SAARC Perspective Workshop on Past, Present & Future of High Voltage DC (HVDC) Power Transmission

Indian Power Sector

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Players In The Indian Power Sector

Central Electricity Authority

Perspective Planning & National Electricity Plan

Generators

Central/State GENCOs, IPPs, Captive

CTU

Inter-State Trans. System, Open Access

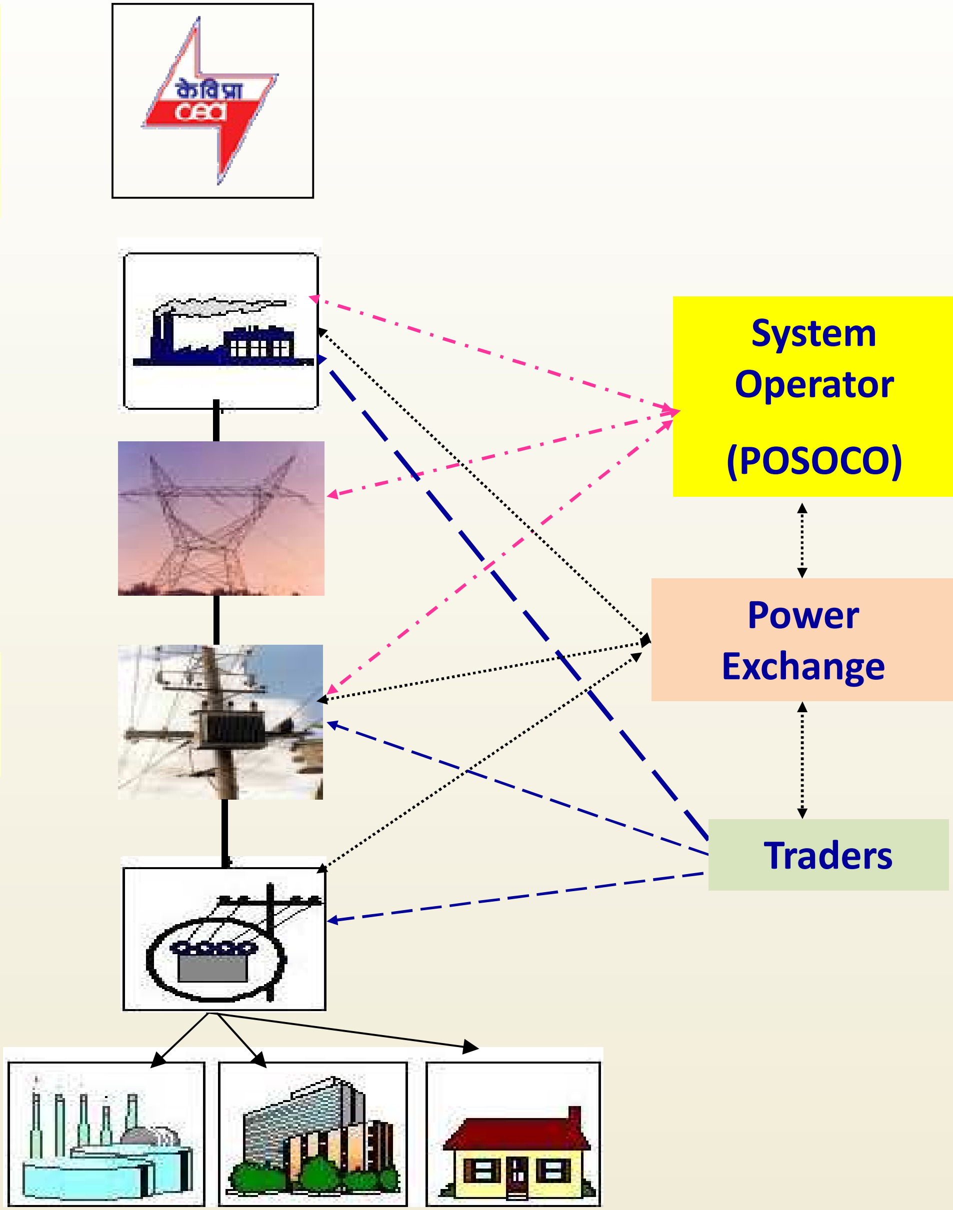
STU

Intra-State Trans./Sub-Trans. System

DISCOMs

Consumers

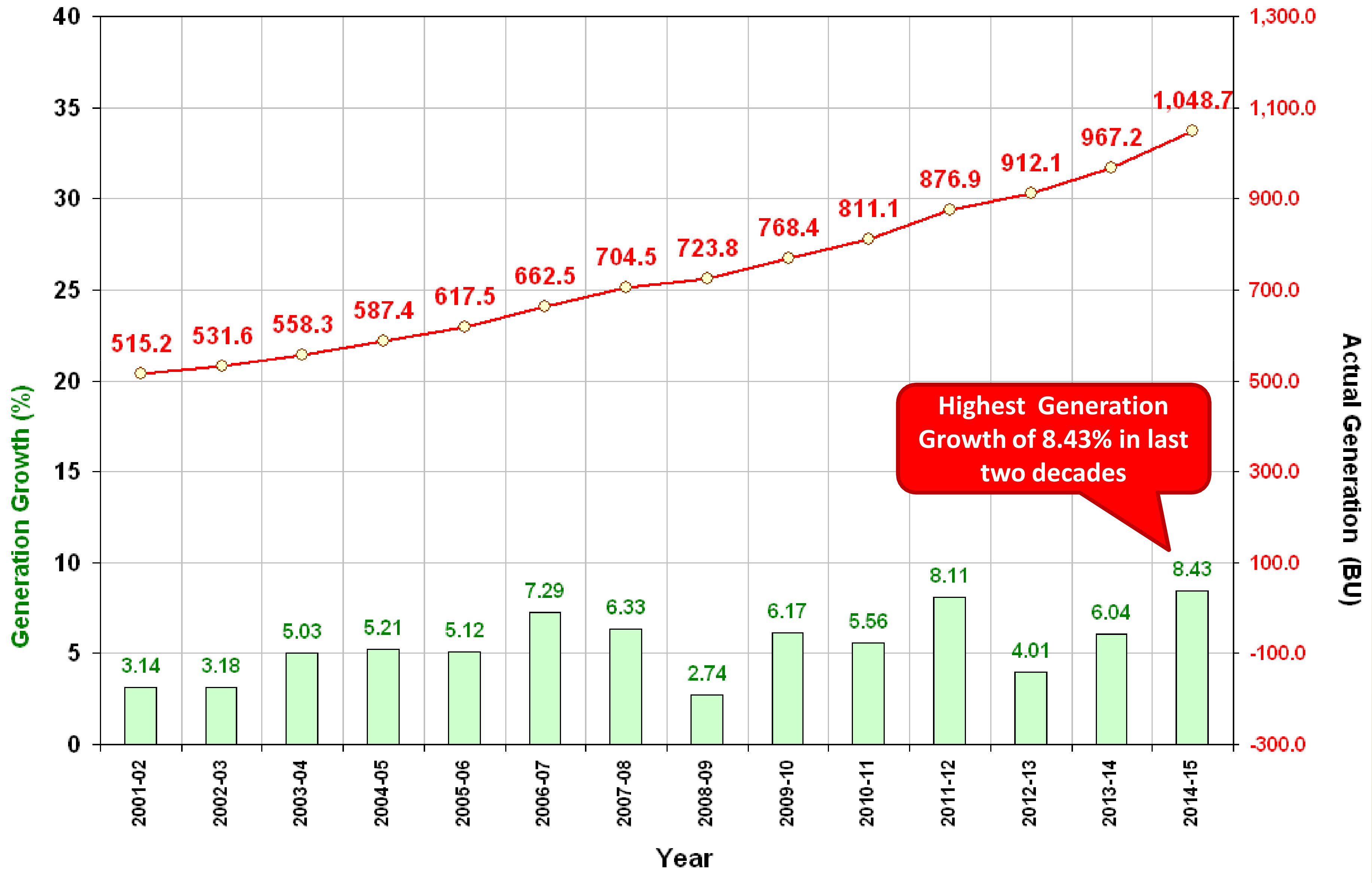
Industries, Household, Agriculture



Generation

Installed Capacity in India over the years

Electricity Generation & Growth over the years



Fuelwise Generation Installed Capacity in India

(As on 31-August-2015)

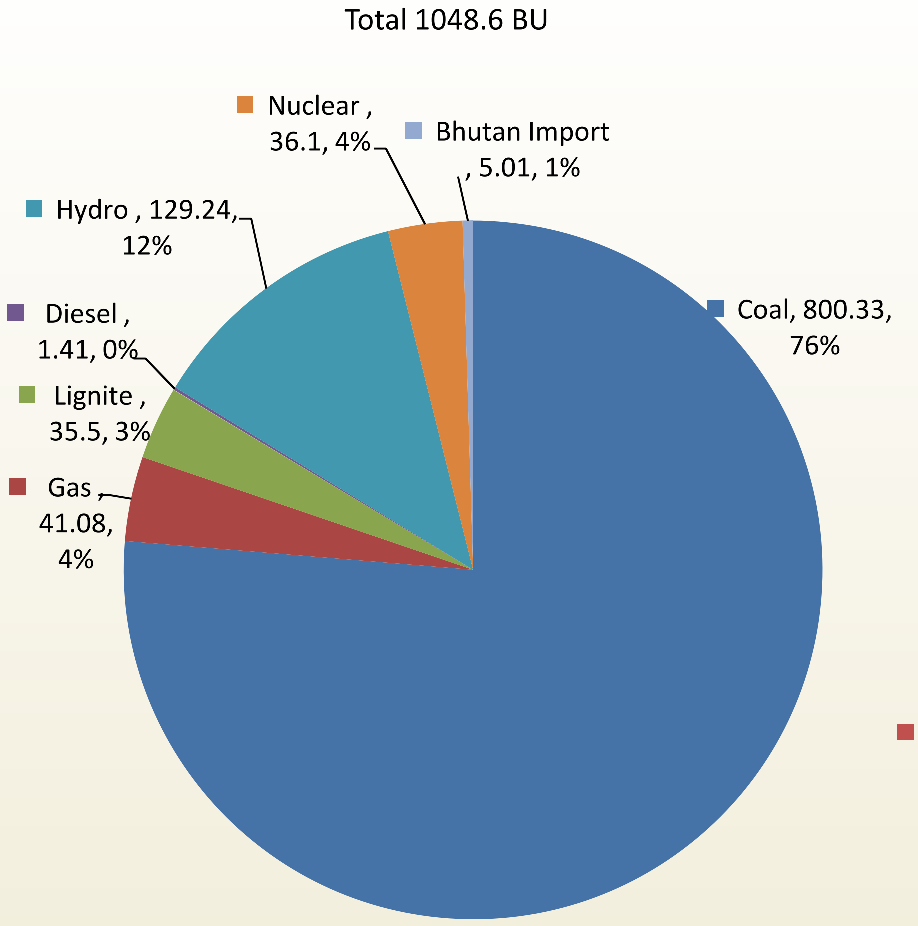
Fuel	Installed Capacity (MW)	% Share in Total
THERMAL	**192,535**	69.6%
Coal	**168,208**	60.8%
Gas	**23,333**	8.4%
Diesel	**994**	0.4%
HYDRO	**41,997**	15.2%
NUCLEAR	**5,780**	2.1%
RES	**36,471**	13.2%
TOTAL	**276,783**	

Sector-wise Generation Installed Capacity in India

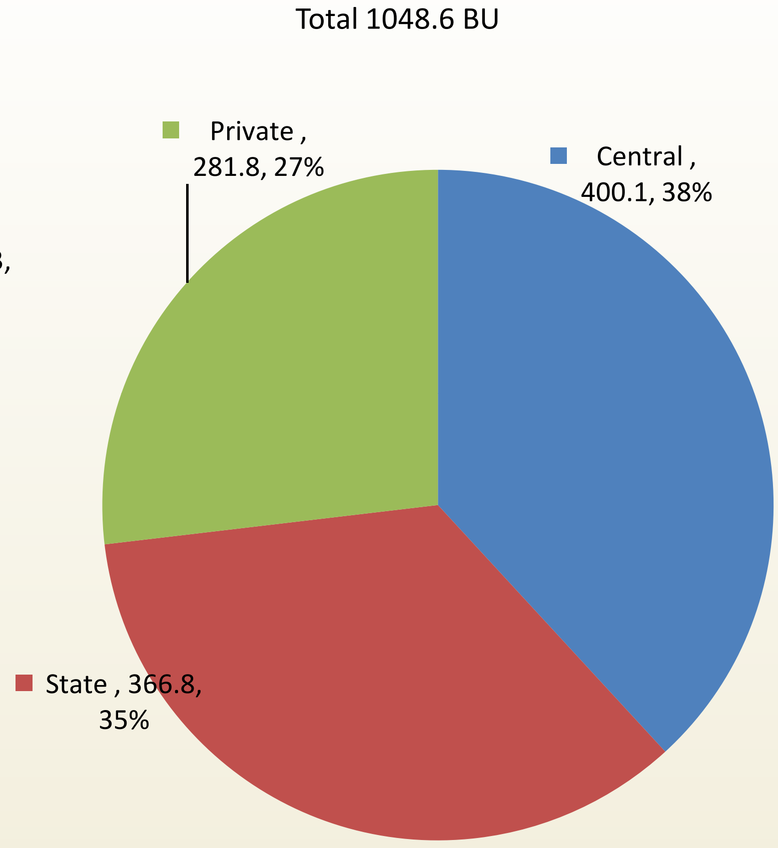
(As on 31-August-2015)

Sector	Installed Capacity (MW)	% Share in Total
Central Sector	74,171	26.8%
State Sector	96,015	34.7%
Private Sector	106,597	38.5%
TOTAL	276,783	

Electricity Generation : Fuelwise & Sectorwise during 2014 -15

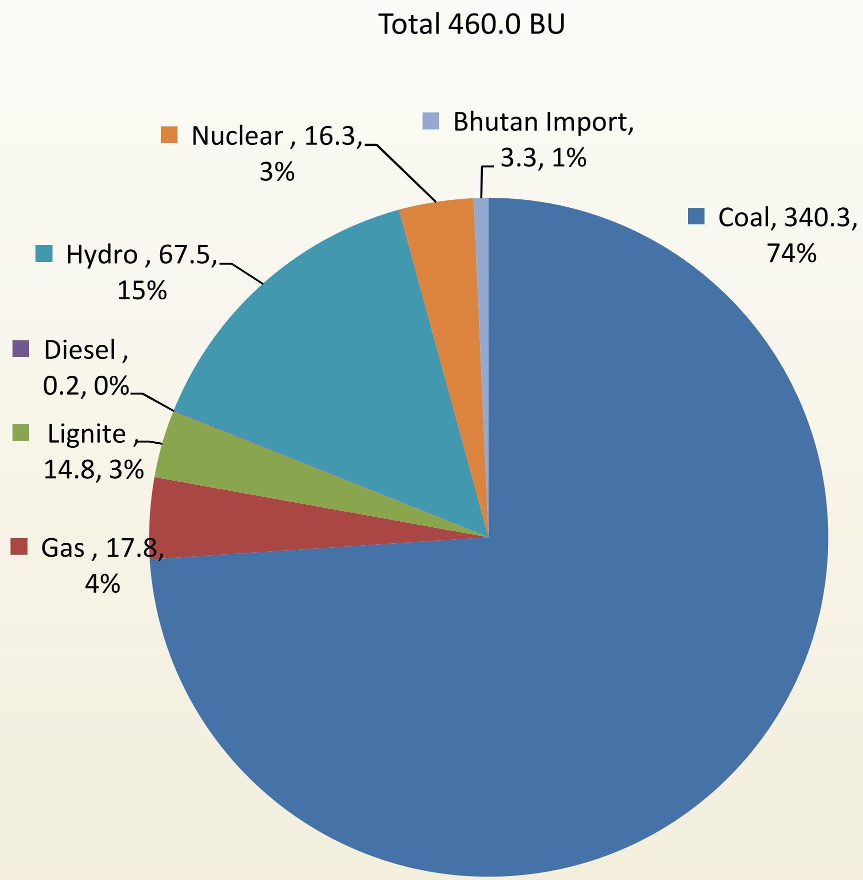


Generation (BU) during 2014-15 (Fuel wise)

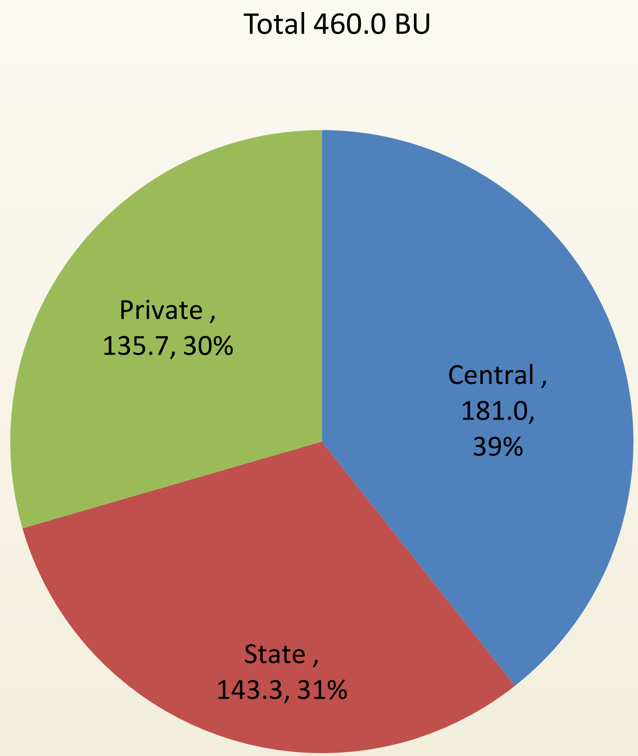


Generation (BU) during 2014-15 (Sector wise)

Electricity Generation : Fuelwise & Sectorwise during 2015 -16 (Upto Aug'15)

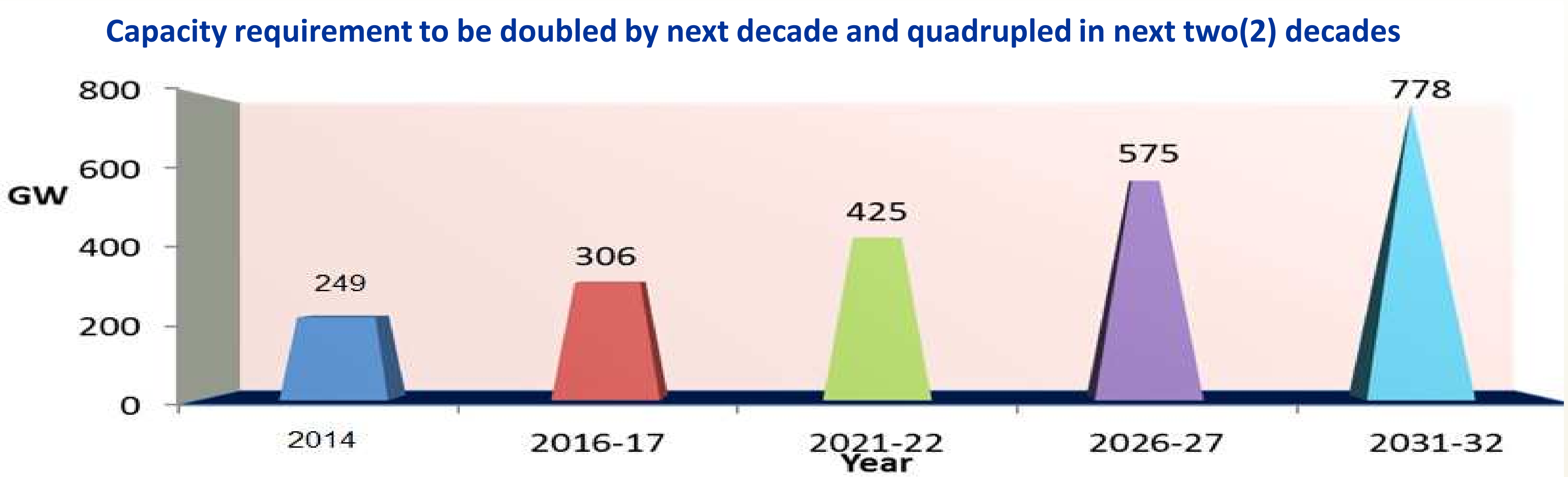


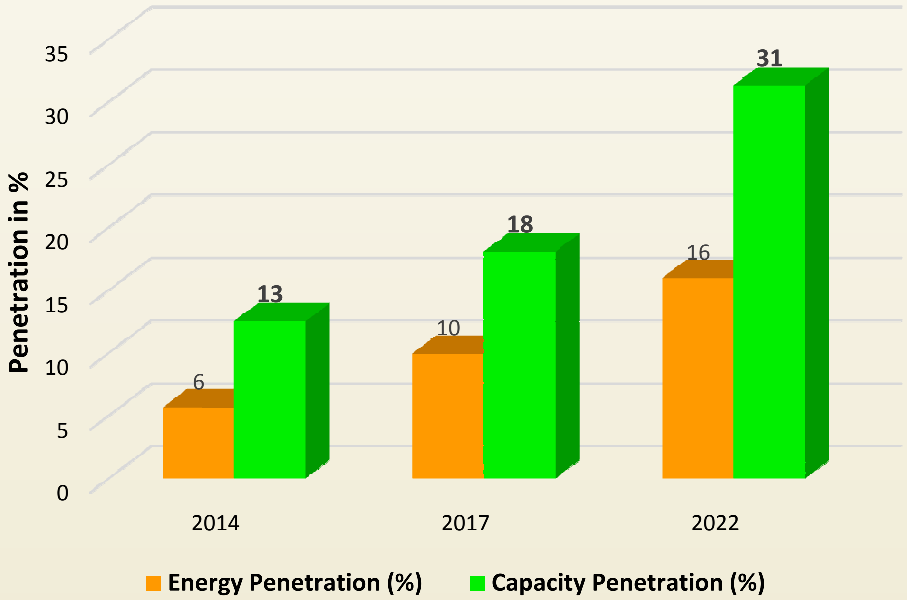
Generation (BU) during 2015-16 (upto Aug' 15) (fuel wise)

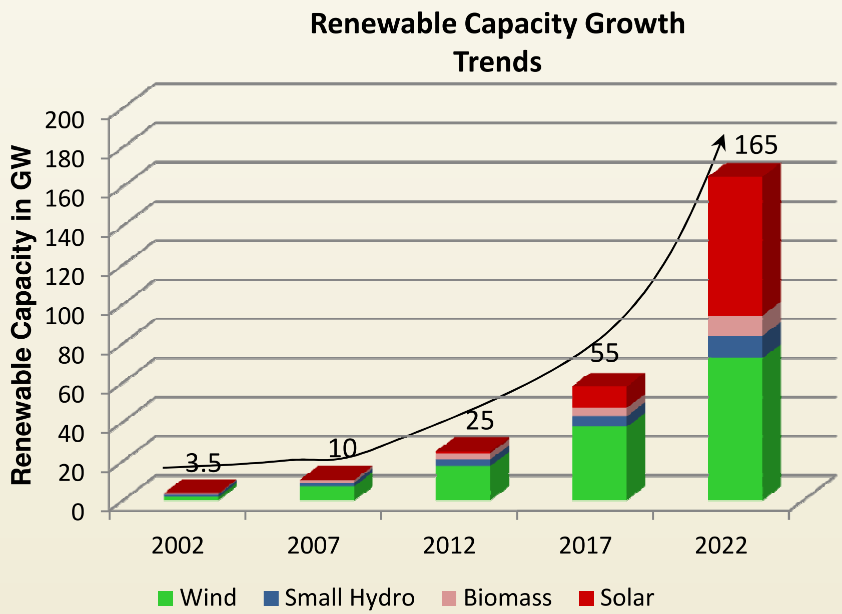


Generation (BU) during 2015-16 (upto Aug' 15) (Sector wise)

Future Scenario



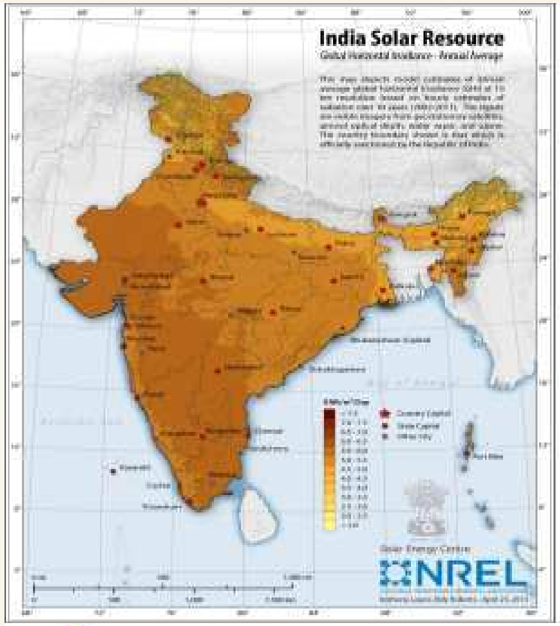


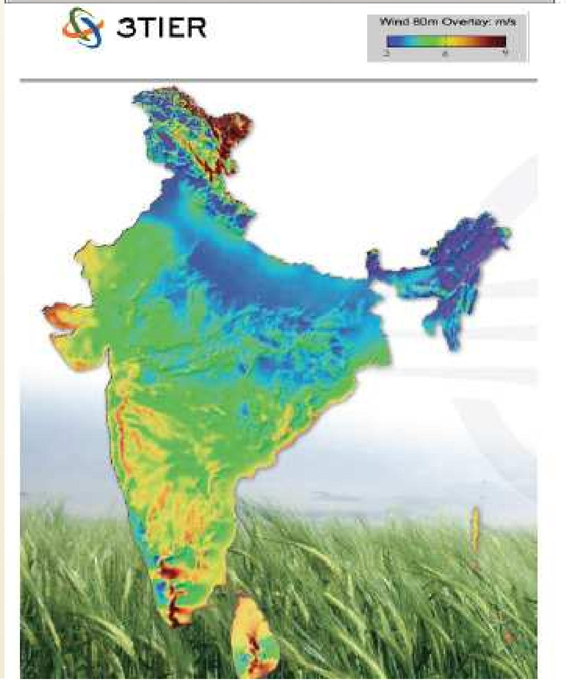


Ambitious Plan to establish 100 GW Solar including 20 GW through Ultra Mega Solar Power Parks

Renewable Potential

- **Solar Potential in India : about 20-30 MW/sq km, about 5000 trillion units annually (about 2800 GW)**
  - ➢ **12th Plan envisaged Solar Capacity addition:10 GW (As per data during GEC Study)**
- **Solar UMPP being envisaged to set up in deserts of Thar, Rann of Kutch, Lauhal & Spiti valley and Ladakh**
  - ➢ **Solar Generation Potential utilizing 5-15% of wasteland area in deserts about 300 GW**
- **Researchers Claim more than 1000GW Wind Generation Potential**
  - ➢ **12th Plan envisaged Wind Capacity addition :20 GW (As per data during GEC Study)**





Transmission

Total Transmission Lines (cKm) & Transformation Capacity (MVA)
As on 31-August-2015

Voltage	Total Transmission Lines (cKm)	% Share in Total
765 kV	20,792	6.45
400 kV	1,40,083	43.43
220 kV	1,52,247	47.20
HVDC	9,432	2.92
Total	3,22,554	

Voltage	Total Transformation Capacity (MVA)	% Share in Total
765 kV	1,33,500	21.51
400 kV	1,96,362	31.64
220 kV	2,77,218	44.67
HVDC	13,500	2.18
Total	6,20,580	

Growth of Transmission System

Transmission Lines (400kV and above system) (values in ckm)				
	11th Plan (2011-12)	Existing as on 30-04-15	12th Plan (2016-17)	13th Plan (2021-22)
HVDC Bipole lines	9432	9432	16872	27472
765 kV	5250	18650	32250	54450
400 kV	106819	136264	144819	174819
Total	**121501**	**164346**	**193941**	**256741**

Substations (AC & HVDC) (400kV and above) (values in MVA / MW)				
HVDC Terminals:				
HVDC back-to-back	3000	3000	3000	3000
HVDC Bipole terminals	6750	10500	19500	34500
Total- HVDC Terminal Capacity, MW	**9750**	**13500**	**22500**	**37500**
AC Substations				
765 kV	25000	121600	174000	253000
400 kV	151027	192997	196027	245027
Total- AC Substation capacity, MVA	**176027**	**314597**	**370027**	**498027**

Total Fund requirement would be about Rs 2,60,000 Crore

(assuming about Rs. 100,000 crore for 220kV and below systems)

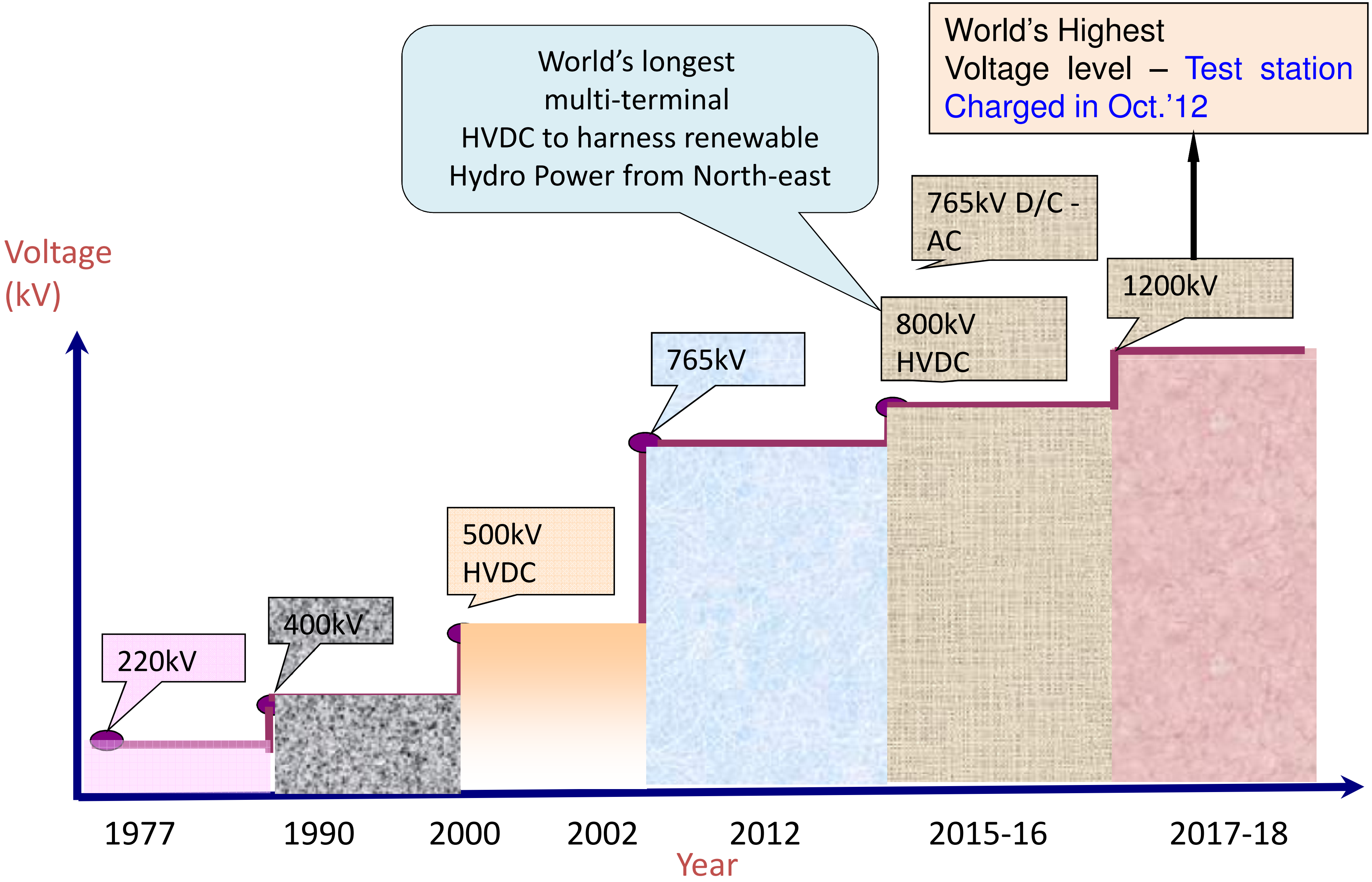
Transmission Planning - Consideration

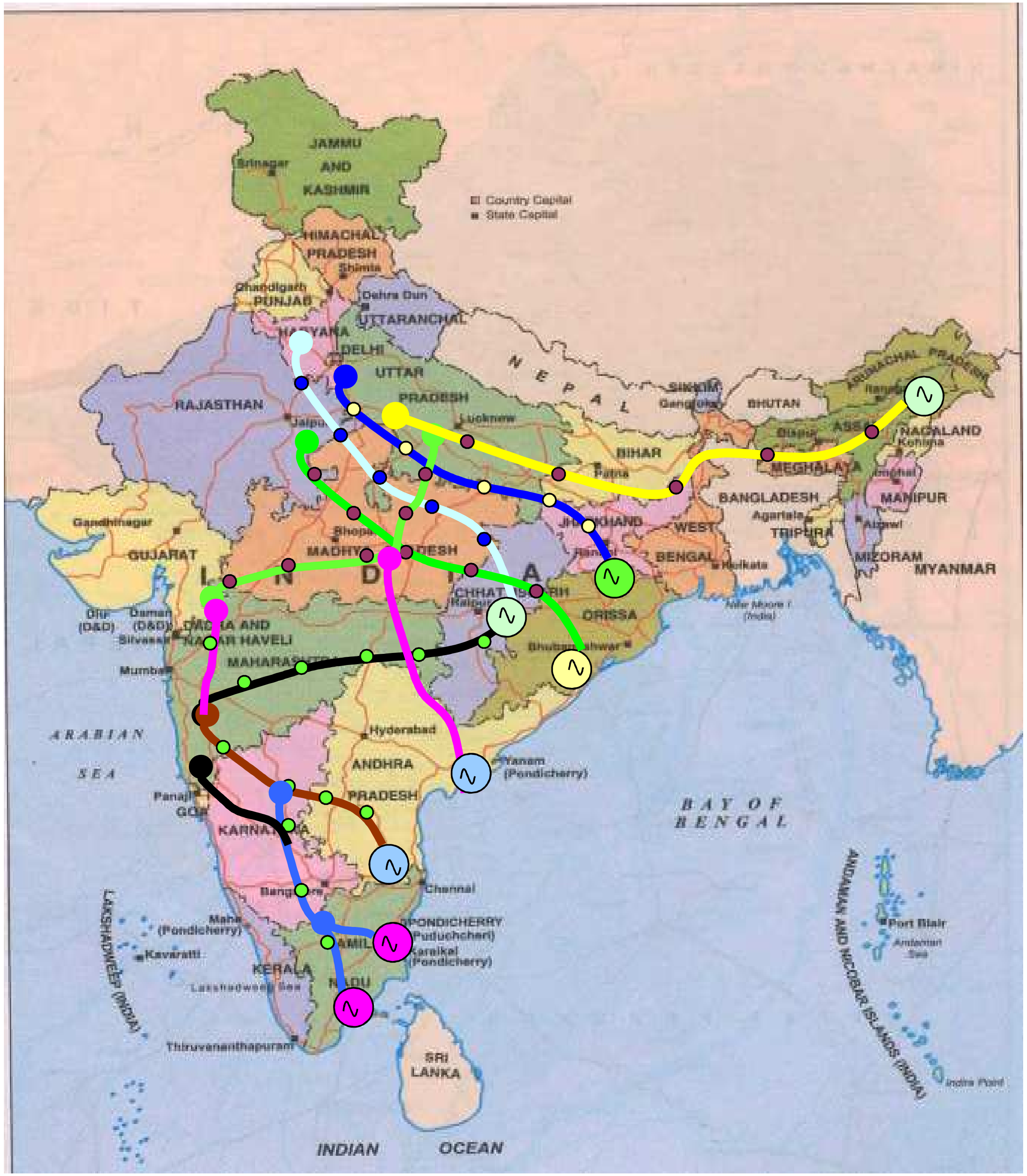
- It is directional and to be known in advance.
- System to be planned for peak power transfer
- (N-1-1) reliability criteria
- Conservation of Right of Way
- To fit into long term perspective
- The transmission system should have enough 'controllability' features (in addition to wires)

Transmission System – As of Today

- Strong back bone of 400 kV – Overlay of 765 kV & high capacity HVDC under Implementation
- All India synchronous grid – One of the largest in the World
- Thriving Pan-India Single Market enabled
- Under new concept of planning, 10 nos. of high capacity corridors evolved - to reduce the dependency on a particular generation
- These corridors shall facilitate about 40,000MW power transfer

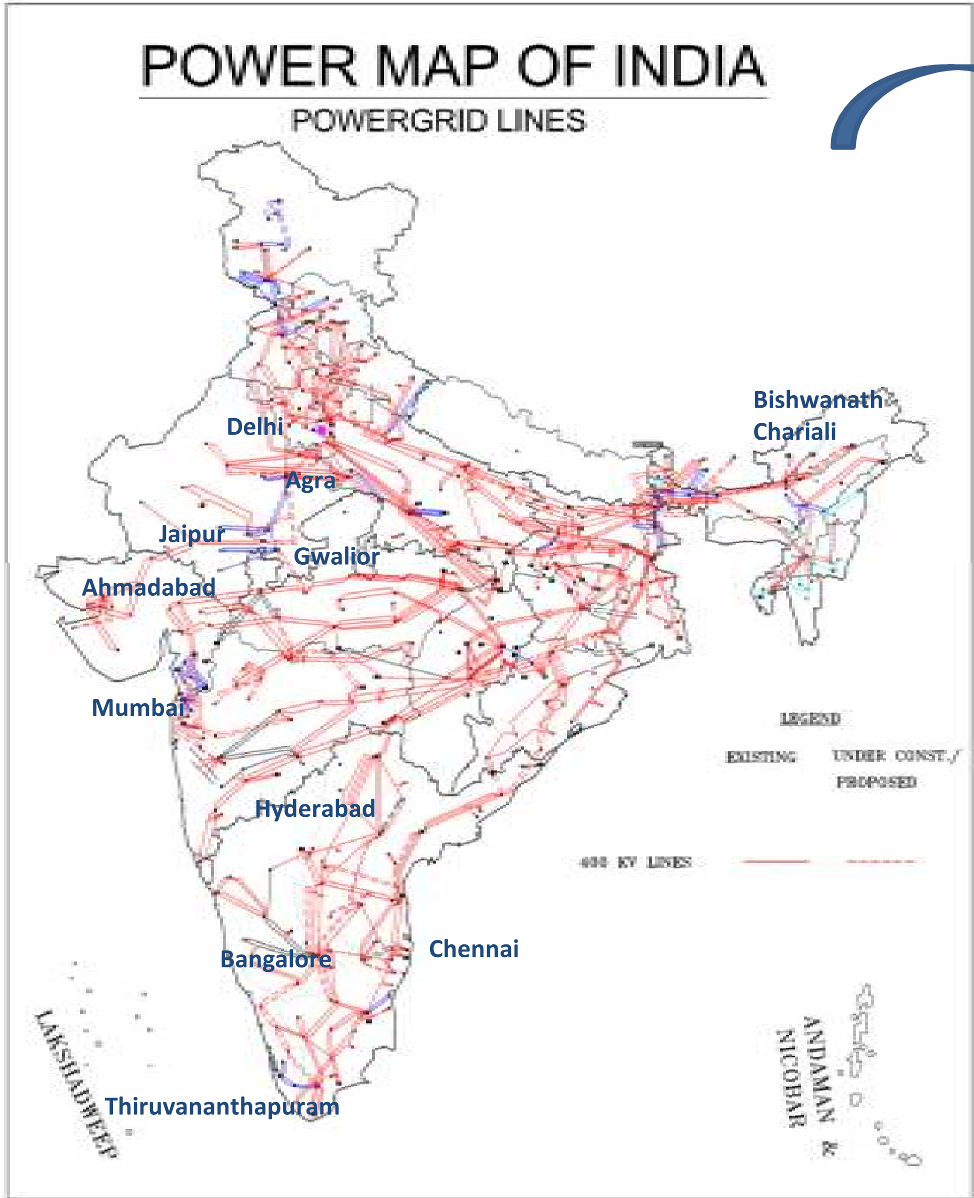
Pursuing Higher Voltage Levels

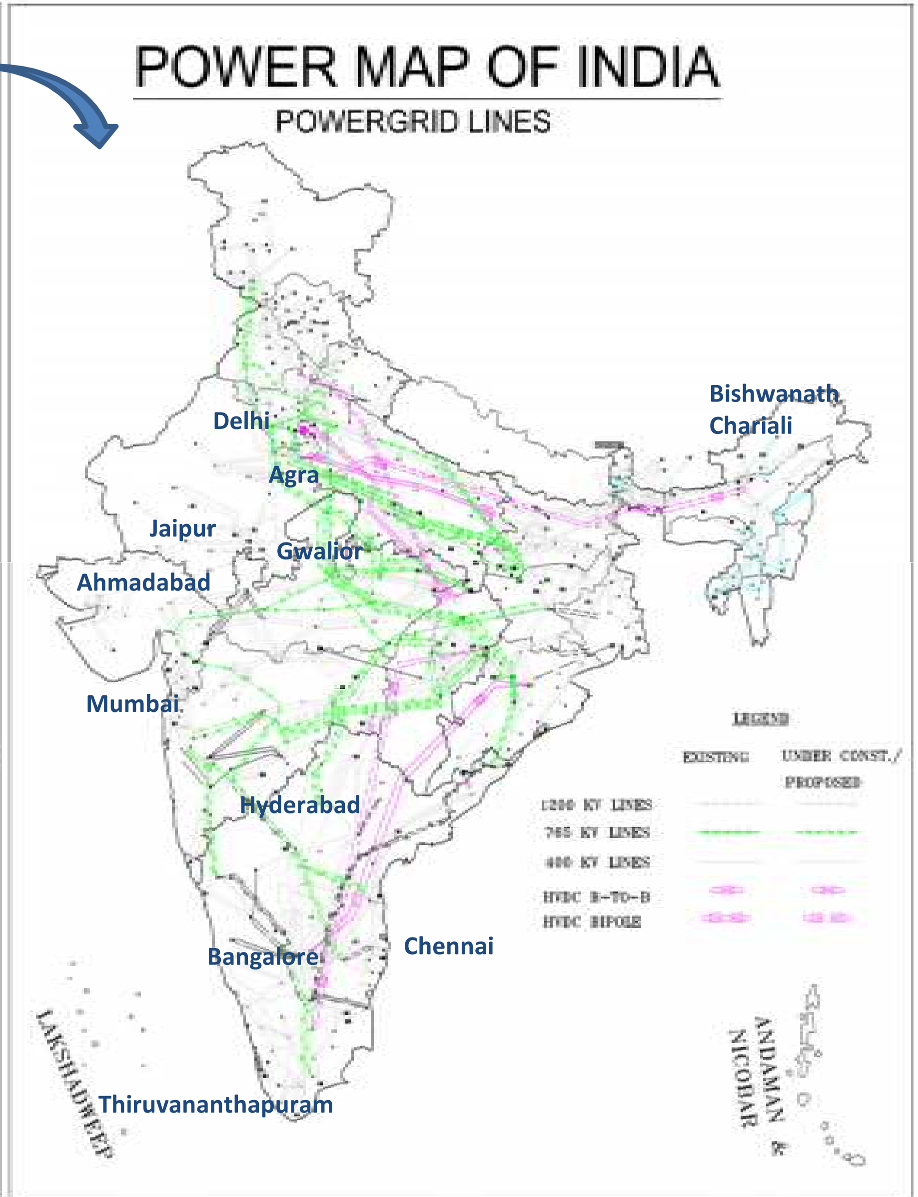




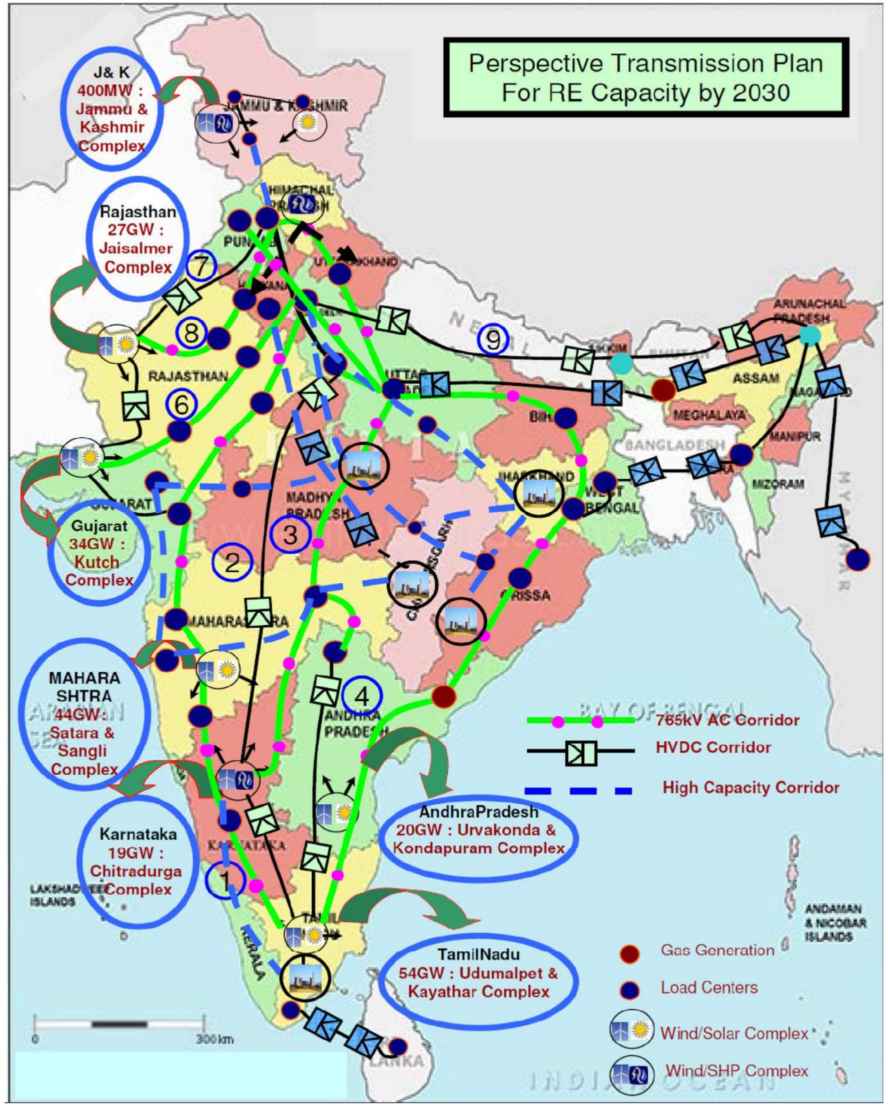
HIGH CAPACITY CORRIDORS

Evolving Voltage Landscape





Green Energy Corridor : Integration of Renewables

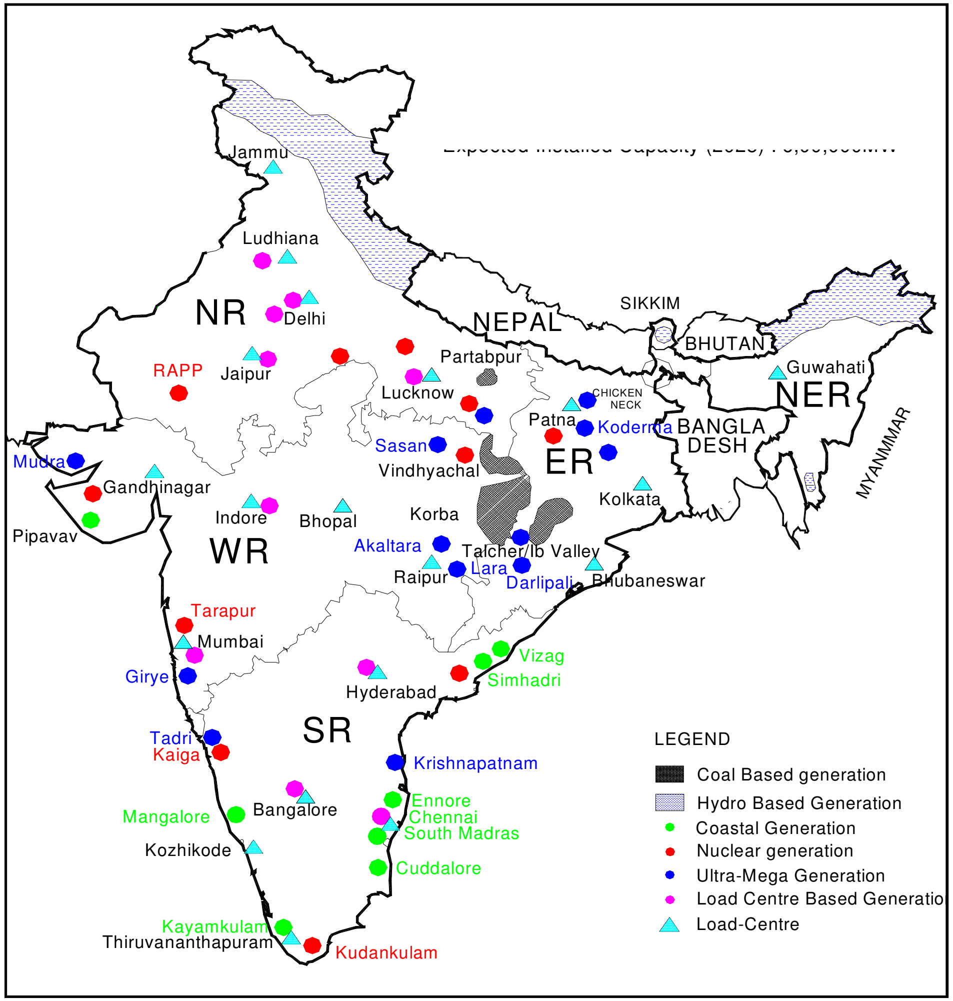


- About 33GW capacity addition envisaged through wind & solar in next 4-5 years
- The Plan includes
  - Transmission strengthening(s)
  - Dynamic reactive compensation,
  - Energy Storage,
  - Smart grid applications,
  - Establishment of Renewable Energy Management Centre enabling forecasting of renewable generation, real time monitoring, etc.

National Grid

Energy Resources Map

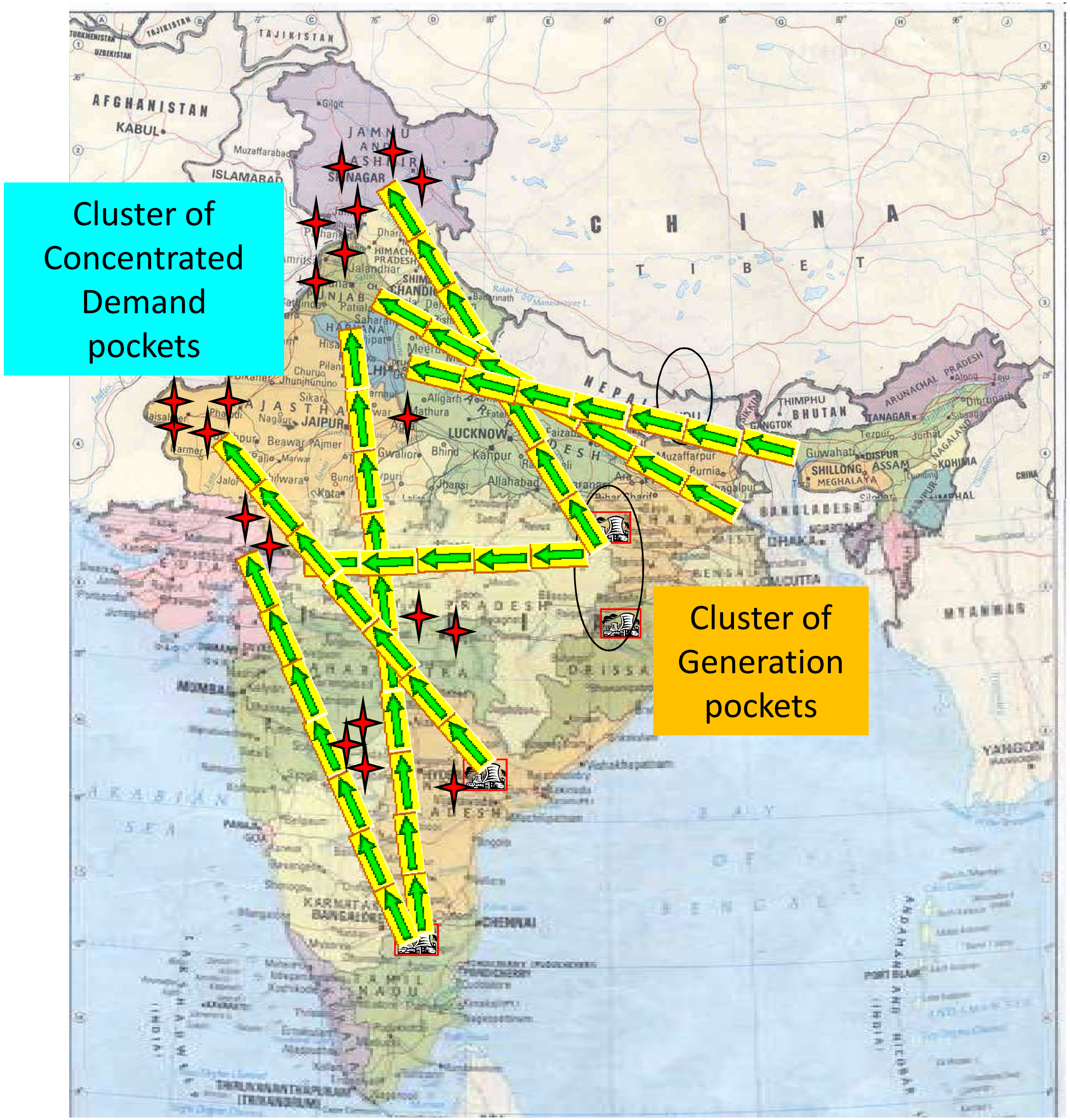
Energy resources (Coal, Water etc.) unevenly distributed



Potential being harnessed to meet demand in next 7-8 years

- **Coal – In Central India**
  - **Chhattisgarh : 58,000 MW**
  - **Orissa : 30,000 MW**
  - **Jharkhand : 15,000 MW**
  - **Madhya Pradesh:16,000 MW**
- **Hydro – In North Eastern & Northern Himalayan region**
- **Coastal based**
  - **Andhra Pradesh: 24,000 MW**
  - **Tamil Nadu : 10,000 MW**
  - **Gujarat : 11,000 MW**

Transmission System Requirement



Evolution of National Grid

State → Region → Nation: A Paradigm Shift

Self Sufficiency at State Level → Self Sufficiency at Regional level → Optimal Utilization of Resources at National level

1950s
- Local

Installed Capacity
1947: 1,362MW

1950s-60s
- State Grid by SEBs

1970s-80s
- Regional Grids with Trans. Systems of Central Gen. Stations

1990s
- Interconnecting Regional Grids with HVDC

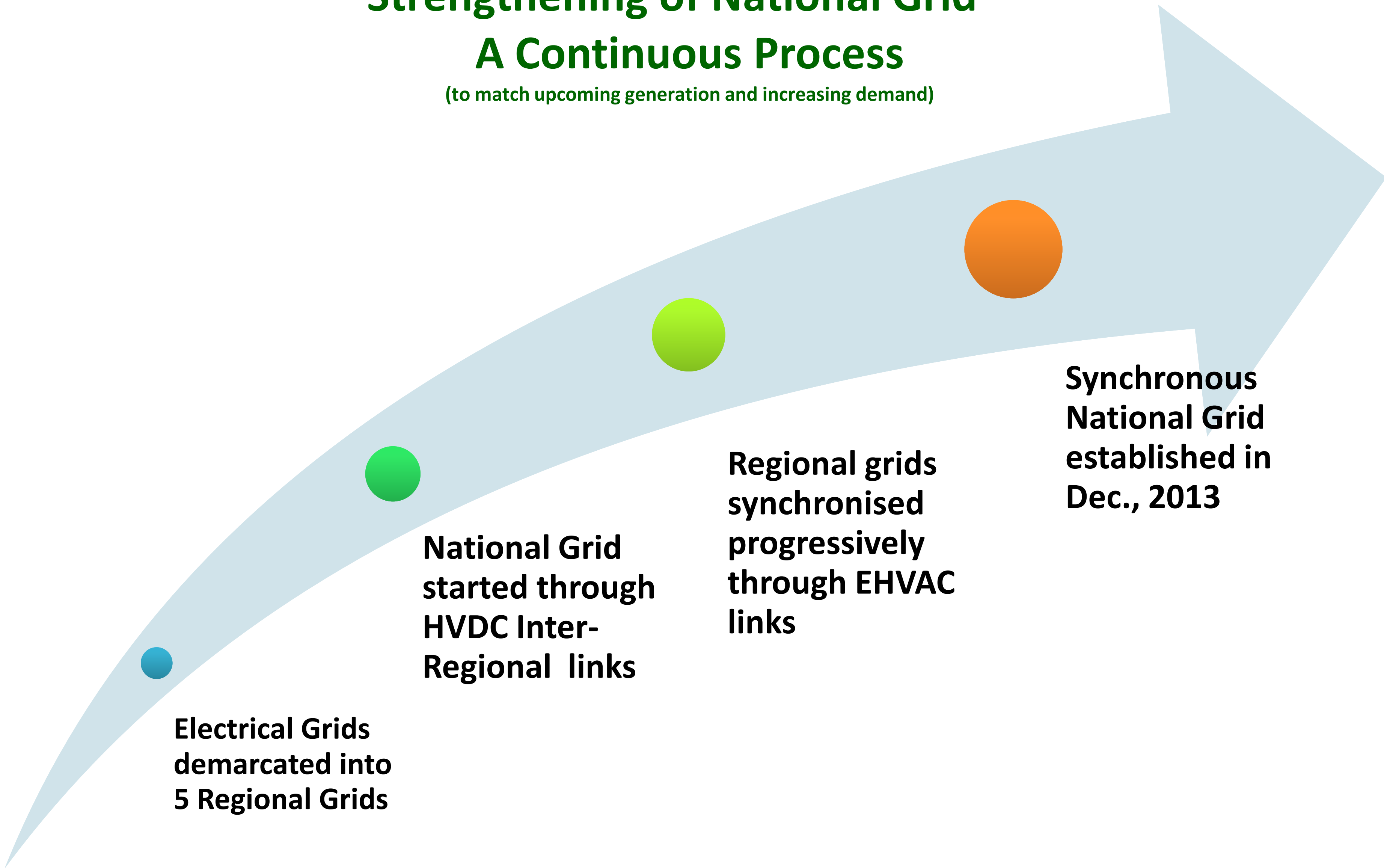
2000s-2010s
- National Grid

Installed Capacity
Aug-15: 277 GW

Development of Synchronous National Grid

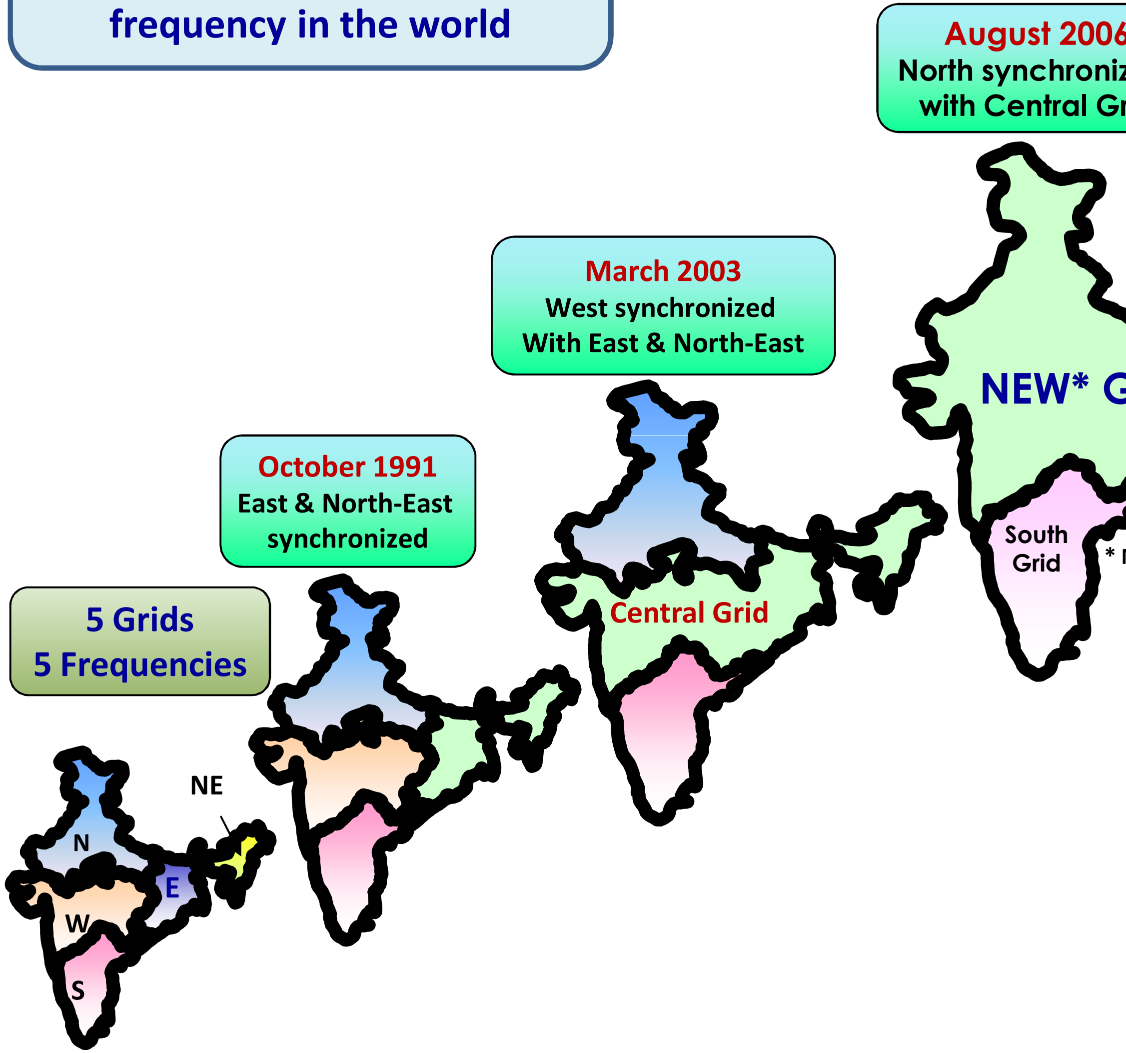
Strengthening of National Grid – A Continuous Process

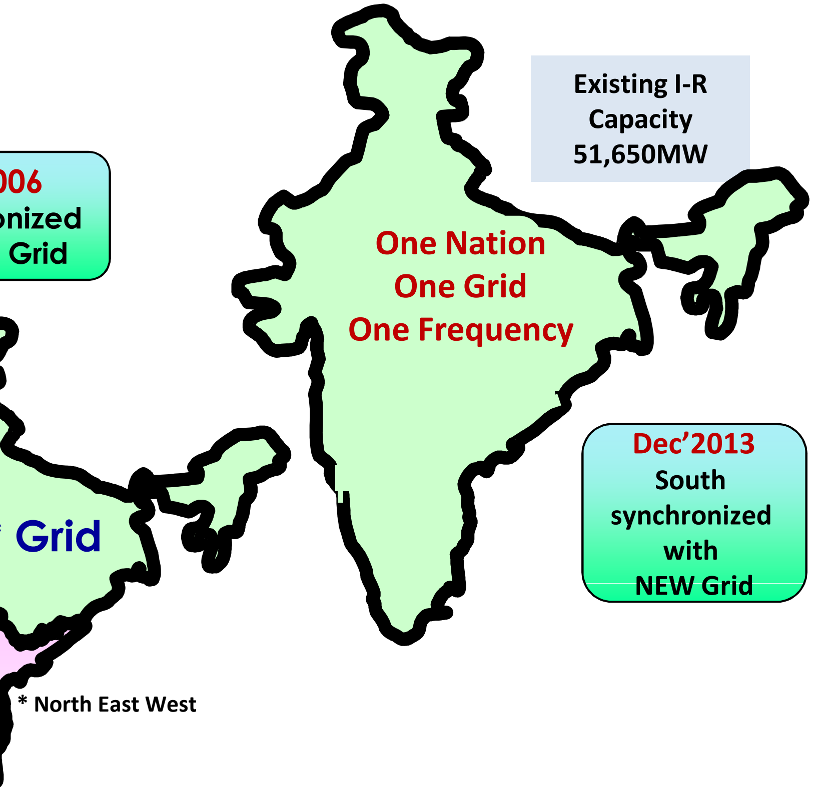
(to match upcoming generation and increasing demand)

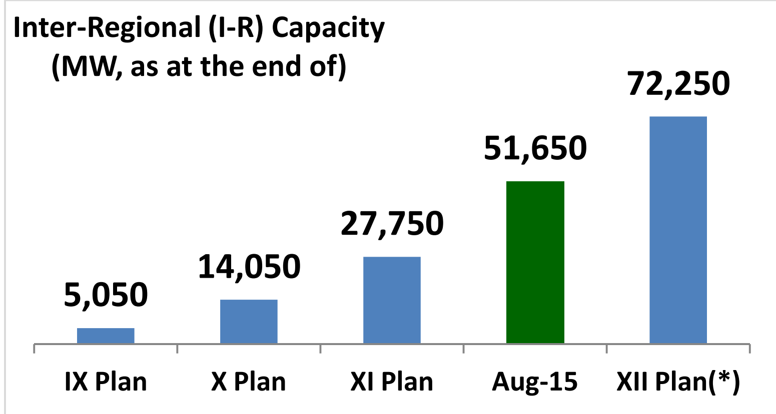


Development of Synchronous National Grid

One of the largest Electricity Grids operating at single frequency in the world

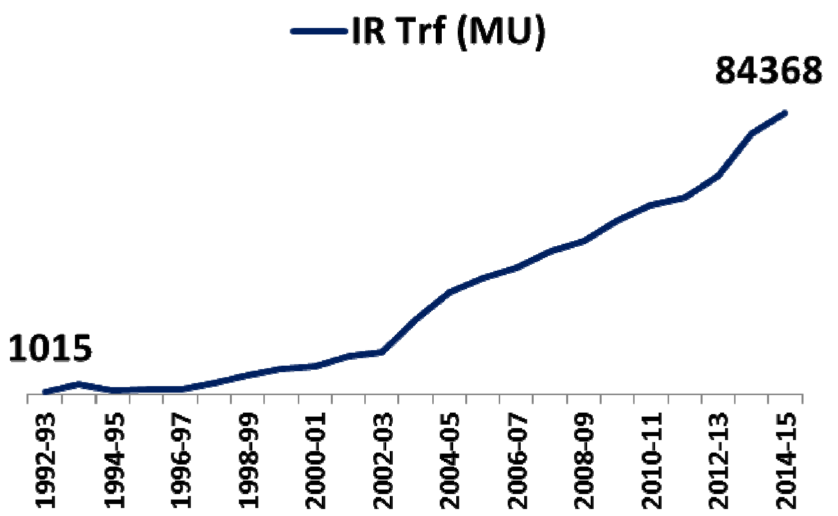


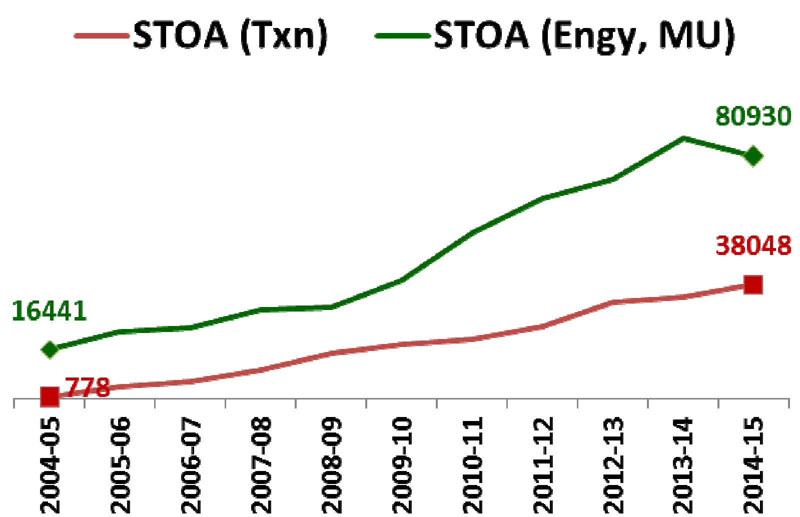




Inter-Regional Transmission Links

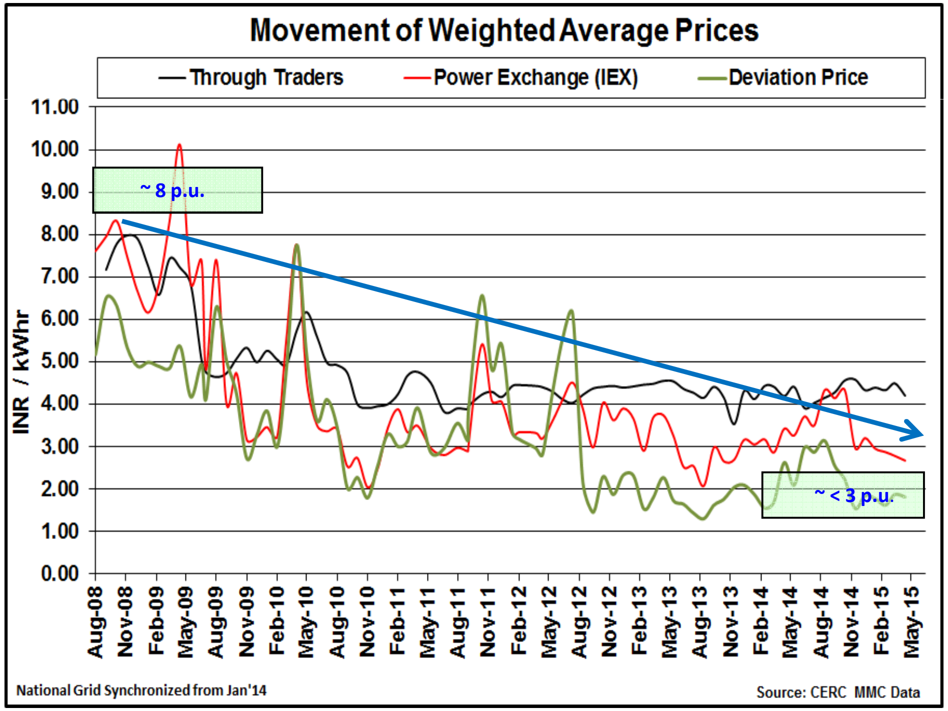
Benefits of National Grid: Development of Vibrant Electricity Market





Optimal Utilization of Resources both Generation & transmission

- ✓ **I-R Transfer has grown 83 times since 1992-93**
- ✓ **Substantial increase in STOA utilizing margins in ISTS network**
- ✓ **Reduction in per unit energy charges**



Interconnection with SAARC Countries

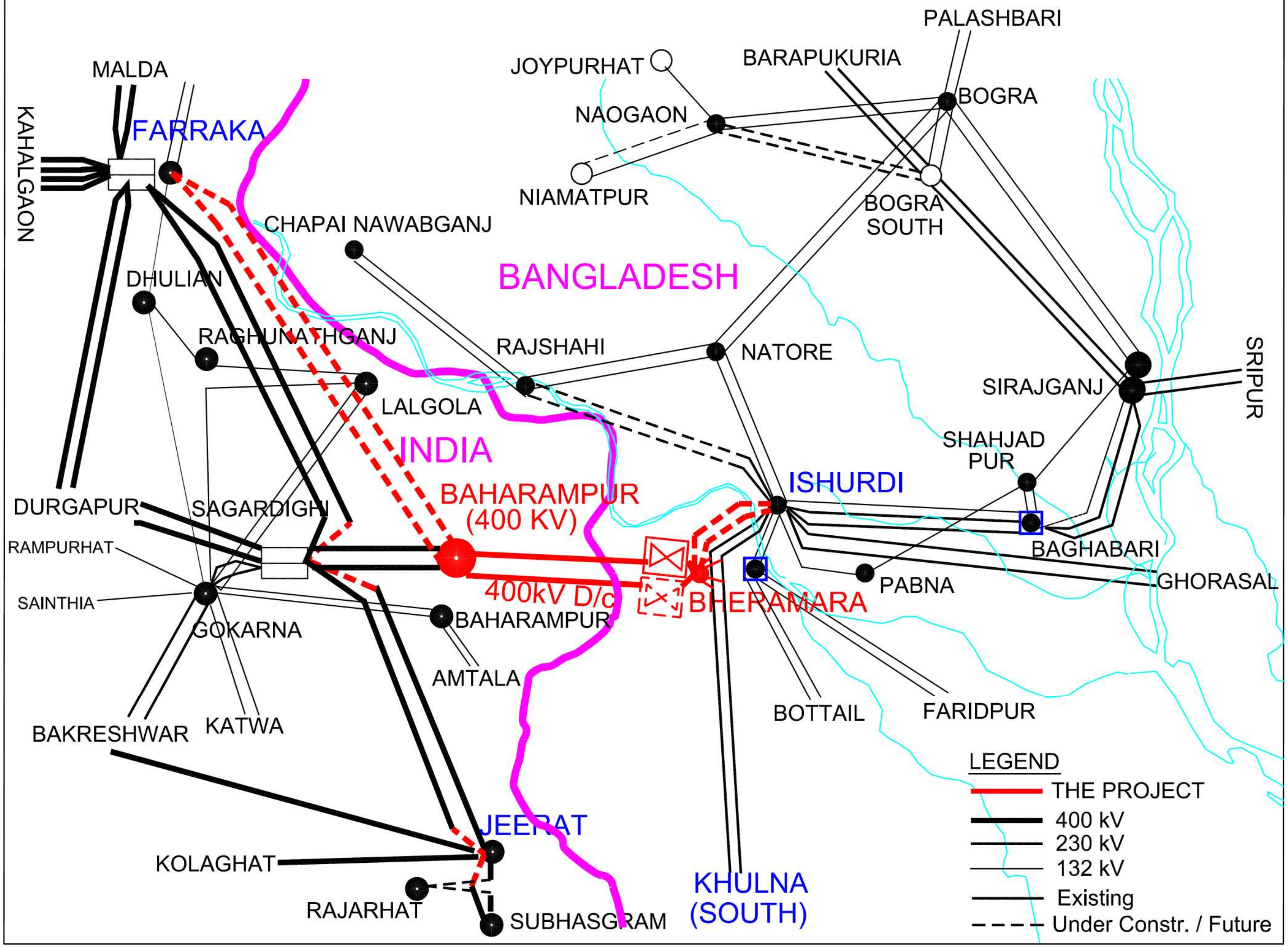
India & Bangladesh Interconnection

- **Existing Interconnection :**
  - Baharampur (India)- Bheramara(Bangladesh) 400kV D/c line (100 km) and 500MW HVDC back-to-back Station at Bheramara

- **Ongoing :**
  - Surjyamaninagar (Tripura) – South Comilla D/C line (400kV upto North Comilla) via North Comilla (58km long) to be operated at 132kV voltage. [expected by Dec. 2015]
  - Upgradation of the existing Baharampur (India) - Bheramara (Bangladesh) interconnection with additional 500 MW HVDC back-to-back converter unit (2^{nd} module) at Bheramara [June 2017]

- **Future :**
  - ±800 KV, 7000MW HVDC multi-terminal bipole line from Rangia(NER, India) to Muzaffarnagar (NR,India) through Bangladesh with 500/1000MW HVDC terminal in Bangladesh

INTERCONNECTION BETWEEN INDIA AND BANGLADESH GRIDS

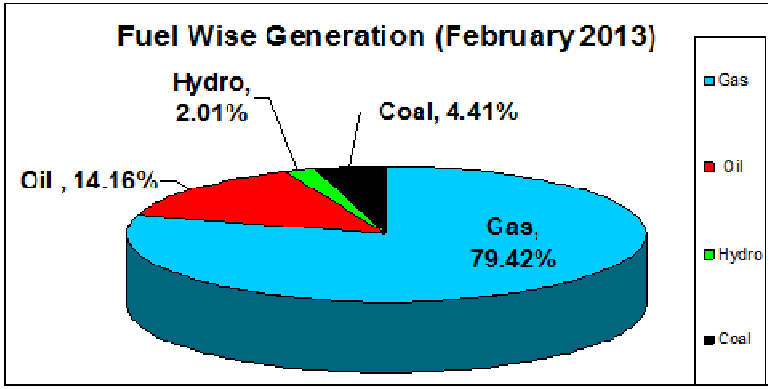


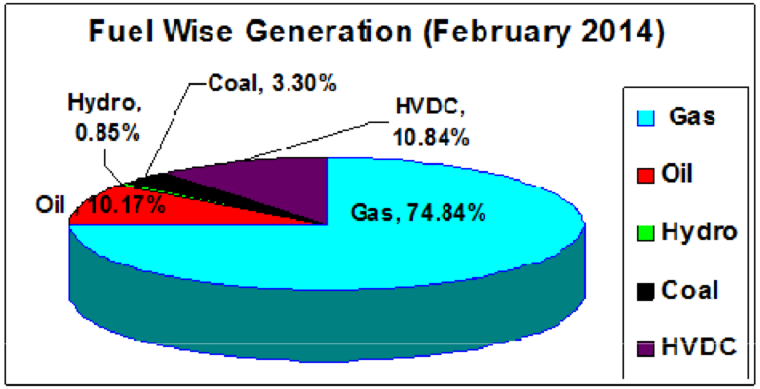
Benefits of Interconnection for Bangladesh

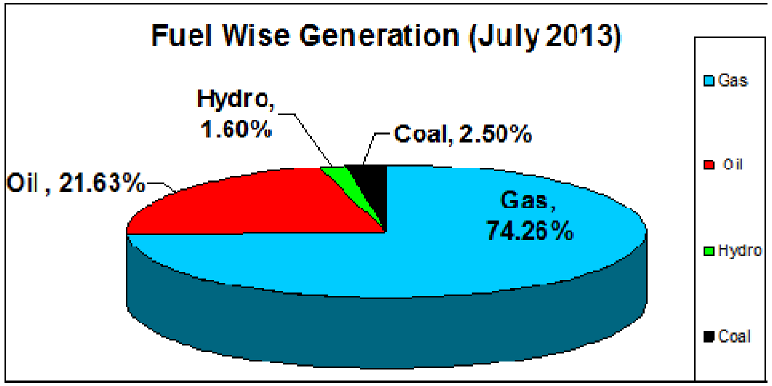
- In Bangladesh, low frequency operation below 48.9 Hz reduced by 60% post interconnection with India
- East to West transfers in Bangladesh reduced significantly leading to reduction in transmission losses
- Voltage profile in West zone of Bangladesh improved by 15-20 kV at 230 kV level
- Reduced dependence on expensive gas and oil resources

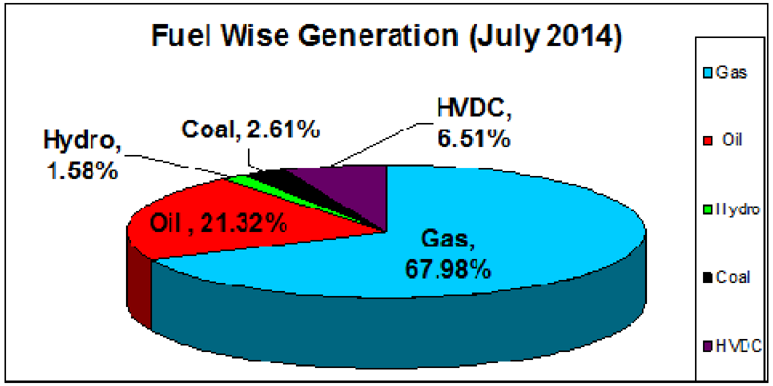
Benefits of Interconnection for Bangladesh

- Reduced dependence on expensive oil and gas









India - Bhutan : Interconnections

- **Existing Interconnection :**

  [For Import from Tala-1000 MW, Chukha-336MW & Kurichu-60MW]

  – Tala – Siliguri 400kV 2x D/c line

  – Chukha – Birpara 220kV 3 ckts

  – Kuruchu - Geylegphug(Bhutan) – Salakati(NER) 132 kV

- **On-going Interconnection :**

  [For Import from Punatsangchu-I:1200MW, Punatsangchu-II: 990MW and Mangdechu-720 MW]

  – Punatsangchu-I – Alipurduar 400kV D/c line (Bhutan portion 2xD/c and Indian portion D/c quad line]

  – Jigmelling – Alipurduar 400kV D/c line (quad)

- **Future Interconnection :**

  [For Import from 14 HEP, 11,784 MW by 2020 and 75 HEP, 26,504 MW by 2030]

  – Total 5(five) no 800kV, 6000-7000MW HVDC high capacity corridors (2 nos. by 2020 & balance 3 nos by 2030) required for transfer of power to Indian Grid.

Propective Bhutan Grid by 2030

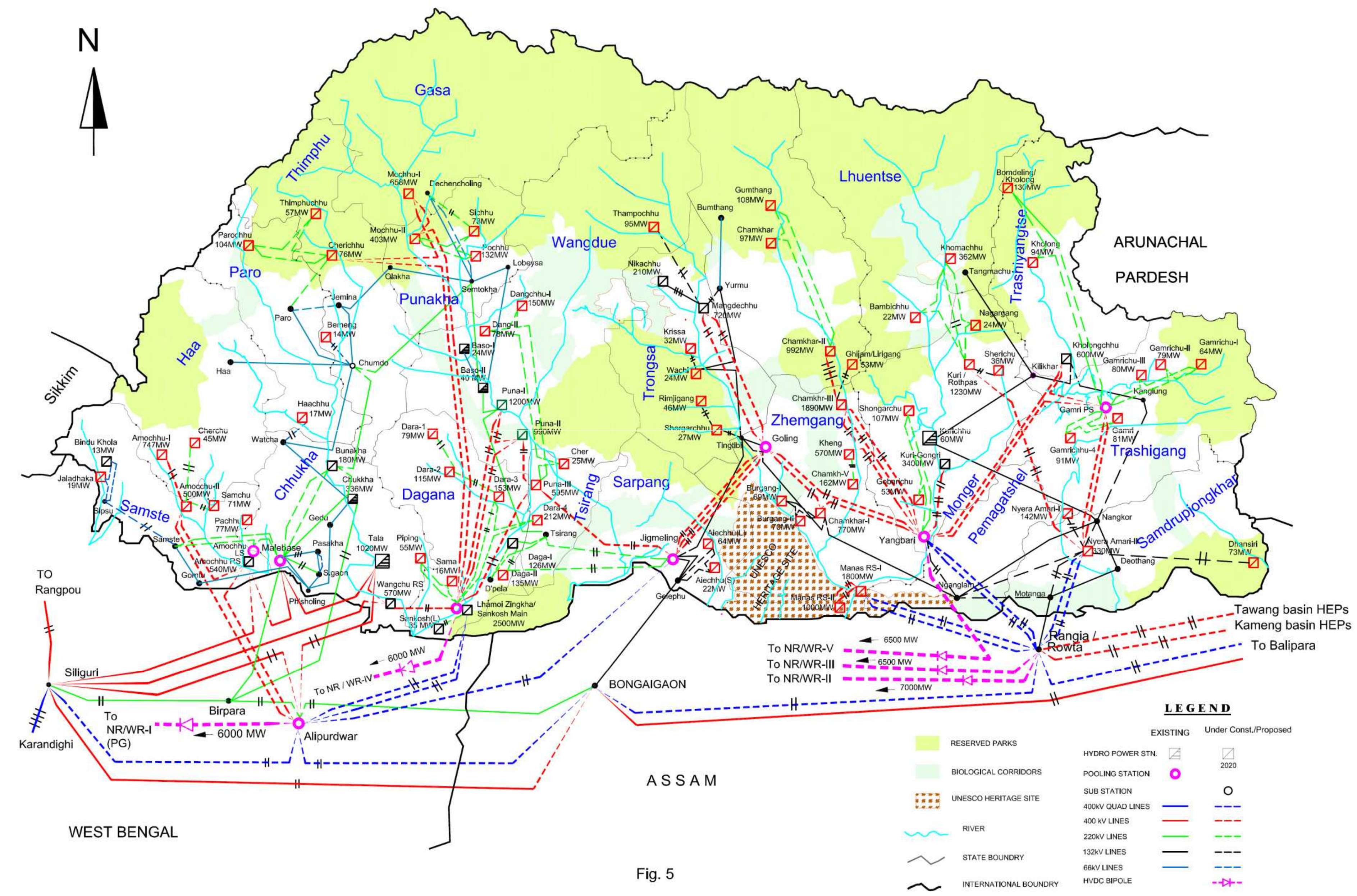


Fig. 5

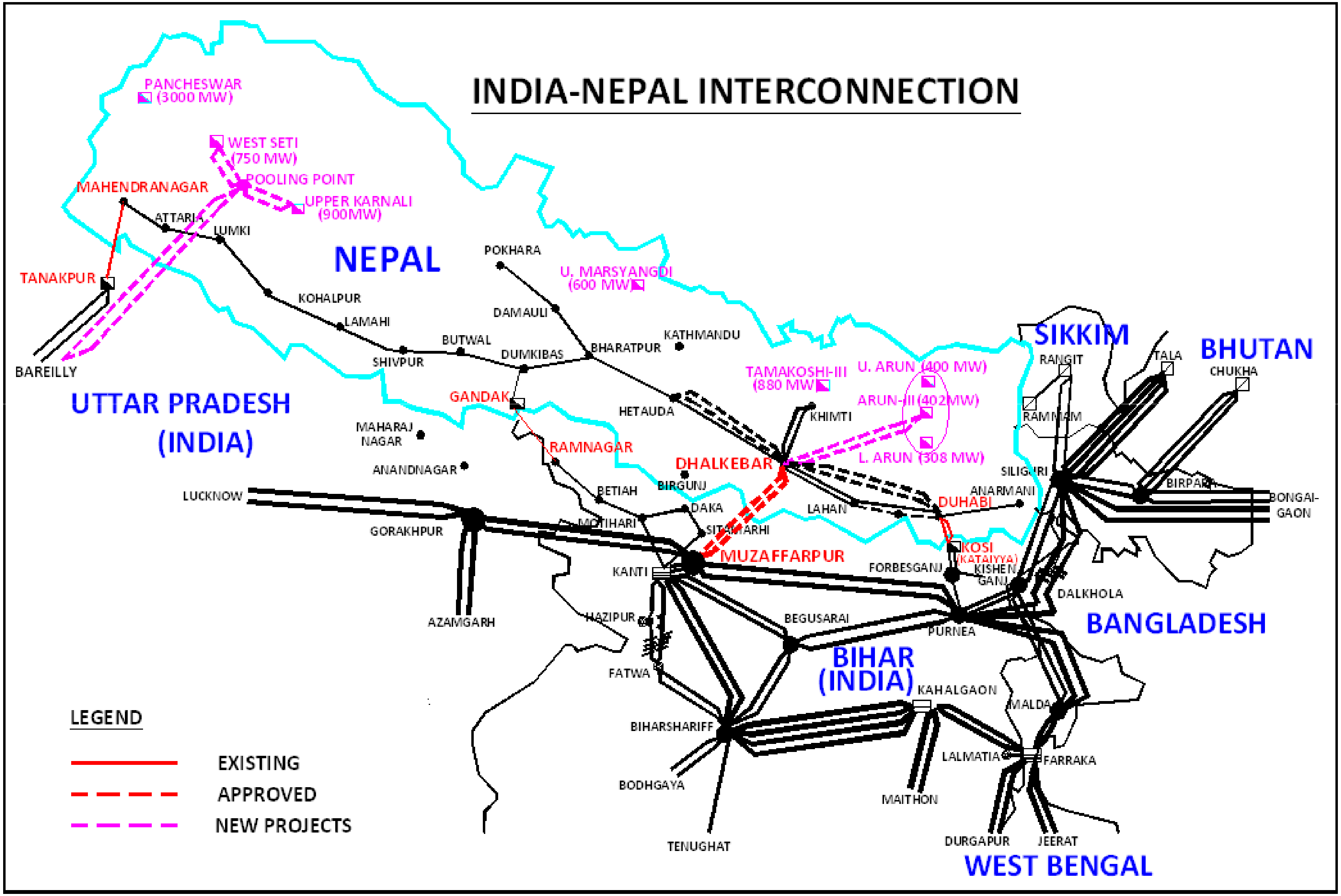
India - Nepal : Interconnections

- **Existing Interconnection :**
  - There are about 12 cross border interconnections at 11kV, 33kV and 132 kV level through which Nepal draws power upto 200MW.

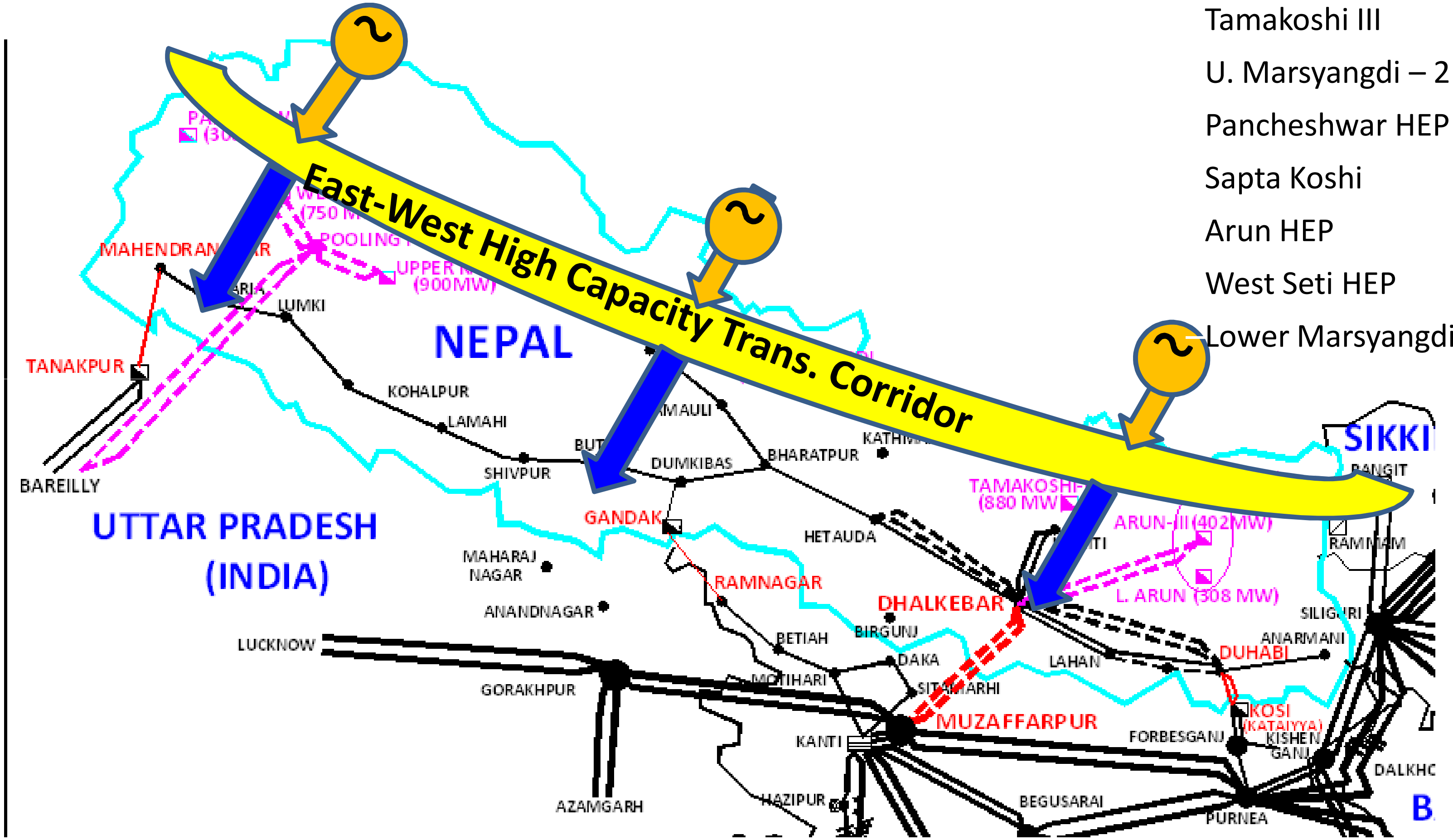
- **On-going Interconnection :**
  - Muzaffarpur(India) – Dhalkhebar(Nepal) 400kV D/c line (to be operated at 220kV) [Dec. 2015]

- **Future Interconnection :**
  - Planning for cross border interconnection under progress for import of power from various hydro power projects to be developed in Nepal

India - Nepal : Interconnections



India - Nepal : Future Plan



Future Hydro Projects :

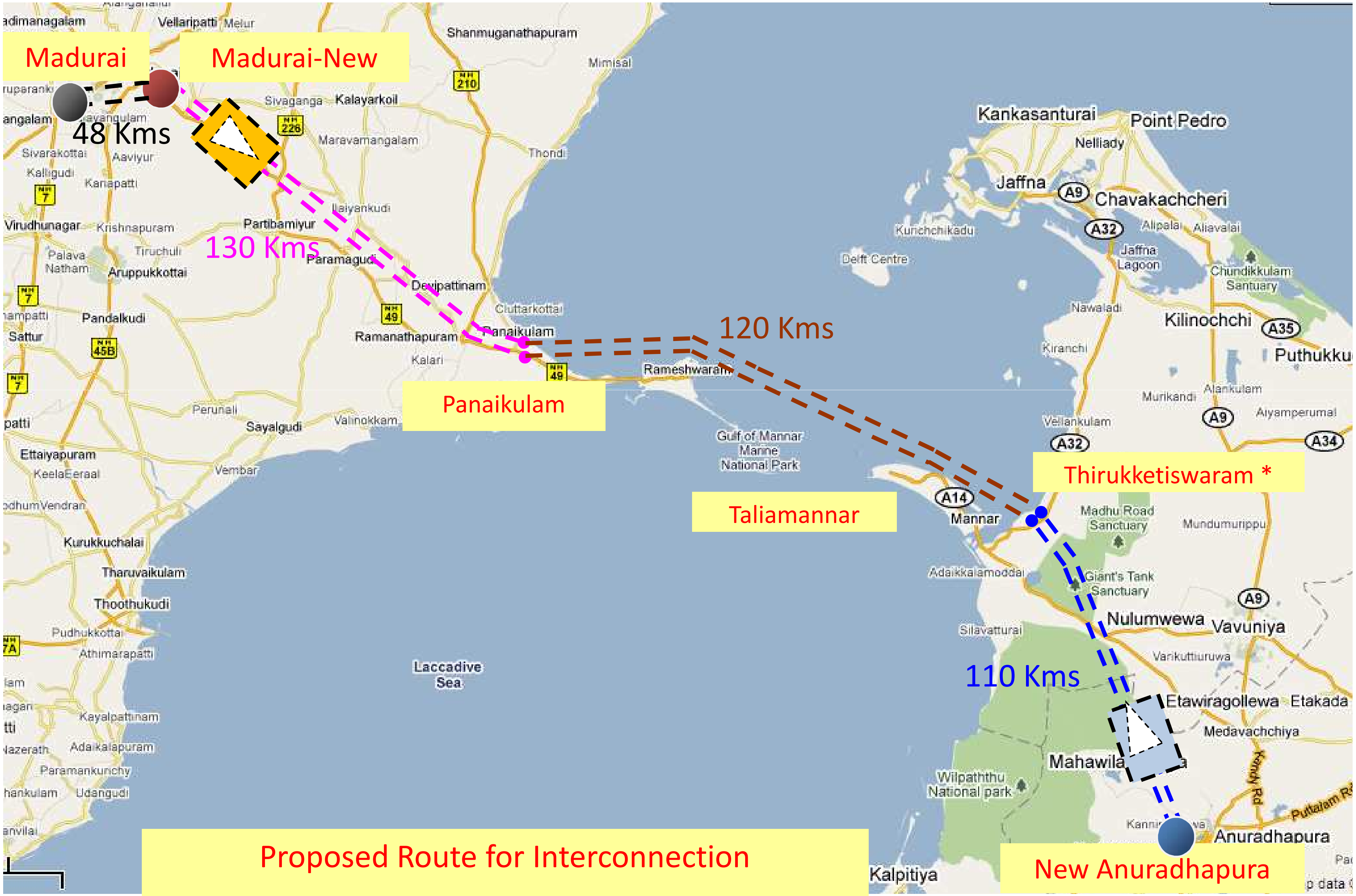
Karnali	- 10,800 MW
(Upper Karnali	- 900MW)
Tamakoshi III	- 880 MW
U. Marsyangdi – 2	- 600 MW
Pancheshwar HEP	- 5,600 MW
Sapta Koshi	- 3,300 MW
Arun HEP	- 1,100 MW
West Seti HEP	- 750 MW
Lower Marsyangdih	- 300 MW

- **East-West High capacity transmission Corridor** to be planned in Nepal
- This is to be **connected with hydro projects in Nepal** and **Load centres in India**

India – Sri Lanka : Interconnections

- Feasibility study carried out for the following interconnection
  - 2x500MW HVDC bipole line from Madurai(India) to Anuradhapura-New (Sri Lanka): 360km
    - Overhead Line (India) : Madurai to Panaikulam : 130km
    - Submarine Cable : Panaikulam (India) to Thirukketiswaram (Sri Lanka):120km
    - Overhead Line (Sri Lanka) : Thirukketiswaram to Anuradhapura(New) : 110km
  - 2x500MW HVDC terminal stations each at India(Madurai) to Sri Lanka (Anuradhapura-New): 360km

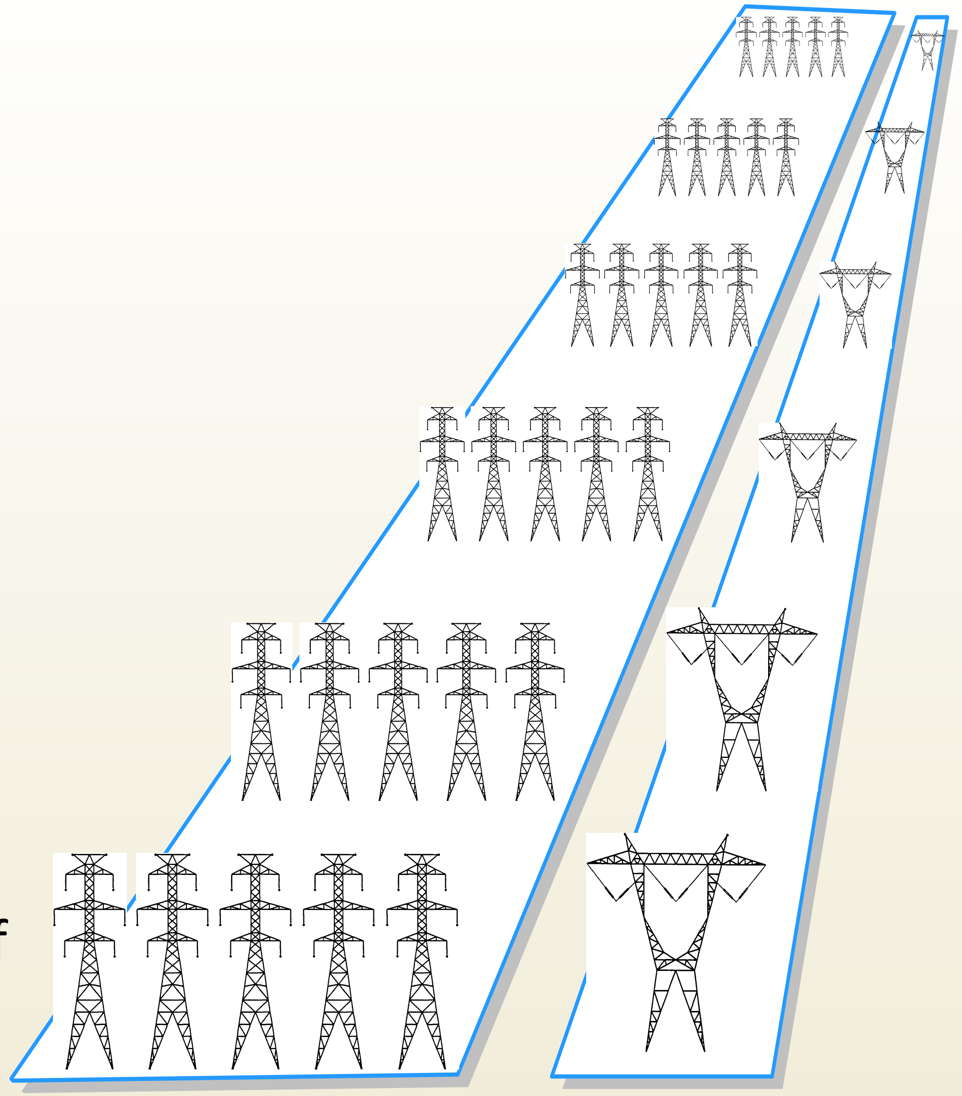
India – Sri Lanka Interconnection



Suitability of HVDC for interconnections

Benefits of HVDC

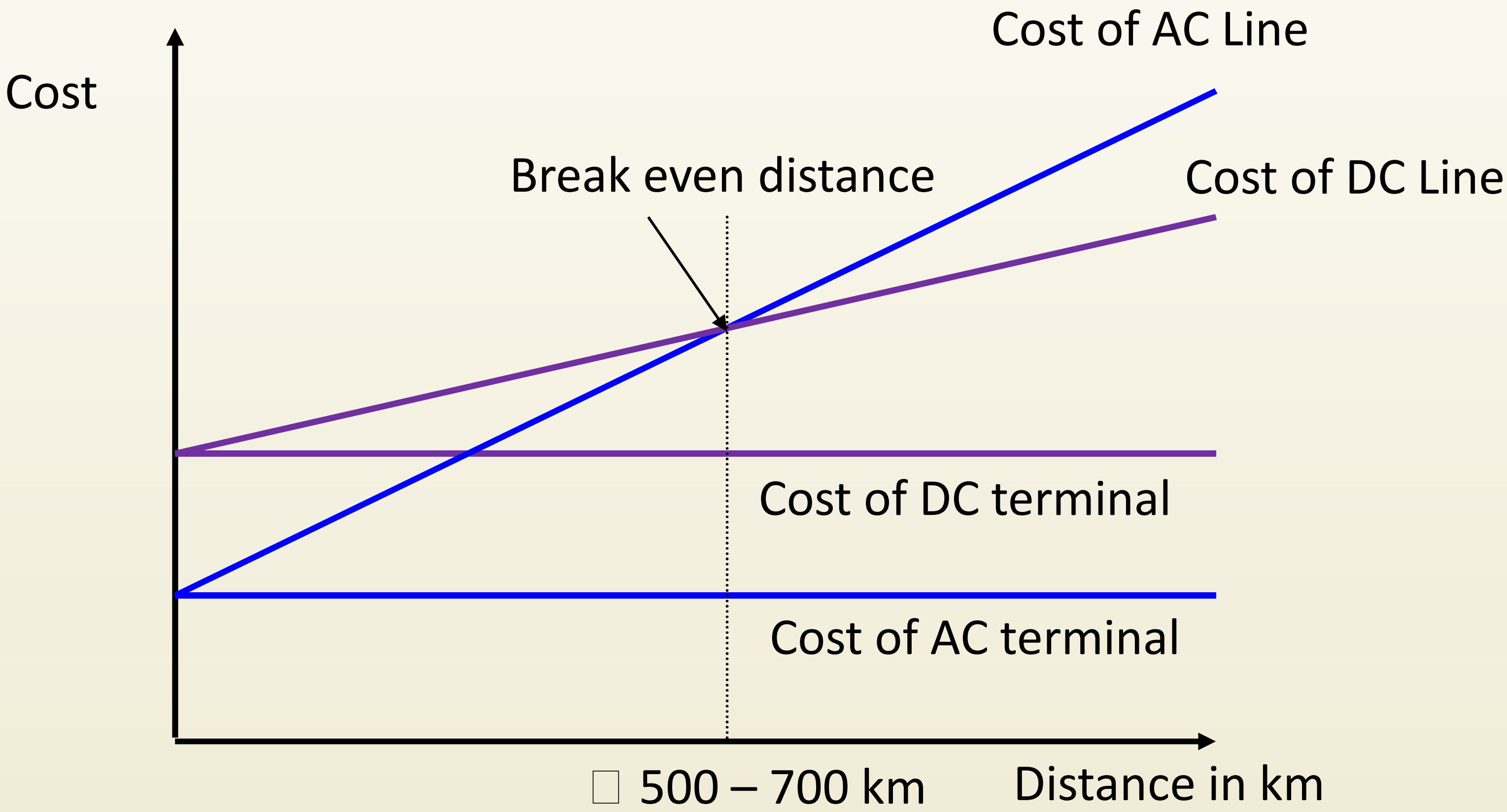
- Greater power density in a given corridor
- Higher efficiency
- Environmental advantages (lesser RoW requirement)
- Improved real time power flow control – Power flows where you want it to
- Increased power system reliability and security
- Improved power system transient and dynamic stability
- Only possible solution for interconnecting AC networks of different frequencies



Distance Break-even points- AC vs DC

Distance break-even point (HVDC versus HVAC)

- Underground or submarine cables > 50 km
- Transmission lines > 700 km

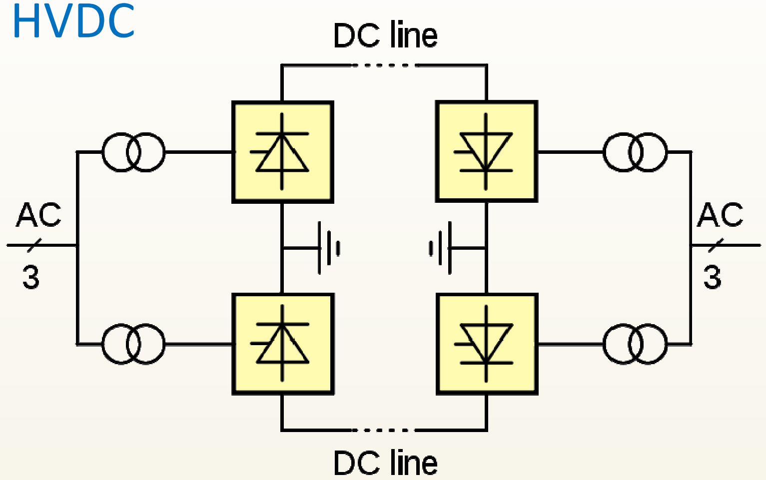


HVDC Configurations

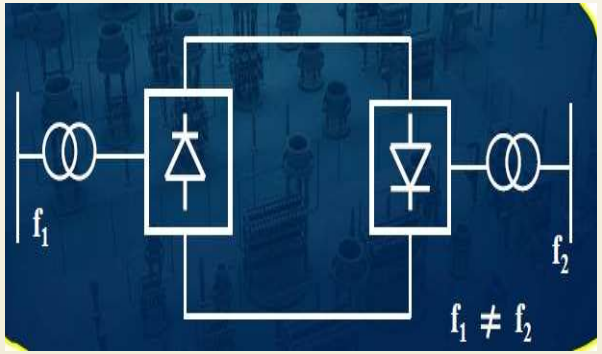
- <u>Bipole HVDC</u> for Bulk Power transmission to Long distances
  - ➢ Inverter & Rectifier placed at two different locations
  - ➢ Interconnection by DC overhead line

- <u>Back to Back HVDC</u> for coupling of electricity grids of different frequencies.
  - ➢ No DC Line
  - ➢ Rectifier & Inverter at the same station

Bipole HVDC



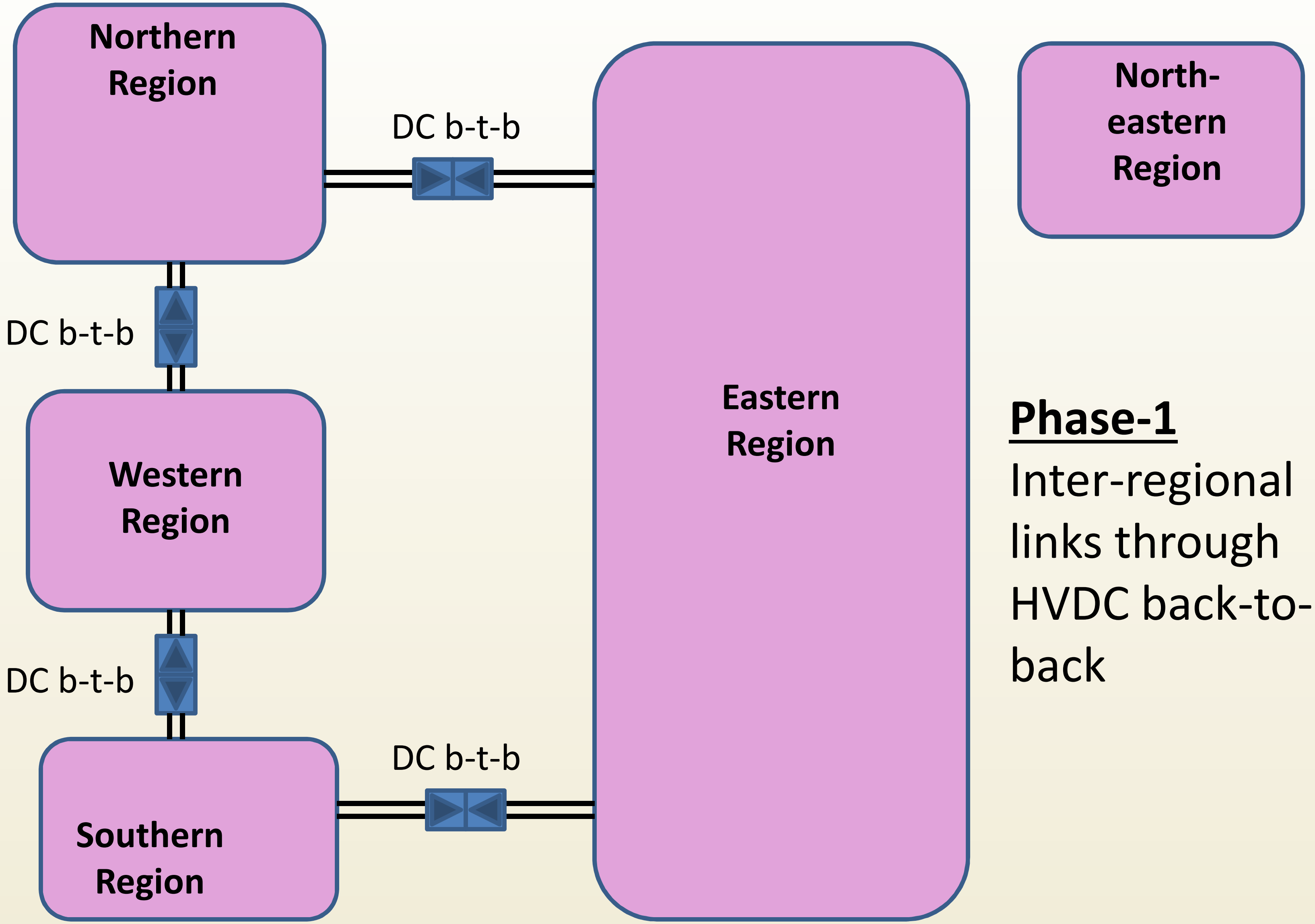
Back To Back HVDC



Applications of HVDC in inter-connection

- In initial stages of interconnection, it is desirable to wholly isolate/insulate the interconnected grids from AC induced grid disturbances by DC back to back interconnection and to gain operational experience of interconnected operation
- For under sea (submarine) connection
- If the volume of power to be transacted is very large and meant for a long distance transfer
- Integration of Renewable energy sources in the Grid
- To re-distribute power in congested load centres

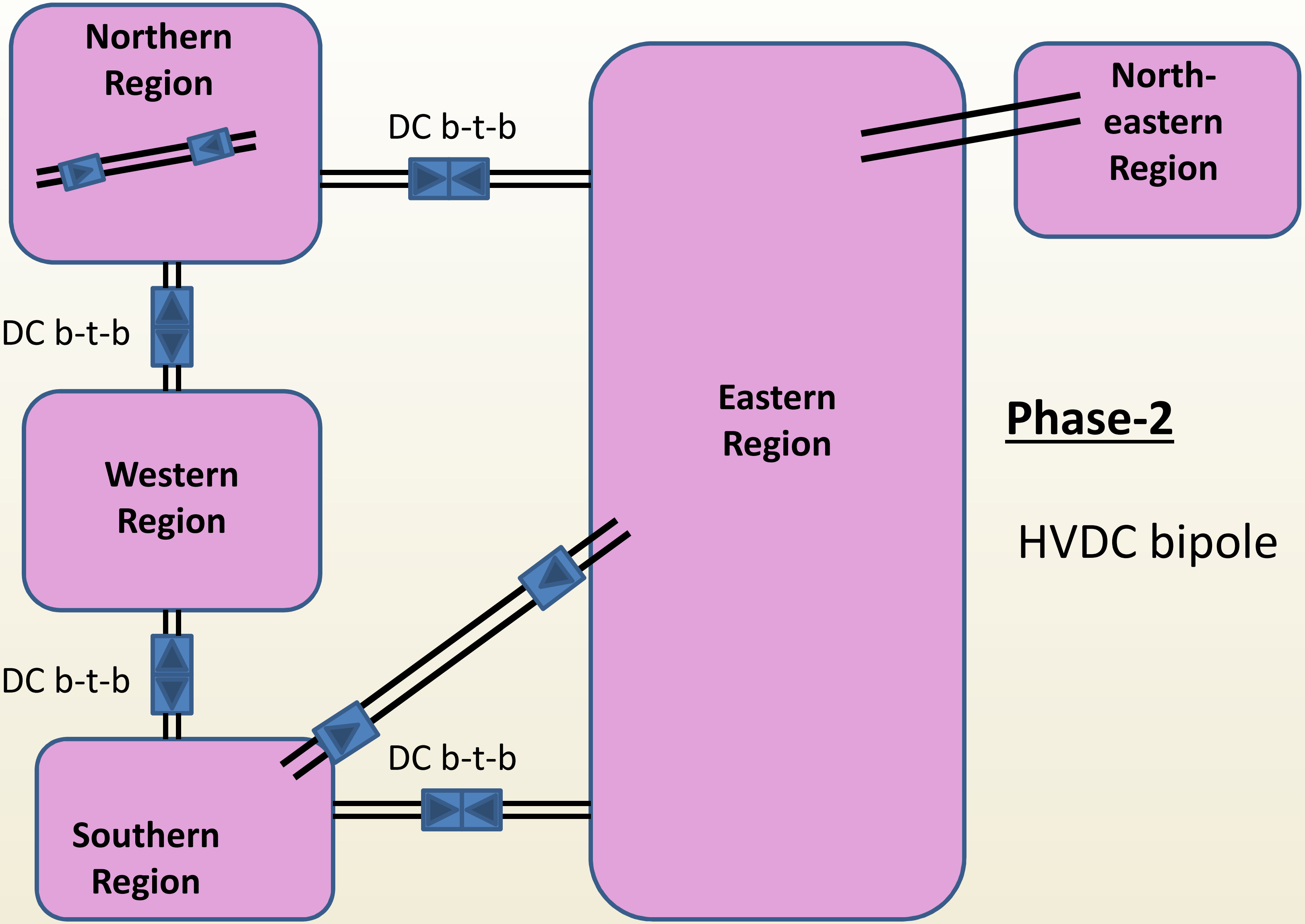
HVDC interconnections – Indian Experience



Phase-1

Inter-regional links through HVDC back-to-back

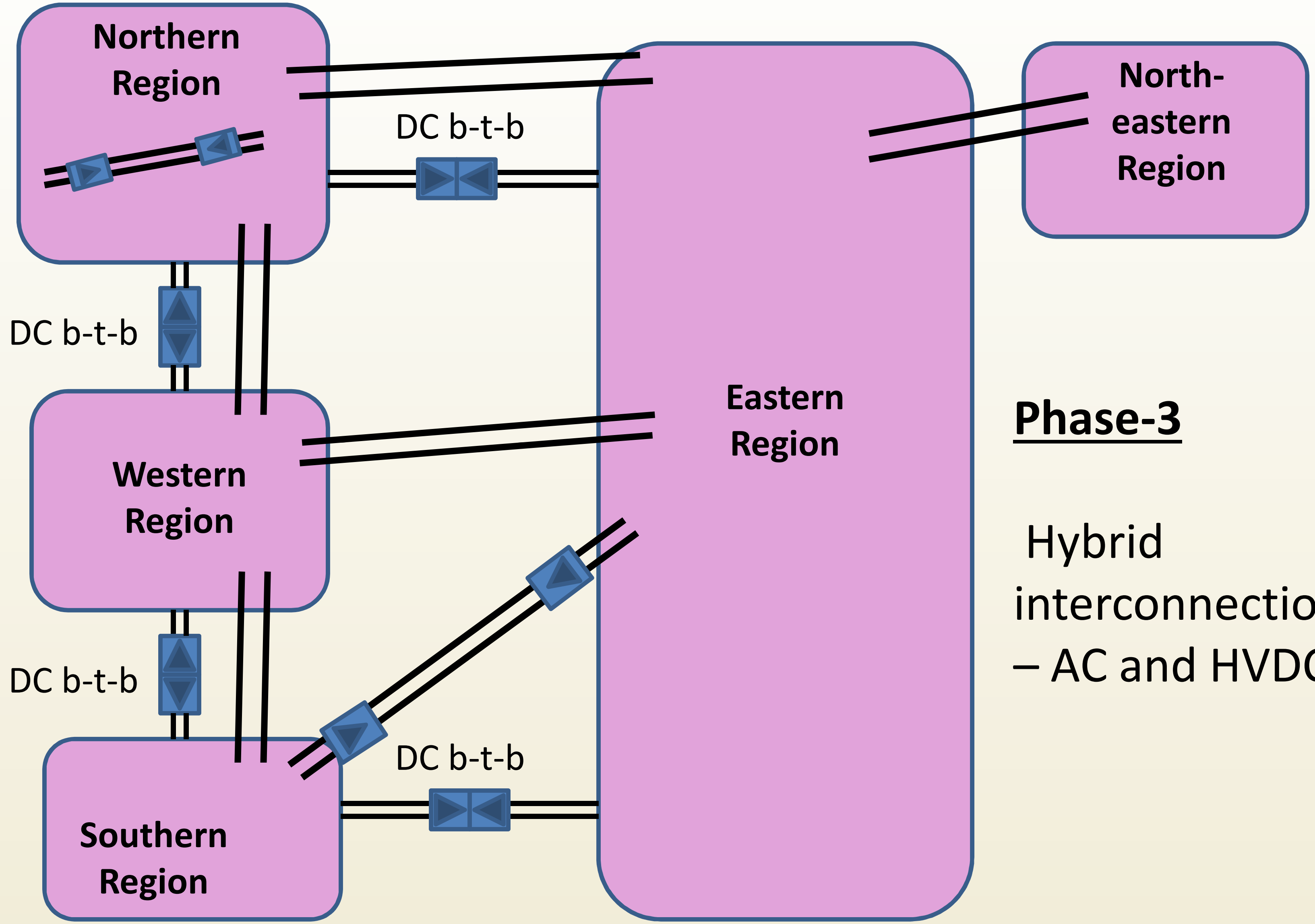
HVDC interconnections – Indian Experience



Phase-2

HVDC bipole

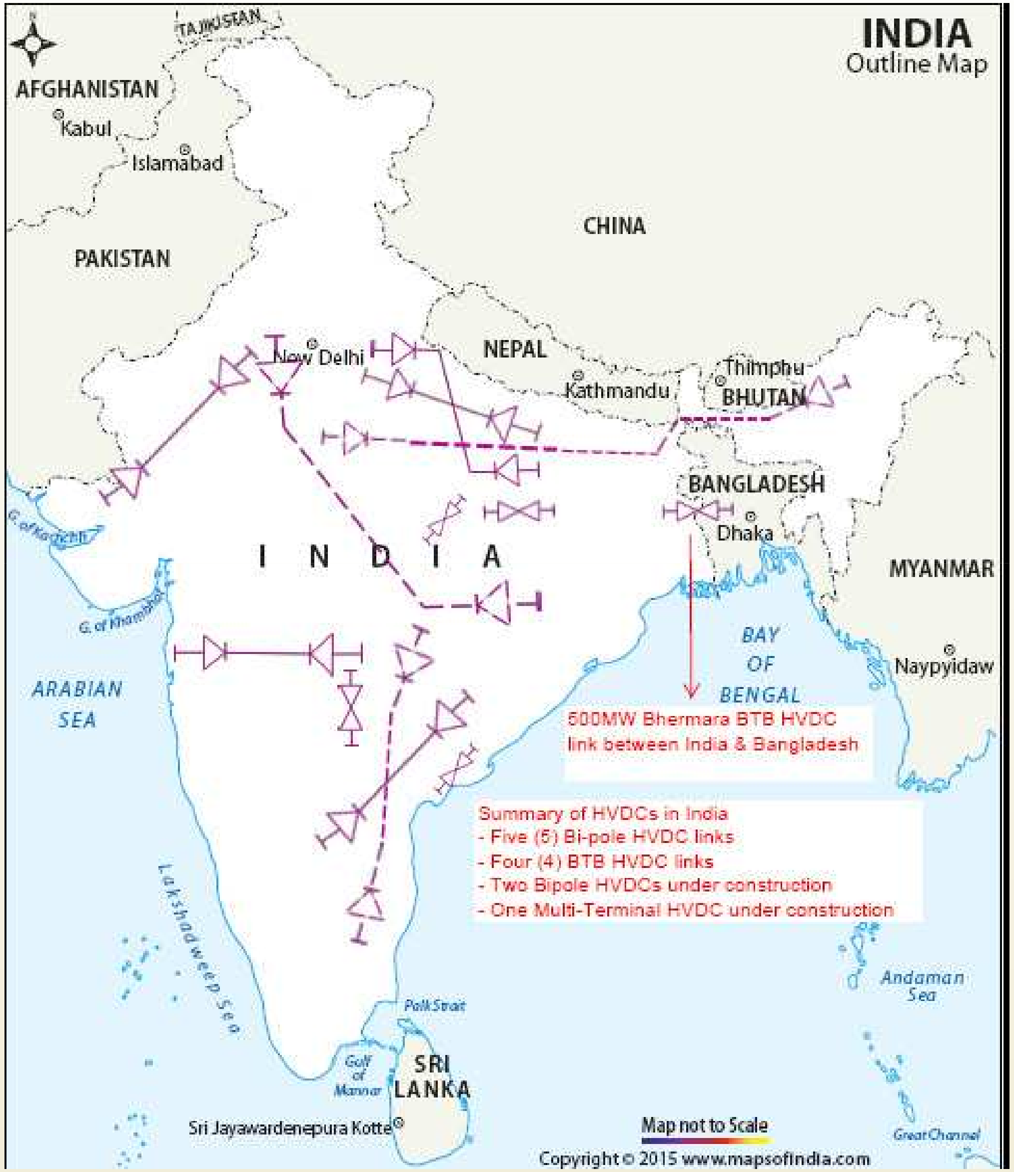
HVDC interconnections – Indian Experience



Phase-3

Hybrid interconnections – AC and HVDC

HVDC interconnections – Indian Experience



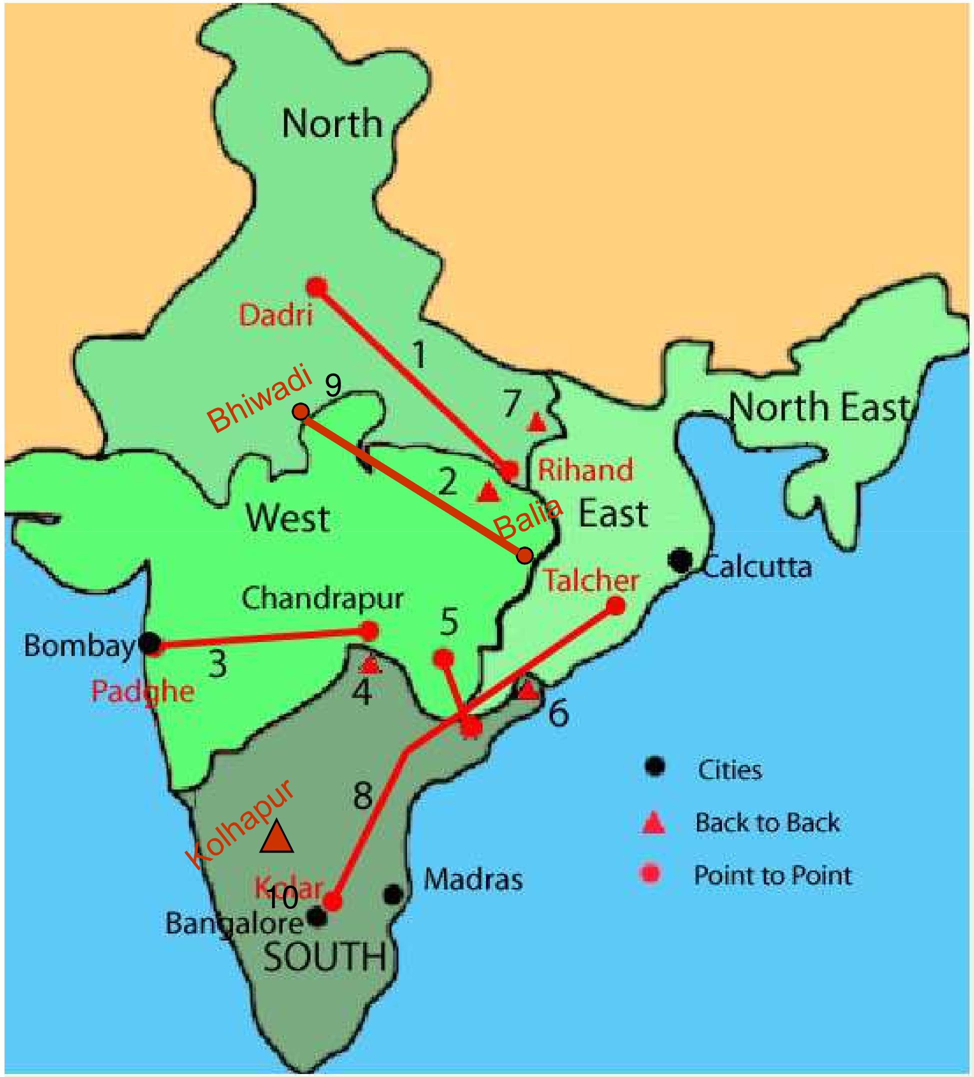
HVDC SYSTEMS IN INDIA

- 4 back to back HVDCs
- 5 bipole HVDC links
- 2 bipoles under construction
- 1 MTDC under construction

With Neighbouring Countries

- Back-to-back with Bangladesh

Existing HVDC interconnections in India



1 – Rihand-Dadri (1500MW) Bipole

2 - Vindyachal (500MW) B-t-B

3 - Chandrapur-Padghe (1500 MW) (MSEB) Bipole

4 - Chandrapur-Ramagundam (1000MW) B-t-B

5 – Barsoor-Lower Sileru (100MW)

6 – Gajuwaka 1 & 2(500MW each) B-t-B

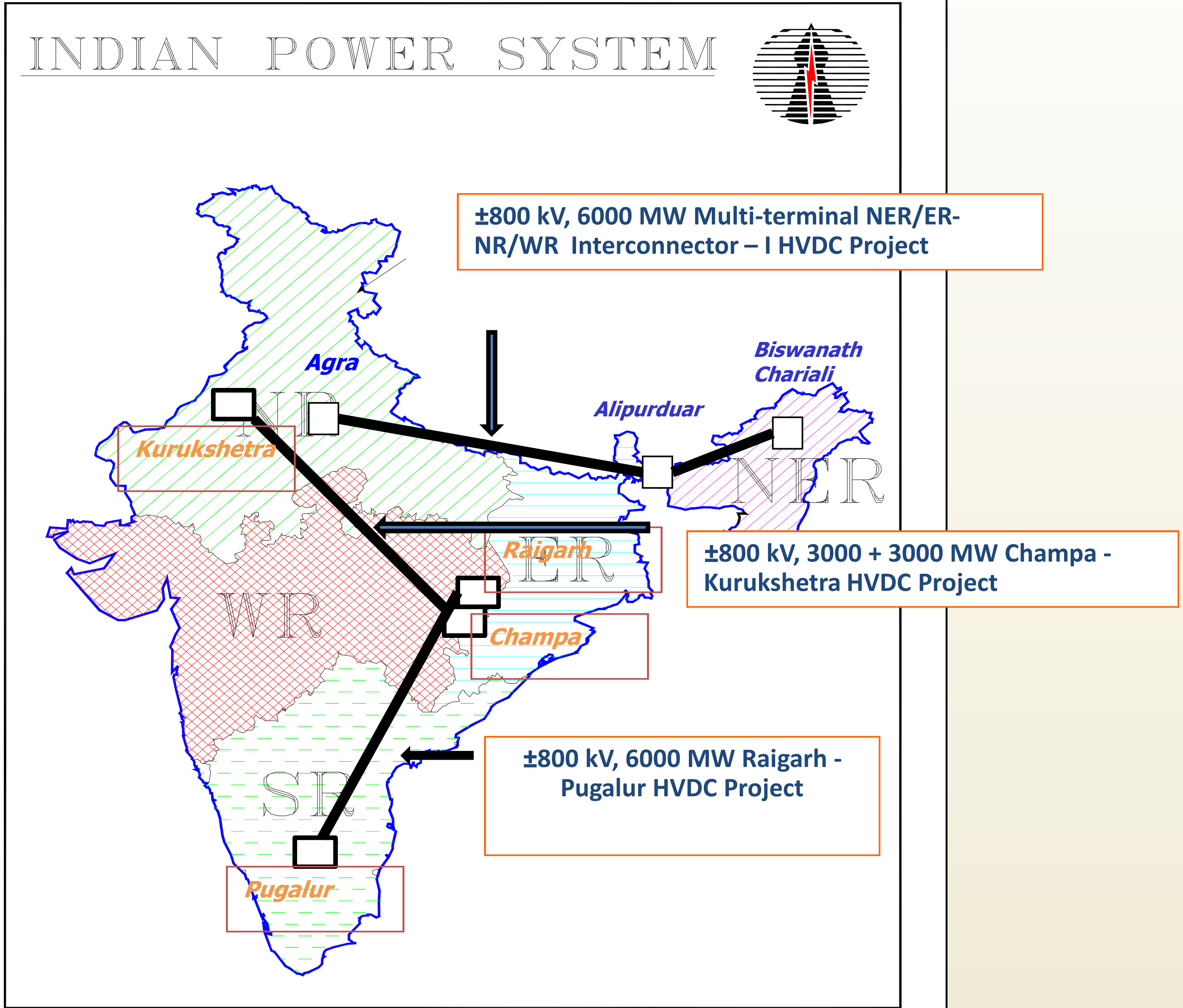
7 - Sasaram (500MW) B-t-B

8 - Talcher-Kolar (2500MW) Bipole

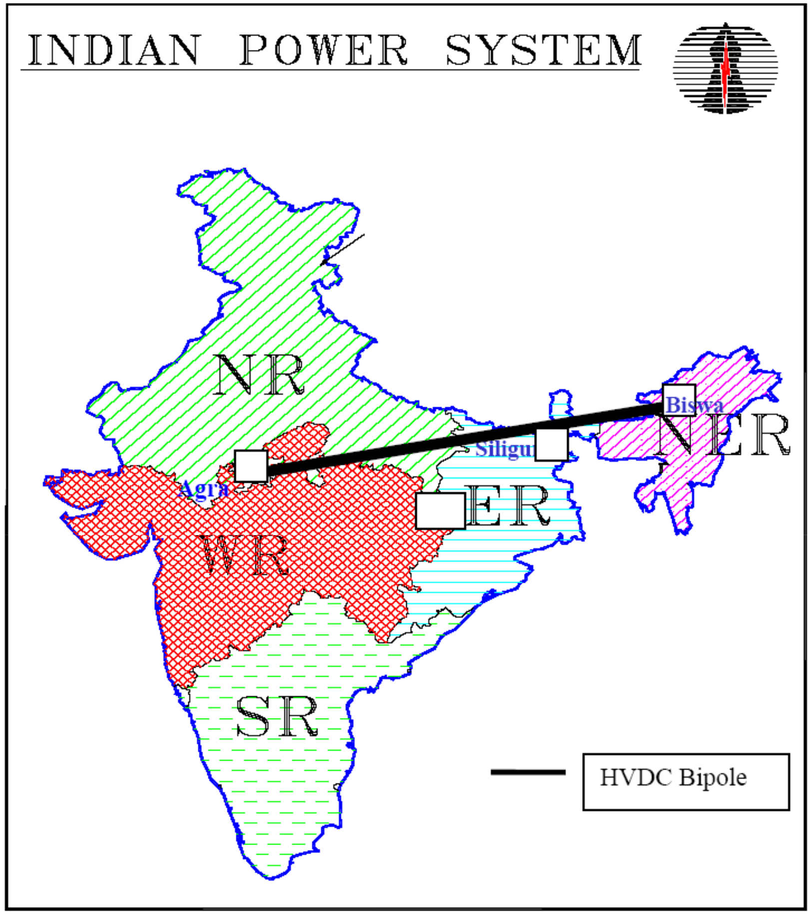
9 – Balia – Bhiwadi (2500 MW) Bipole

10- Mundra-Mahendragarh (2500 MW) (Adani Power) Bipole

HVDC interconnections in India – Under Implementation

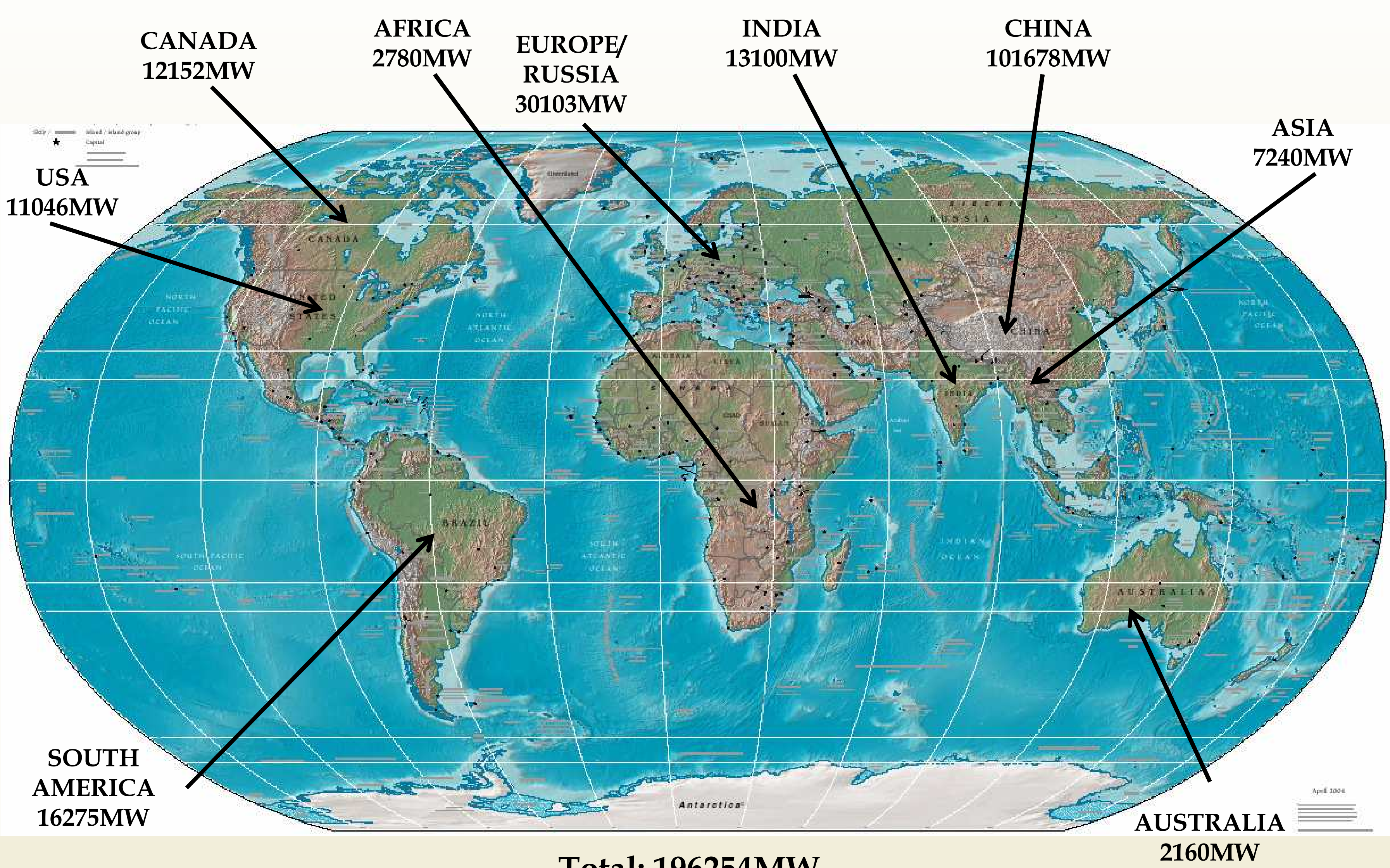


Multi-Terminal HVDC interconnection in India



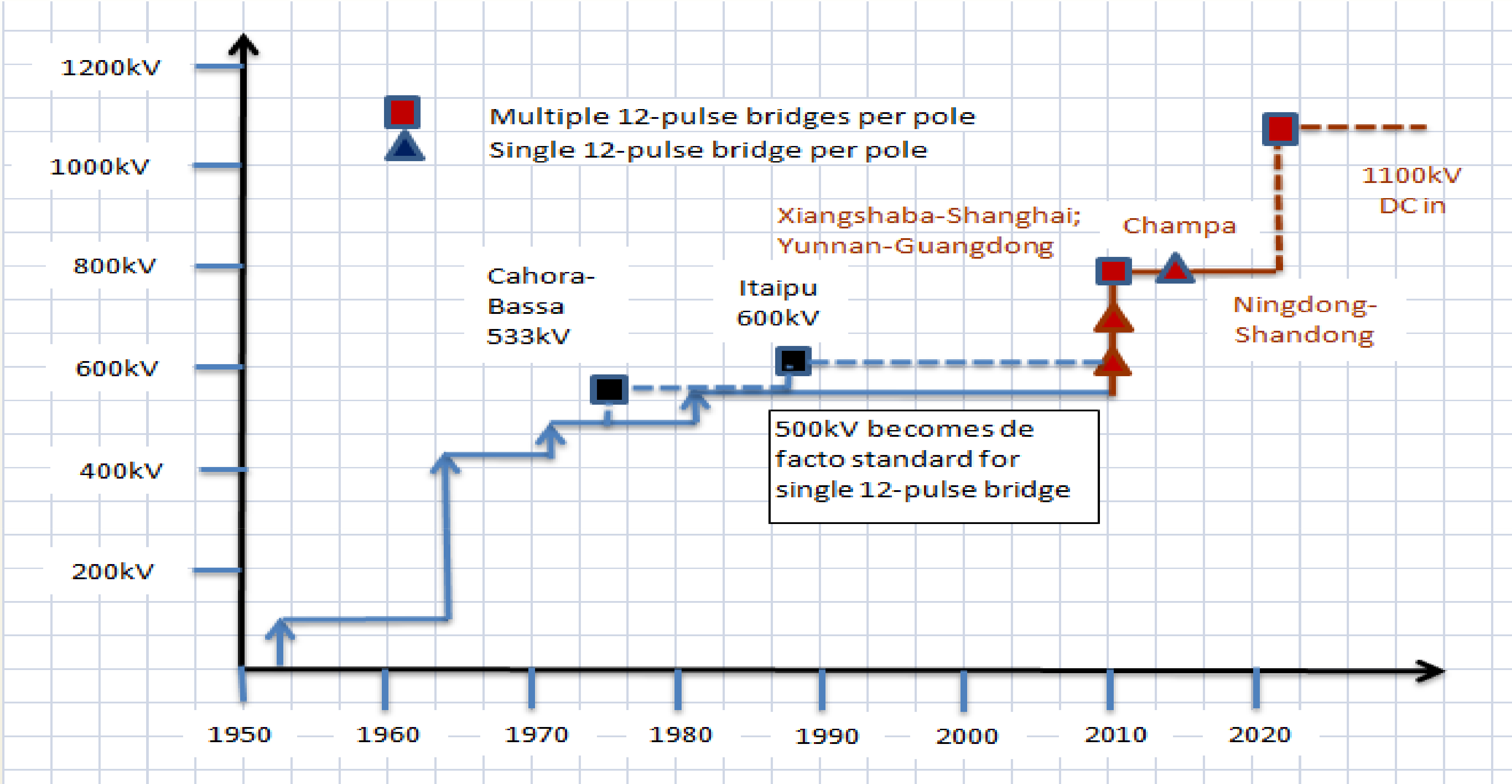
- POWERGRID is installing +/-800 kV, 6000 MW HVDC multi-terminal system of approx length of 1750 km
  - ➢ One Rectifier station in Biswanath Chariali (in North Eastern Region), second one in Alipurduar (in Eastern Region) and Inverter station at Agra (in Northern Region)
  - ➢ First ±800 KV Multi-Terminal HVDC project in the world.

HVDC Worldwide - 2015



Total: 196254MW

Evolution of HVDC Transmission Voltage

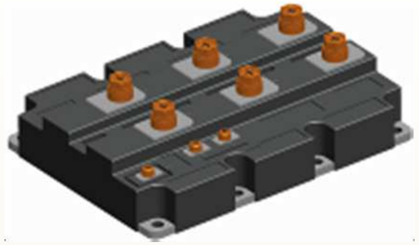


1972	1986	1992	2005	2009	2012

100kV	270kV	500kV	285kV	660kV	800kV

HVDC using Transistors – VSC Technology

- Recently introduced (first commercial scheme commissioned in 1999)
- Uses IGBT, IGCT or similar device
- Ratings
  - Typically ± 320 kV dc at 1000MW
  - ± 500 kV dc at 1400 MW
- Reduced overall site footprint
- Easier construction
- Simultaneous control of MW and Mvars
- Faster response to events
- Can “black start” a network
- Enables use of lower cost XLPE cable

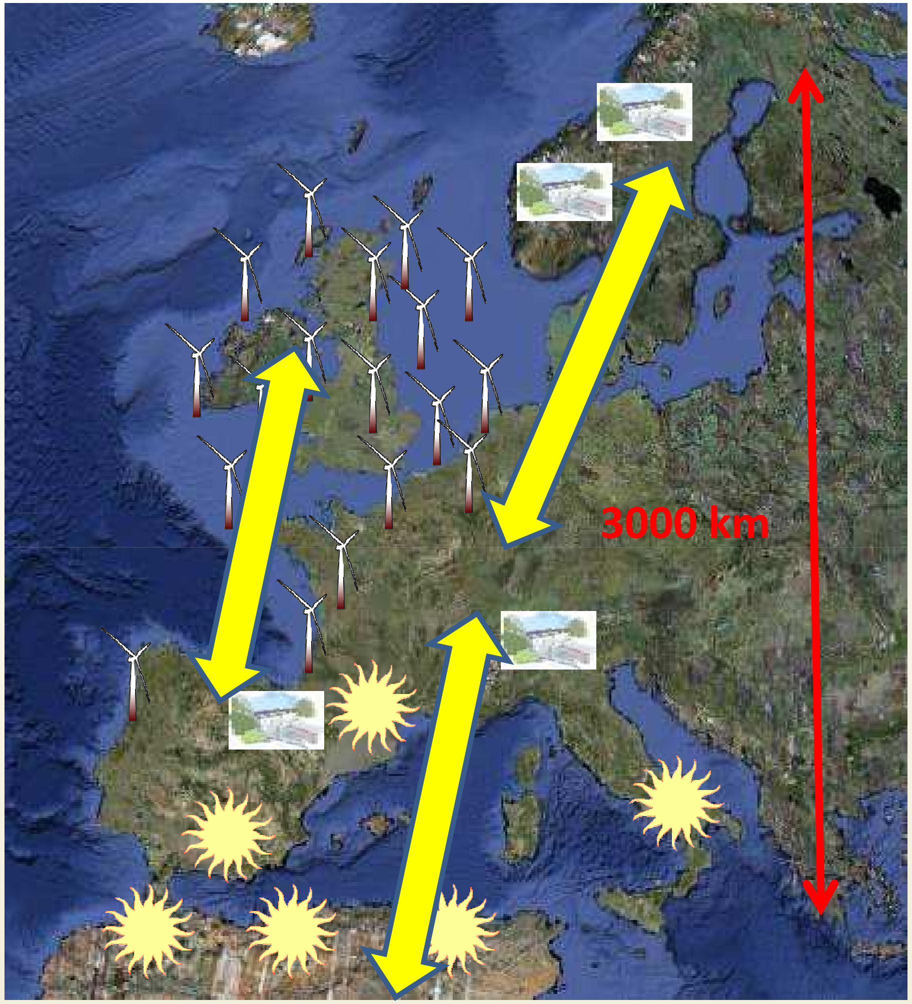


HVDC to re-distribute Renewable Energy

- Renewable energy is not evenly distributed
  - Solar power in N Africa and S Europe
  - Wind power in NW Europe
  - Hydro power (can be used for storage) in mountainous areas

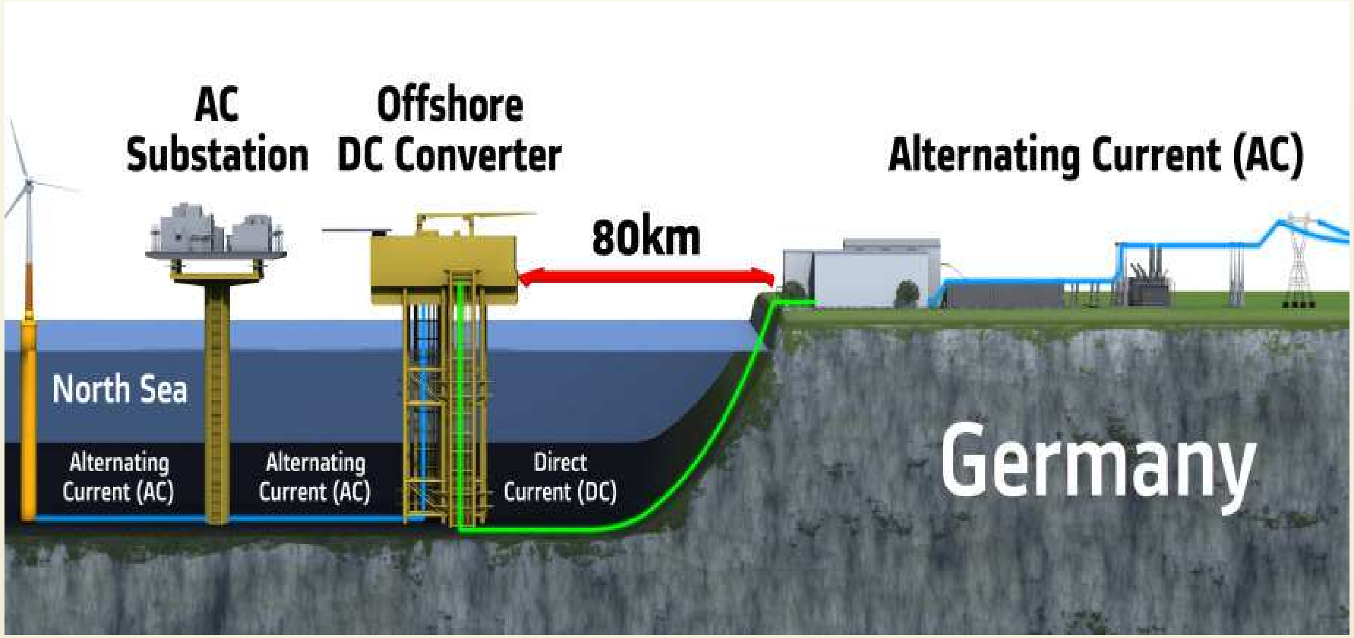
- HVDC is the most efficient way of transporting energy over such long distances

- HVDC also gives great benefits of controllability, “firewall” functionality etc



Offshore HVDC

- LOCATION: German North Sea, 83 km North of Germany
- Offshore ±320 kV, 900 MW HVDC VSC converter



Thank You

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