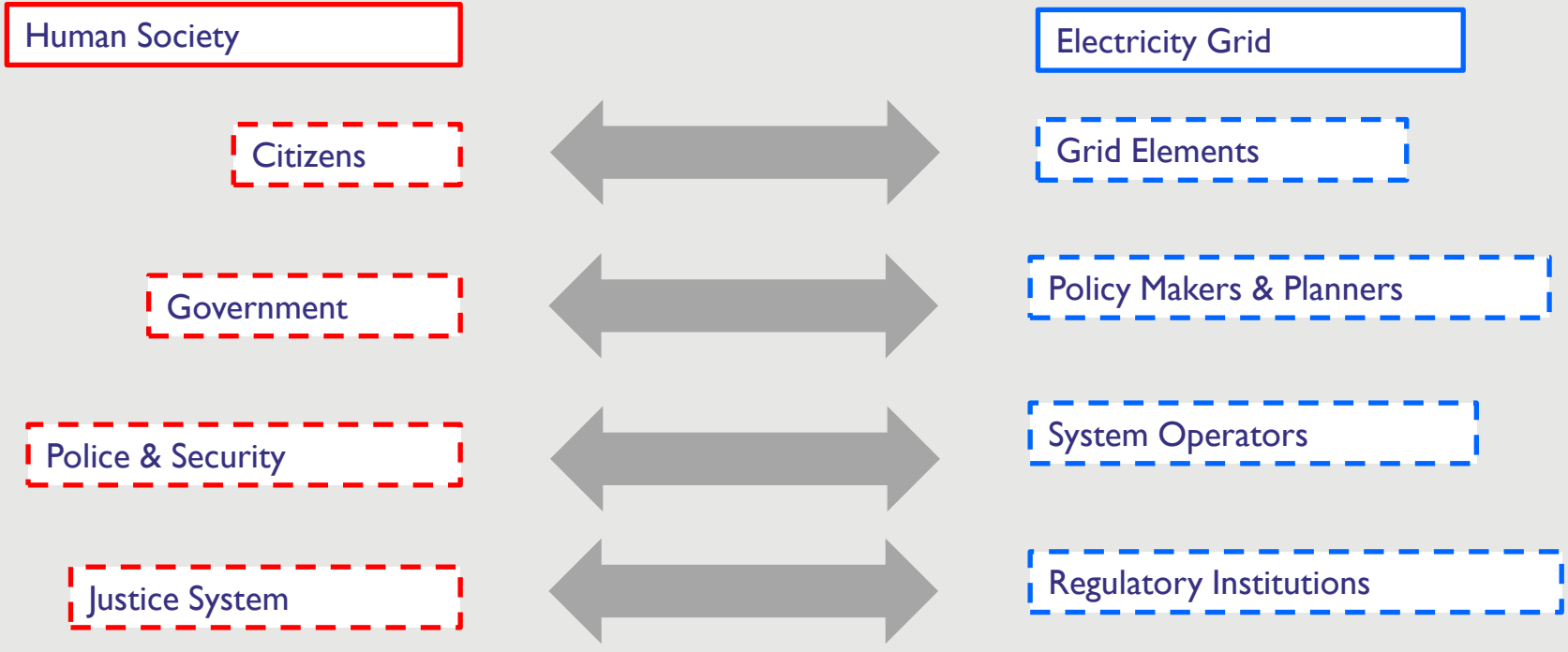
- Ancillary Services
- Deviation Settlement Mechanism
- Renewable Energy Certificate
- Connectivity and General Network Access

Evolution of Indian Electricity Market

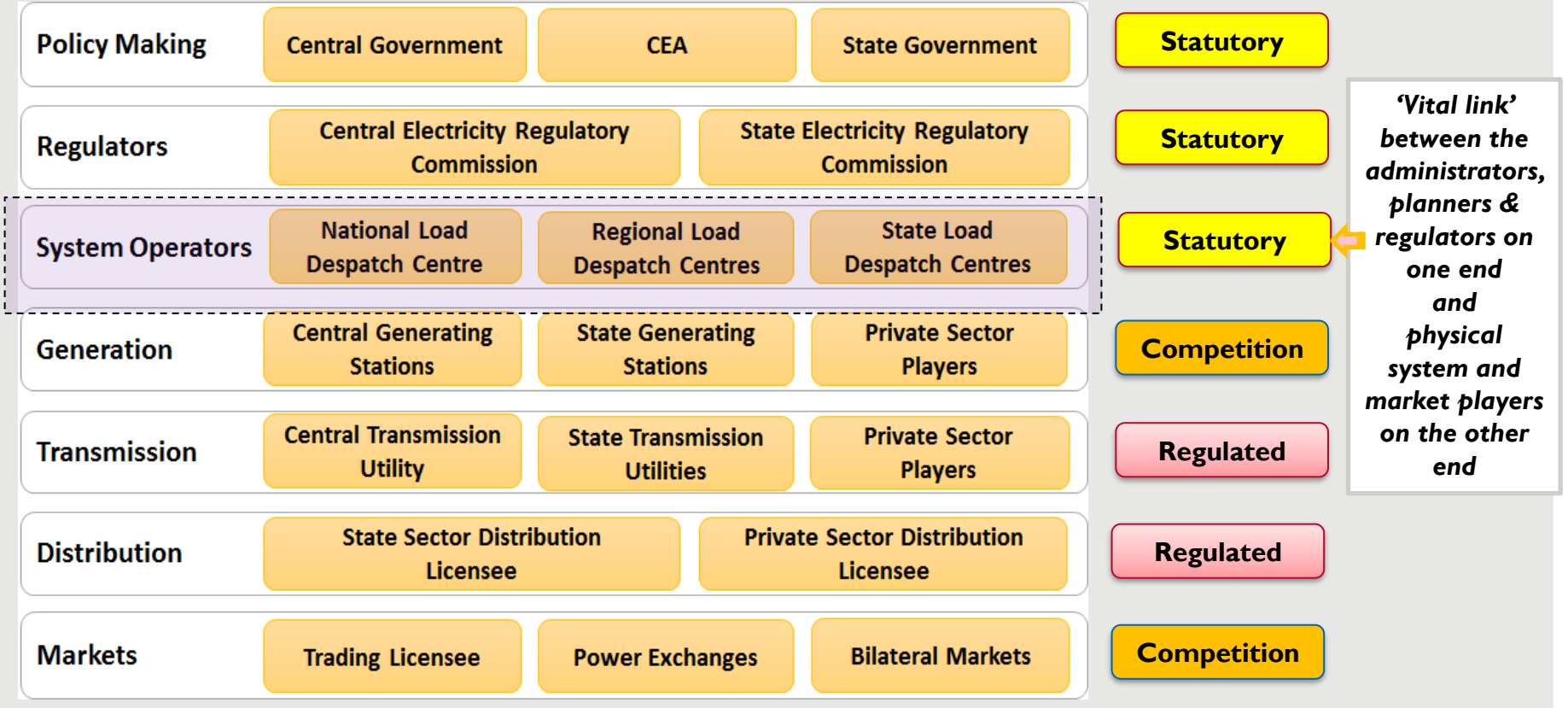


NEED FOR GOVERNANCE OF ELECTRICITY

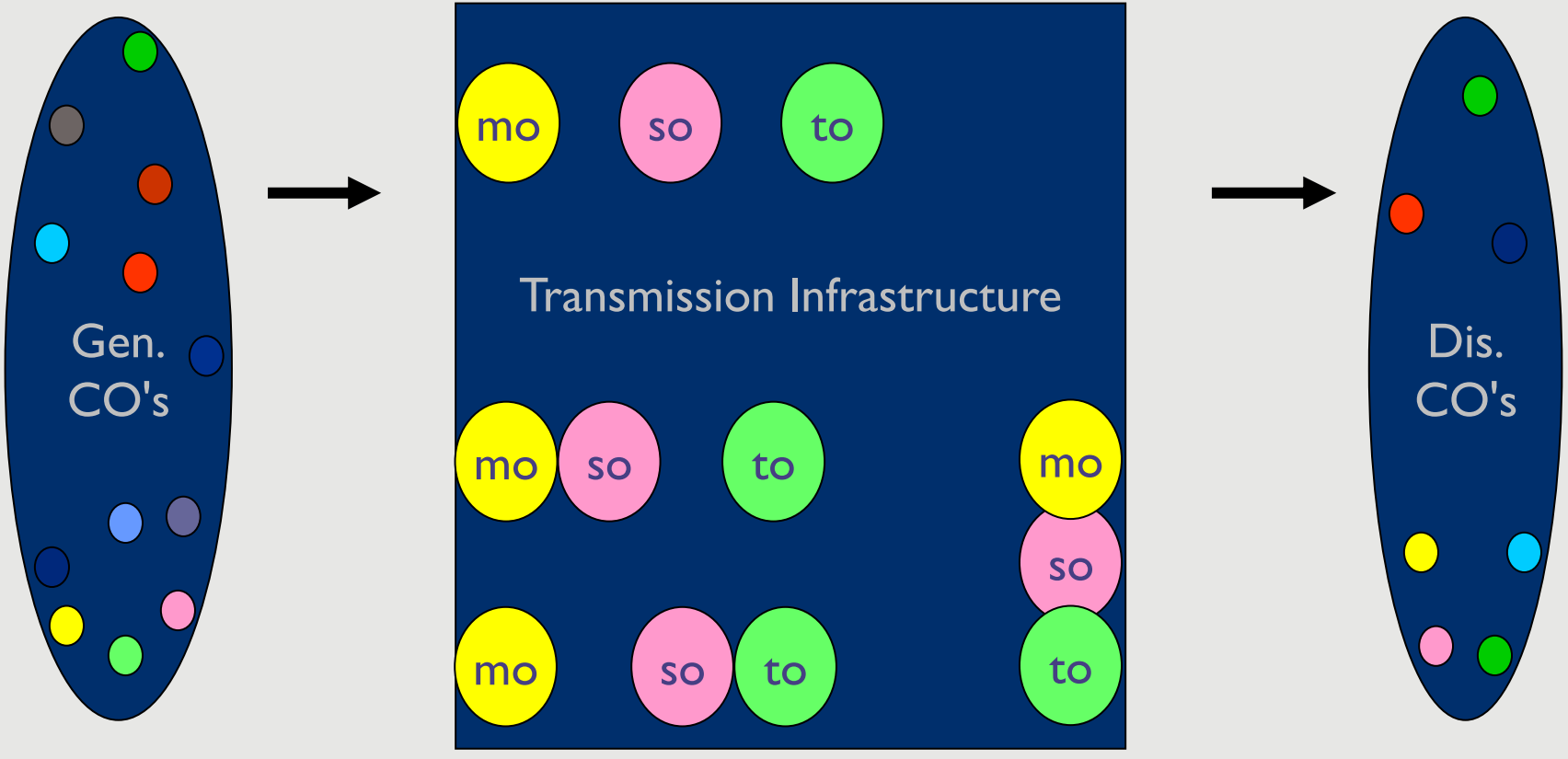
Electricity Grid is a manifestation of Human Society



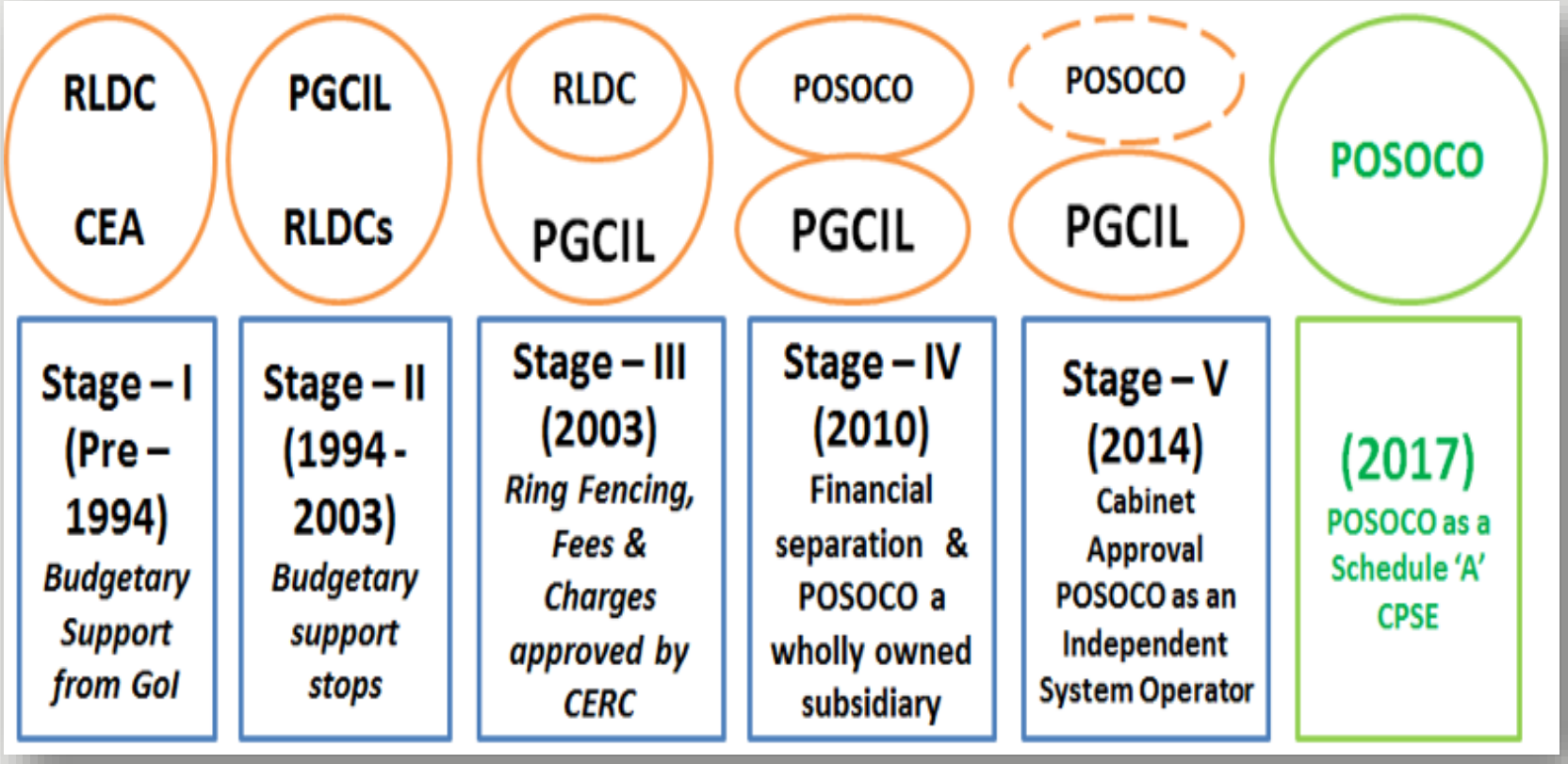
INDIA – Role of System Operators in Power Sector



POSSIBLE MODELS OF GOVERNANCE

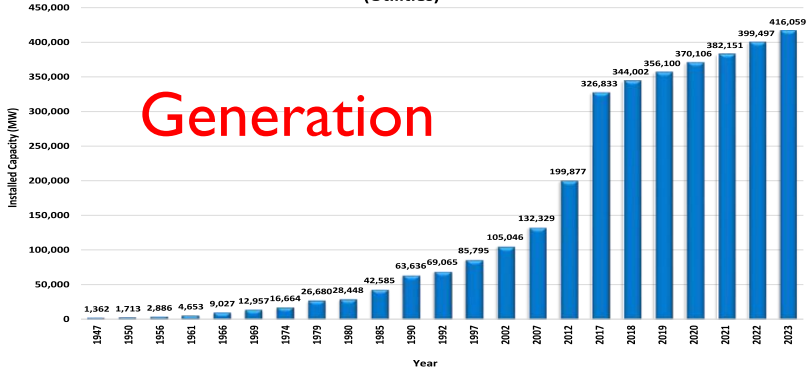


INDIA – EVOLUTION OF POSOCO



India's Power sector Growth story –post Reforms

Chart : 1



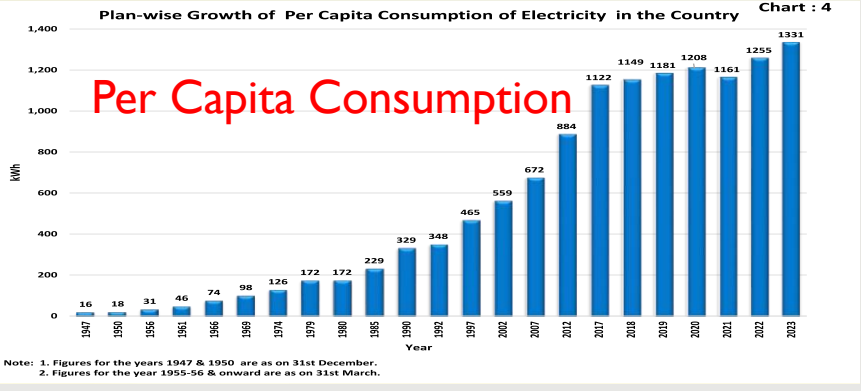
Note: 1. Figures for the years 1947 & 1950 are as on 31st December.
2. Figures for the year 1955-56 & onward are as on 31st March.

Chart : 2A

@ Estimated

Note: 1. Figures for the years 1947 & 1950 are as on 31st December.
2. Figures for the year 1955-56 & onward are as on 31st March.

Chart : 4



Note: 1. Figures for the years 1947 & 1950 are as on 31st December.
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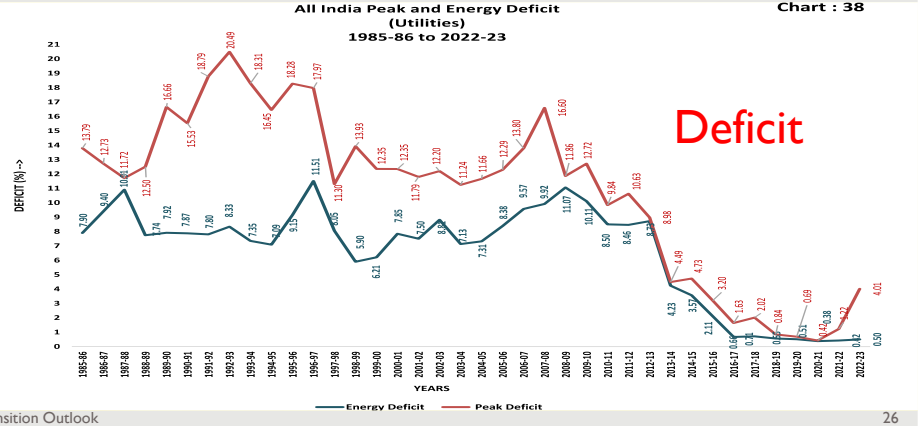
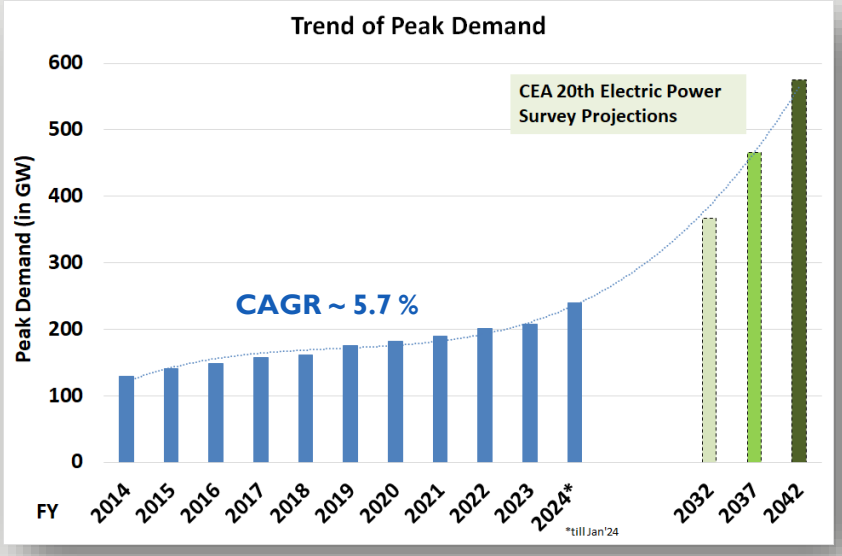
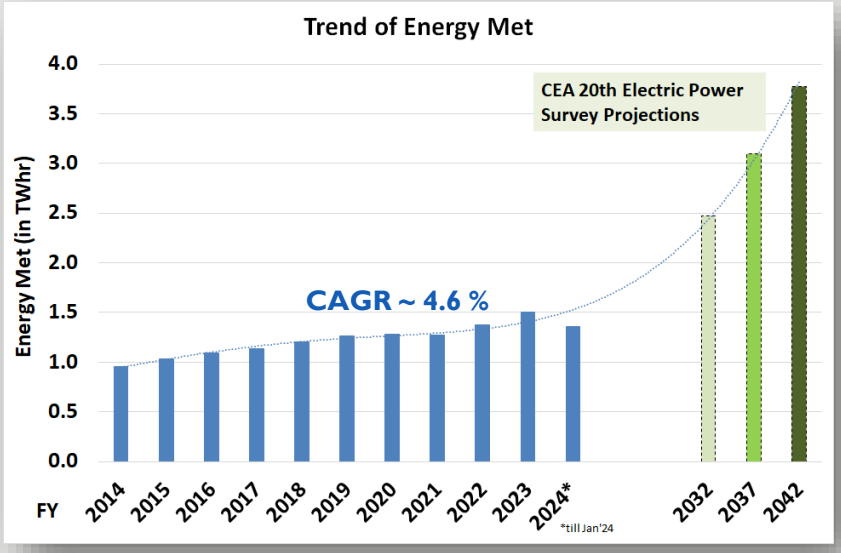
Chart : 38



Growth Story…looking back to leap forward…





Drivers for Future Growth

- **Electric Cooking**
- **Electric Vehicles**
- **Electrolyzers**
- **Data Centres**
- **Space Cooling**

\+ **Decarbonization Goals**

Thank You

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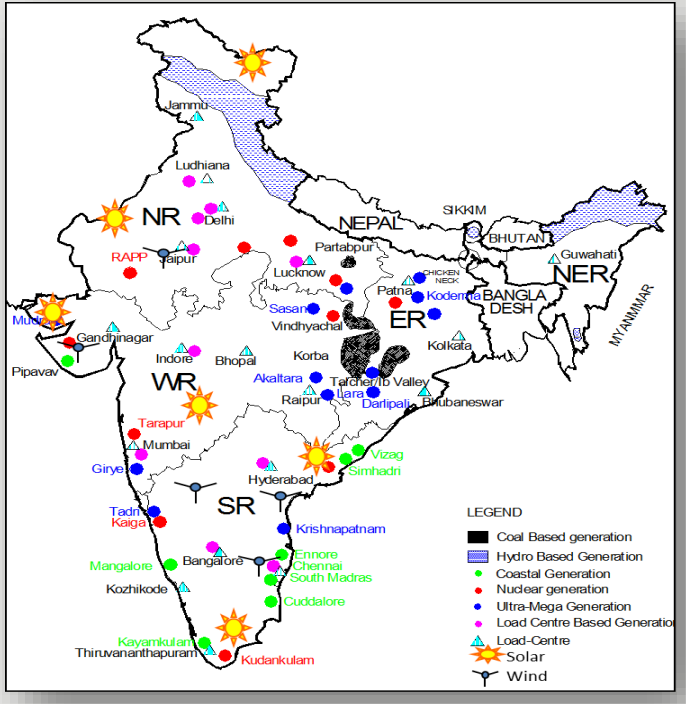
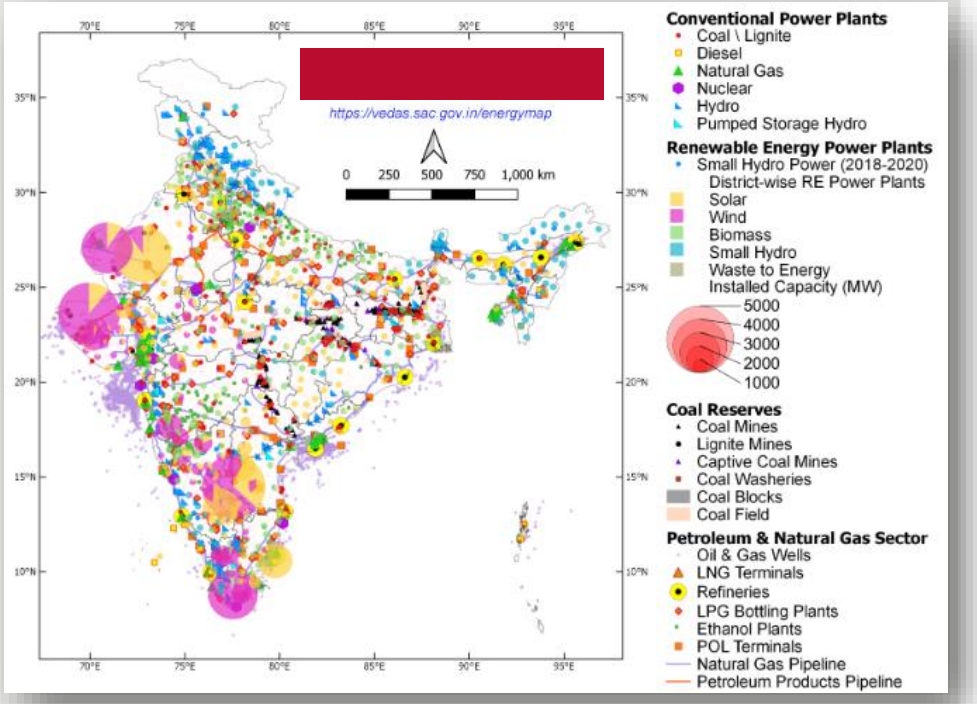
Resource Spread across India





Hydro – North-Eastern & Northern India; Coal - Central India

Renewables – Northern, Western and Southern India

Changing Generation Resource Mix towards 2030

ALL INDIA INSTALLED CAPACITY (MW)			
Resource	**Mar 2023**	**Mar 2030**	**% Addition**
Hydro	42104	53860	28%
PSP	4746	5350	13%
Small Hydro	4944	18986	284%
Solar PV	66780	292566	338%
Wind	42633	99895	134%
Biomass	10802	14500	34%
Nuclear	6780	15480	128%
Coal+ Lignite	211855	251683	19%
Gas	24824	24824	0%
Total	**415469***	**777144****	87%
BESS	0	41650 (5-hr)	

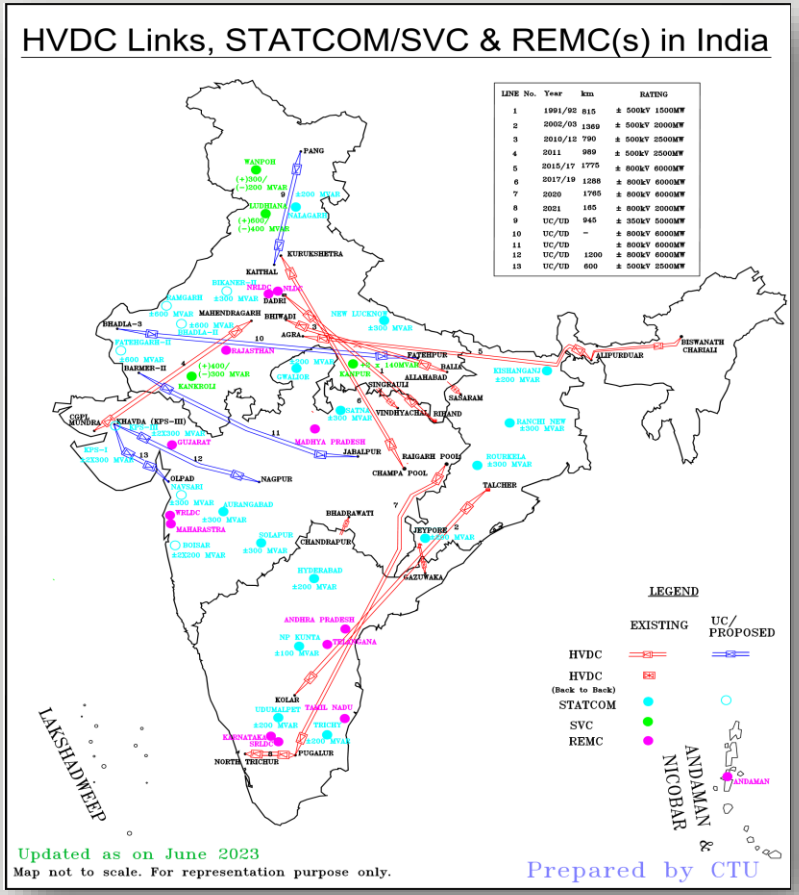
*Excluding 2136 MW of Hydro imports from neighboring countries and 589 MW Diesel based capacity
**Excluding Hydro Imports of 5856 MW

Source: CEA Report On Optimal Generation Capacity Mix for 2030 (Ver 2.0)
https://cea.nic.in/wp-content/uploads/notification/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf

	2024	2030
Maximum Demand Met (GW)	~240#	334^
Total Generation Installed Capacity (GW)	428*	777
Non-fossil Fuel Based Generation Installed Capacity (GW)	188*	500
Wind & Solar Installed Capacity (GW)	117*	393

As on 31st Dec 2023 as per Operational Data of Grid-India
* **As on 31st Nov'23** from CEA Installed Capacity Report
^ CEA Report on Optimal Capacity Mix 2030 (Version 2.0)
https://cea.nic.in/wp-content/uploads/irp/2023/05/Optimal_mix_report__2029_30_Version_2.0__For_Uploading.pdf

Transmission Infrastructure gearing up towards 2030



- **Transmission Lines (≥220kV) - 4,81,326 ckm**
  - 765 kV: 54,672 ckm
  - 400kV: 2,01,541 ckm
  - 220kV: 2,05,738 ckm
  - HVDC: 19,375 ckm
- **Transformation Capacity (≥220kV) : 12,25,260 MVA**
  - 765 kV: 284200 MVA
  - 400kV: 447433 MVA
  - 220kV: 460127 MVA
  - HVDC: 33500 MVA
- **3 nos. of ±800kV HVDC Bipole (18 GW)**
- **5 nos. of ±500kV HVDC Bipole (10.5 GW)**
- **1 no. of ±320kV VSC HVDC (2 GW)**
- **4 nos. of HVDC Back-to-Back (3 GW)**
- **20 no. of Hybrid STATCOMs (11,350 MVAr)**
- **4 nos. of SVC (2500 MVAr)**
- **48 nos. FSC/TCSC**

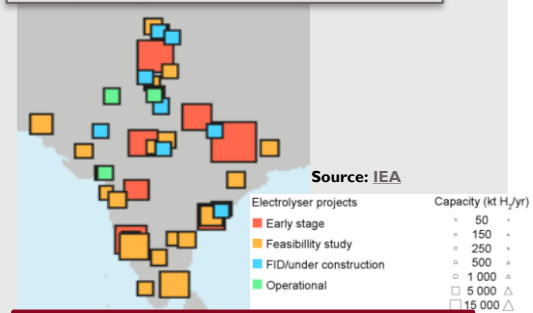
Transmission System Augmentation
Strengthening Integration of over 500 GW Renewables by 2030

- Additional requirement of Inter State Transmission System by 2030 for 66.5 GW Renewable Energy Zones (REZs)
  - Transmission Lines: 50,890 ckm
  - Transformation Capacity: 433,575 MVA
- 37 GW wind power auction trajectory announced till 2030
  - Evacuation system of off-shore wind power has been identified for 10 GW
- Green Hydrogen Mission
  - 5 MMT per annum by 2030
- Cross Border Interconnections
  - >5000 MW additional capacity planned

Gujarat – Khavda 30 GW REZ

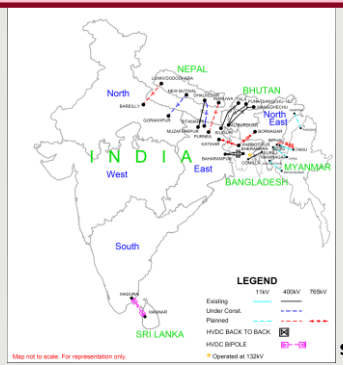
Source: CEA

Hydrogen Electrolyzers



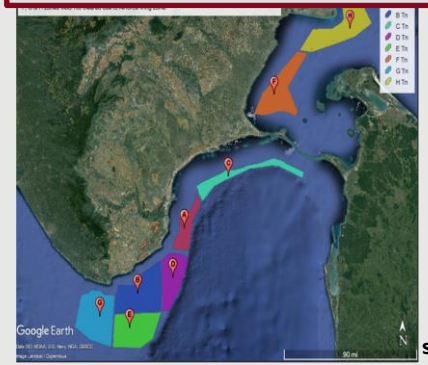
Source: IEA

Cross Border Interconnections



Source: CEA

Off-Shore Wind



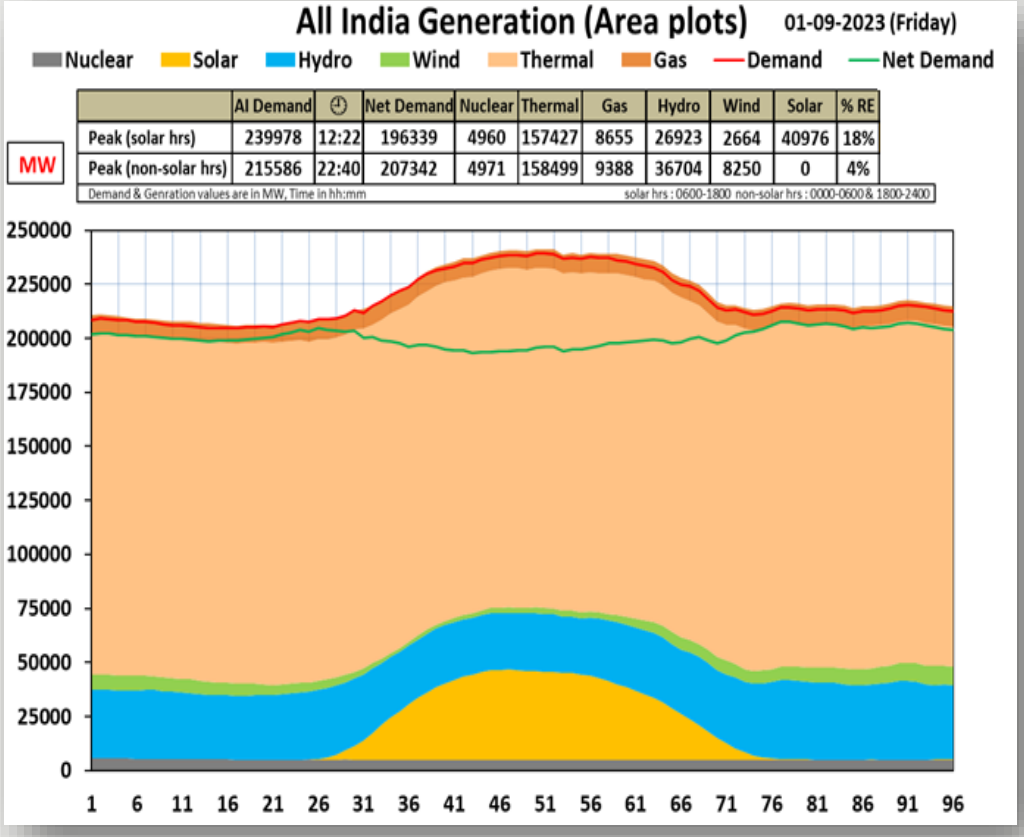
Source: CEA

2 nos. of ±800kV HVDC Bipole and 3 nos. of ±350kV VSC HVDC Hybrid STATCOMs, SVCs also planned

Distribution Reforms

- Promotion of Agricultural Solar Pumps
  - PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan) Scheme
- Unnat Jyoti by Affordable LED for All (UJALA) Programme
  - LED bulbs, LED tube lights and energy efficient fans to replace conventional and inefficient variants
- Street Lighting National Programme (SLNP)
  - Smart and energy efficient LED street lights across India
- Shifting of agricultural power consumption to solar hours
  - Reliable power supply to farmers during daylight hours
- Revamped Distribution Sector Scheme (RDSS) nationwide Smart Meter program under implementation
  - 43 million smart meter contracts awarded since the start of 2023

Resource Adequacy



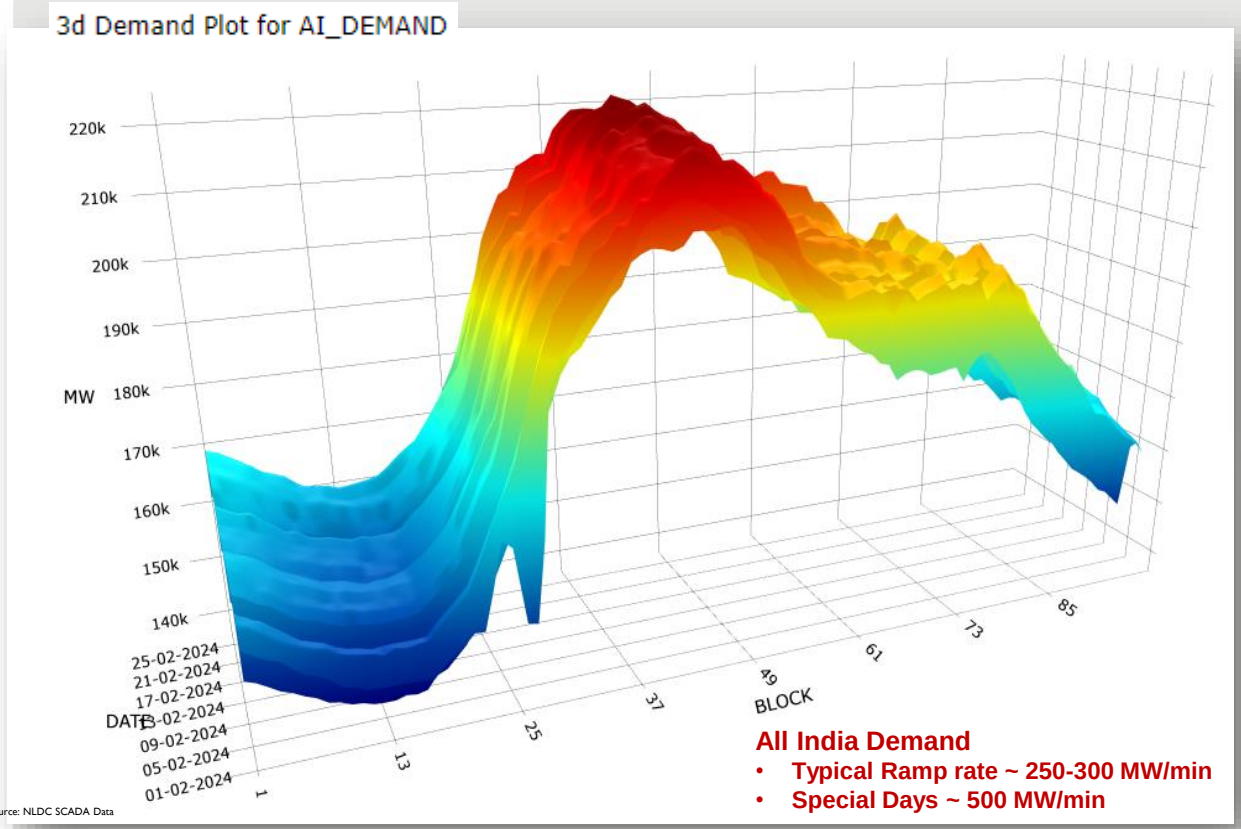
	AI Demand		Net Demand	Nuclear	Thermal	Gas	Hydro	Wind	Solar	% RE
Peak (solar hrs)	239978	12:22	196339	4960	157427	8655	26923	2664	40976	18%
Peak (non-solar hrs)	215586	22:40	207342	4971	158499	9388	36704	8250	0	4%

- Increasing non-solar peak
- Limited support from wind during non-solar hours
- Cloud cover, sandstorm
- RE generation loss due to fault ride through issues
- Resource droughts
  - Long duration storage, quick starting thermal
- Adequacy of reserves vital to handle contingencies

Assessment of Reserve Requirement

Type of reserve	Inter-state level MW	Intra state level MW	Total All India level MW
Secondary	3788	3211.6	7000
Tertiary	3788	8887.6	12676
Total	7576	12099.2	19676

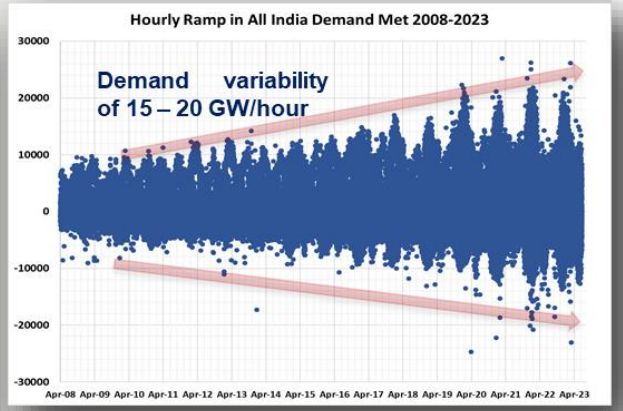
Growing Need for Flexibility – Increasing All India Demand Ramp

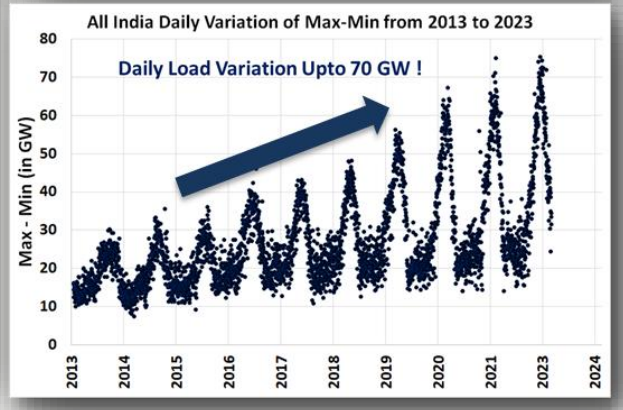


All India Demand

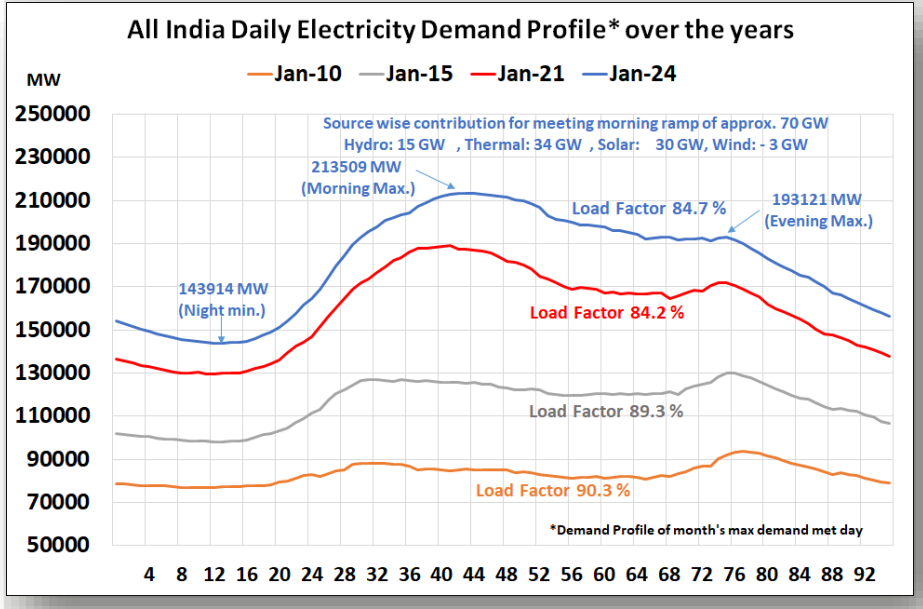
- **Typical Ramp rate ~ 250-300 MW/min**
- **Special Days ~ 500 MW/min**

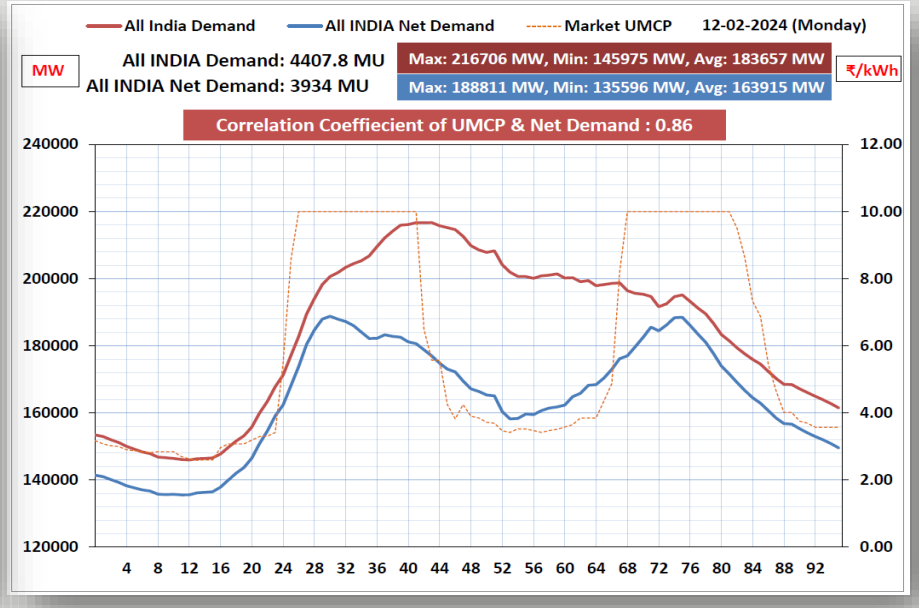
Source: NLDC SCADA Data





Flexibility Requirement



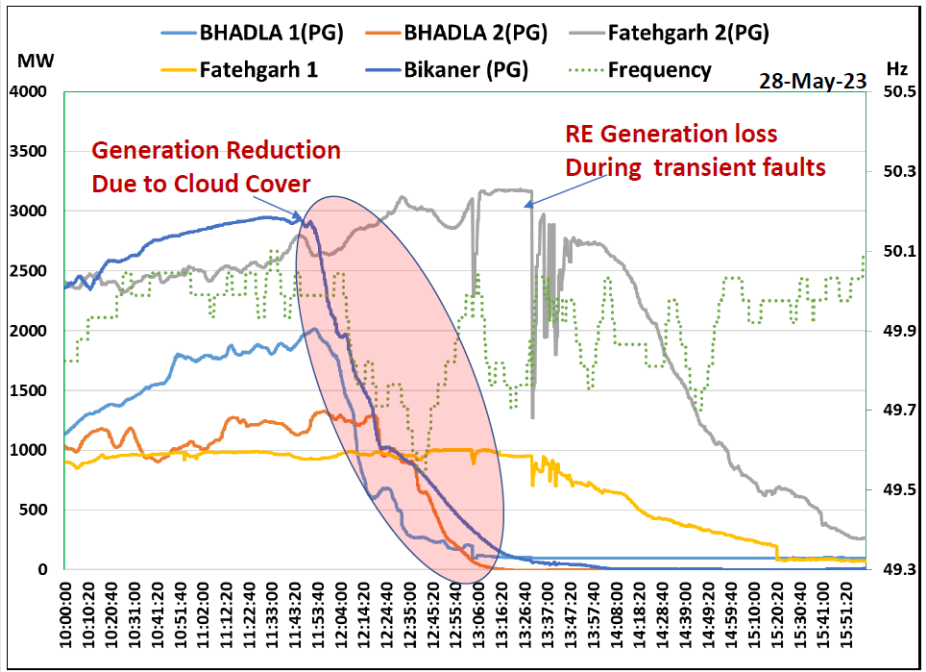


CEA: Flexibilization of Coal-Fired Power Plants (Tech. min upto 40 %)

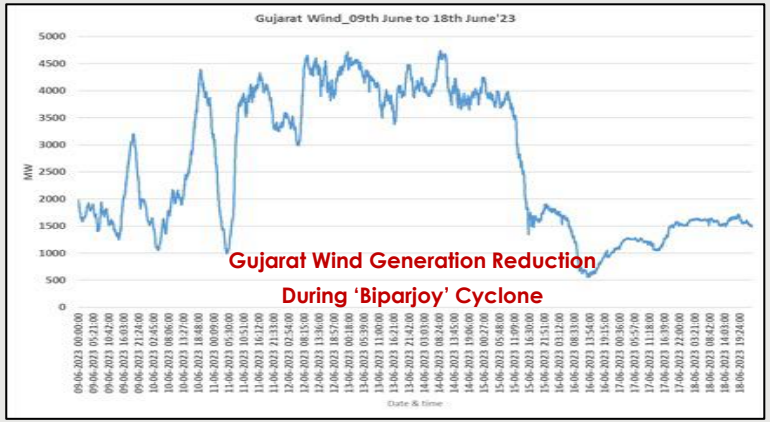
Phase 1: July,2024-Jun,2026 : 90 Units, Phase 2: July,2026-Jun,2028 : 160 Units

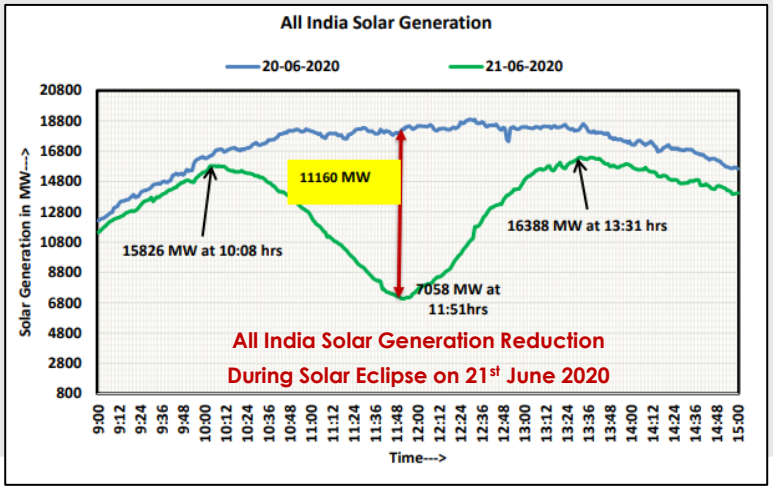
Phase 3: July,2028-Dec,2029 : 143 Units, Phase 4: Jan,2030-Dec,2030 : 196 Units

Growing Need for Flexibility – Cloud Covers and Increase in Extreme Weather Events

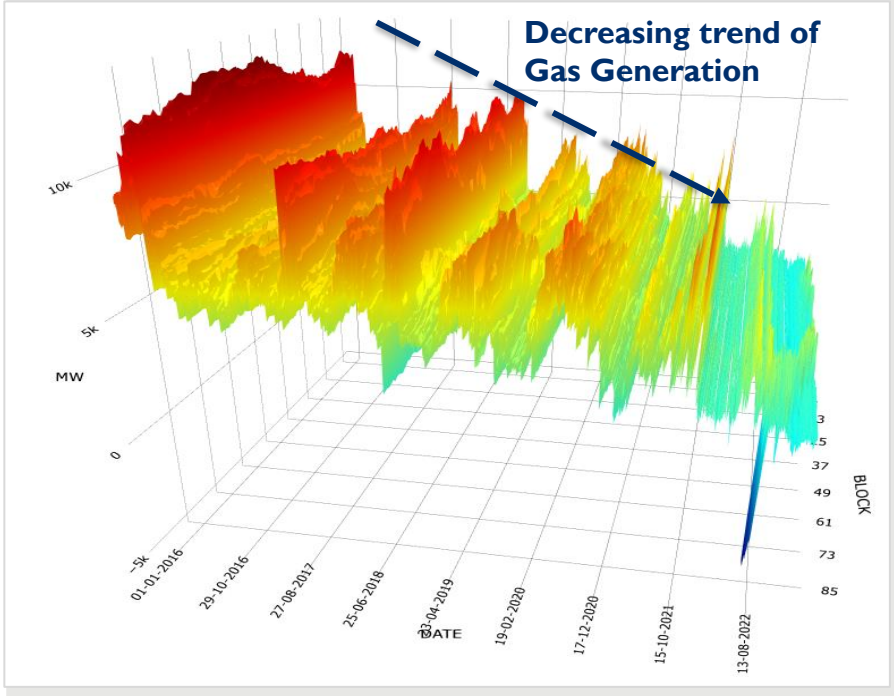


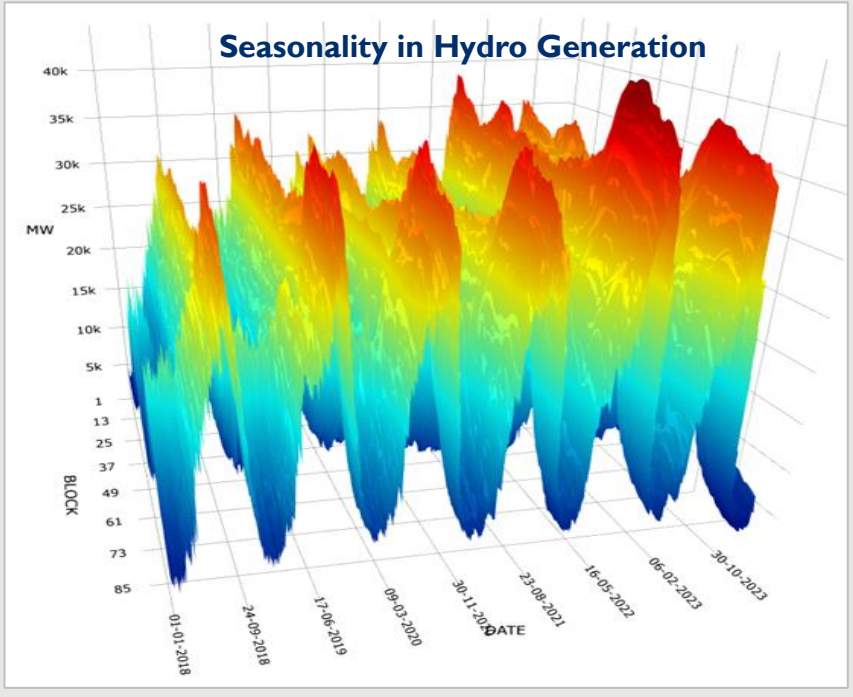
- Solar generation loss during peak solar hour due to cloud cover
- Approx. 8000 MW solar generation reduced within 1 hour.
- After 13:00 hrs, multiple transient faults occurred in RE complex





Flexibility Providers – Gas and Hydro Based Generation

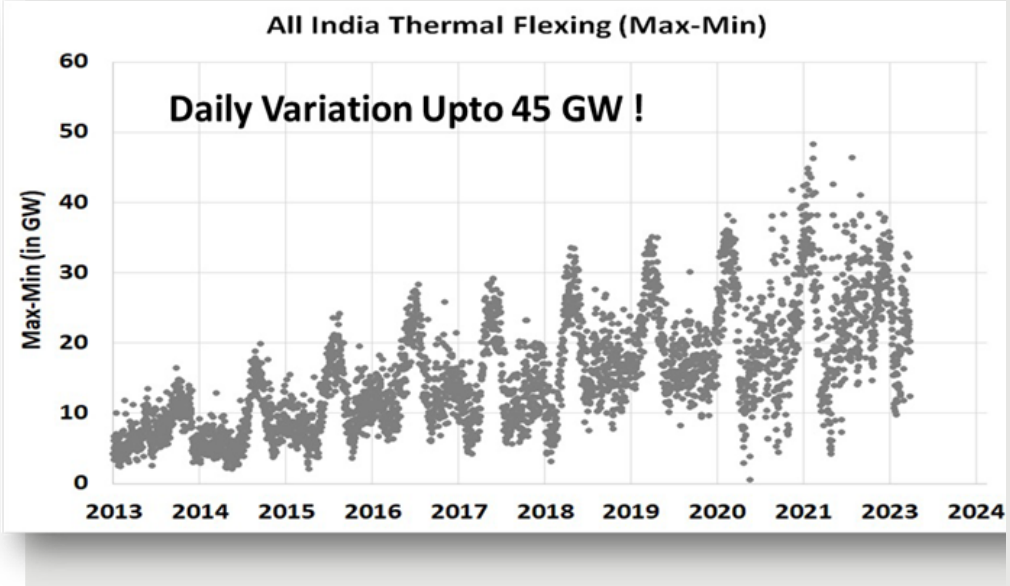


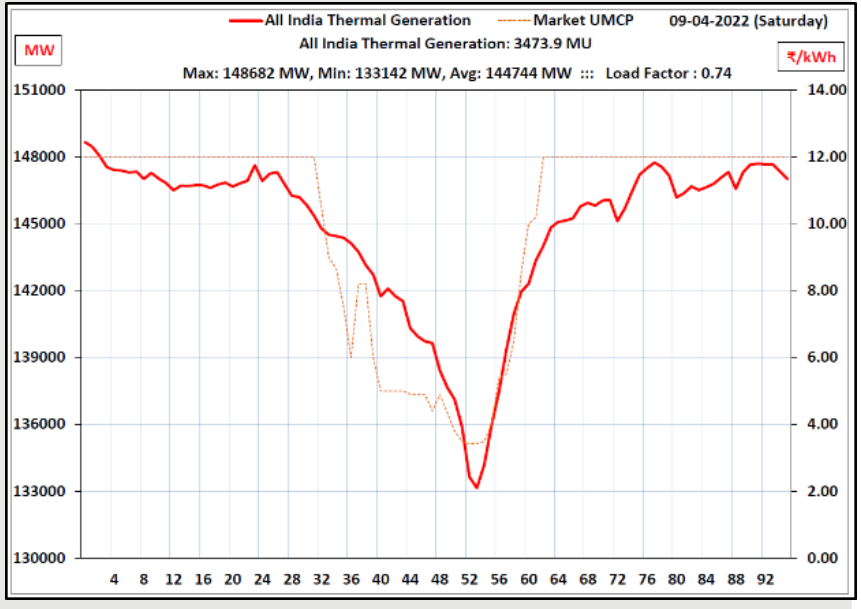


- **Flexibility from Gas Generation constrained by availability of Gas !!**
- **Limited flexibility in Off-grid Gas Stations; Limited flexibility in gas stations where open cycle operation is not possible**

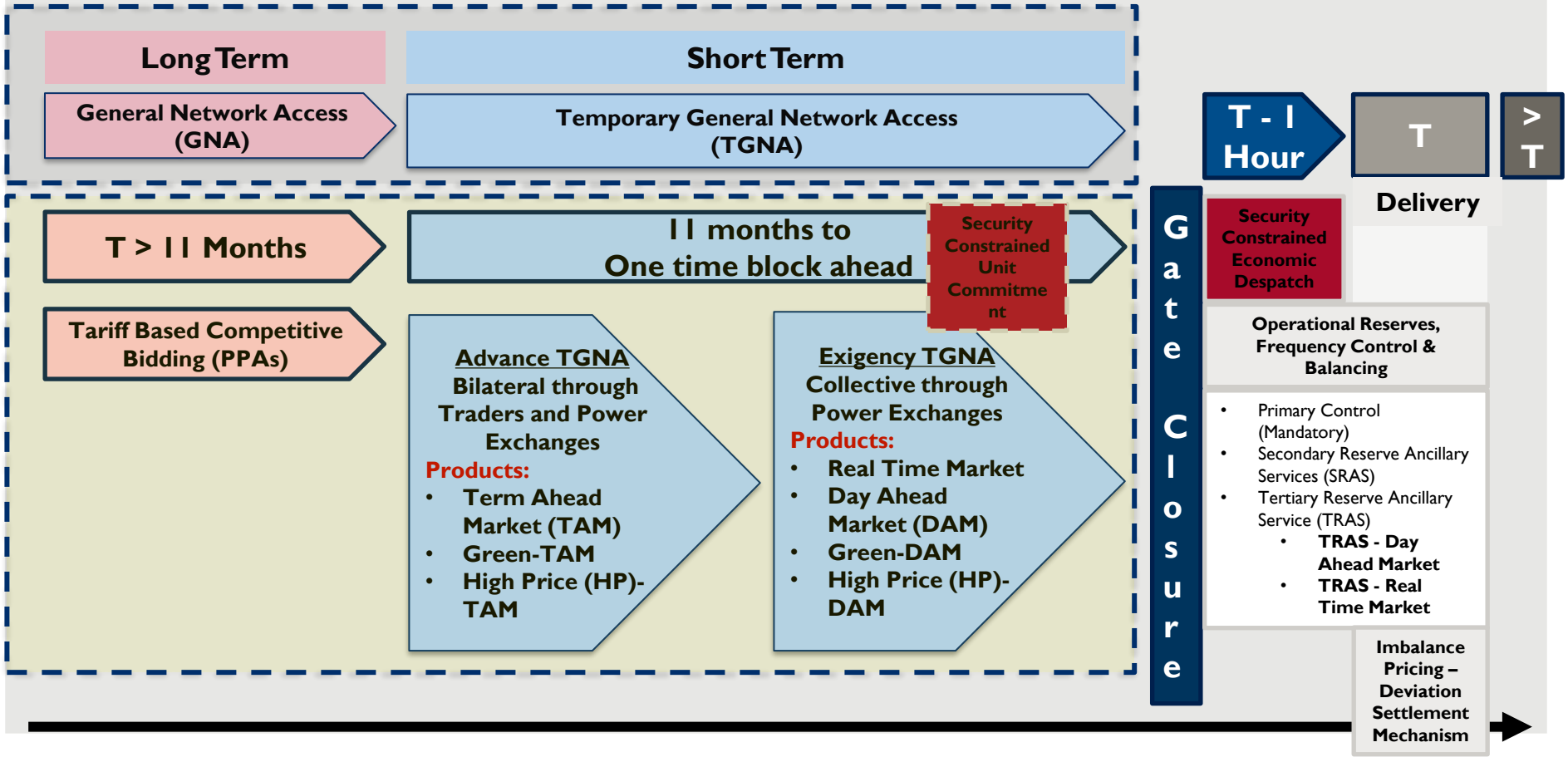
Flexibility from Hydro Generation is highly seasonal !!

Flexibility Providers – Coal/Lignite fired Generation



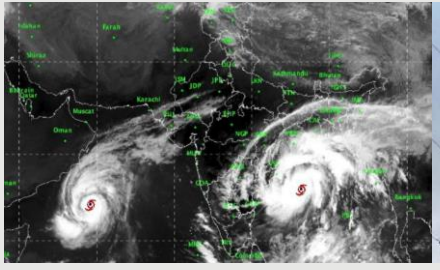


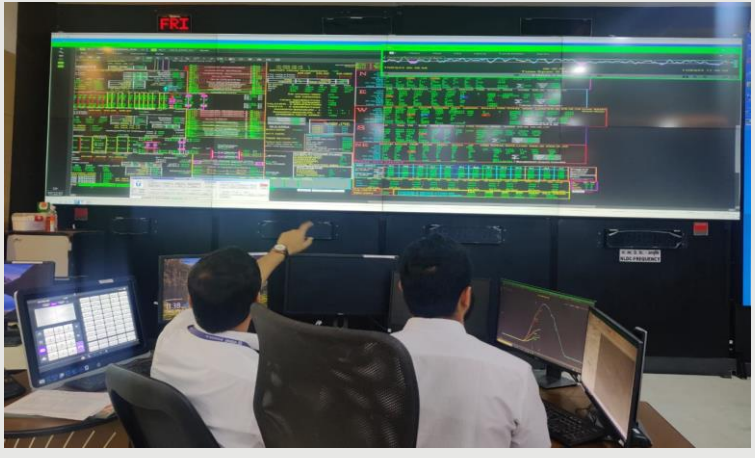
Market Structure – Access & Contracts delinked



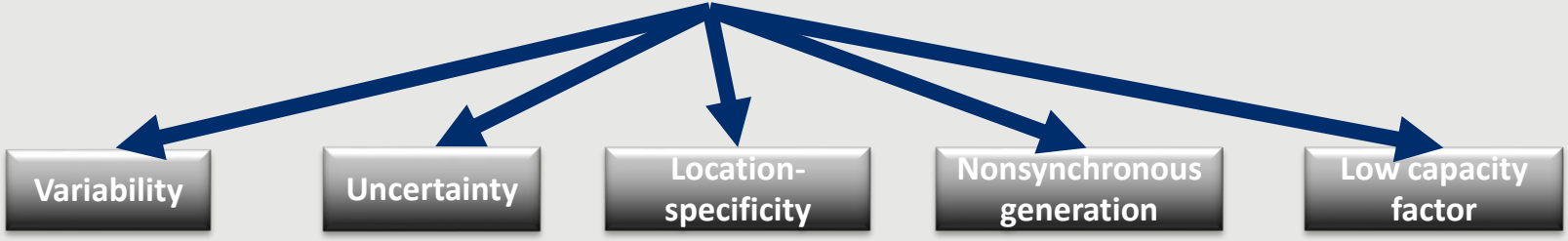
Power System Resilience – Climate Change Induced Events

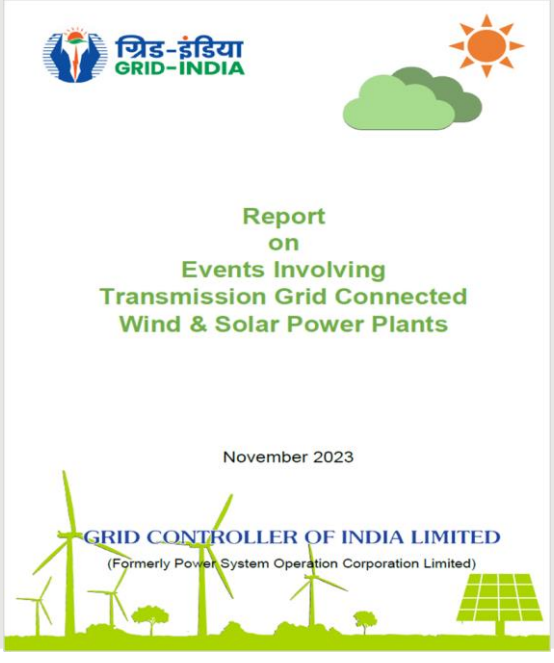
- Periodic mock drills for system restoration and operation of backup control centres
- Decongesting large RE pooling stations in cyclone prone areas at transmission planning stage
- Feedback for ensuring provision for start-up power from low voltage feeders at large generating station
- Reconfiguration of transmission system for flexibility under different operating conditions
- Creation of war-rooms during disaster
- Cyber security





Renewable Integration Challenges





> **31 events** involving **generation loss of above 1000 MW** from renewable power plants - **January'22 to May'2023**

https://posoco.in/wp-content/uploads/2023/12/Report-on-Events-Involving-Transmission-Grid-Connected-Wind-Solar-Plants.pdf

Challenges

- **Non-compliance of Plants in real-time during fault ride through**
- **Sanctity of simulation models:** Compliances shown in simulation models not visible in real-time
- **Equipment Design:** Derating of PV inverters with ambient temp> 40 deg cel & WTG with ambient temp> 30 deg cel
- **Post-event Analysis:** Inadequate recording & data retention facilities at IBR/PPC level

Clean Energy Transition – Way Forward

S. No.	Voltage & Frequency Support	New behavior of the Power System
1.	Increasing Rate of Change of Frequency (RoCoF)	Identifying power system restoration services near RE rich areas
2.	Decreasing nadir frequency	Reduced fault currents, LCC commutation failures, Fault ride through failures etc.
3.	Excessive frequency deviations	Decreased damping
4.	Static reactive power balance	Resonances due to cables and PE
5.	Dynamic reactive power balance	Sub-synchronous control interaction
6.	Larger voltage dips	Control of bi-directional flows
7.	Ramp management / Flexibility	
8.	Portfolio management, day-ahead resource adequacy, unit commitment	
9.	Estimation of generation reserves	

Bulk of essential reliability services such as inertia, frequency and voltage control, system restoration support, power oscillation damping, short-circuit power, etc. being provided by conventional generation sources

With transition to a high renewables system, VRE plants need to be equipped to provide these essential grid services

Thank You

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