“Advance & Innovative Transmission System Design and Optimization: Professionals from Bhutan”

14-16 Oct, 2025

Session 1.3: Transmission System Expansion Planning

Presented By

Dr Netra P. Gyawali

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Date: 10/14/2025

About the Presenter

Key Qualification & Experiences

- CEO, National Transmission Grid Co Ltd, Nepal (Past)
- Associate Professor, Institute of Engineering, TU (Nepal)
- Doctorate in Engineering, Kyoto University Japan, 2011

Key Workin/Research Area

- Transmission Planning, Integrated Resource Planning
- Integration of Renewables into Power Grid
- Power System Operation and Control

Disclaimer

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These materials are intended **solely for educational and illustrative purposes**. They should not be interpreted as definitive or authoritative representations of current conditions, nor should they be used for decision-making without independent verification.

The views expressed during this presentation are those of the presenter and do not necessarily reflect the official policy or position of any affiliated organization or institution.

Agenda of Discussion

01

Introduction

02

TS Planning Process

03

TS Planning Practices

04

AI Application in TS Planning

05

Summary

1. Introduction

Electric power system is a **Technology Wonder**, which encompasses:

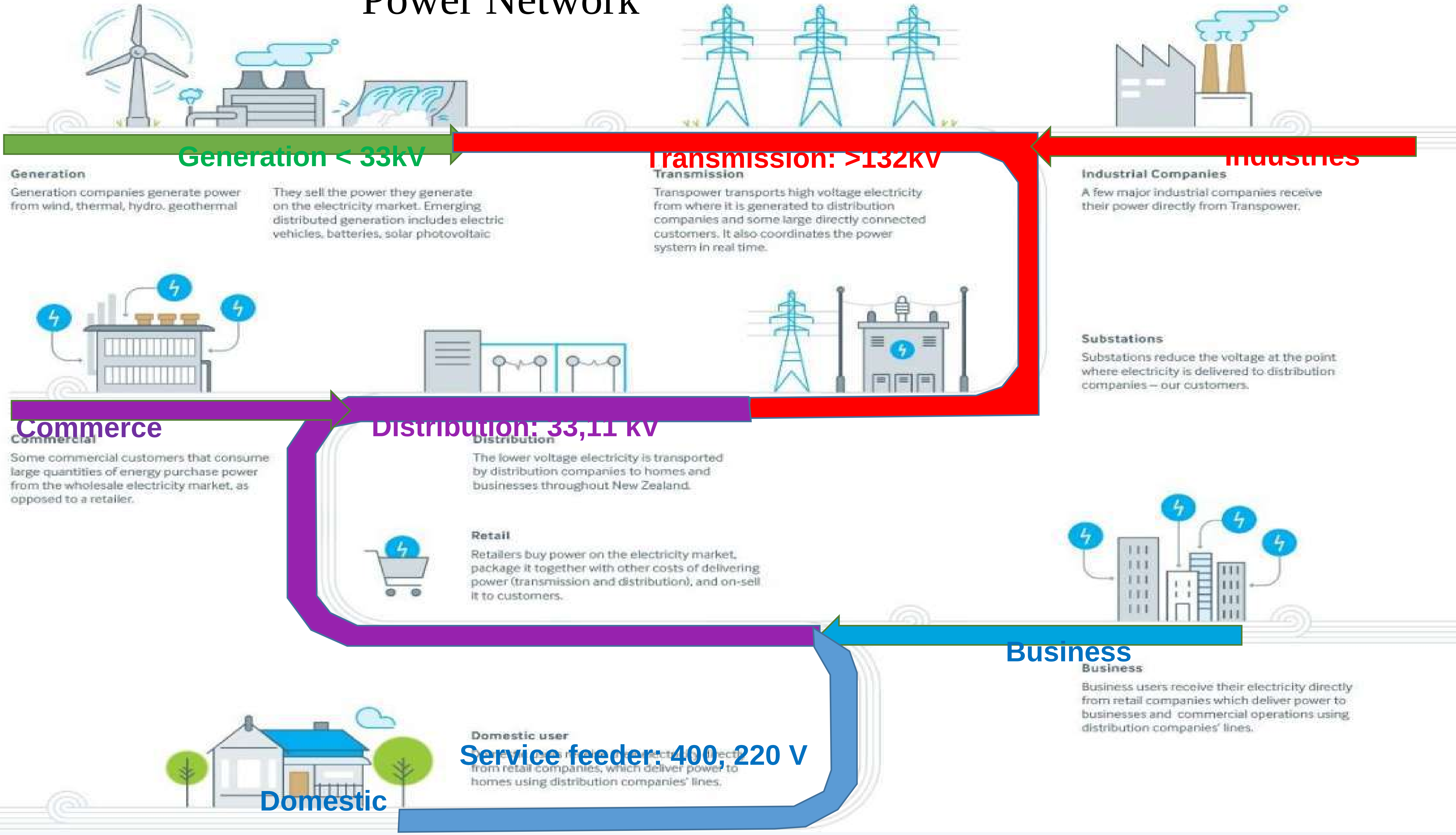
- Hundreds of Thousands of km
- Billion of consumers
- Hundreds of Thousands MW

Operate Automatically:

- balancing supply and demand instant by instant,
- with no storage

By virtue of Grid, Electricity is "God", It is 'Omnipresent', not Seen (Formless), but Underlying Force of All Actions;

Power Network



1. Introduction

What	Process of designing and developing the high-voltage power lines and substations
Who	ISO, TSO or agency designated by the government
Why	to safely and efficiently transmit electricity from generation sources to load centers
How: Inputs	**Volume, location and Pattern of Load and Generation; Policy, goals**
How: Practice/Code	Reliability, availability standards
When	Short Mid Long

1. Introduction: General

- Transmission System Exists as Demand and Generation are in wrong places
- Dependent on the Size, pattern, time and location of **Demand and Gen**
- Linear project (multitude of social and environmental situations)
- Huge Sunk Cost
- Not in My Back Yard attitude
- 10-15% of Generation cost, but challenge is multifold
- Low rate of return
- RoW and forest clearance issue

Transmission Management is Basically Power Flow Management (MW), NOT Energy Flow Management (MWh): underutilized most of the time

1. Introduction: TS Expansion Plan?

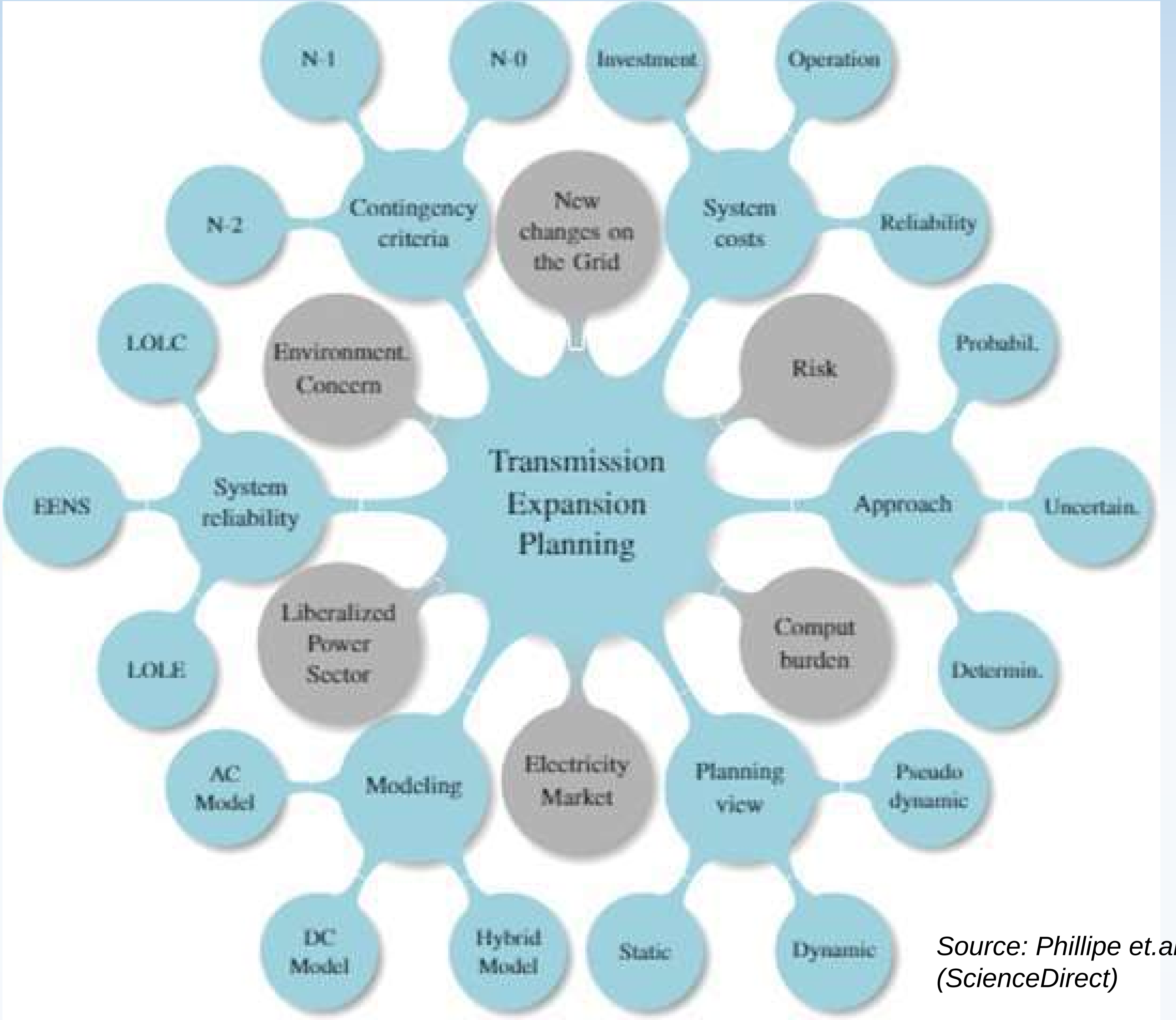
- Avoid Duplicity and Inadequacy in Transmission Line: Examples?
- Identify and Implement Common Transmission Corridor
- Provide connection hub to IPPs and Renewables
- Prudent management of Right of Way
- Avoid power spillage and Underutilization
- Identify the cost associated with transmission expansion
- Identify the financing plan
  - Utility?
  - Private?
  - PPP?
- Identify the cost recovery mechanism

1. TS Planning: Issues & Concerns

- Economic and Financial Constraints
  - High CAPEX
  - Low rate of return
  - Sunk cost
- ROW Limitations
- Various Uncertainties and Risks
- Service Reliability and Cost Considerations

TS Planning:
Scope

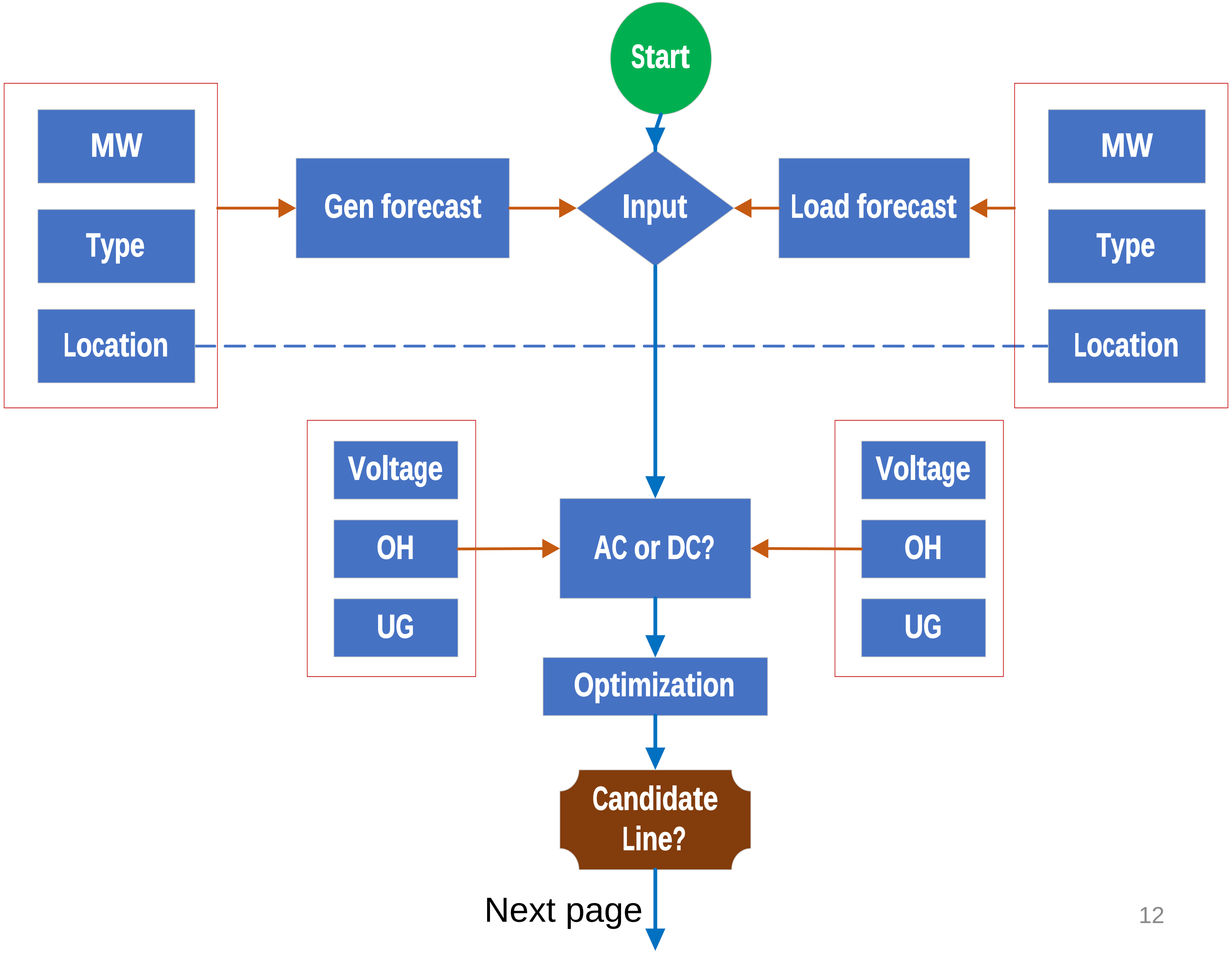
Wide scope demands priority as per the specific need



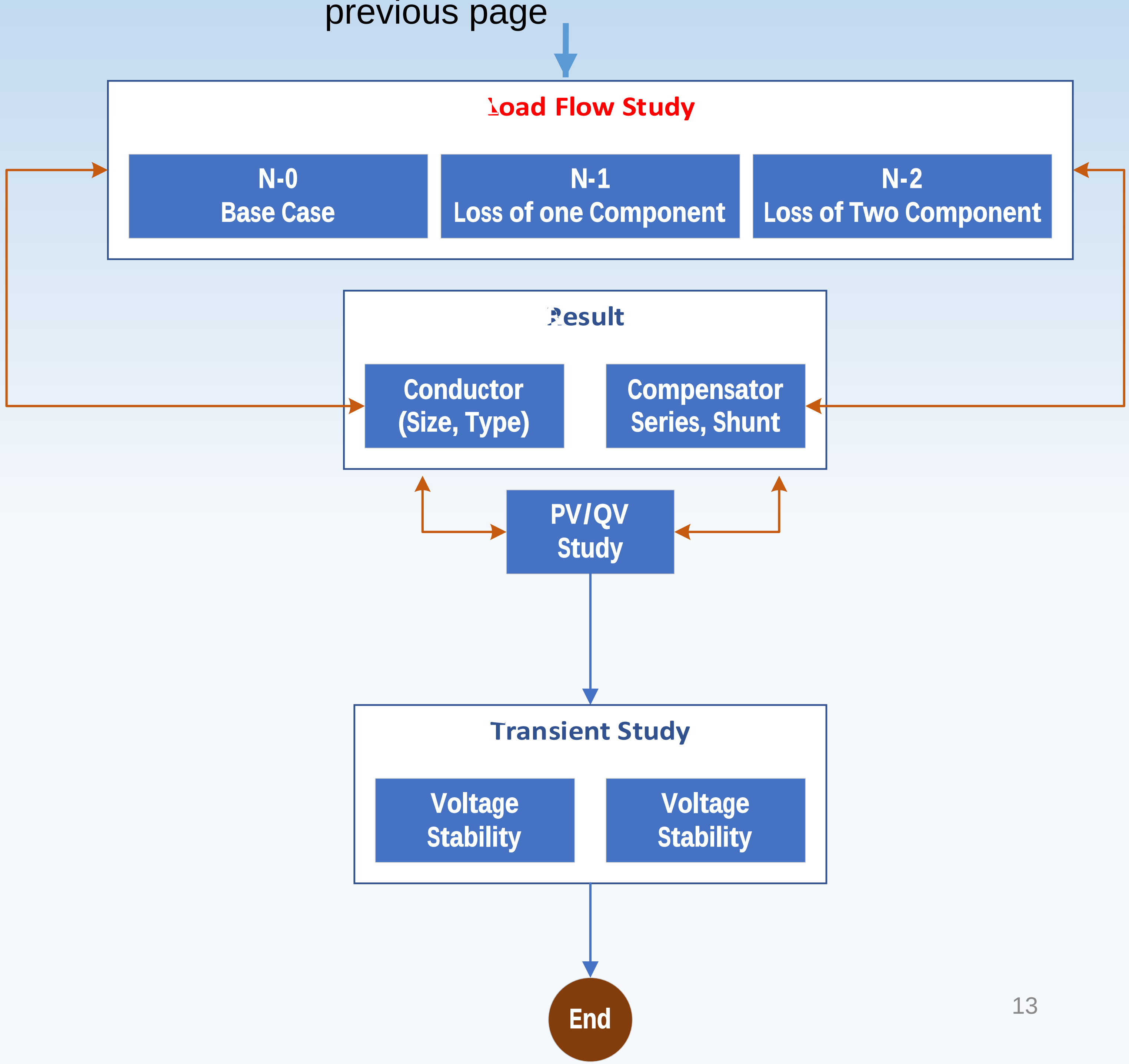
Source: Phillipe et.al (ScienceDirect)

TS Planning:
Flowchart

Level-1:
Optimization Problem



TS Planning: Flowchart



Level-2:
Network Analysis

1. Introduction: AC vs DC

Inputs:

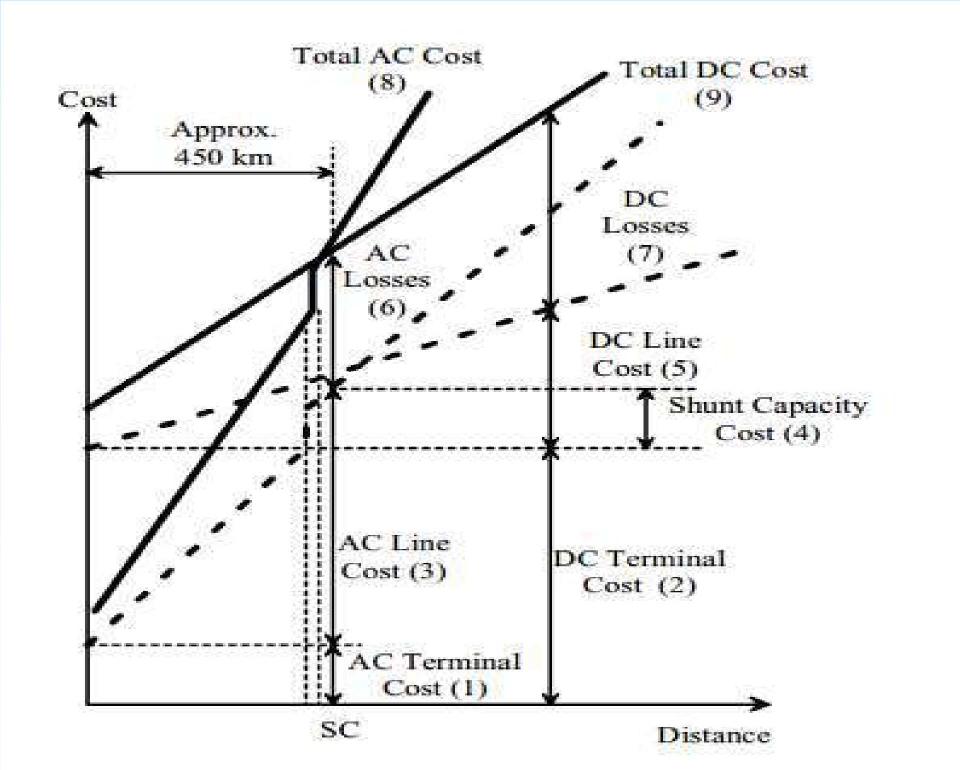
- Load forecast: Amount and Location of Load
- Gen Expansion Plan: Amount and Location of Load

Outputs:

Distance and Volume of Power

- AC vs DC

Thumb Rule: Distance, Volume, Isolation



AC vs DC cost

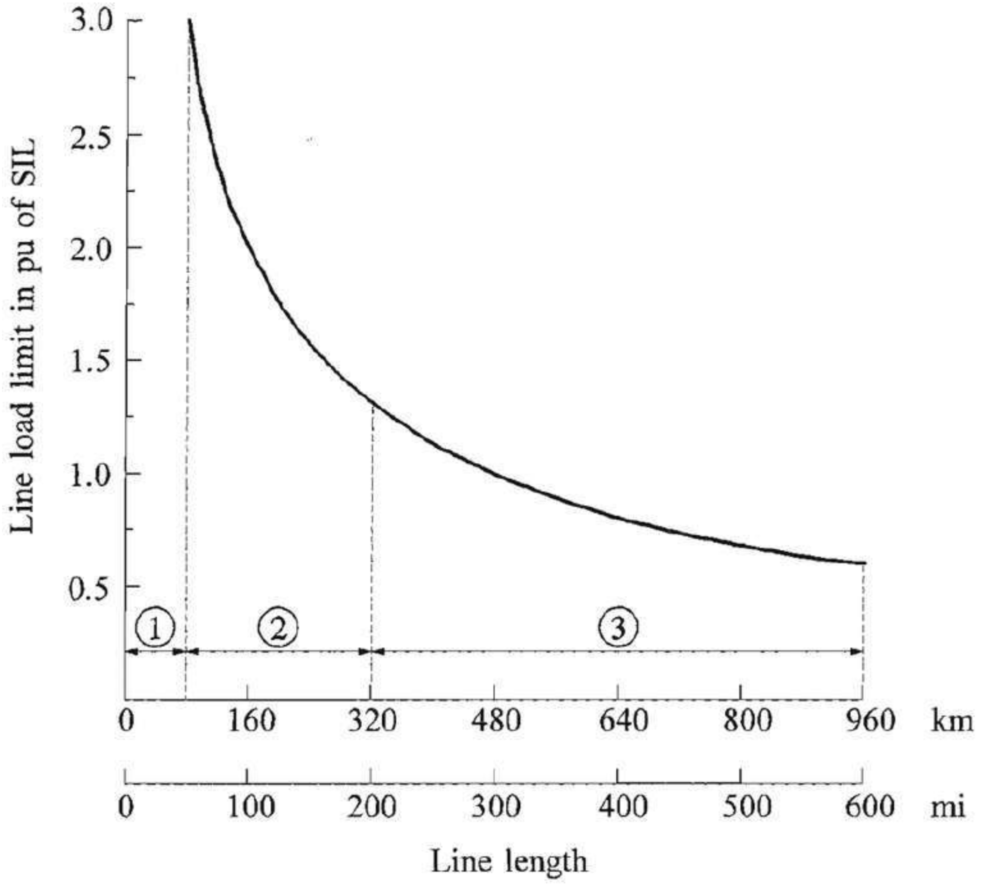
Source: Kim et al. *HVDC Transmission*

(1) illustrates the initial cost for HVAC power transmission and
(2) illustrates the initial cost of HVDC power transmission with a bigger initial cost due to a higher valve cost for HVDC transmission. In addition,
(3) and (5) represent the cost for transmission line construction in HVAC and HVDC power transmissions, respectively and they demonstrate that HVDC power transmission has a lower cost for transmission line construction.
(4) In the case of HVAC power transmission, a shunt capacitor must be installed typically at every 100 km or 200 km because of its electrostatic capacity
(6) and (7) illustrate losses of HVDC and HVAC systems during power transmission

1. Introduction: Line Capacity

St. Clark Curve

- 0-80km (short TL)
  - Region of thermal rating
- 80-320 km (Mid TL):
  - Region of voltage stability
- 320-960 km (Long TL):
  - Region of Angle stability



1 0–80 km: Region of thermal limitation
2 80–320 km: Region of voltage drop limitation
3 320–960 km: Region of small-signal (steady-state) stability limitation

1. Introduction: Reliability (Contingency) Criteria

Normal Conditions

- All circuit in-service,
- No equipment loaded above 100 percent of normal *rating,*
- Voltage in the transmission system in the range of 95 *to 105 percent of rated kV.*

Faulted Conditions (N-1)

- Loss of any ONE unit among the N units
- Outage of one circuit, one bus bar, one generating unit etc
- All bus voltage : >0.95p.u. and <1.05pu
- Line loading in the 2nd Circuit: <120% of design MVA
- Line loading in other circuits : <100% of design MVA

1. Introduction: Reliability (Contingency) Criteria

1.1 Contingency Analysis

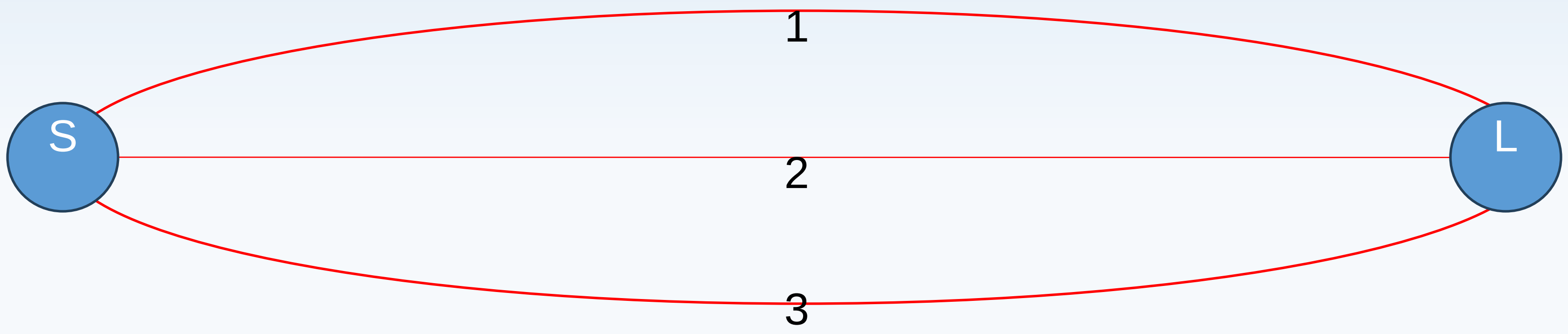
a) Tower Contengency Stress Condition(N-1-1):

- *Both circuit out (Tower collapse, both breaker out etc)*
- System capable of operating in emergency mode for about half an hour
- All bus voltage : $\geq$0.95p.u. and $\leq$1.05p.u.
- Line loading in other circuits : <120% of design MVA

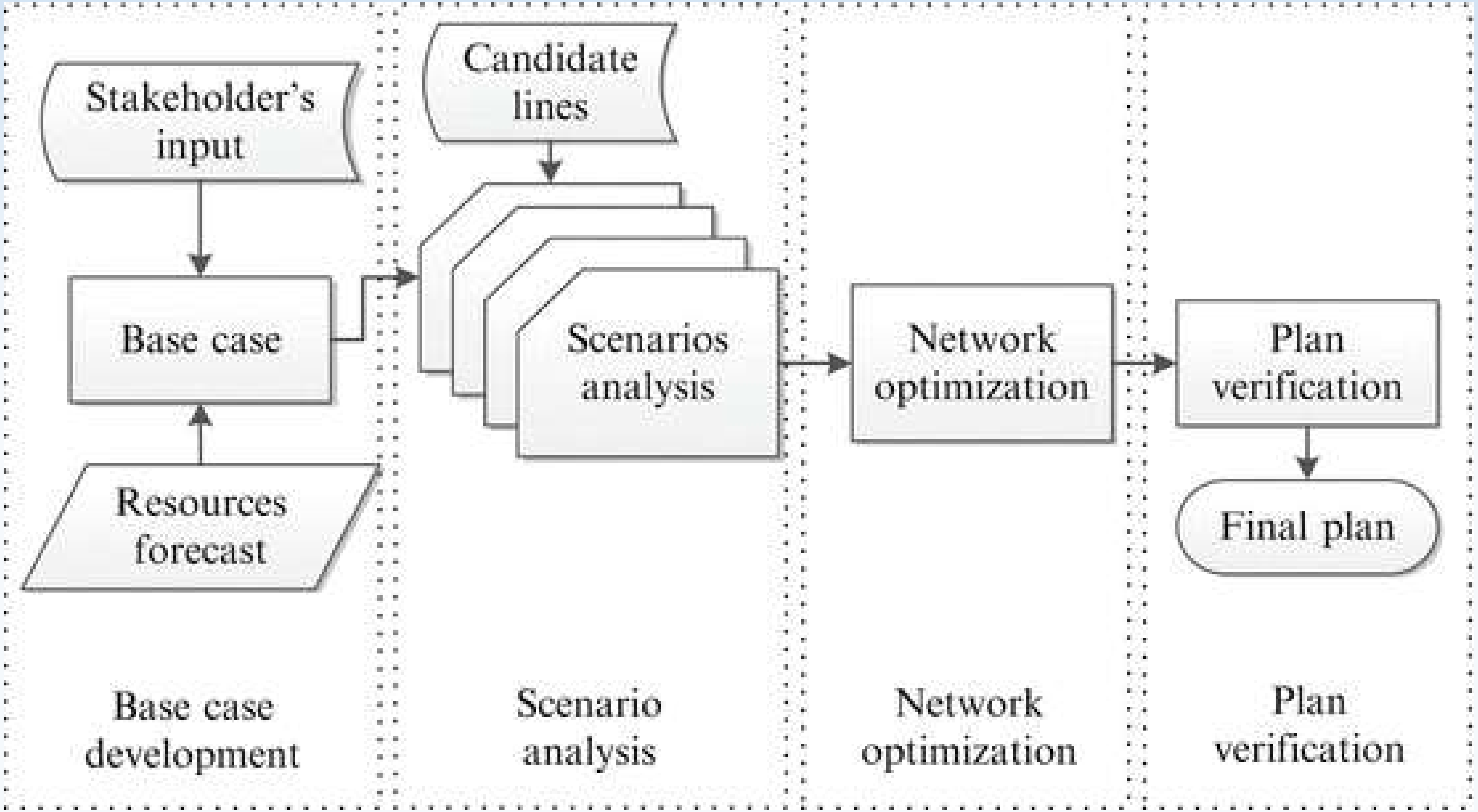
For faults of permanent nature, there may be requirement of load shedding/ rescheduling of generation to bring the system variables within normal limit.

2. TS Planning:

An Optimization problem



2. TS Planning: An Optimization problem



2. TS Planning: An Optimization problem

TS expansion planning is basically the optimized solution among the alternatives

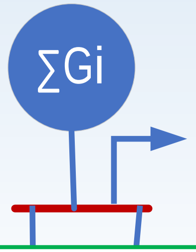
- Objective functions: *Cost (Transmission (O+M), Generation (O+M), Outage)*

- Constraints: *Generation Capability, Power Flow, Voltage regulation, Reliability, Network Capacity,..)*

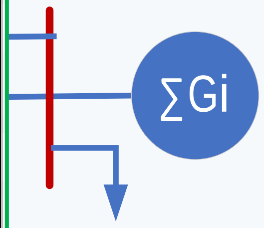
- *Associated with the Generation Planning*

2. TS Planning: Base Case

Generators and Load connected with TLs (Before Renewables)



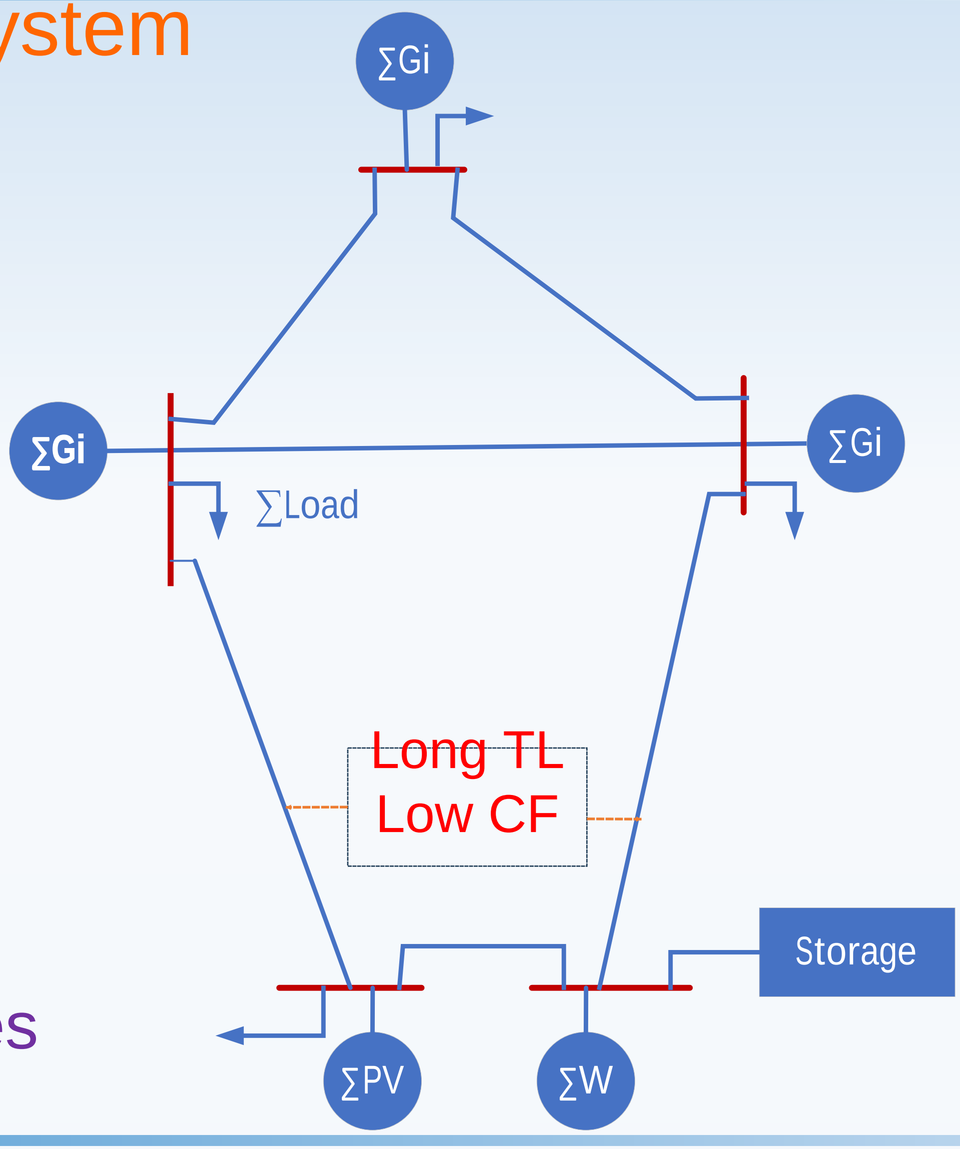
		System Expansion Alternative		
		A	B	C
1.	Smallest net present worth (NPV)	2	3	1
2.	Least environmental impact	1	2	3
3.	Least interference with operations	2	2	1
4.	Least impact on neighbors	2	2	1
5.	Highest transmission strength	3	2	1
6.	Most favorable financing requirements	1	2	3



Network Constraint

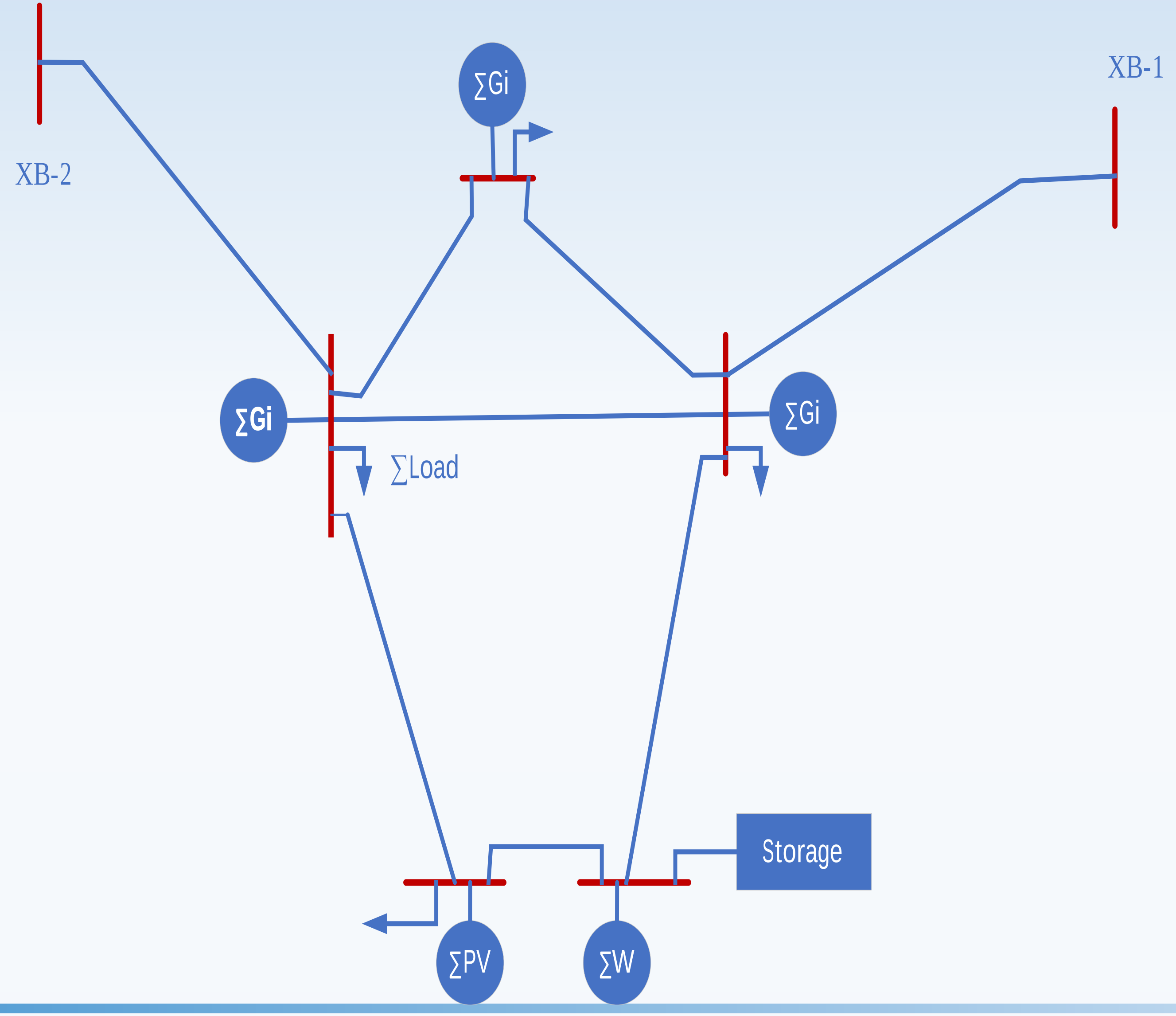
2. TS Planning: Integrating Renewables

Integrating the Renewables on existing system



TEP often be financially infeasible: need incentives

2. TS Planning: Adding the CBET



3. Guidelines

The rule **requires transmission operators to conduct and periodically update long-term transmission planning over a 20-year time horizon to anticipate future needs**. It also provides for cost-effective expansion of transmission that is being replaced, when needed, known as "right-sizing" transmission facilities. May 13, 2024

RM21-17-000

Federal Energy Regulatory Commission (.gov)
https://www.ferc.gov › news-events › news › ferc-takes-l...

FERC Takes on Long-Term Planning with Historic ...

NERC
https://nerc.com › Stand › Reliability Standards PDF

TPL-001-5 — Transmission System Planning Performance ...

Transmission System Planning Performance Requirements. 2. Number: **TPL-001-5**. 3. Purpose: Establish Transmission system planning performance requirements.

31 pages

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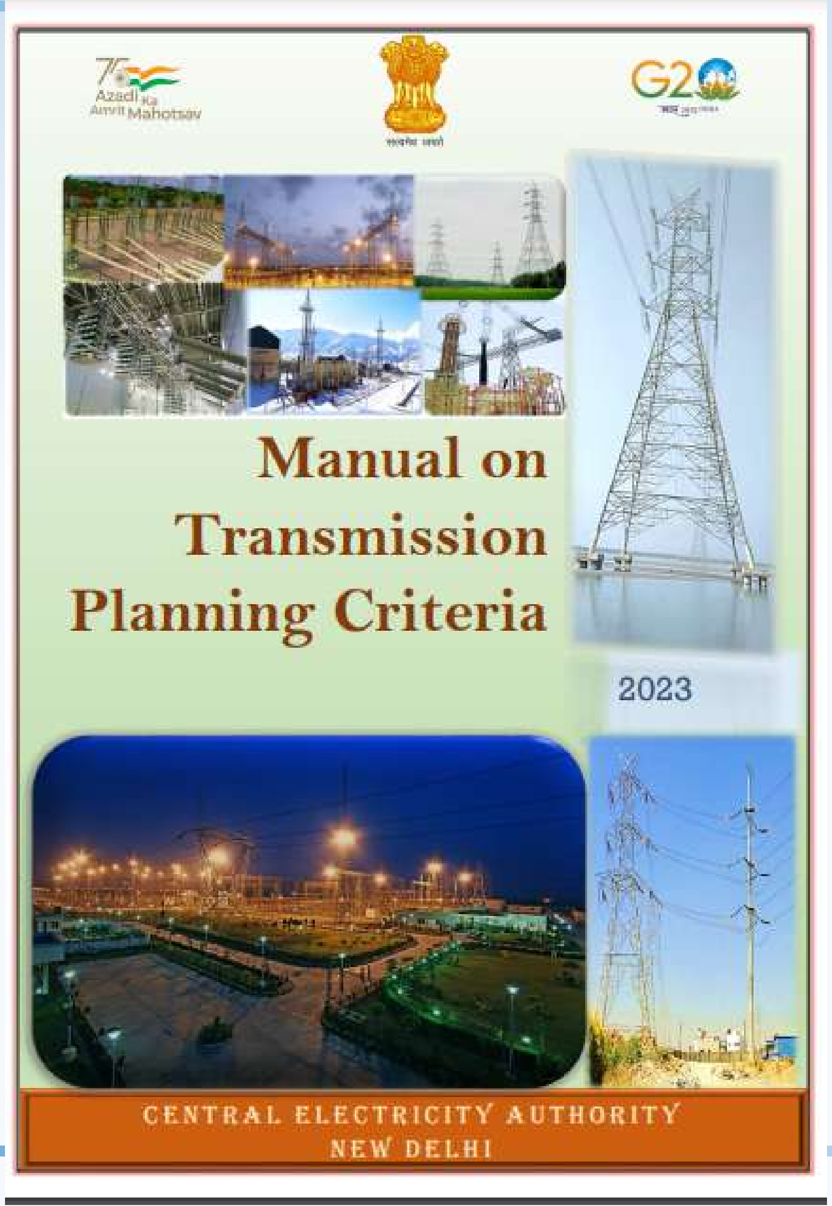
Electricity Regulatory Commission
https://www.erc.gov.np › contents › September2023 PDF

nepal electricity grid code, 2080

SHORT TITLE AND COMMENCEMENT: The name of this **grid code** shall be "**Nepal Electricity Grid Code, 2080**". This may be referred to as "**Nepal Electricity Grid Code** ...

157 pages



3. Transmission Planning: Guidelines

Criteria for transmission planning

केविप्रा
cea

GOVERNMENT OF INDIA
MINISTRY OF POWER
CENTRAL ELECTRICITY AUTHORITY
SEWA BHAWAN, R.K.PURAM
NEW DELHI-110066
Website:www.cea.nic.in
(RA DIVISION)

No. CEA/NRC/RA-2015

Dated 20.2.2015

To

Ms. Shubha Sarma
Secretary
Central Electricity Regulatory Commission,
3rd & 4th Floor, Chanderlok Building,
36, Janpath, New Delhi- 110001

Subject: Progress of National Reliability Council for Electricity (NRCE)

IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors

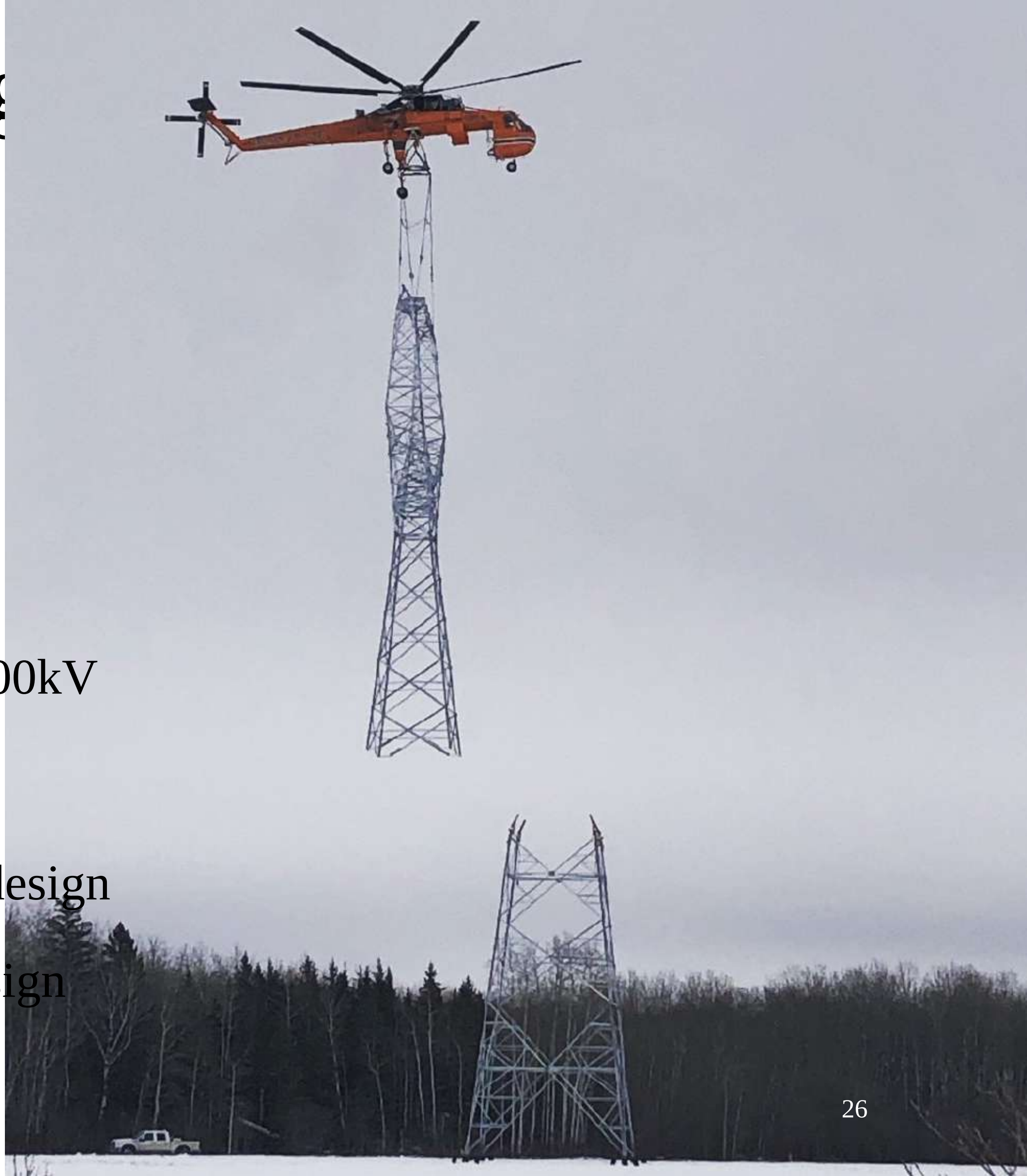
IEEE Power and Energy Society

Sponsored by the
Transmission and Distribution Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 738™-2012
(Revision of
IEEE Std 738-2006/
Incorporates
IEEE Std 738-2012/Cor 1-2013)

3. Transmission Planning



Reliability Guidelines

Normal Condition

- All line: <60% of rated Value
- All bus voltage : >0.95p.u. and <1.05p.u.
- Rotor angle: 30 deg

Contingency (N-1)

- Outage of one circuit of major 220kV or 400kV transmission line
- Fault affecting single circuit
- All bus voltage : >0.95p.u. and <1.05p.u.
- Line loading in the 2nd Circuit: <120% of design MVA
- Line loading in other Lines : <100% of design MVA

3. Transmission Planning: Load Model

Load Model

Load	Voltage Dependency of the system loads	Frequency Dependency of the system loads
Active loads (P)	$P = P_0 \left(V / V_0 \right)$	$P = P_0 \left(f / f_0 \right)$
Reactive loads (Q)	$Q = Q_0 \left(V / V_0 \right)^2$	Q can be taken as independent of frequency. However, if appropriate relationship is known, Q may also be simulated as dependent on frequency, on case to case basis.
(where P_o, Q_o, V_o and f_o are values at the initial system operating conditions)		

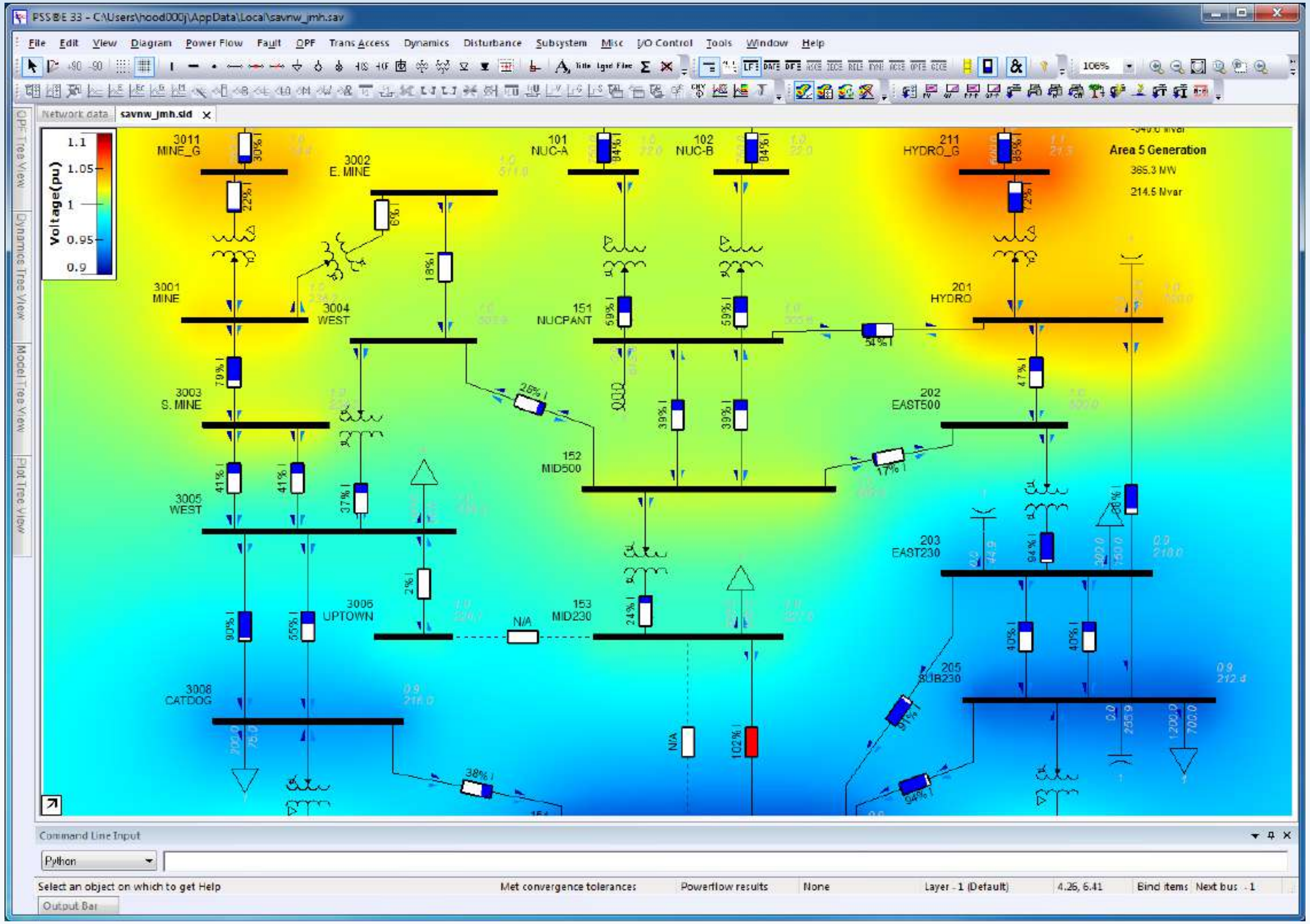
3. TS Planning: Network Analysis

Grid Impact Study (GIS)

- Load Flow Analysis
- PV and QV Analysis
- Short Circuit Analysis
- Transient/Dynamic Analysis

Additional

- Ferranti Effect
- Shut and Series Compensation
    - FACTS Devices



3. Transmission Planning

GIS for transmission planning
- Load Flow study
- Short Circuit Studies
- Stability Studies
- TTC/ATC Calculations

Load Flow Study

Modelling transmission network
- Steady state parameters
- Positive sequence impedance

Short Circuit Study

Terminal voltage: Pre-fault flat voltage
SM: Xd” → sub-transient reactance
Inverter: Xd” → 1-1.2 pu

Stability studies

1) **Rotor angle stability:** angular separation of adjacent rotor

Contingent:
- phase-to-ground,
- phase-to-phase-to-ground,
- or three phases to ground.

Time: 10s

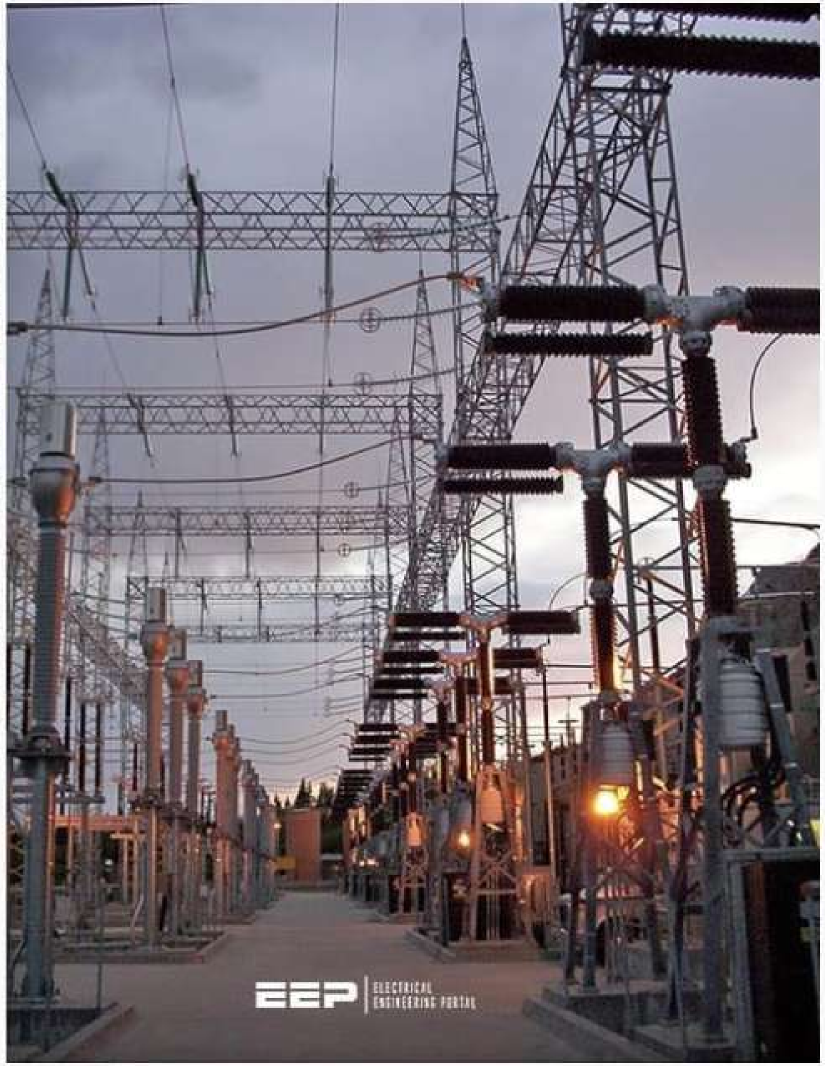
2) Voltage stability

System is voltage
- stable if V-Q sensitivity is positive for every bus and voltage
- unstable if V-Q sensitivity is negative for at least one bus

TTC/ATC Calculations
- TTC: Total power transferable under reliability
- ATC: Set by commercial transaction scheduling

2. Choice of Substation

AIS vs GIS



3. Choice of Substation

Substation: AIS, GIS or Hybrid?

S. No.	Parameters	AIS	GIS	Hybrid
1	Land Requirement	High	Low	Moderate
2	Initial Cost	Low	High	Moderate
3	Civil Cost	Low	High	Low
4	Flexibility	High	Low	High
5	Safety	Low	High	Moderate
6	Reliability	Low	High	Moderate
7	Maintenance Cost	High	Low	Moderate
8	Maintenance Periodicity	High	Low	Moderate
9	Maintenance Hours/year	High	Low	Moderate
10	Breakdown Restoration Time	Low	High	Low
11	Losses	High	Low	Moderate

Thumb Rule: Land Availability

3. Substation: AIS or GIS

Substation:

- Max Fault level: 400 kV (63 kA); 220 kv (50 kA); 132 kV (40 kA)
- Bus bar: Breaker and half (gen and load mix in one diameter)
- Series compensator
  - For long TL
- Shut Compensator
  - Impedance for long TL to avoid Ferranti effect
  - Capacitive Compensator to supply reactive load locally

3. Choice of Conductor

- **AAAC, ACSR or HTLS**

Thumb Rule: Cost, Transmission Route, Upgrade

- ACSR: Noncritical line
- HTLS: High Tower, River crossing, congested corridor, low voltage high power application, Upgrade

3. TL Planning: Conductor

Line Loading Guidelines

- **Thermal Rating:**
  Depends on ambient and maximum allowable temperatures.
- **Temperature:**
  - Plain: 45°C ambient, 85°C max.
  - Hills: 35°C ambient, 85°C max.
- **Normal Line Loading:**
  Up to 60% of Thermal Capacity

Cases

- **Dry:** Winter Peak and Low Gen
- **Wet:** Peak Generation and Low Load

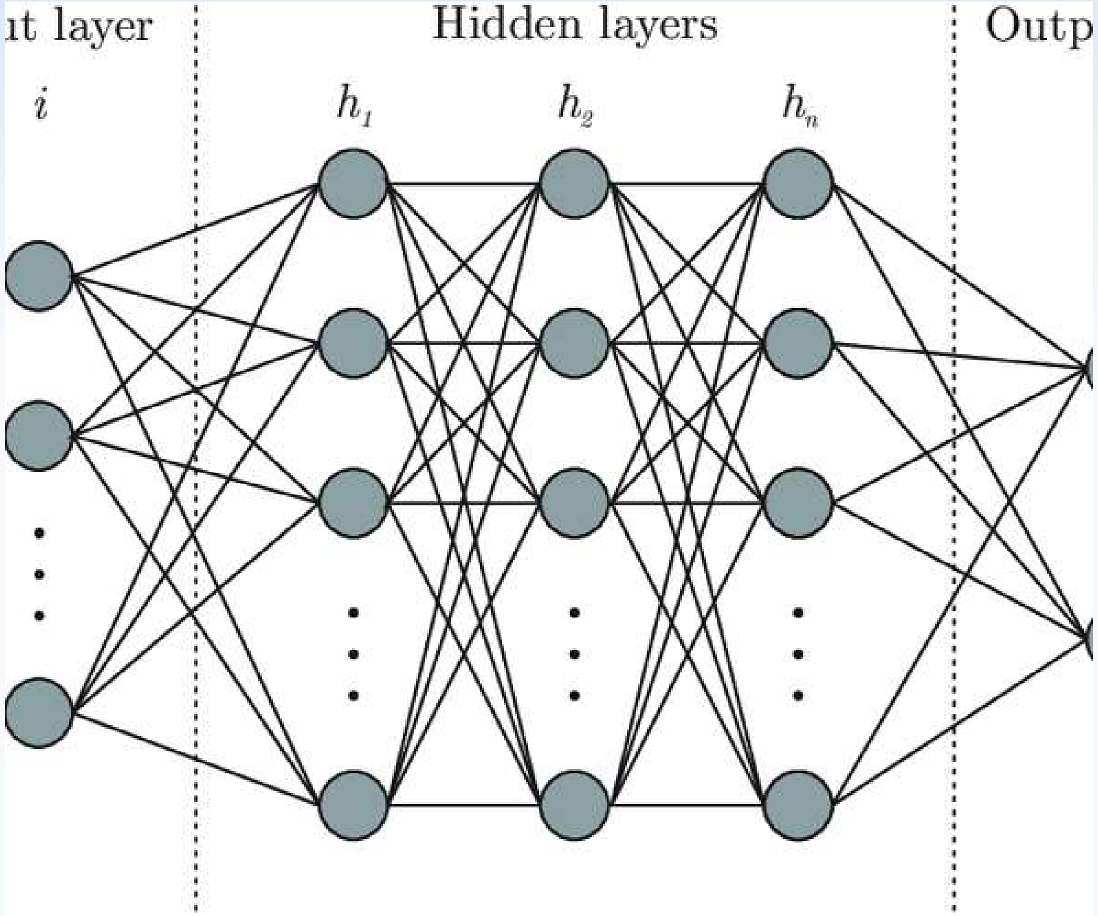
3. Transmission Planning: Guidelines

Conductor current Carrying capacity

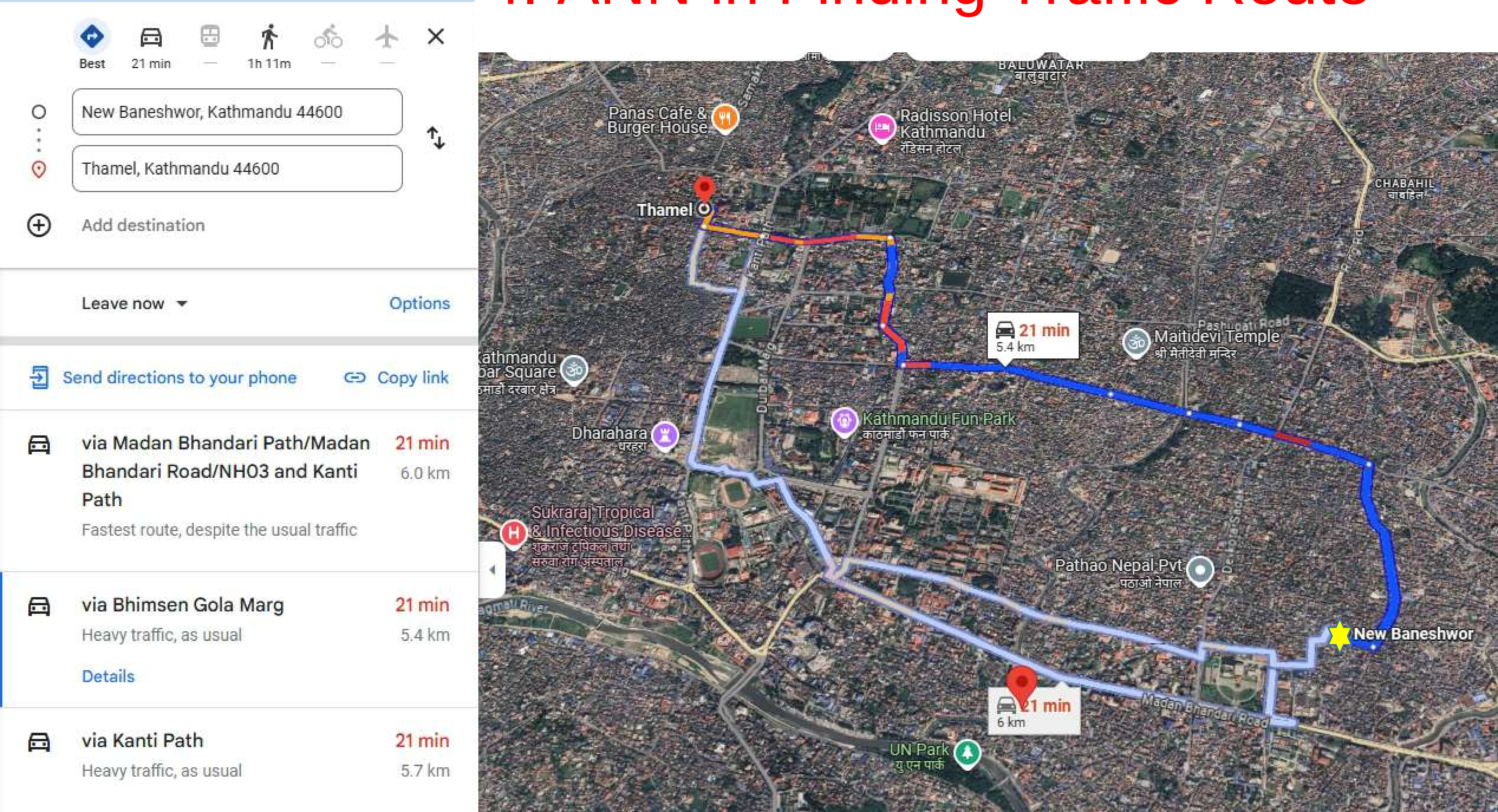
Conductor	Current Carrying capacity@35/85 (A)	Current Carrying capacity@45/85 (A)
Bear	542	485
Duck	696	623
Cardinal	975	872
Bison	711	636
Moose	906	798

4. Transmission Planning: AI tools

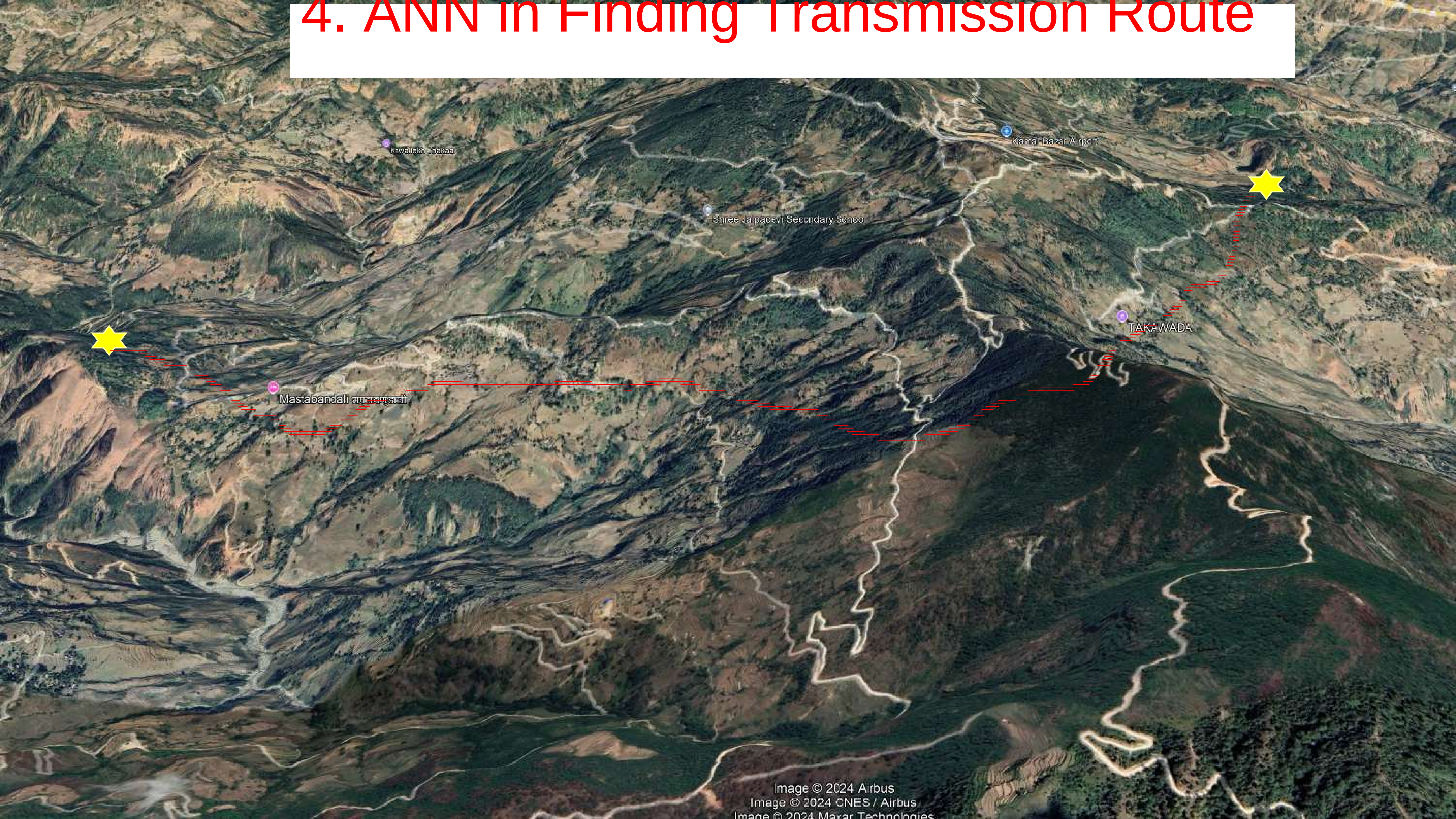
- Artificial Neural Network
  - Transmission Line Routing
- Digital Twins
  - Design and Prototype Testing
  - Line Operation & Maintenance



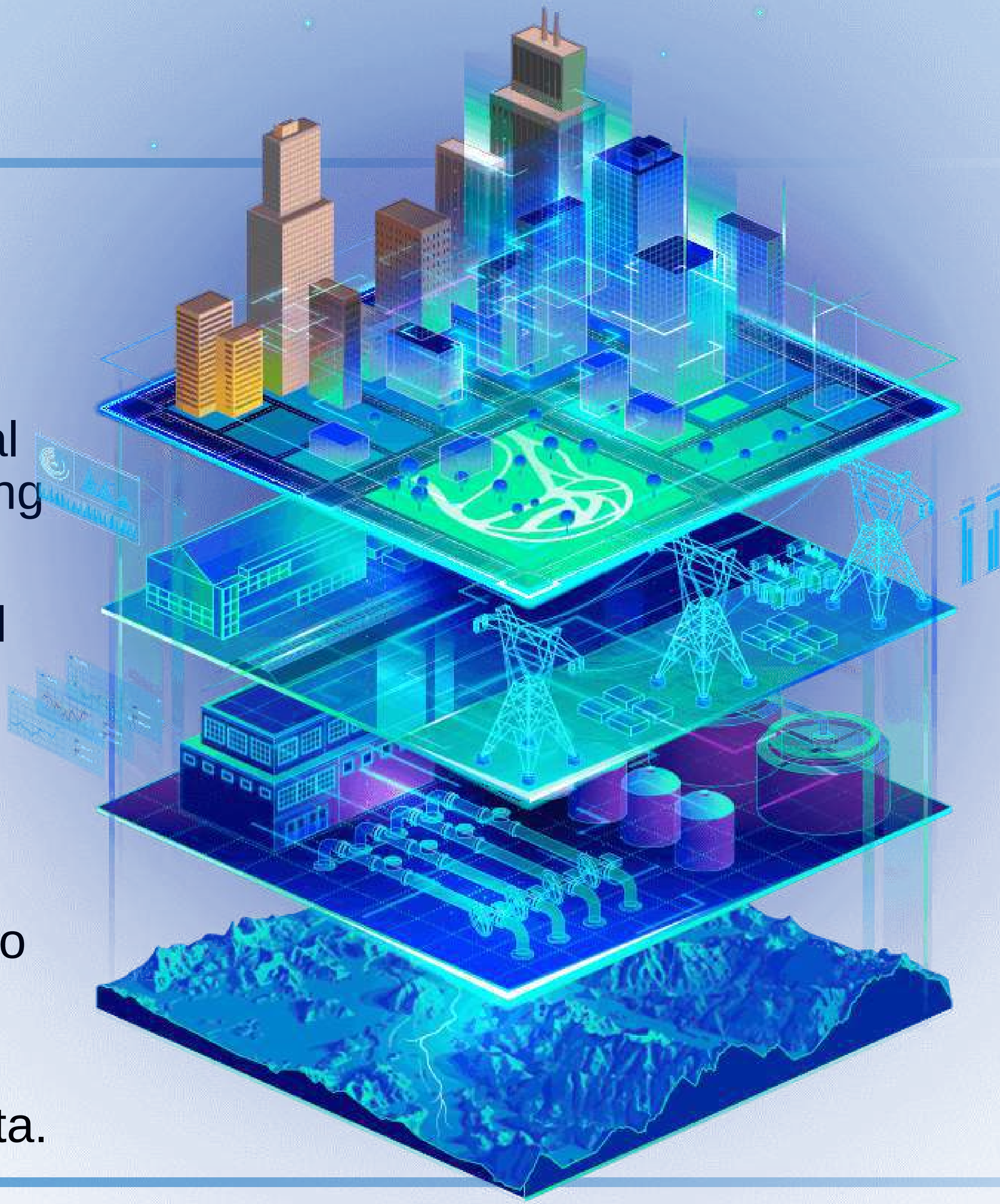
4. ANN in Finding Traffic Route



4. ANN in Finding Transmission Route



4. Digital Twins of Transmission Lines



Creating Digital Twins of Transmission Lines

- **Data Collection** : Gather real-time and historical data (environmental, operational, physical) using sensors.
- **Model Development** : Develop a computational model representing the physical transmission line.
- **Integration** : Link collected data to the digital model for real-time updates.
- **Simulation and Analysis** : Simulate scenarios to predict issues and optimize performance.
- **Validation and Calibration** : Continuously validate and calibrate the model with actual data.
- **Application** : Use for asset management,

4. Digital Twins for TL: Grid O&M

Digital twins allow operators to monitor the data collected from grid components in real-time, providing a comprehensive view of the network’s performance. This includes:

- Gaining accurate visibility on the load flow even at low voltage levels where most solar energy, for example, is injected
- Identifying congested areas,
- Monitoring the health of critical portions
- **Identifying the DLR of Transmission Line**
- Study the impact of Renewable integration

4. Output of Transmission Planning

- **Construction Schedule**
- **Project cost**
- **O&M cost**
- **Annual transmission charges**
- **Expected Benefit**

Thank You!!
Q&As

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14-16 Oct, 2025

Session 1.4
Transmission System Plan: Regional Perspective

Presented By

Dr Netra P. Gyawali

Former CEO, National Transmission Grid Co Ltd
Associate Prof. IOE, Tribhuvan University

Date: 10/14/2025

Transmission System Plan: A Case of Nepal

Content

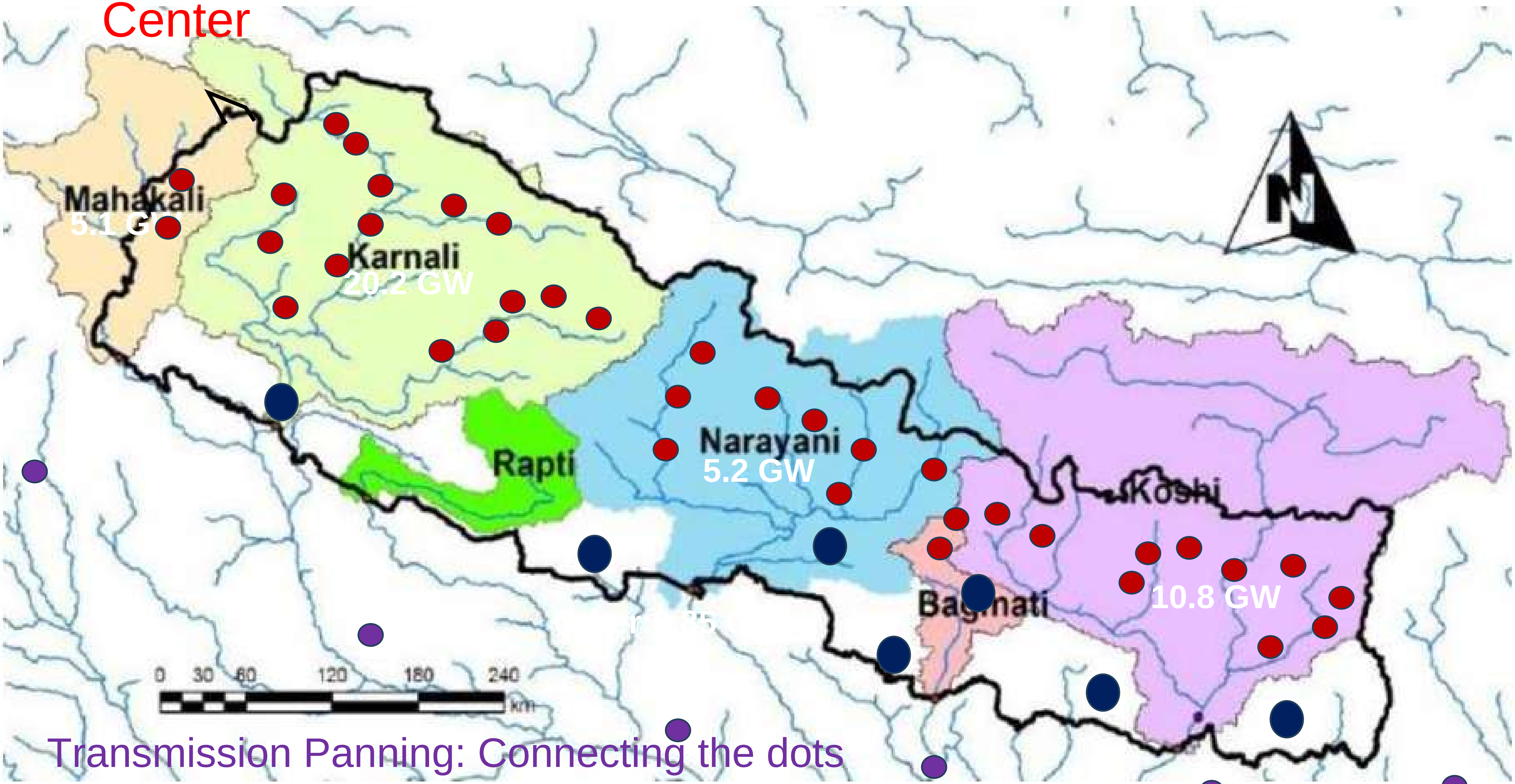
1. TS Planning in Nepal: Generation

Hydropower Potential

Major River Basins	Theoretical Potential in MW			Technical Potential		Economical Potential	
	Major river courses having catchments areas above 1000 km^2	Small river courses having catchments areas 300-1000 km^2	Total	Number of Project Sites	Technical Potential in MW	Number of Project Sites	Economical Potential in MW
Sapta Koshi	18750	3600	22350	53	11400	40	10860
Sapta Gandaki	17950	2700	20650	18	6660	12	5270
Karnali and Mahakali	32680	3500	36180	34	26570	9	25125
Southern River	3070	1040	4110	9	980	5	878
Country Total	**72450**	**10840**	**83290**	**114**	**45610**	**66**	**42133**

With 3100 MW under operation, More than 90% Capacity remain untapped

1. TS Planning in Nepal: Generation and Load Center



Transmission Panning: Connecting the dots

राष्ट्रिय प्रसारण लाइनको गुरुयोजना तयार
सेतोपाटी संवाददाता
काठमाडौं, असार १७
सेतोपाटी
२२ वर्षको योजना सहित प्रसारण लाइन गुरु
सार्वजनिक
क्लिकमाण्डु
प्रकाशित मिति : १७ असार २०७५, आइतबार १८:३९
57 Shares

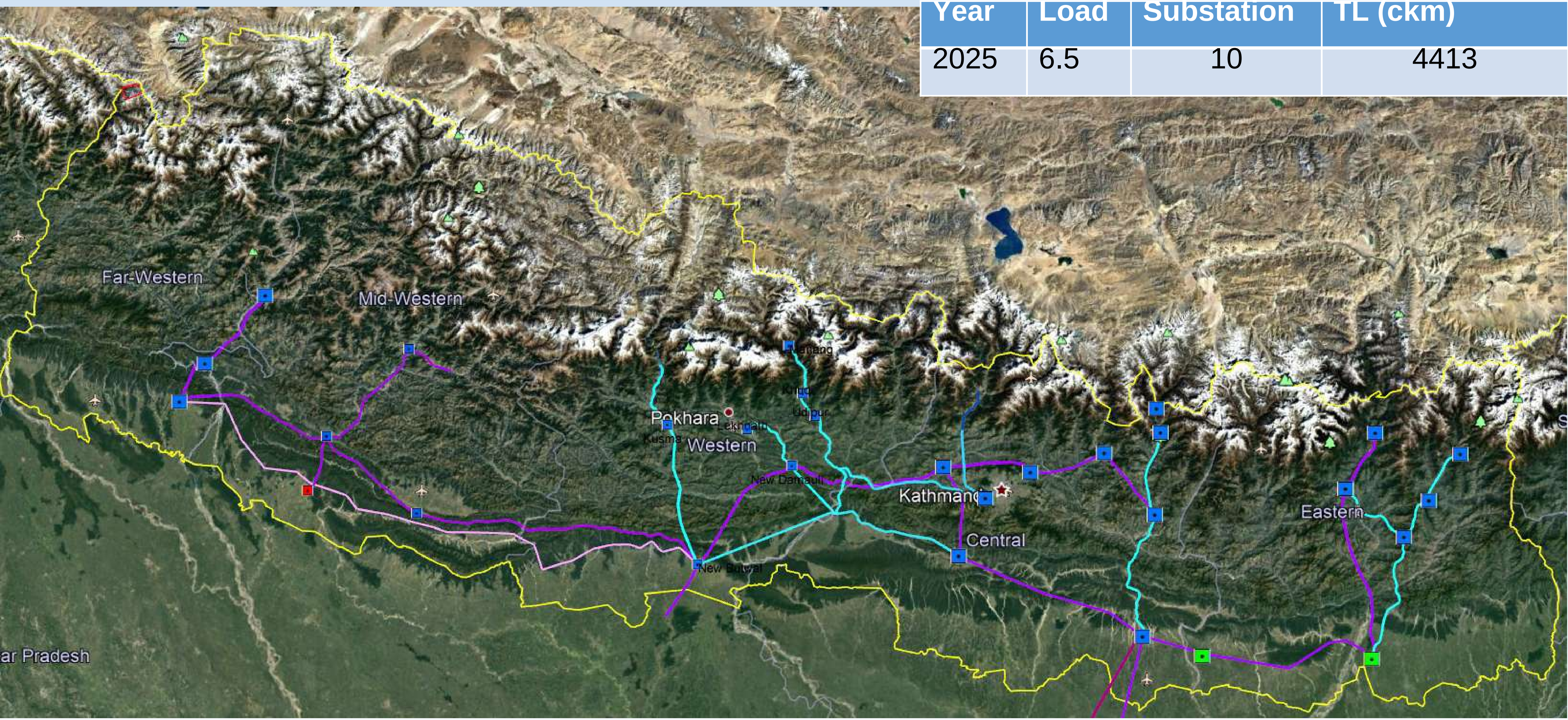
TS Master Plan(R1)

प्रसारण ग्रीड कम्पनीले तयार गर्‍यो १५ वर्षे 'प्रसारण लाइन गुरुयोजना' : ९१० अर्ब लगानी चाहिने

ऊर्जा खबर २०८१ भदौ १९

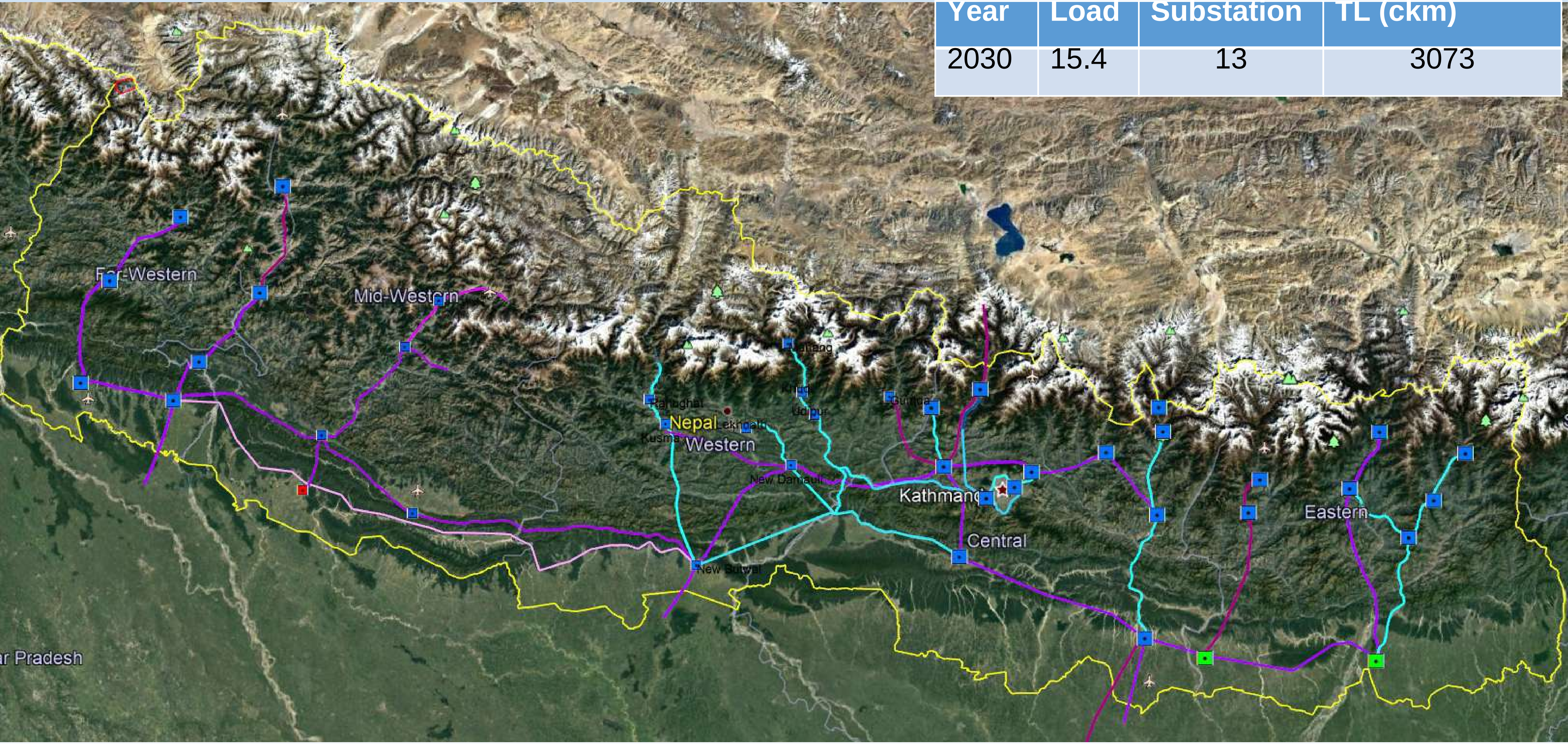
1. TS Master Plan(Year 2025)

Year	Load	Substation	TL (ckm)
2025	6.5	10	4413



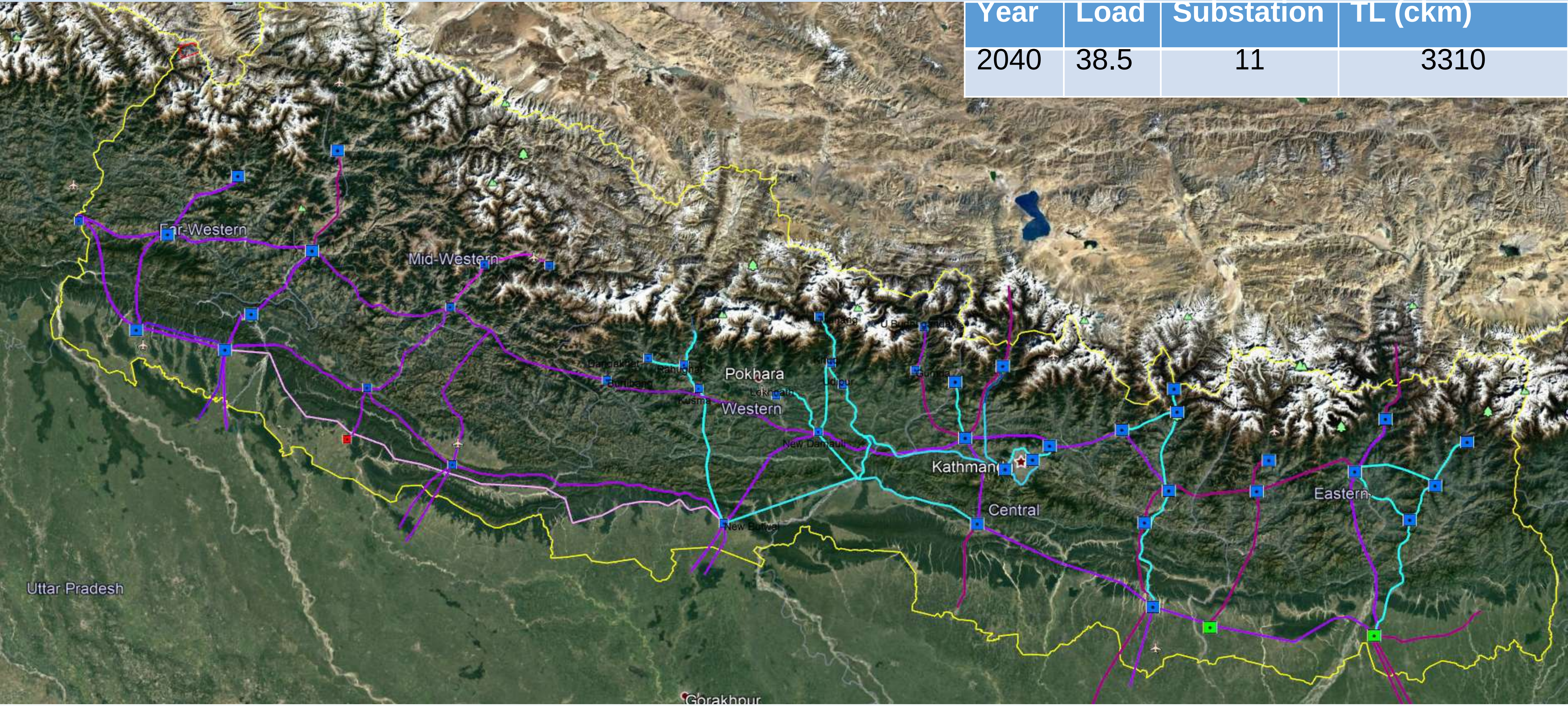
2. TS Master Plan (Year 2030)

Year	Load	Substation	TL (ckm)
2030	15.4	13	3073

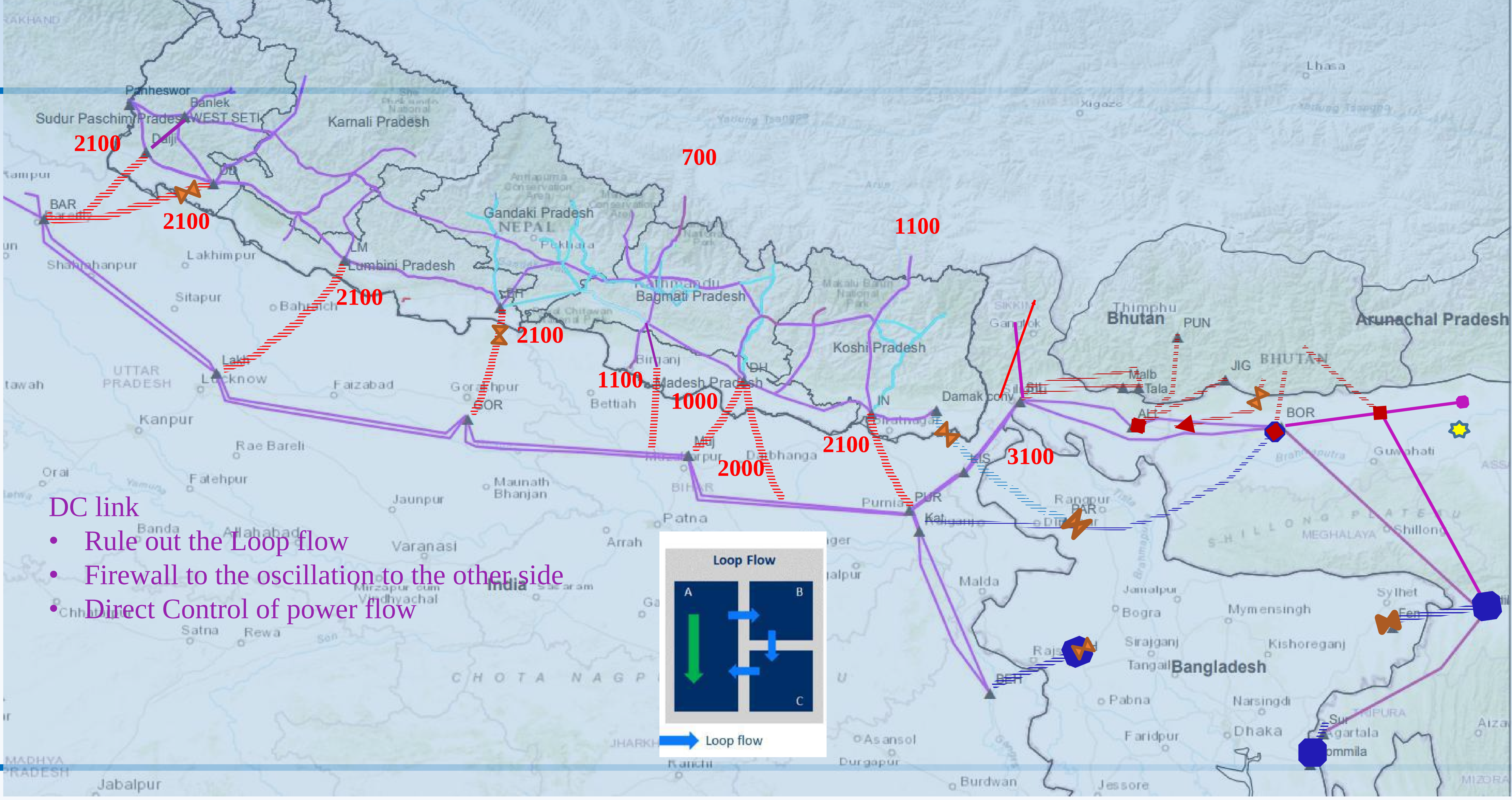


3. TS Master Plan (Year 2040)

Year	Load	Substation	TL (ckm)
2040	38.5	11	3310



1. Cross Border Lines



DC link

- Rule out the Loop flow
- Firewall to the oscillation to the other side
- Direct Control of power flow

2. TS Master Plan: Contingency Analysis

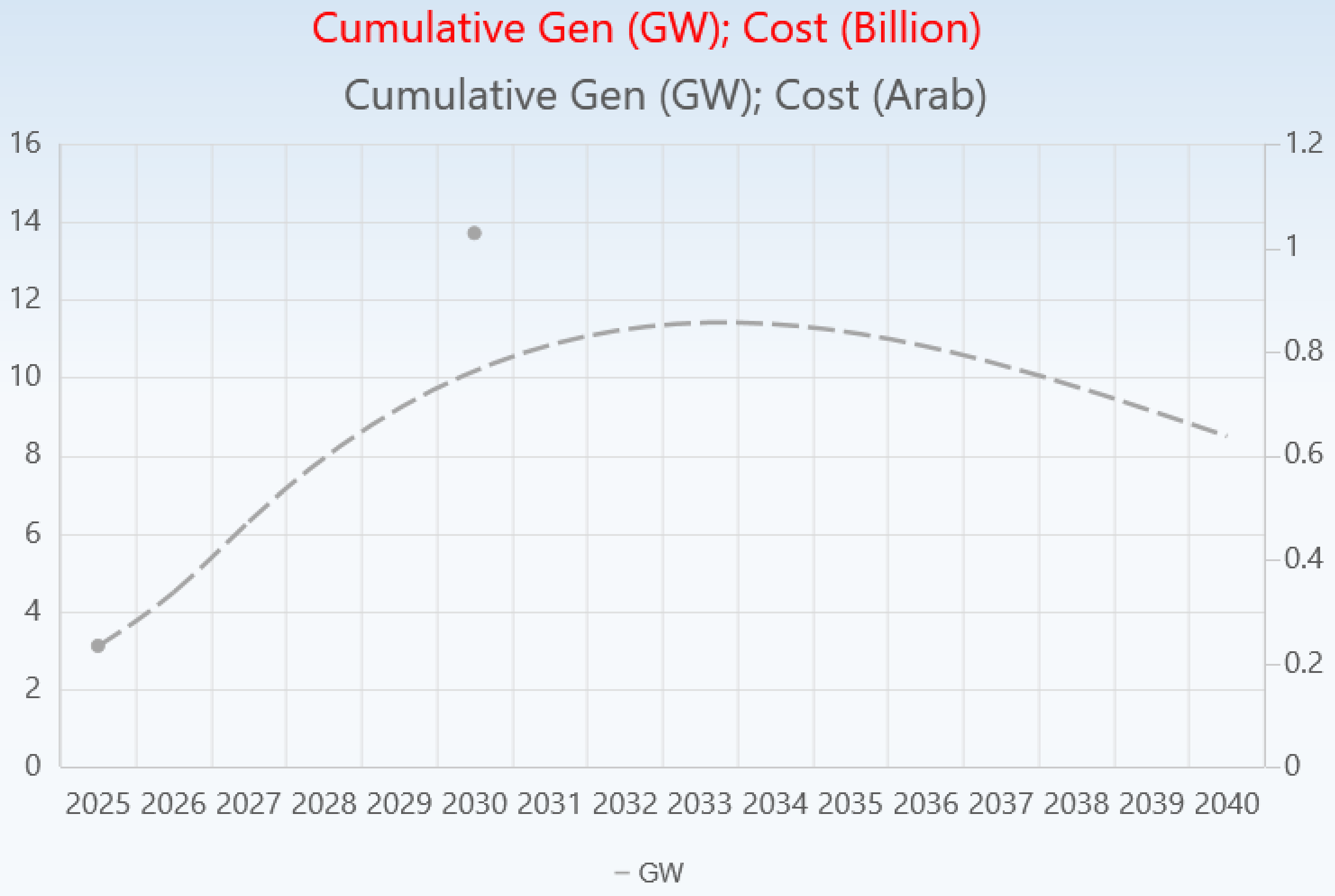
Contingency Mitigation Approaches

- Load Redistribution:
  Shift load from 220 kV to 400 kV networks to reduce overload risks.
- Line Upgrade
  Upgrade overloaded lines with High-Temperature Low-Sag (HTLS) conductors.
- FACTS Devices:
  Use devices like SVC or STATCOM for voltage stability and power flow control.
- Modern Technologies:
  Employ Dynamic Line Rating (DLR) for real-time monitoring of transmission capacity.

2. Financial Requirements

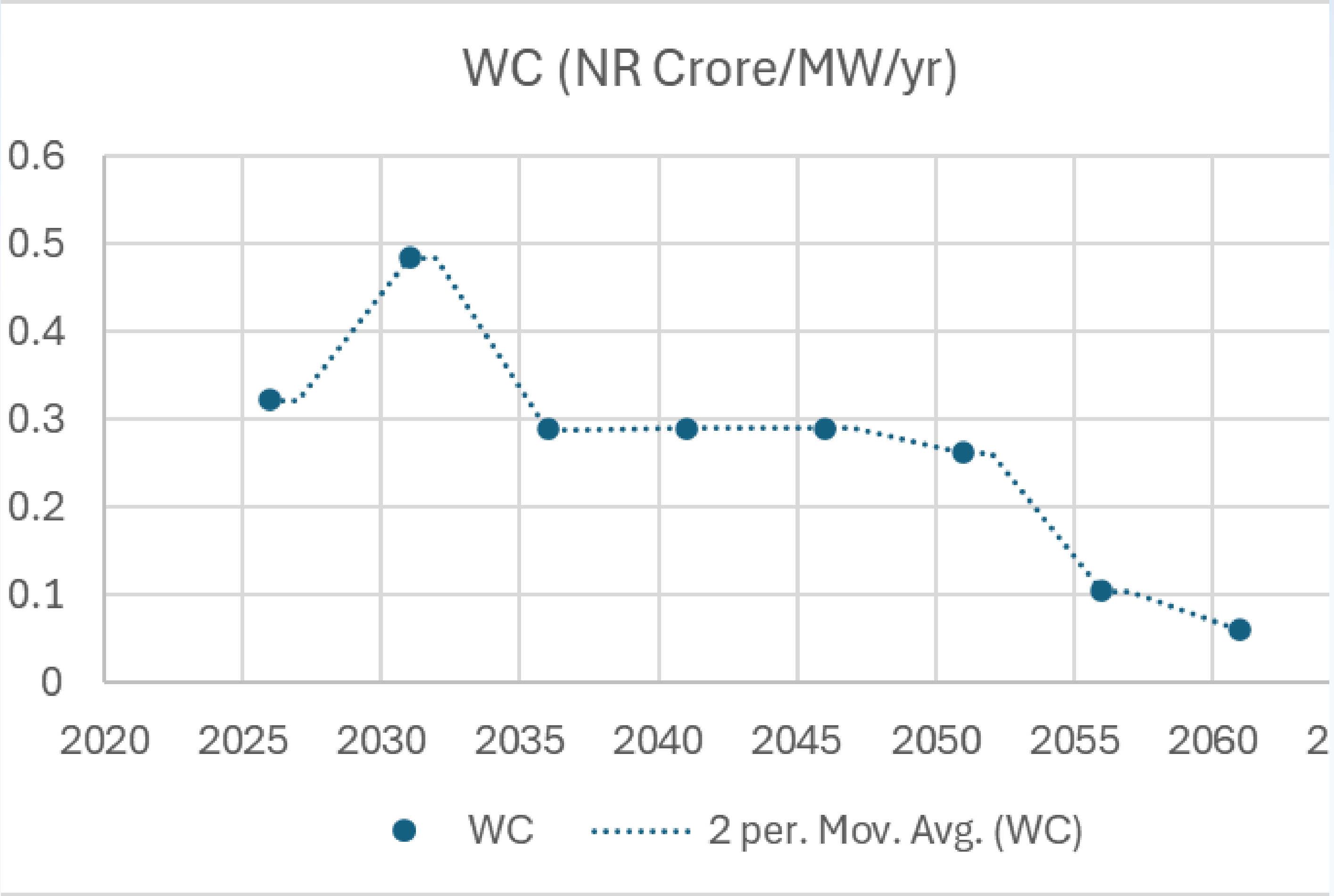
Input (Cost,Bn)		Output (ckm, Trans, Reactor)
910	Yr 2040	17035 ckm, 35622 MVA, 5610 MVAR
720	Yr 2035	13814 ckm, 32168 MVA, 4525 MVAR
580	Yr 2030	11327 ckm, 29278 MVA, 3340 MVAR
150	Yr 2025	5993 ckm, 13050MVA, 749 MVAR

2. Financial Requirements



Year	NRs (Billion)	GW
2025	140	03.1
2030	490	13.5
2035	140	28.5
2040	190	39.1

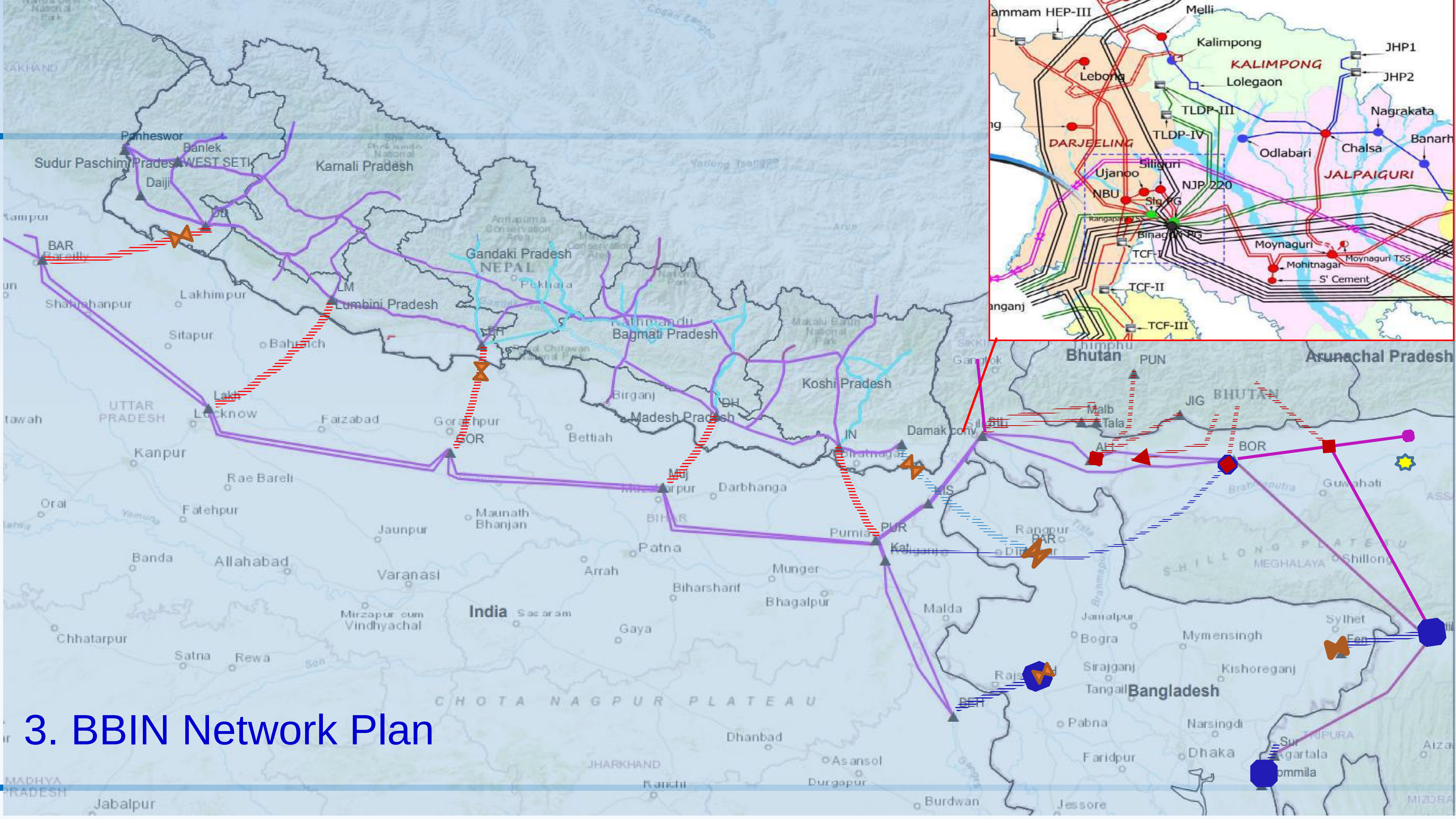
2. Financial Requirements: WC



- Average: 26 (Lakh/MW.yr)

BBIN Grid

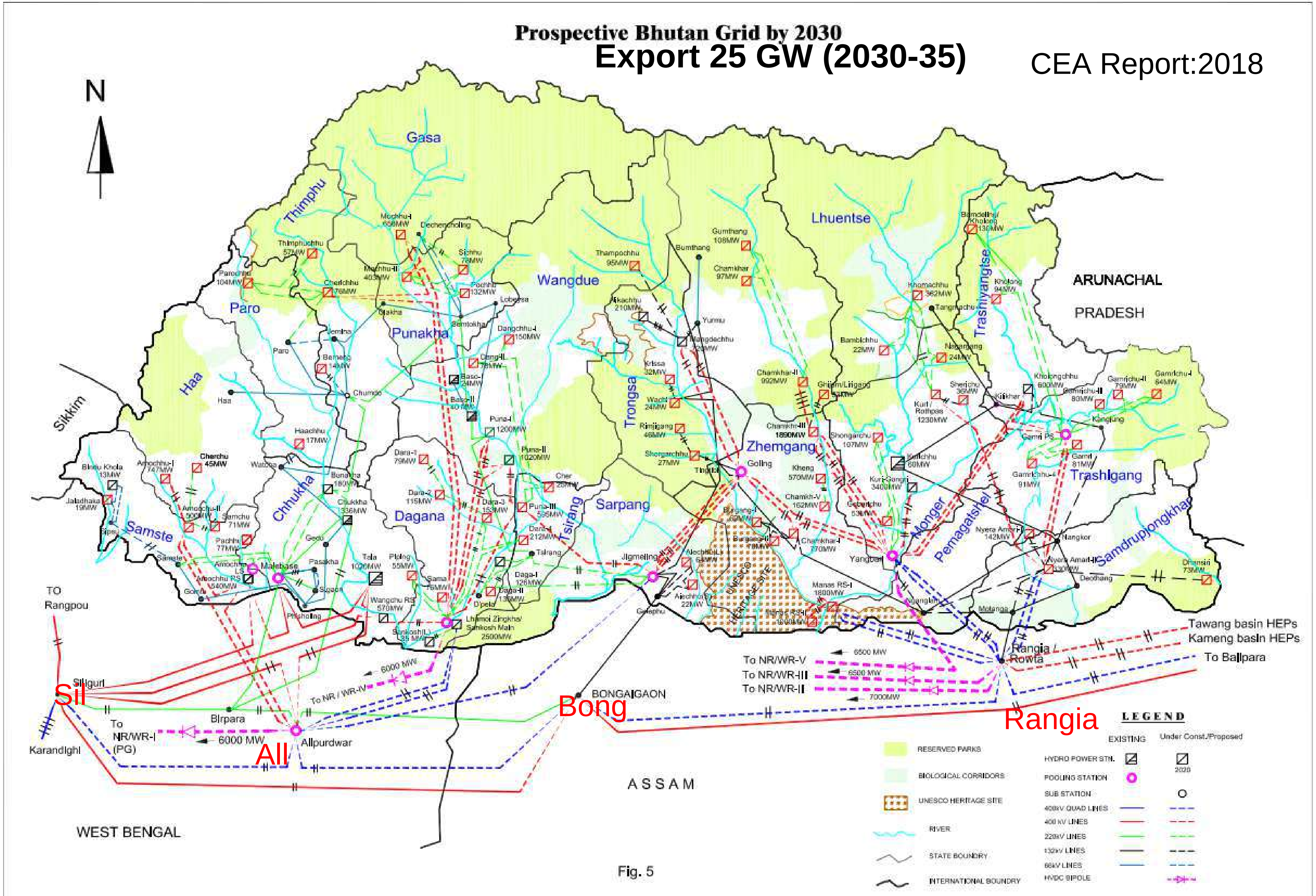
3. BBIN Network Plan



3. Nepal-India X-Border Link

Name of the Link	Key Features of the Line	Associated generation projects
Attariya-Bareily	Single line of double circuit 400kV quad Moose transmission line of distance about 140 KM	From export-oriented HPP in the Mahakali, Karnali and Seti corridors in Zone-1 area of Nepal
Dododhara–Bareily	2 No. of double circuit 400kV quad Moose transmission line of distance about 200 KM	From export-oriented HPP in the Mahakali, Karnali and Seti corridors in Zone-1 area of Nepal
Phulbari–Lukhnow	2 No. of double circuit 400kV quad Moose transmission line of distance about 200 KM	Evacuating the power from Nalsyau Gad, Bheri Corridor in Zone-2 of Nepal to Lukhnow, India
New Butwal–Gorakhpur	2 No. of double circuit 400kV quad Moose transmission line of distance about 125 KM	Evacuating the power from Marsyandi, Kaligandaki and Gandaki Corridor in Zone-3 of Nepal to Gorakhpur
Dhalkebar – Muzzafarpur	2 No. of double circuit 400kV quad Moose transmission line of distance about 130 KM	evacuating the power from Khimti, Tamakoshi and Dudhkoshi Corridor in Zone-4 of Nepal to Muzafarpur
Inaurwa – Purnea	2 No. of double circuit 400kV quad Moose transmission line of distance about 110 KM	evacuating the power from major corridor likes Arun and Koshi in Zone-5 of Nepal to Purnea, India

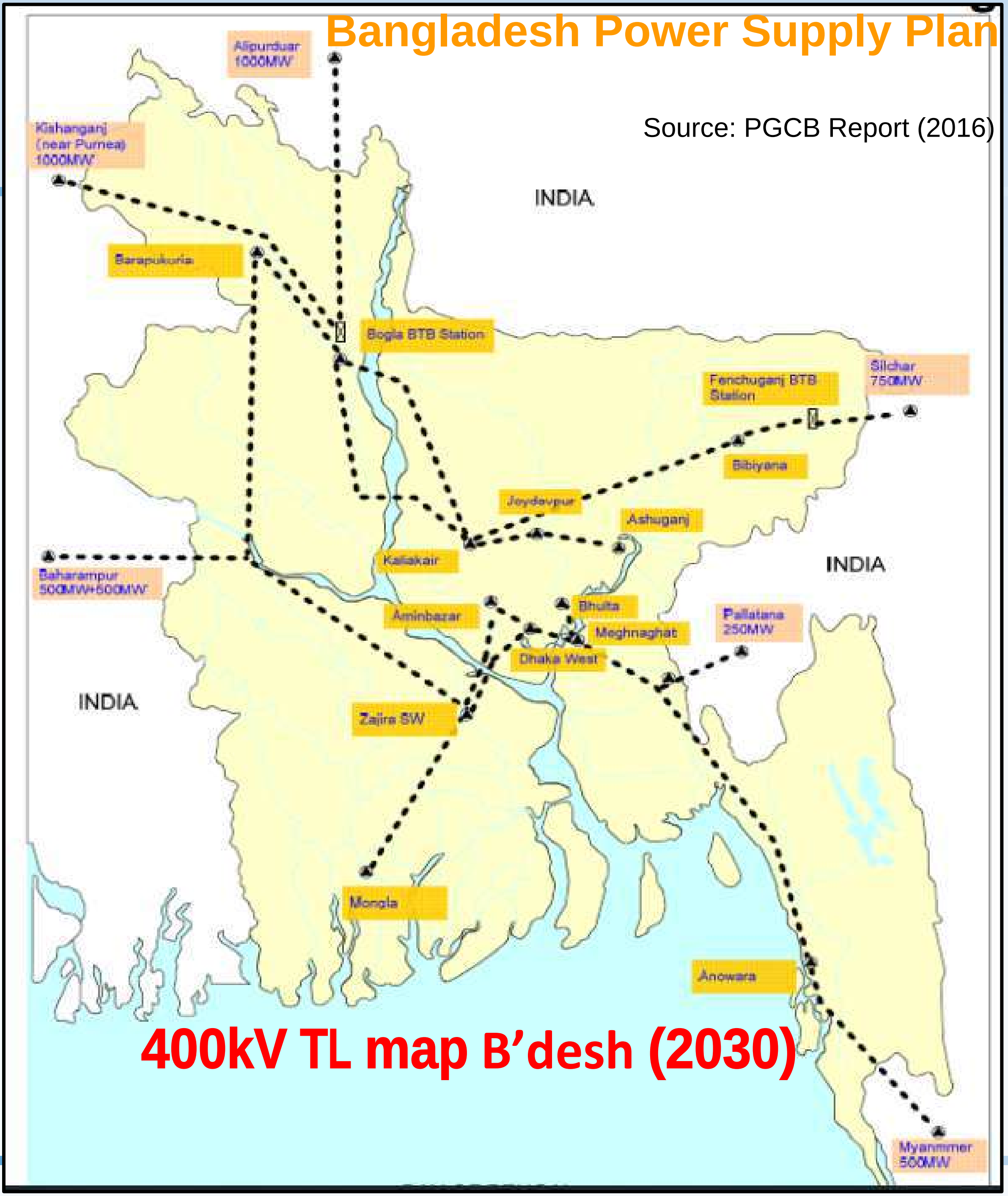
2. Transmission Master Plan: Bhutan



2. Power Supply Plan: Bangladesh

Name of Interconnection	Power Import (MW) by Year 2015	2020	2025	2030
Bheramara – Bahrampur	500	500	1,000	1,000
Myanmar - Bangladesh	0	500	500	500
Palatana - Comilla	0	0	250	250
Shilchar - Fenchuganj	0	0	750	750
Kishanganj - Bogra (Hydro Power from Nepal)	0	0	500	500
Alipurduar - Bogra (Hydro Power from Bhutan)	0	0	500	500
Total	500	1,000	3,500	3,500

	Demand forecast Government Policy	Considering GDP: 06%	Considering GDP: 07%	*Generation Plan* Gen. Capacity Present Proposition
2015	10 GW	8 GW	9 GW	18.2 GW
2020	18 GW	10 GW	13 GW	22.5 GW
2025	25 GW	14 GW	19 GW	29.3 GW
2030	33 GW	18 GW	28 GW	38.3 GW

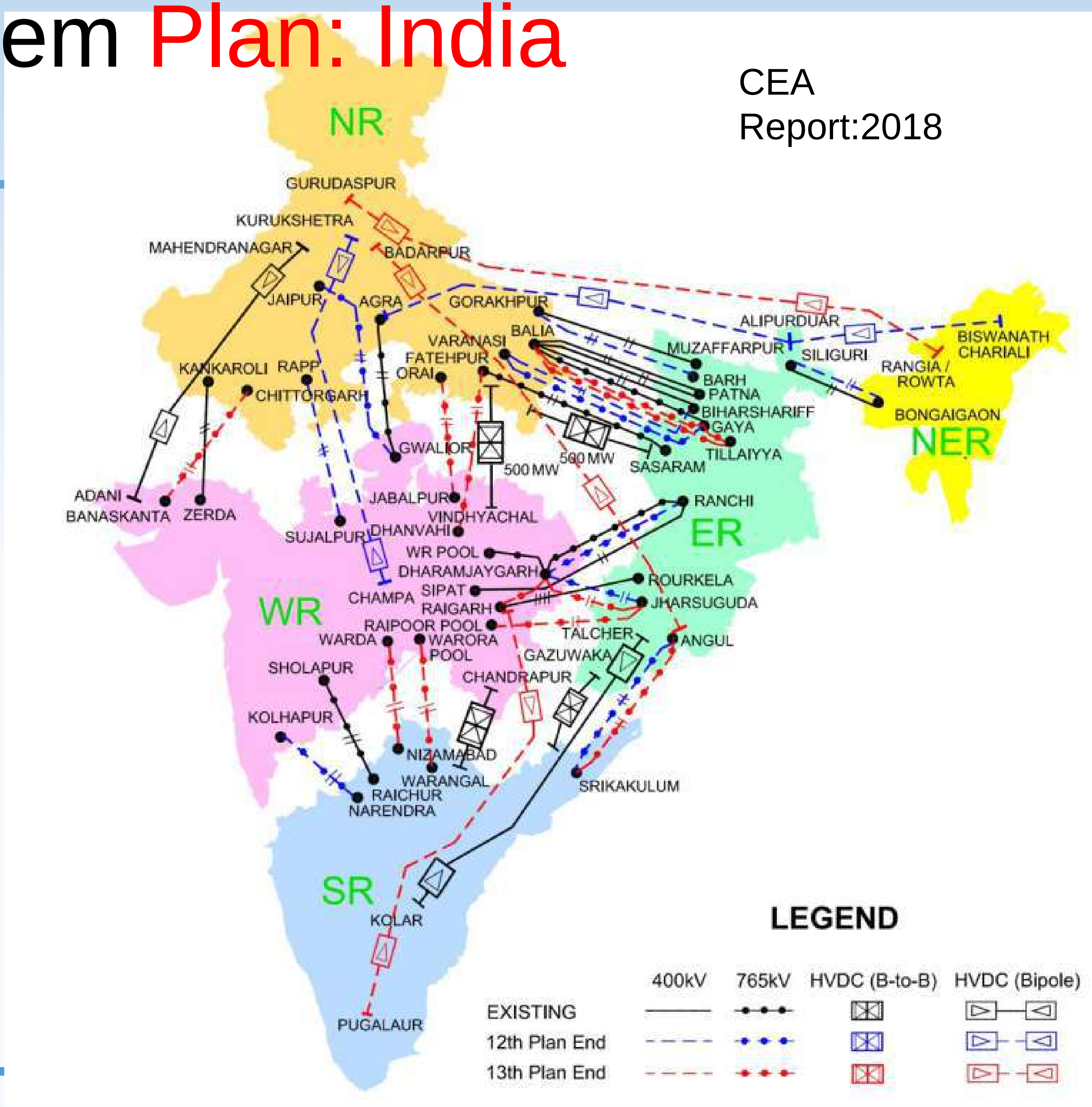


3. Transmission System Plan: India

CEA Report:2018

Inter State	Power (MW)		% Load
	Pmax	TTC	
ER-NR	2784	22530	12.36
ER-WR	-3120	21190	14.72
ER-SR	4327	7830	55.26
WR-NR	16731	36720	45.56
WR-SR	8095	23920	33.84
NER-ER	-3033	5860	51.76

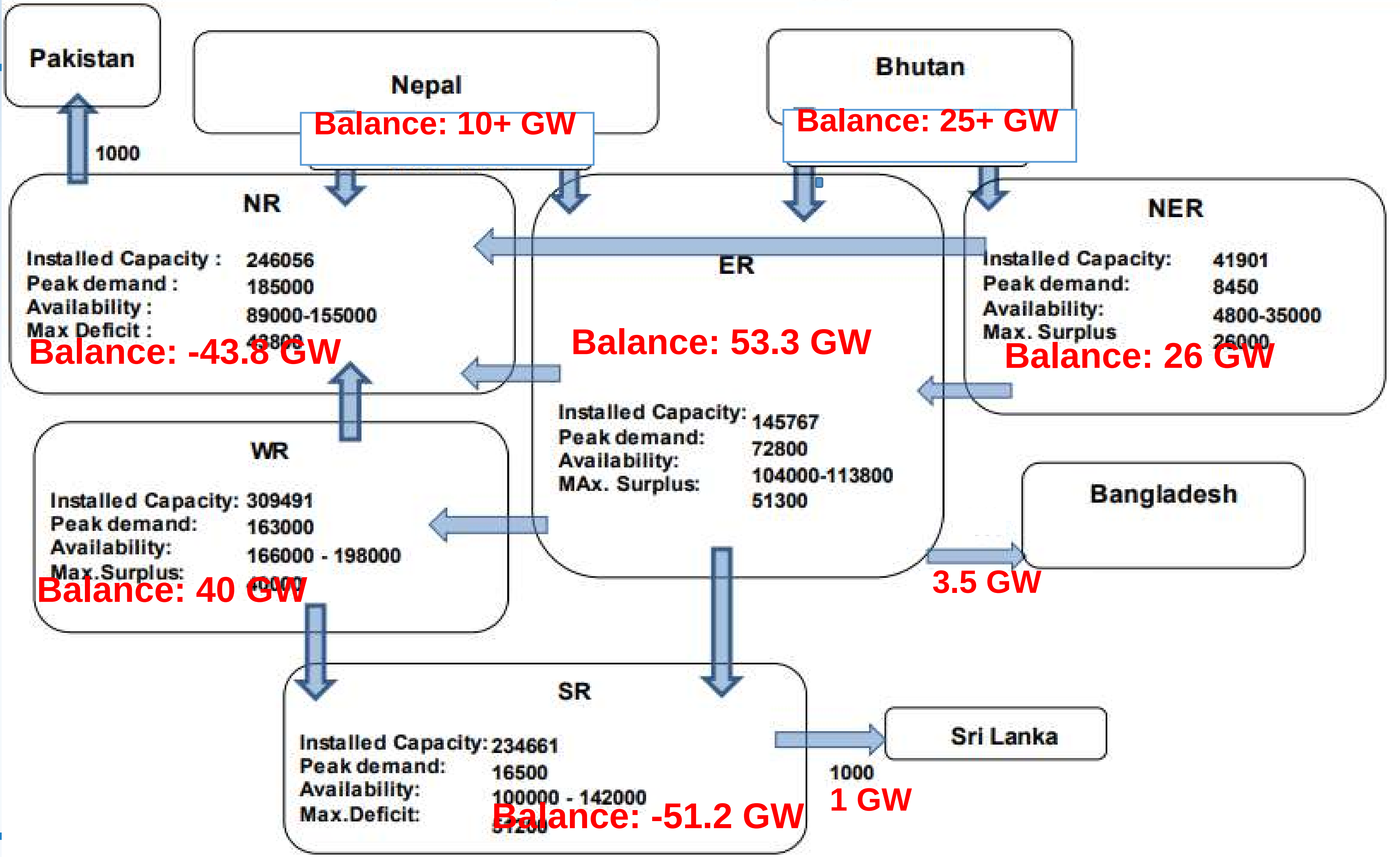
Source: Perspective Transmission Plan for Twenty Years (2014-2034), MoP, India



3. Transmission Grid:

BIN X-Border Grid

BBIN Grid: How much X-Border Power can Indian Grid Handle?



3. Summary

A Strategic Roadmap to Elevate Nepal's Transmission Infra

- **Elevate TS to Accommodate prospective Generation Expansion and Demand with;**
  - Compliance with standard contingency criteria
  - Accommodates PV integration: Solar Peak and Load Peak in different time
- **Roadmap with Budget Plan for year 2030, 2035 and 2040**

BBIN Grid Plan

Thank You!!


Integration of Renewables into the Grid: Challenges and Opportunities

Agenda

- Overview of Renewables and Grid Integration
- Issues of Integration
- Mitigating the Issues
- Interconnection Layout: Power Electronic Interfaces
- International Codes and Practices
- RES and Transmission Planning
- Conclusion and Q&A

Overview

- Renewables (solar, wind, hydro, biomass) provide clean, sustainable energy.
- Global share: ~30% of electricity in 2025, projected 50% by 2030.
- Grid integration: Connecting variable renewable energy sources (VRE) to existing AC grids.
- Drivers: Climate goals (e.g., Net Zero by 2050), energy security, cost reductions.

Overview of RES Integration

- **Context**:
  - RES rapidly expanding to meet decarbonization goals
  - Targeting at least 10s of TW of new capacity by 2035.
  - Requires transforming transmission planning to handle variable, remotely located RESs.
- **Core Issue**:
  - Transmission Planning should evolve from centralized plants evolve to accommodate distributed and intermittent RES, ensuring reliability while minimizing costs.
- **Opportunity**: Enhanced transmission can unlock economic benefits:
  - May Reduce system costs,
  - Reduce transmission Loss
  - Reduce CO_2 emission
  - Energy Security

Overview of Renewable Integration

- **Depth Insight**:
    - Integration involves not just adding lines but rethinking planning horizons
    - extending from 10-15 years to 20-30 years
    - account for uncertainties in RES growth, electrification, and climate impacts

Overview of RES Integration

Key Challenges in Transmission Planning

Challenge	Technical Impact	Example
Variability	Increased curtailments and energy not served	Solar output drops during cloudy periods, requiring backup transmission paths.
Geographic Mismatch	Higher transmission losses over distances	Wind farms in Midwest need HVDC to reach East Coast loads.
Infrastructure Barriers	Delayed interconnections	600+ GW backlog due to insufficient planning coordination.

What is Grid Integration?

Process of incorporating renewables into the electric grid without compromising reliability.

Involves synchronization, control, and balancing supply-demand.

Key components: Inverters, transformers, control systems.

Types: Distributed (rooftop solar) vs. Utility-scale (wind farms).

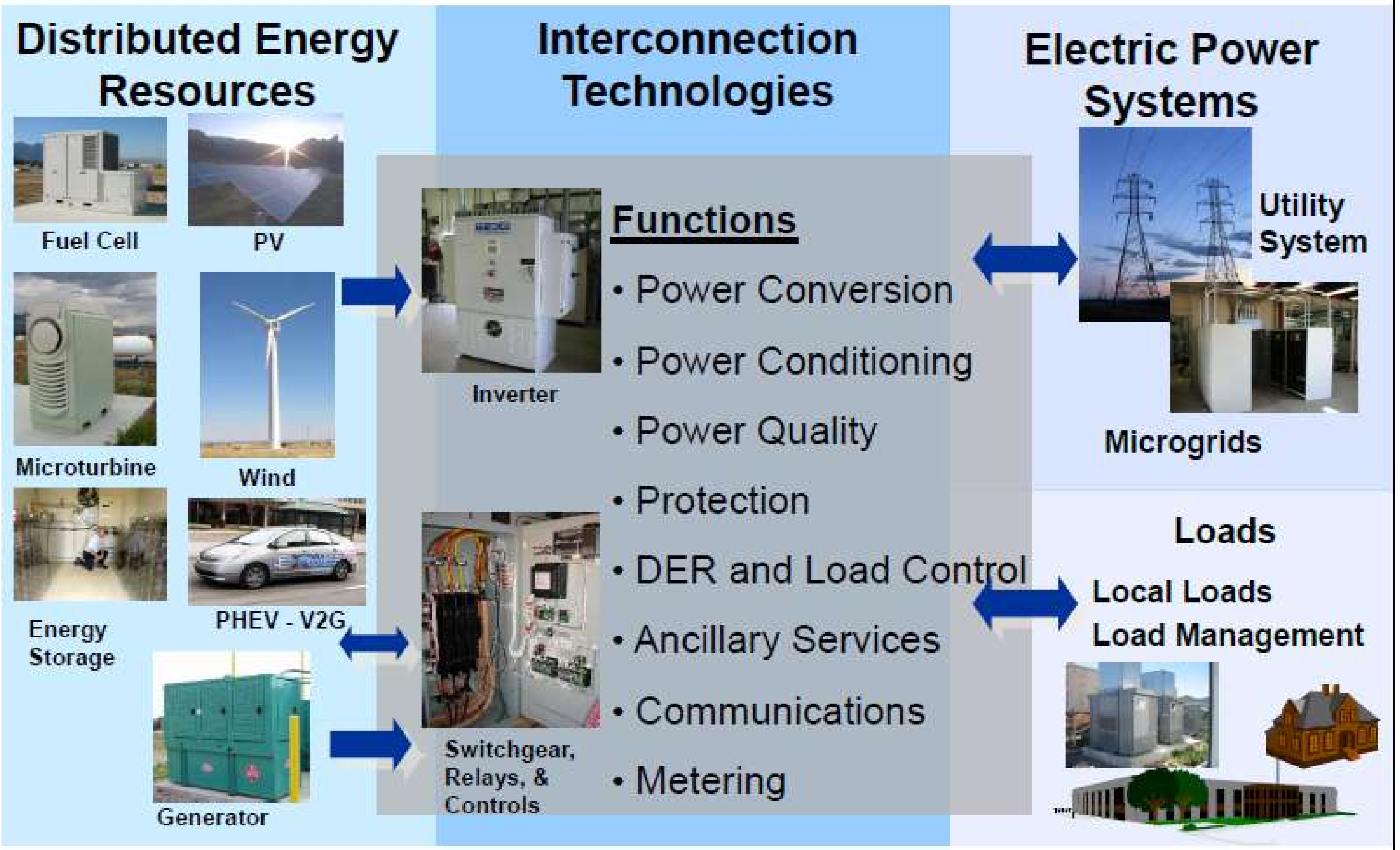
Overview of RES Integration

What is Integration?

- Integration is the addition of RES to the power grid at the system level. Important integration issues are:
  - Protection systems
  - Connection standards
  - Power electronics
  - Power quality issues
  - Simulation and computer modeling

Overview of RES Integration

Integration Function



Network Issues with interconnection

- Forecasting errors lead to over/under-supply
- High penetration (>20%) amplifies issues in weak grids.
- Grid instability: Frequency deviations, voltage swings.
- Voltage profiles change along the network, depending on how much power is produced and consumed at that system level
- Voltage transients will appear because of connection and disconnection of generators or even because of their operation

Network Issues with interconnection

- Load losses change as a function of the production and load levels
- Power quality and reliability may be affected
- Short circuit levels are increased
- Utility protection and DG protection measures must be coordinated.

Issues with interconnection

Network voltage changes

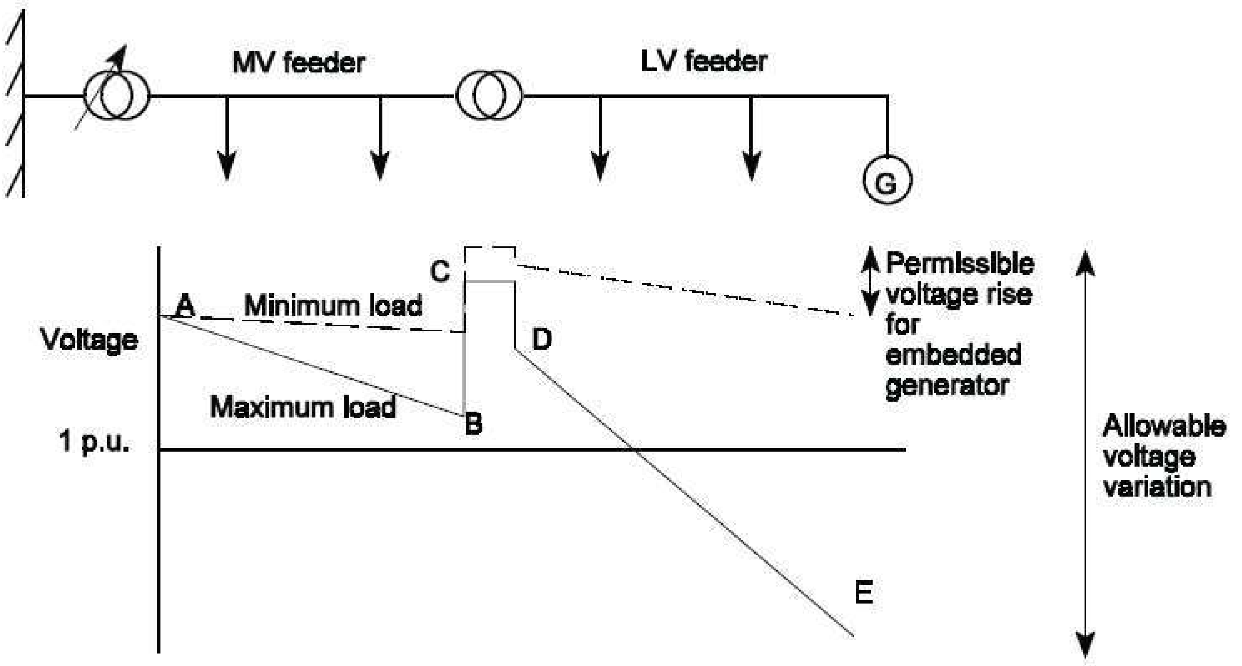


Figure 1.6 Voltage variation down a radial feeder (after Reference 8)

A	voltage held constant by tap-changer of distribution transformer
A–B	voltage drop due to load on MV feeder
B–C	voltage boost due to taps of MV/LV transformer
C–D	voltage drop in MV/LV transformer
D–E	voltage drop in LV feeder

Network voltage changes

- Voltage drop equation

$$\Delta V = (PR + XQ)/V$$

where
P = active power output of the generator
Q = reactive power output of the generator
R = resistance of the circuit
X = inductive reactance of the circuit
V = nominal voltage of the circuit

- Presence of high R/X

Network voltage changes

- Guideline for connecting DG

Table 1.5 Design rules sometimes used for an indication if an embedded generator may be connected

Network location	Maximum capacity of embedded generator
out on 400 V network	50 kVA
at 400 V busbars	200–250 kVA
out on 11 kV or 11.5 kV network	2–3 MVA
at 11 kV or 11.5 kV busbars	8 MVA
on 15 kV or 20 kV network and at busbars	6.5–10 MVA
on 63 kV to 90 kV network	10–40 MVA

Fault Level and Protection

Protection issues

- protection of the generation equipment from internal faults
- protection of the faulted distribution network from fault currents supplied by the embedded generator
- anti-islanding or loss-of-mains protection
- impact of embedded generation on existing distribution system protection

  – Increase in short circuit current
  – Redistribute the current/less current from network
  – Protection coordination due to bi-direction power flow

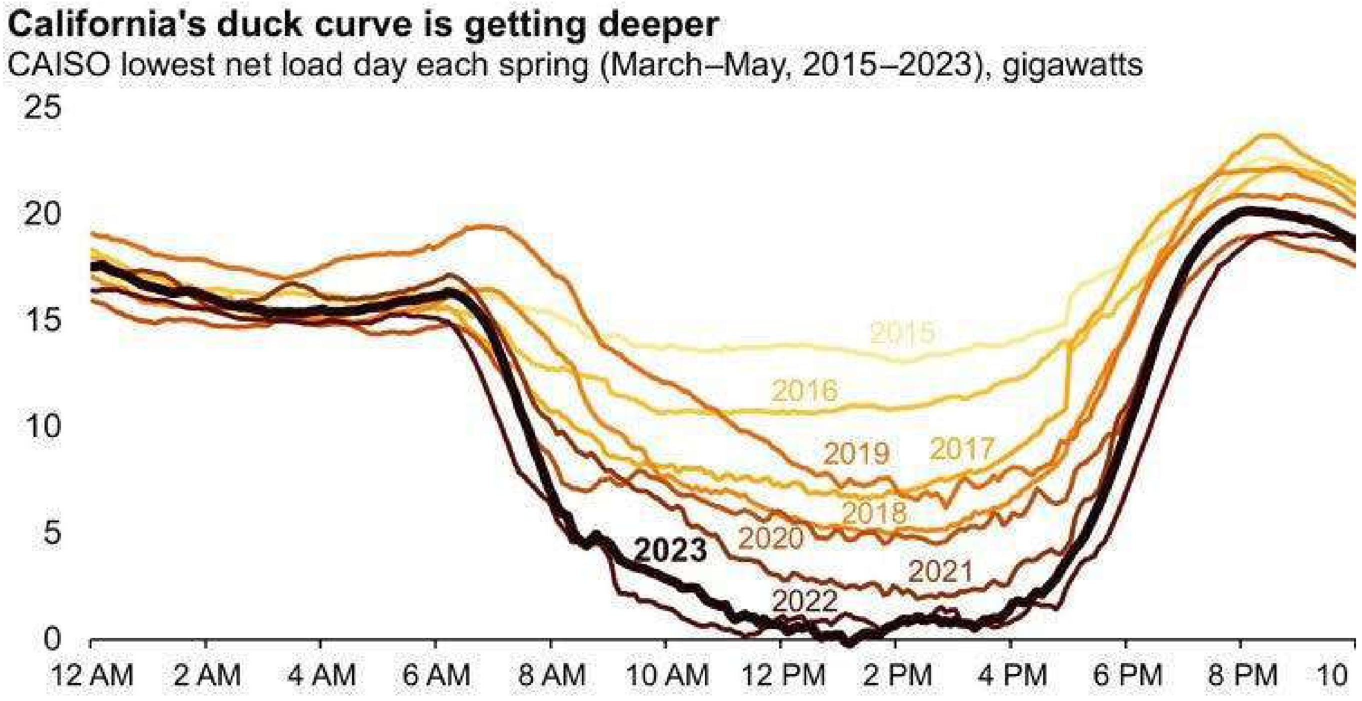
Stability and Quality

- Stability
  - Angle stability (lack of inertia and Negative Load)
  - voltage stability (lack of reactive power support and intermittency on PV and QV curve)
- Quality
  - Properly designed RES suppress fault at the remote location to the upstream
  - Transient voltage variation (Flicker)
  - Harmonics
    - PE Converter
  - Draws Reactive Current by IG
    - Further deteriorate the voltage to collapse
  - Unbalanced current
    - Draw large imbalance current hence voltage balance further is deteriorated

$$\frac{\boxed{2H}}{\omega_s}\frac{d^2\delta}{dt^2} = P_a = P_m - P_e + P_{RES}$$

The Duck Curve Phenomenon

- Midday solar generation drastically reduces net load, while evening demand remains high.
- Steep ramping is required from dispatchable sources during sunset, increasing system stress and operational cost.
- Distribution networks face fluctuating loading conditions within short durations.
- Example: California ISO “duck curve” shows >13 GW ramping need in 3 hours due to solar generation drop.



Economic Impacts – Negative Pricing & Market Shifts

- Surplus PV generation during midday can push market prices below zero.
- In some regions, operators **sell power at negative prices** to maintain system balance (as load cannot be curtailed easily).
- Example: In Germany and California, wholesale electricity prices have gone negative during high solar output.

Impact of Integration: Some Benefit too

- Overall
  - Environmental Protection and tool for Net Zero CO_2 emission
  - Sustainable Measure of Power Supply
- At distribution network
  - Loss reduction
- Transmission system
  - Transmission plan deferral
  - Transmission loss reduction
  - Transmission congestion reduction

Mitigation Measures of Integration:

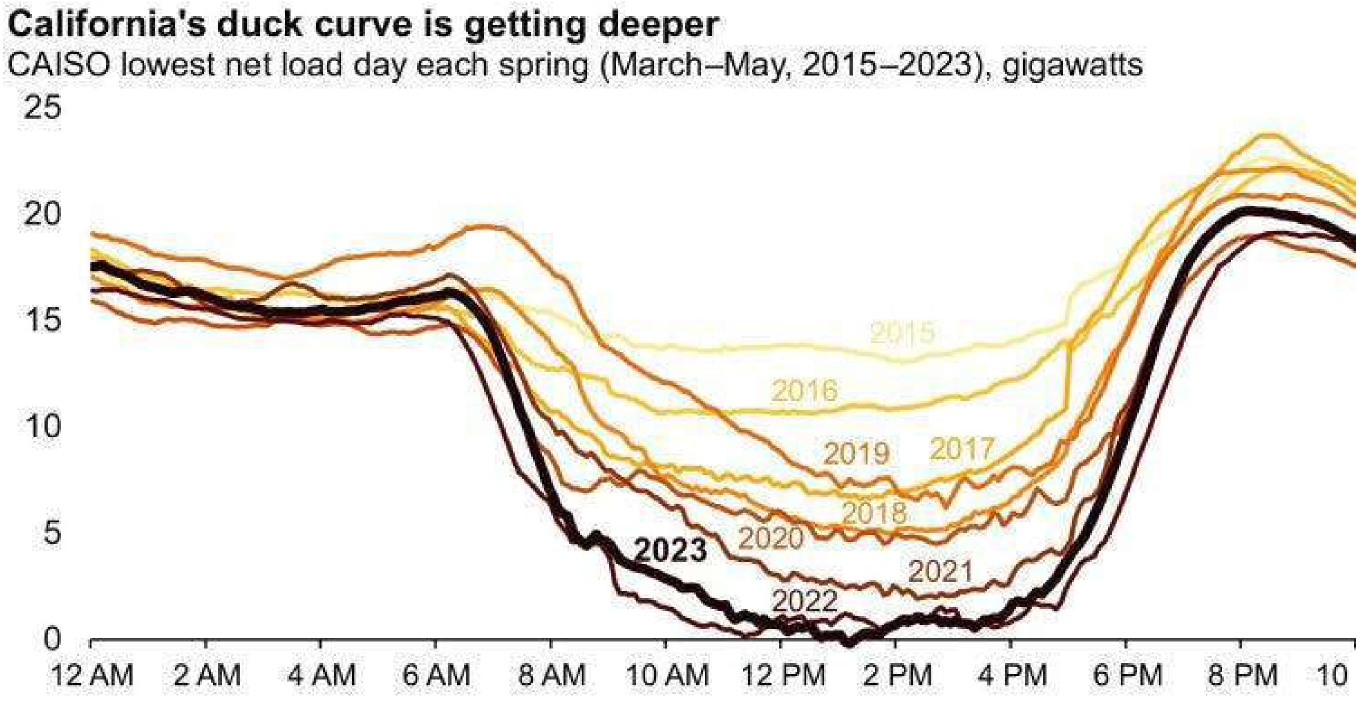
- Virtual Power Plant
  - Grid Forming Inverter
  - BESS
- Reactive Power Support
  - FACTS/STATCOM
  - At distribution network
- Ancillary Services for frequency and voltage support
- Implementation of demand response and TOU metering
- Extent Connectivity, larger grid-better grid
- Power Bank via X-Border power trade
- Improved weather forecasting and generation dispatch
- Hybrid Power system
  - Deploy sufficient Hydro reservoir/pump hydro along with renewables

Mitigation Measures of Integration

Decide Optimum Penetration Level

How to decide the penetration level?

- 1 MW RES vs 1 MW Dispatchable
- Ramping capacity and the Reserve capacity



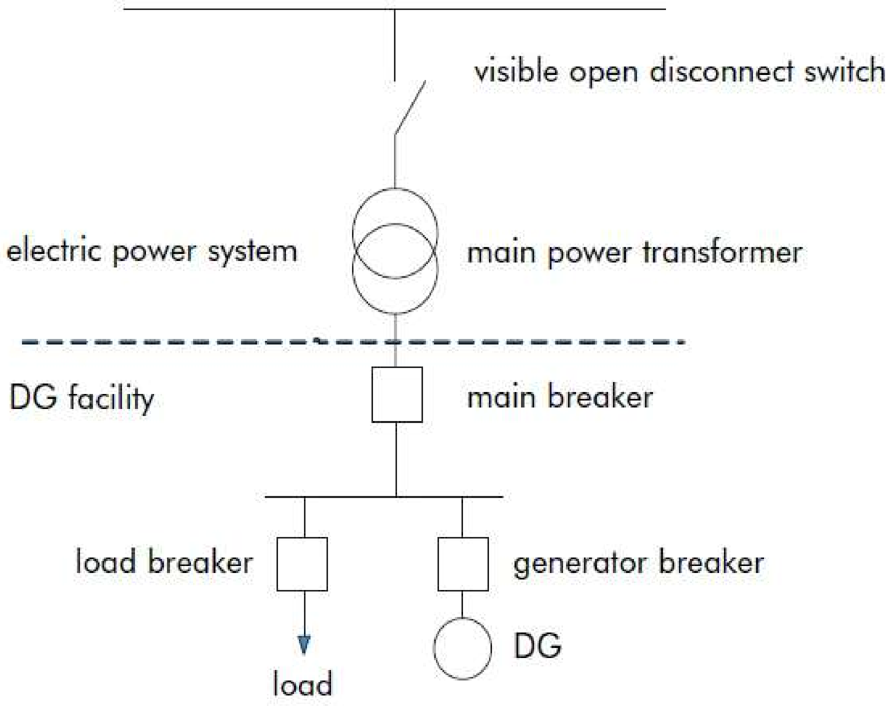
Interconnection Layout

What is Interconnection?

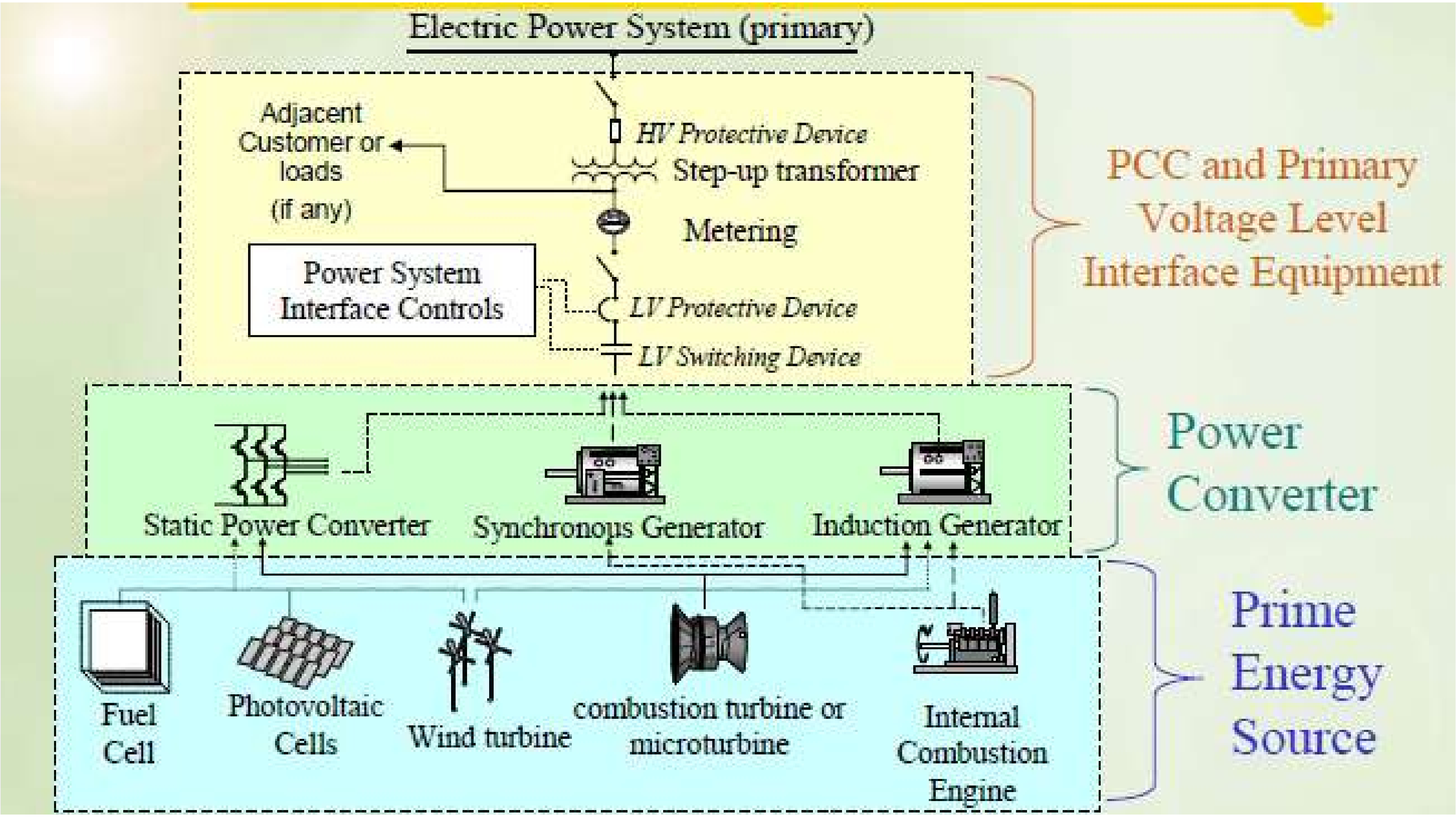
Deals with the electrical characteristics

there are three different types of DG:

- synchronous generator
- asynchronous generator
- electronic inverter.



Interconnection Layout



Interconnection Layout

General PE Interconnection Topology with DG

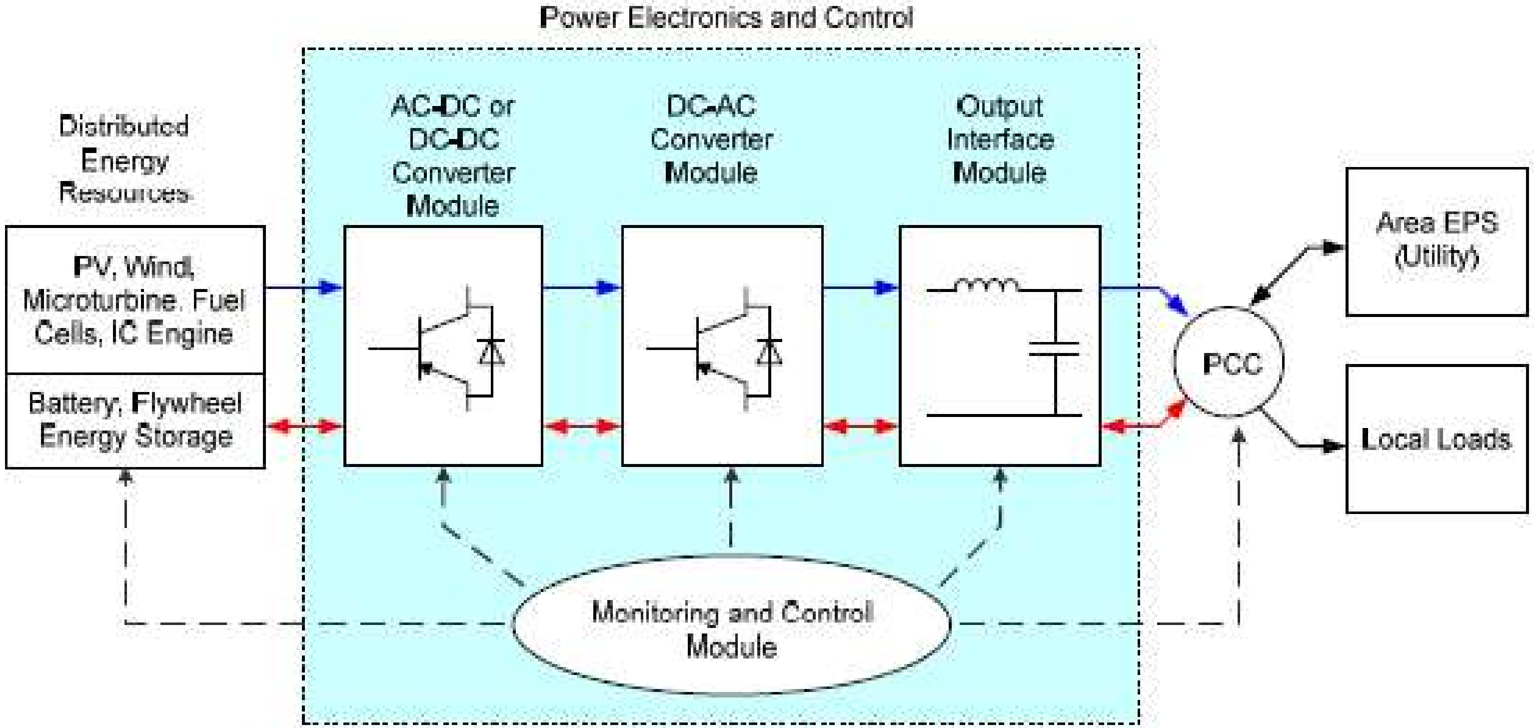
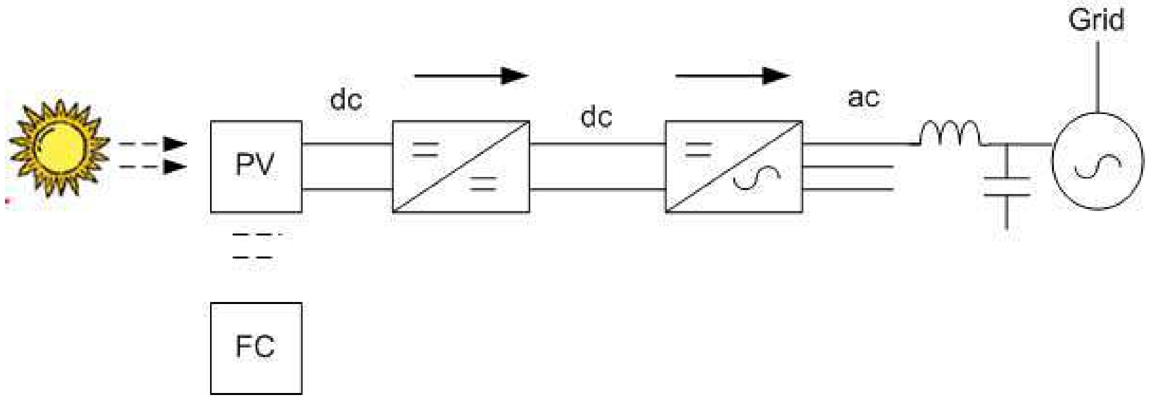


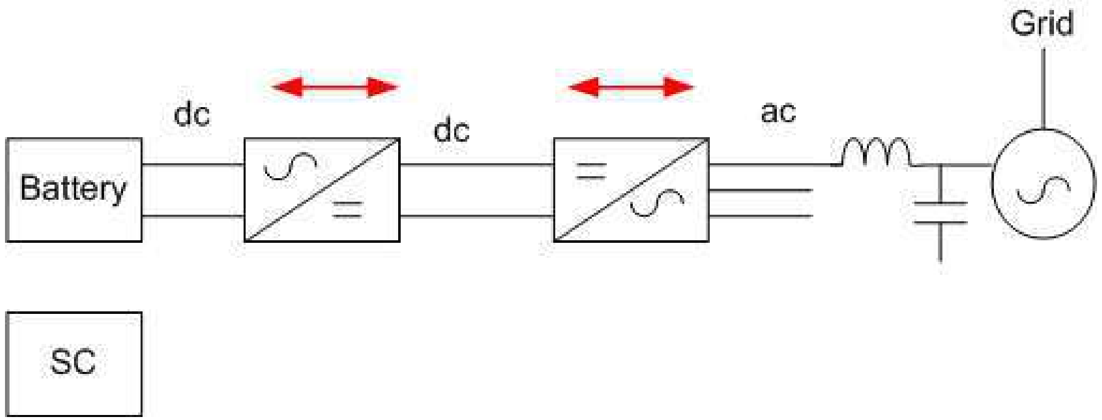
Figure 1. General block diagram of typical DE power electronic systems

Interconnection Layout

- PV Interconnection



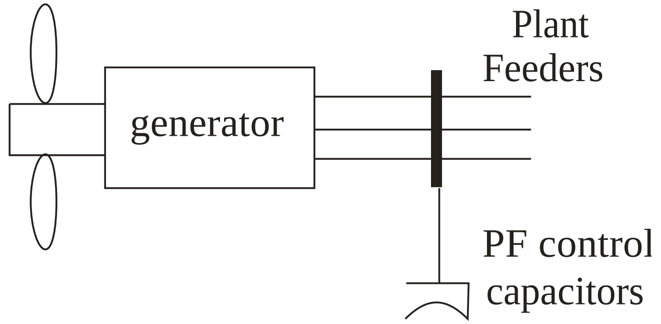
- Battery Interface



Interconnection Layout: WTG Standard Models

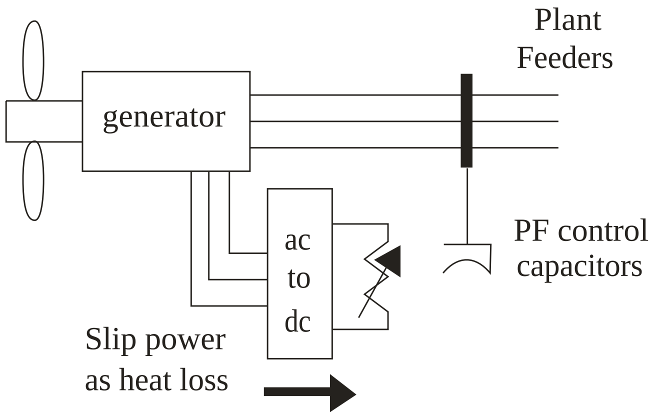
Type A- Fixed speed

(Conventional squirrel caged IG)



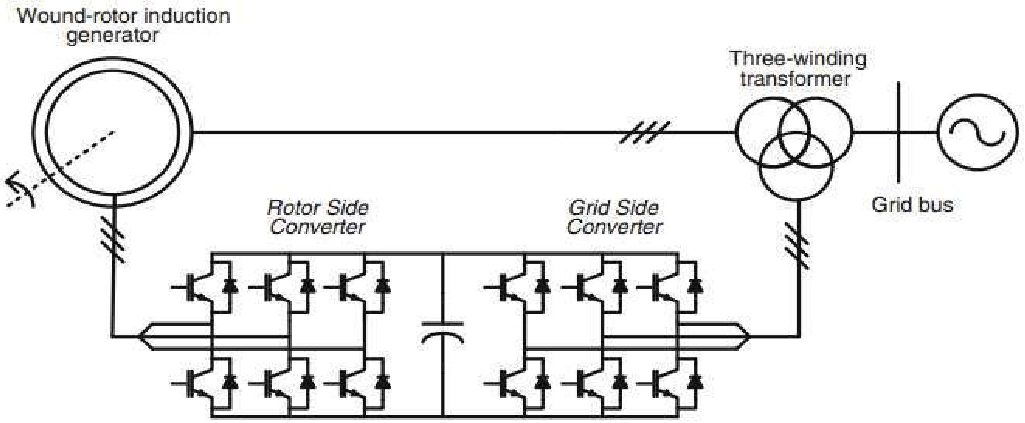
Type-B: Fixed speed

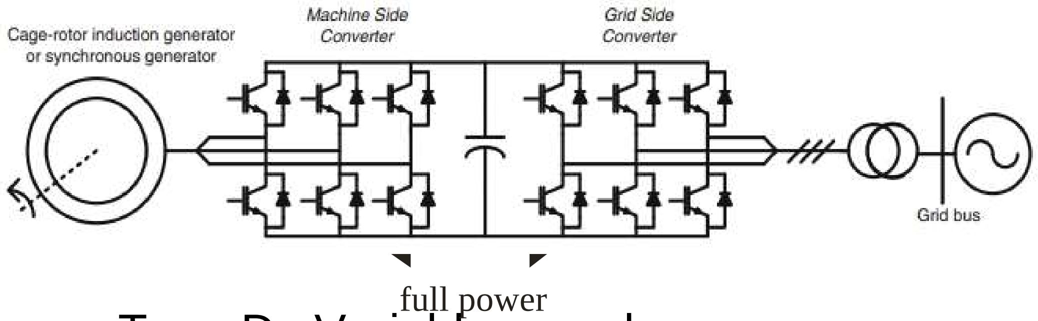
(Wound rotor IG)



Type C- Variable speed

(doubly-fed induction generator IG)

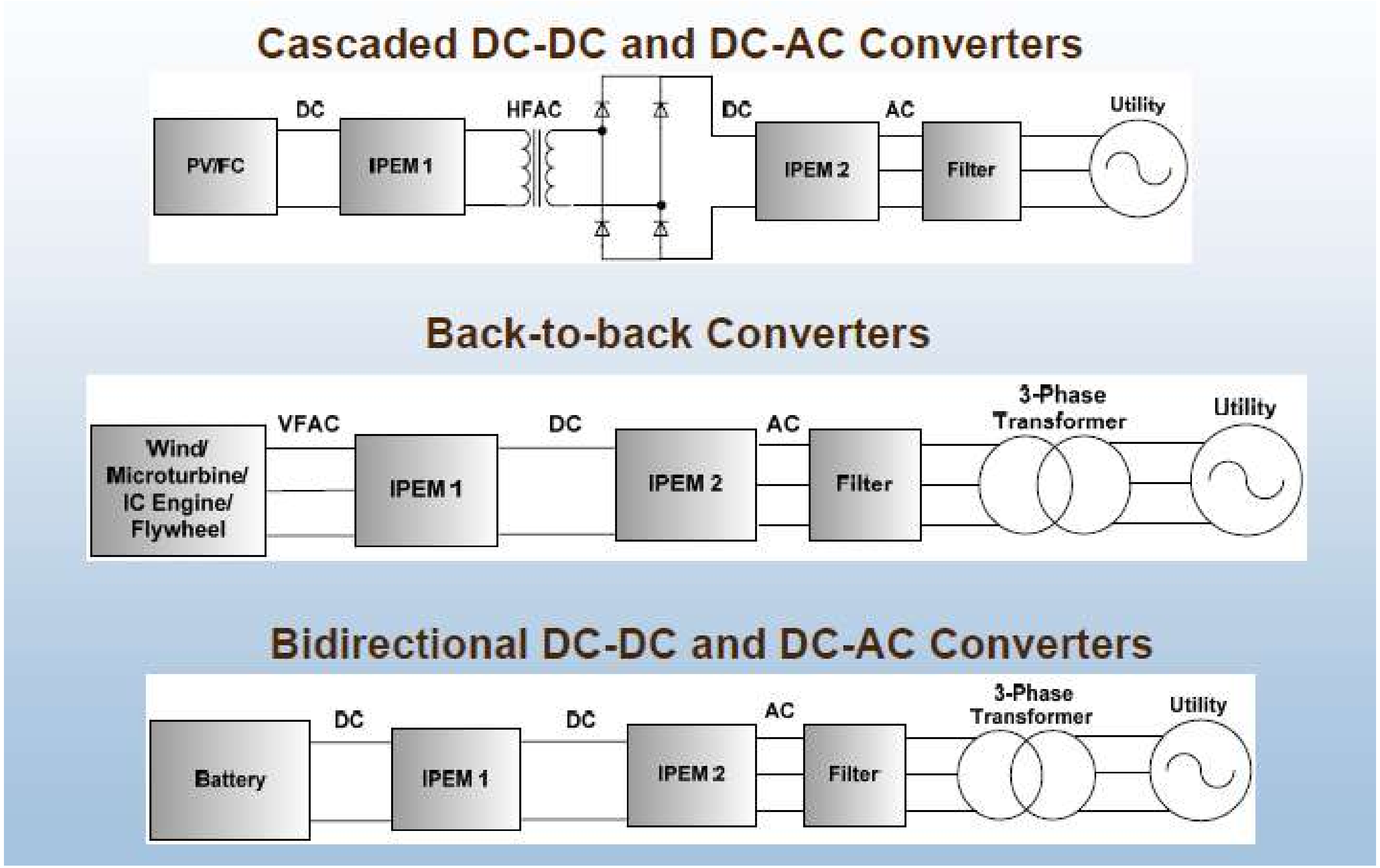




Type-D: Variable speed

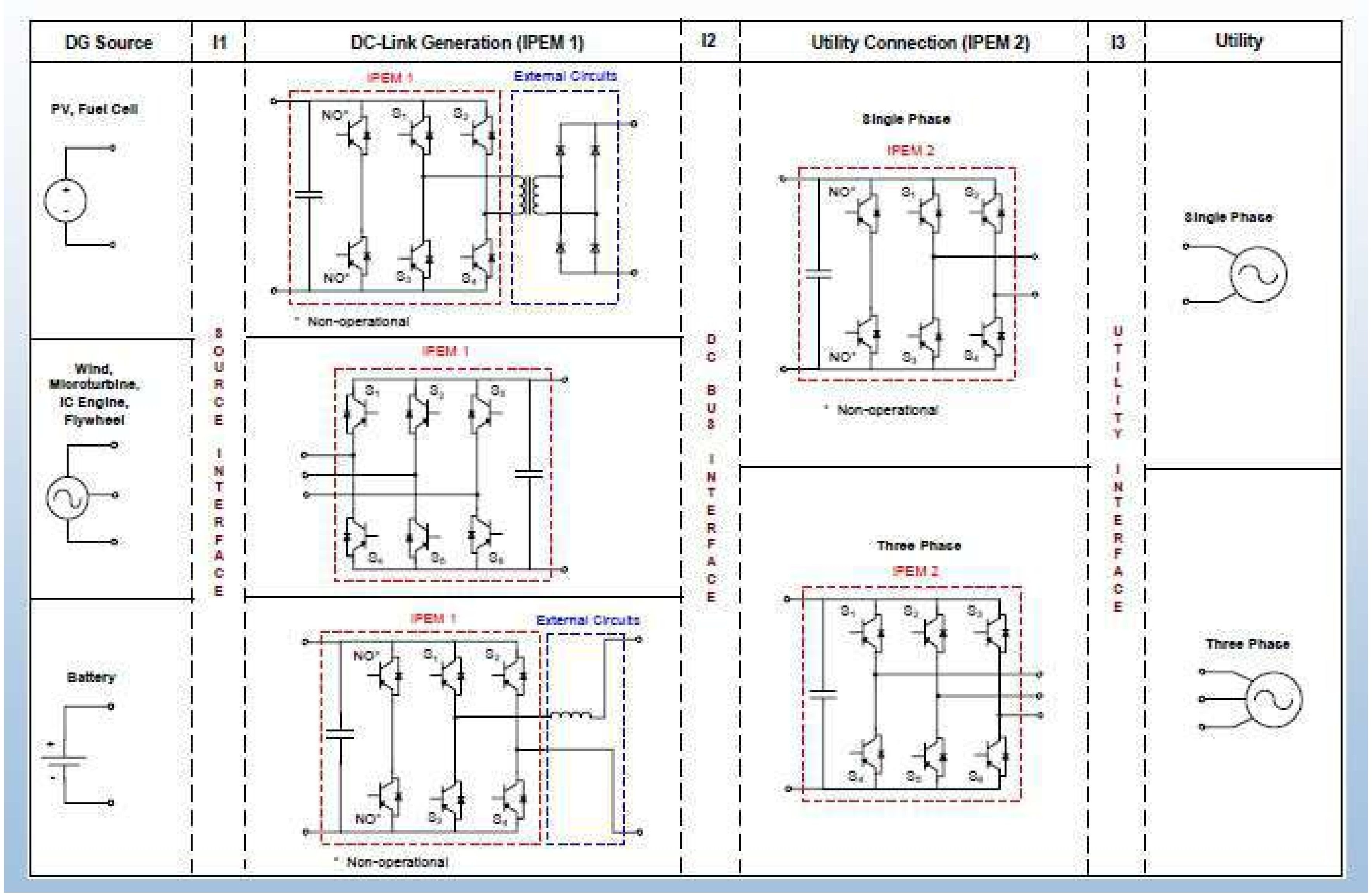
(IG, PDSM, SM)

Summary of PE Topologies with RER



Source: NREL

PE Topologies for DER



Source: NREL

Standard for Interconnection

Standard is needed with Interconnection, because it:

- Safeguards against hazards
- Fosters quality design and manufacture
- Increases competitiveness in industry
- Creates and expands markets
- Facilitates Trade and Commerce
- Assurance is provided when products meet quality standards, then users need not be concerned with redundant testing or evaluation of the product

Interconnection Standards

- IEEE Standards
  - **IEEE 1547™ Series (DG Integration):** This series of standards covers the interconnection and interoperability of Distributed Energy Resources (DERs)—such as solar PV, wind, and battery storage—with the electric power system.
  - **IEEE P2800™ Series**
    These draft standards focus specifically on larger, utility-scale resources connected at the transmission or sub-transmission level.
- IEC standards
  - **IEC 62109 Series:** These are a foundational set of standards for substation automation that have been extended to enable digital technologies for renewable integration and DER communication.
  - **IEC 62109 Series:** This standard ensures the safety of power conversion equipment (PCE) used in photovoltaic (PV) systems, including grid-tied and hybrid inverters.
- **FRT Requirement**
- **Other** Regulations
  - **Grid Codes**
  - **Compliances of Testing**

IEEE 1547

- IEEE 1547 Voltage and Frequency Tolerance

Voltage Range (% Nominal)	Max. Clearing Time (sec) *
V < 50%	0.16
50% ≤ V < 88%	2.0
110% < V < 120%	1.0
V ≥ 120%	0.16

(*) Maximum clearing times for DER ≤ 30 kW; Default clearing times for DER > 30 kW

Frequency Range (Hz)	Max. Clearing Time (sec)
f > 60.5	0.16
f < 57.0 *	0.16
59.8 < f < 57.0 **	Adjustable (0.16 and 300)

(*) 59.3 Hz if DER ≤ 30 kW

(**) For DER > 30 KW

- Additional disconnection requirements
  - Cease to energize for faults on the Area EPS circuit
  - Cease to energize prior to circuit reclosure
  - Detect island condition and cease to energize within 2 seconds of the formation of an island ("anti-islanding")

IEEE 1547

- Other applicable codes and standards (not

	Requirement
Voltage Regulation	Maintain service voltage within ANSI C84 Range A (+/-5%)
Voltage control	Not permitted (IEEE 1547)
Flicker	Maximum Borderline of Irritation Curve (IEEE 1453)
Harmonics	<5% THD; <4% below 11th; <2% for 11th – 15th, <1.5% for 17th – 21st; 0.6% for 23rd – 33rd; <0.3% for 33rd and up (IEEE 519)
Power Factor	Output power factor 0.85 lead/lag or higher (equipment typically designed for unity power factor)
Direct Current Injection	<0.5% current of full rated RMS output current (IEEE 1547)
Synchronization and Protection	Dedicated protection & synchronization equipment required, except smaller systems with utility-interactive inverters
Safety	NFPA NEC, IEEE NESC

IEEE 1547

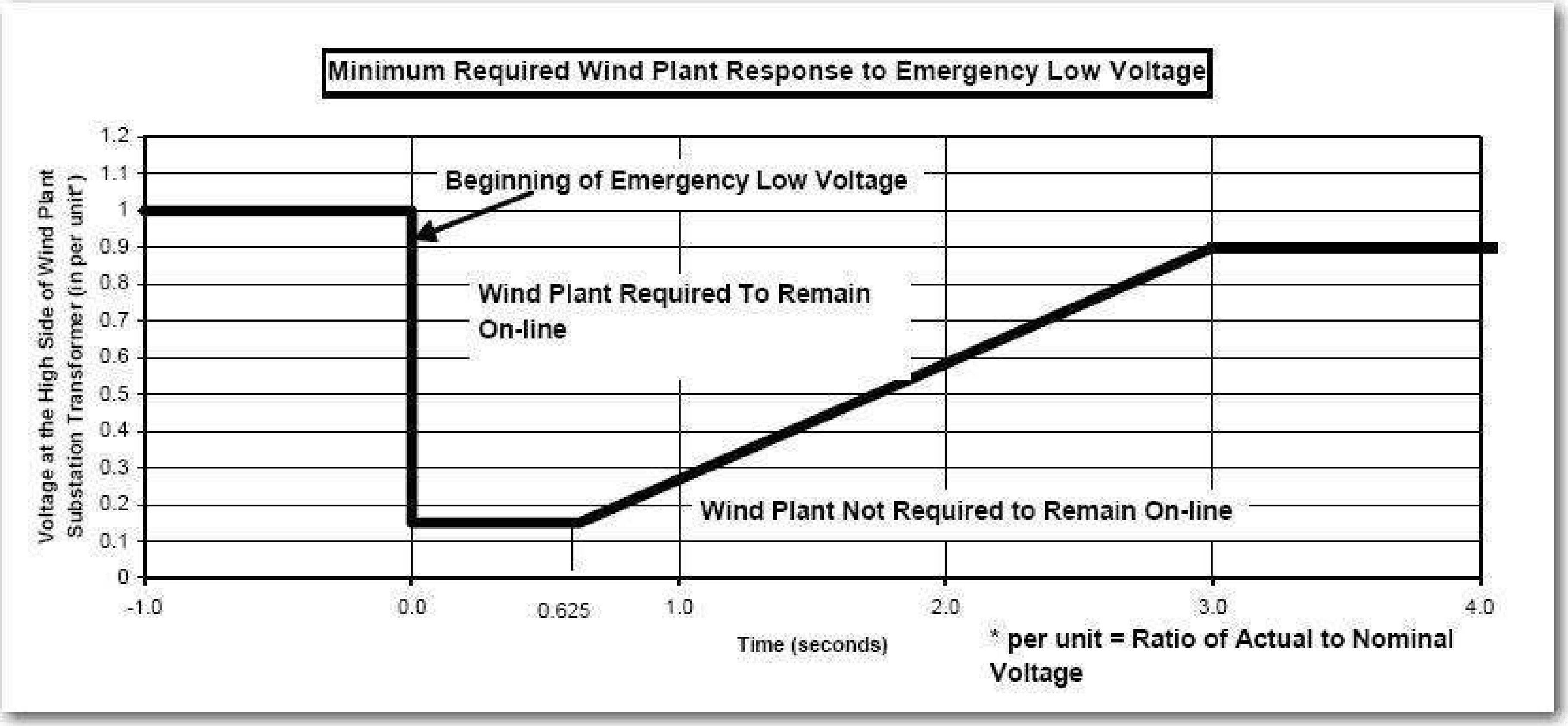
Tolerance Standards (Bulk System)

- Voltage Tolerance (LVRT)
  - Tolerate bolted fault (0 volts) at POI for up to 9 cycles (150 ms)
  - FERC Order 661-A: applies to wind generators >20 MVA
  - WECC LVRT criterion: applies to all generators >10 MVA
- Frequency Tolerance
  - For example, WECC ONF standard, which applies to all generators
- Rules still evolving in the US and elsewhere

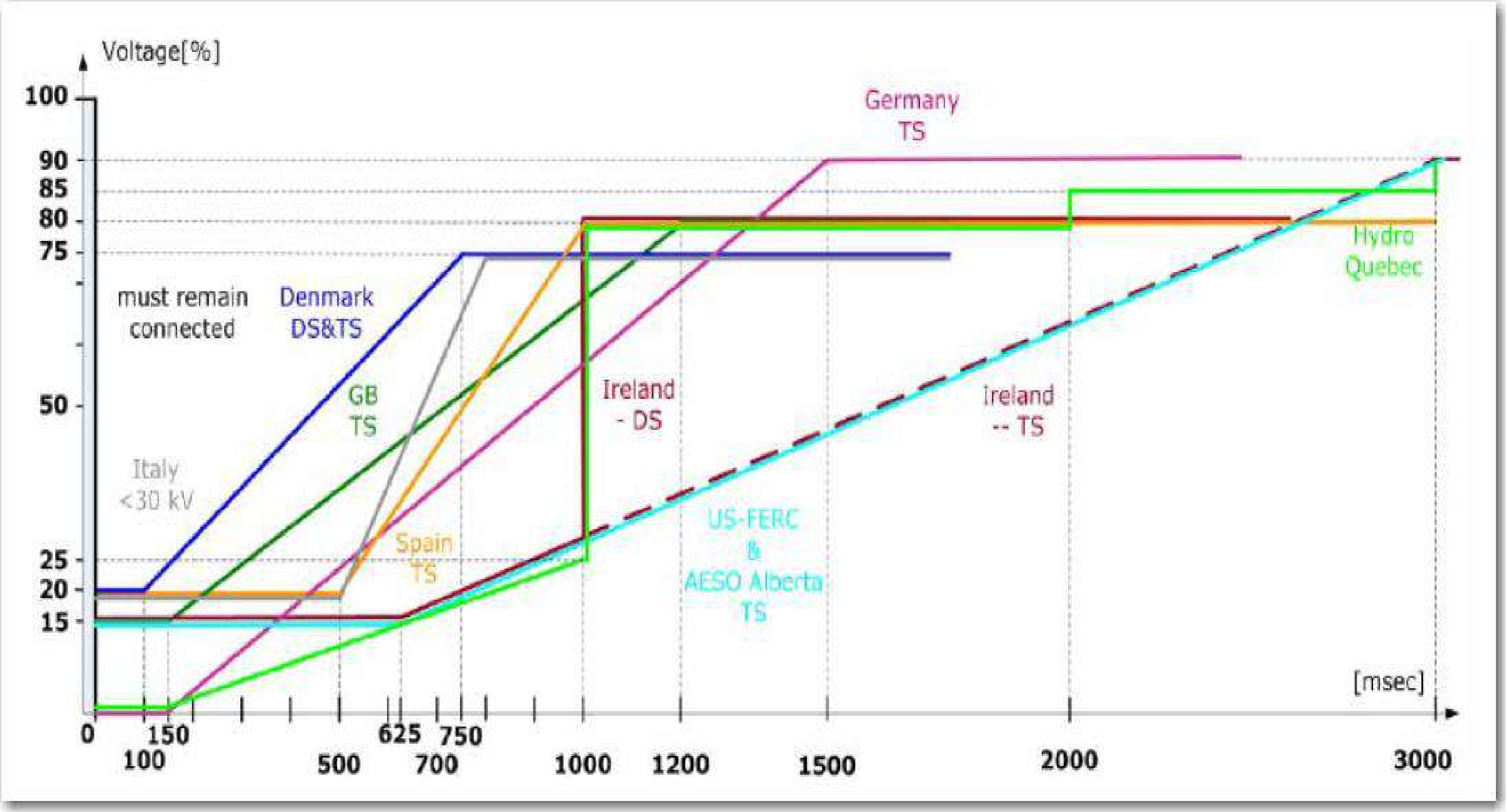
WECC Off-Nominal Frequency Tolerance

Frequency Range (Hz)	Max. Clearing Time (sec) *
59.4 – 60.5	N/A
59.4 – 58.5 or 60.6 – 61.5	3 min
58.4 – 57.9 or 61.6 – 61.7	30 sec
57.8 – 57.4	7.5 sec
57.3 – 56.9	45 cycles
56.8 – 56.5	7.2 cycles
< 56.4 or >61.7	instantaneous

LVRT Requirement

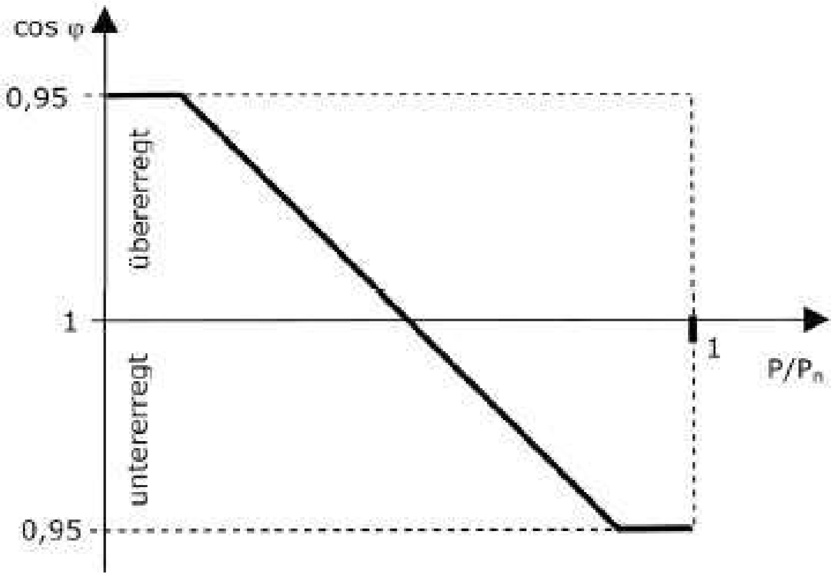


LVRT


Voltage[%]
100
90
85
80
75
50
25
20
15
must remain connected
Denmark DS&TS
GB TS
Italy <30 kV
Spain TS
Germany TS
Ireland - DS
Ireland -- TS
US-FERC & AESO Alberta TS
Hydro Quebec
[msec]
0
100
150
500
625
700
750
1000
1200
1500
2000
3000

German Standard for PV connection

- Static Voltage Support
  - Provide capability of +/- 0.95 pf at full output (impacts equipment rating)
  - Dispatch could be constant pf, constant Var, Var support based on power output (see example below) or Var support based on voltage
  - Applies to PV as of 2010



Source: E. Troester, New German Grid Codes for Connecting PV to the Medium Voltage Power Grid, 2nd International Conference on Concentrating Photovoltaic Power plant

RES and Transmission Planning

Geographic Mismatch: Remote RES and the Need for Long-Distance Transmission

- **The Challenge**: RES sites situate far from major load centers, creating a fundamental geographic mismatch that demands extensive new transmission infrastructure.
- **Long Transmission Lines Required**: To bridge these distances, utilities must build high-capacity lines.
- **Economic Burden from Low-Capacity Factors**:
    - RES operate at low plant factors (20-35% for solar, 25-45% for onshore wind, vs. 70-85% for gas/coal),
    - leading to underutilized lines for much of the year.
    - This inflates the levelized cost of transmission
    - potentially extending payback periods to 15-25 years and risking stranded assets if utilization stays below 30%.
- **Depth Insight**:
    - Without aggregated corridors, individual projects face prohibitive costs,
    - justified only through multi-project sharing to achieve 40%+ average loading despite intermittency.

Opportunities for Enhanced Planning

- **Technological Advances**:
  - Deploy HVDC lines for efficient long-distance transfer (lower losses than AC)
  - Deploy dynamic line ratings (DLR) to boost capacity by 20-30% based on real-time conditions.
  - For low-capacity-factor RES, hybrid AC-DC designs can optimize costs by using HVDC only for bulk export segments.
- **Planning Reforms**:
  - Establish national authorities for macro grid development, including Renewable Energy Zones (REZs) to cluster RES and connect via proactive corridors, as in Texas's CREZ model.
  - This clusters generation to improve average line loading from 20% to 40-50%, offsetting low plant factors.
- **Stochastic Modeling**:
  - Use AI-driven scenario-based tools to incorporate uncertainties,
  - Including sensitivity to capacity factors and line utilization.
- **Flexibility Integration**:
  - Combine with storage and flexibility services (e.g., inertia procurement) to mitigate intermittency, enabling conditional connections that allow RES output based on grid status

Summary and Takeaway

Regional Power Market and Cross Border Power Trade: A Case of SAARC Region

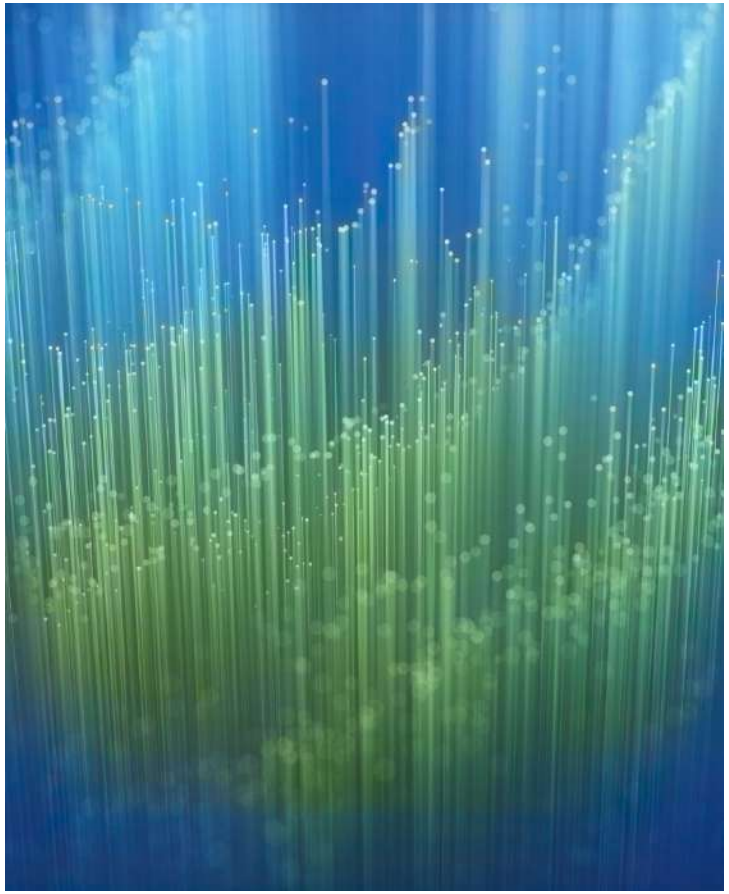
By

Dr. Netra Prasad Gyawali

Session 2.4

Agenda

- Introduction
- SAARC Grid and CBET
- SEC and its Role for CBET
- BBIN Grid and CBET
- Open Access
- Summary



1. Introduction: Rationale of SAARC Grid

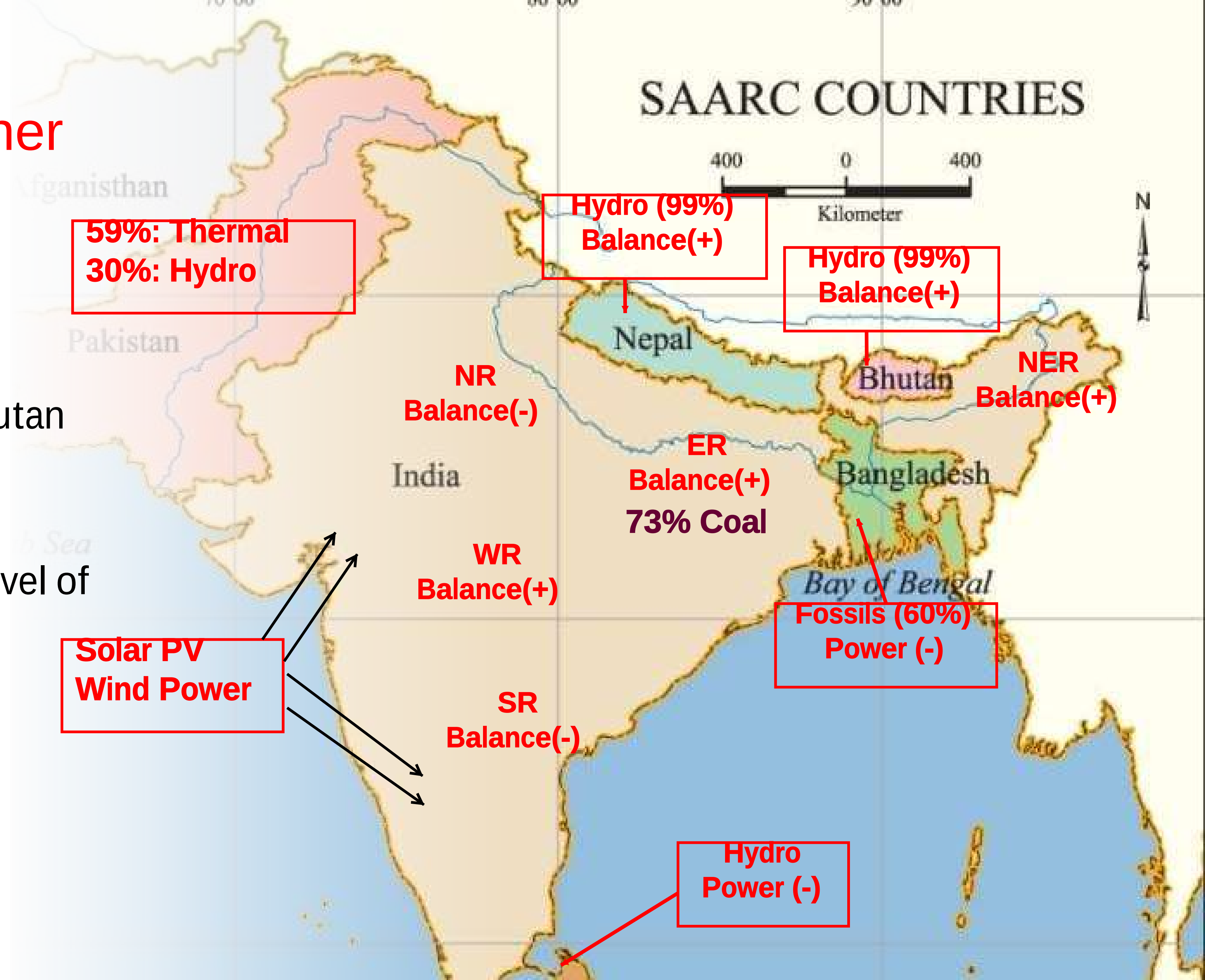
Category	Key Facts	Implication for Regional Grid
Resource Diversity	Hydro-rich (Nepal/Bhutan:	Foundation for energy trade; reliance on 80% fossil imports makes cross-border resource sharing crucial.
	Coal deposits (India/Pakistan:	
	Untapped Solar/Wind (all countries).	
Demand-Supply Mismatch	Peak Summer Demand (India/Bangladesh, up to 200 GW) aligns with Monsoon Hydro Surplus.	Clear opportunity for seasonal power exchange (Hydro for Thermal/Load); Grids essential for Island Nations' energy security.
	Off-peak hydro complements thermal in dry seasons.	
	Srilanka' island isolation requires grid connectivity.	

Introduction: Rationale of SAARC Grid

Category	Key Facts	Implication for Regional Grid
Geographic Synergies ◊◊	Himalayan hydro naturally flows south to deficit plains.	Natural transmission corridors and shared resources reduce infrastructure costs and drive regional cooperation
Geographic Synergies ◊◊	Arid western solar complements humid eastern hydro.	Natural transmission corridors and shared resources reduce infrastructure costs and drive regional cooperation
Geographic Synergies ◊◊	Cross-border rivers (e.g., Sindhu/Ganges/Brahmaputra) enable shared projects.	Natural transmission corridors and shared resources reduce infrastructure costs and drive regional cooperation

1. Integrating Other Renewables

- Energy Mix in SAR
- Hydro in Nepal and Bhutan support
- Grid Sustainability
- Increase Penetration level of Wind Solar in SAR



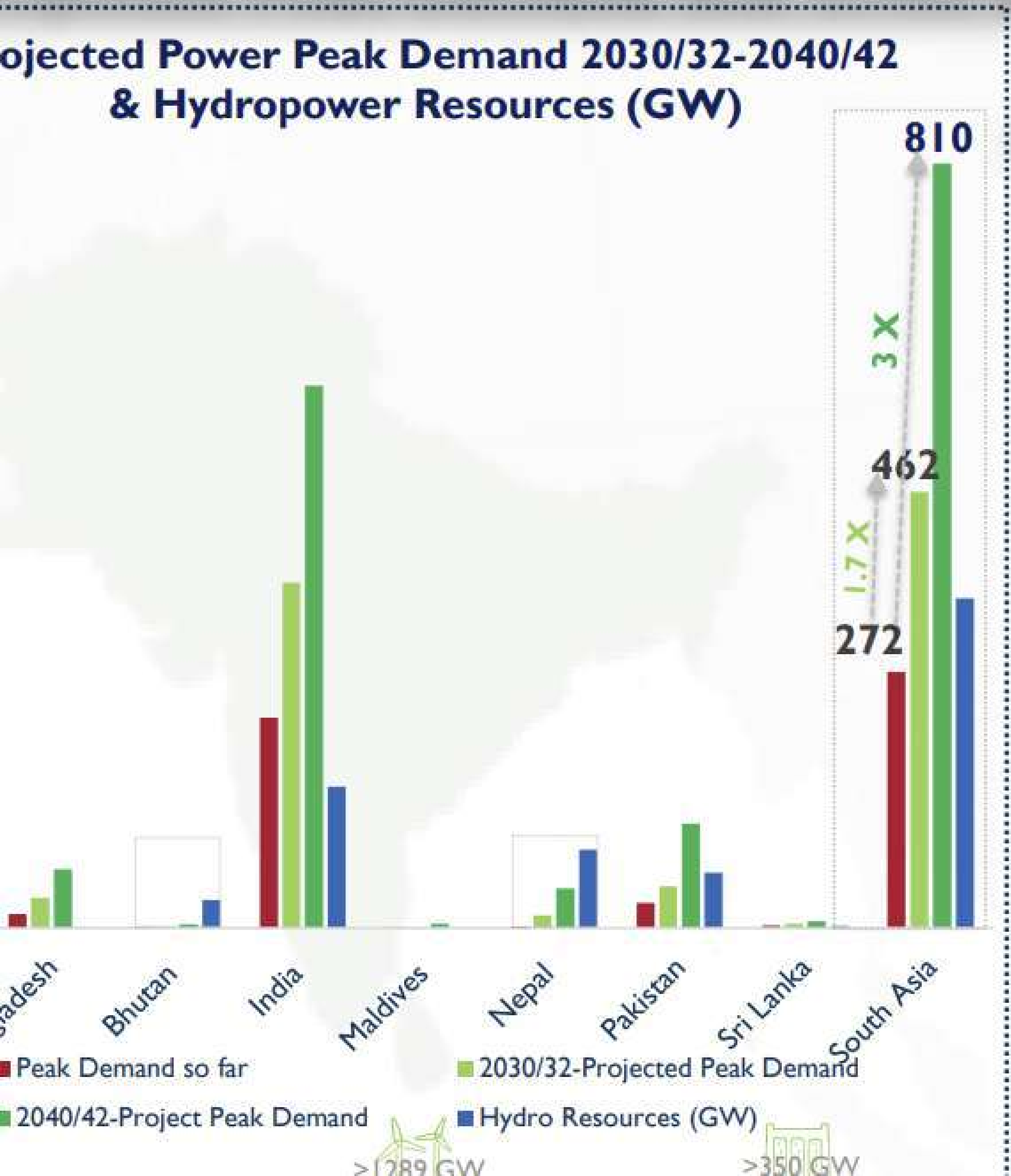
1. Cross-Border Power Exchange for Energy Security

Diversification :	Reduces single-fuel dependence (e.g., oil/coal imports costing $100B/year); balances seasonal fluctuations via hydro-thermal swaps; mitigates supply shocks from global fossil price volatility.
Resilience & Stability:	Integrated grids improve reliability, cut outages (e.g., 2021 India blackout affected 600M); enables RE flexibility (e.g., wind/PV trade across time zones); disaster recovery via mutual aid (e.g., flood-prone Nepal exporting dry-season power).
Economic/Environmental Gains:	Saves $226B (2015-2040) in costs; cuts 8% CO2 emissions (equivalent to 1 Gt); stabilizes prices through competitive markets; fosters tech transfer for efficient RE storage.
Strategic Autonomy:	Reduces vulnerability to external disruptions (e.g., geopolitical oil routes); builds regional buffer against climate impacts (e.g., erratic monsoons); promotes equitable access for LDCs like Bhutan/Nepal as exporters

2. SAARC Grid and CBET

2. SAARC Grid and CBET

Projected Peak Demand and Cross Border Electricity Trade Future Outlook



Source: SARE/USAID

2. SEC for Regional Energy Coope

- **SAARC Framework Agreement:** The *SAARC Framework Agreement on Energy Cooperation (Electricity)* was established facilitate cross-border electricity exchanges and trade.
- **SAARC Energy Centre (SEC):** Created in 2005, the SEC is a specialized vehicle to realize the vision of an "Energy Ring" in South Asia. It supports policy formulation and research.
- **Expert groups:** Various expert groups and councils, such as the *SAARC Council of Experts of Energy Regulators-Electricity (CEERE)*, work on policy and regulatory issues to promote cros border electricity trade (CBET).
- **International support:** Organizations like the Asian Developme Bank (ADB) and the United States Agency for International Development (USAID) support regional initiatives.

2. Prerequisite of CBET

- Cross Border Transmission Link
- Harmonization of Grid Code
- Level Playing Field to optimize Power Trade
- Open Access in Transmission Service

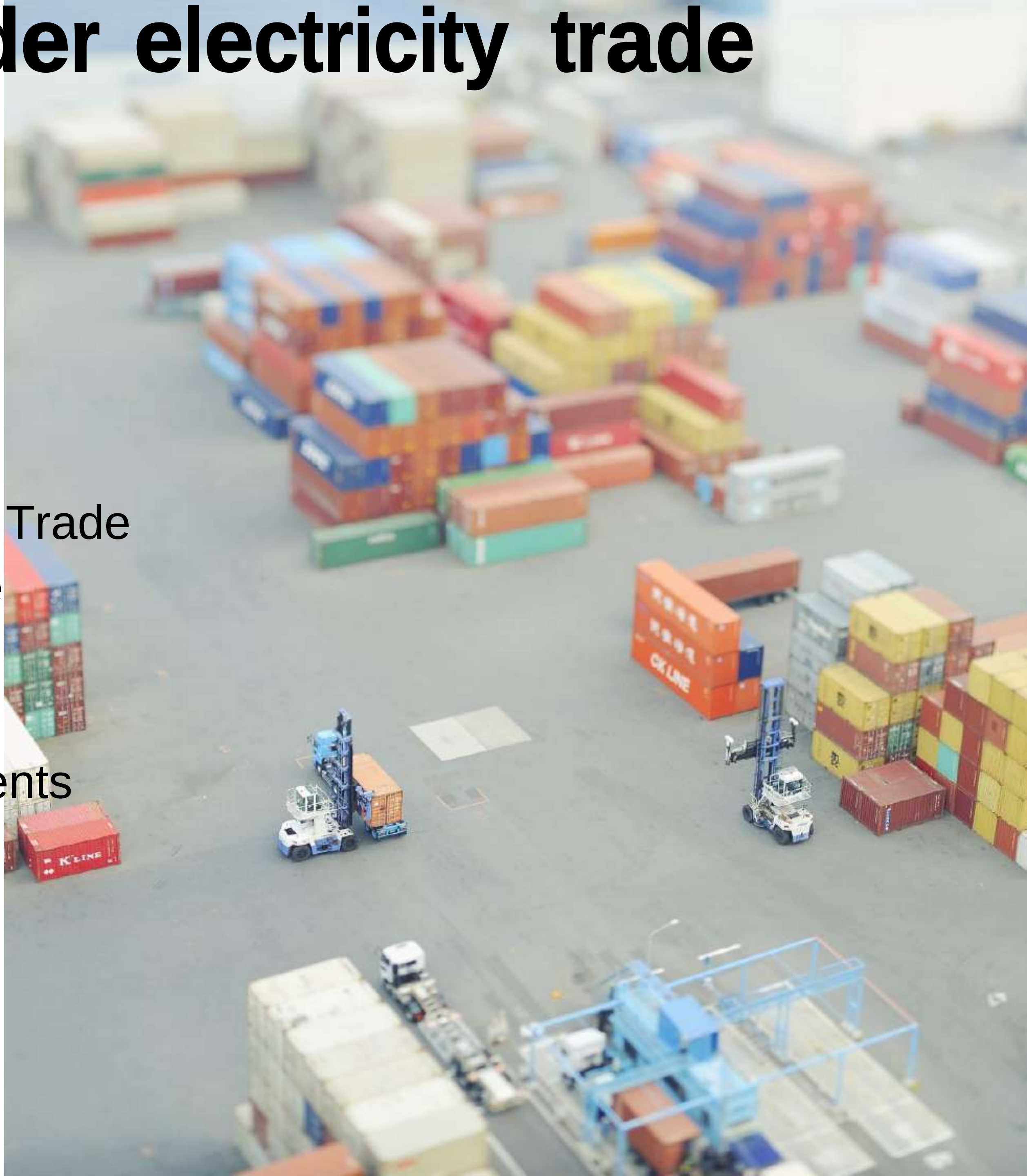
2. Status of cross-border electricity trade (CBET)

Prerequisite of CBET

- Cross Border Transmission Link
- Harmonization of Grid Code
- Level Playing Field to optimize Power Trade
- Open Access in Transmission Service

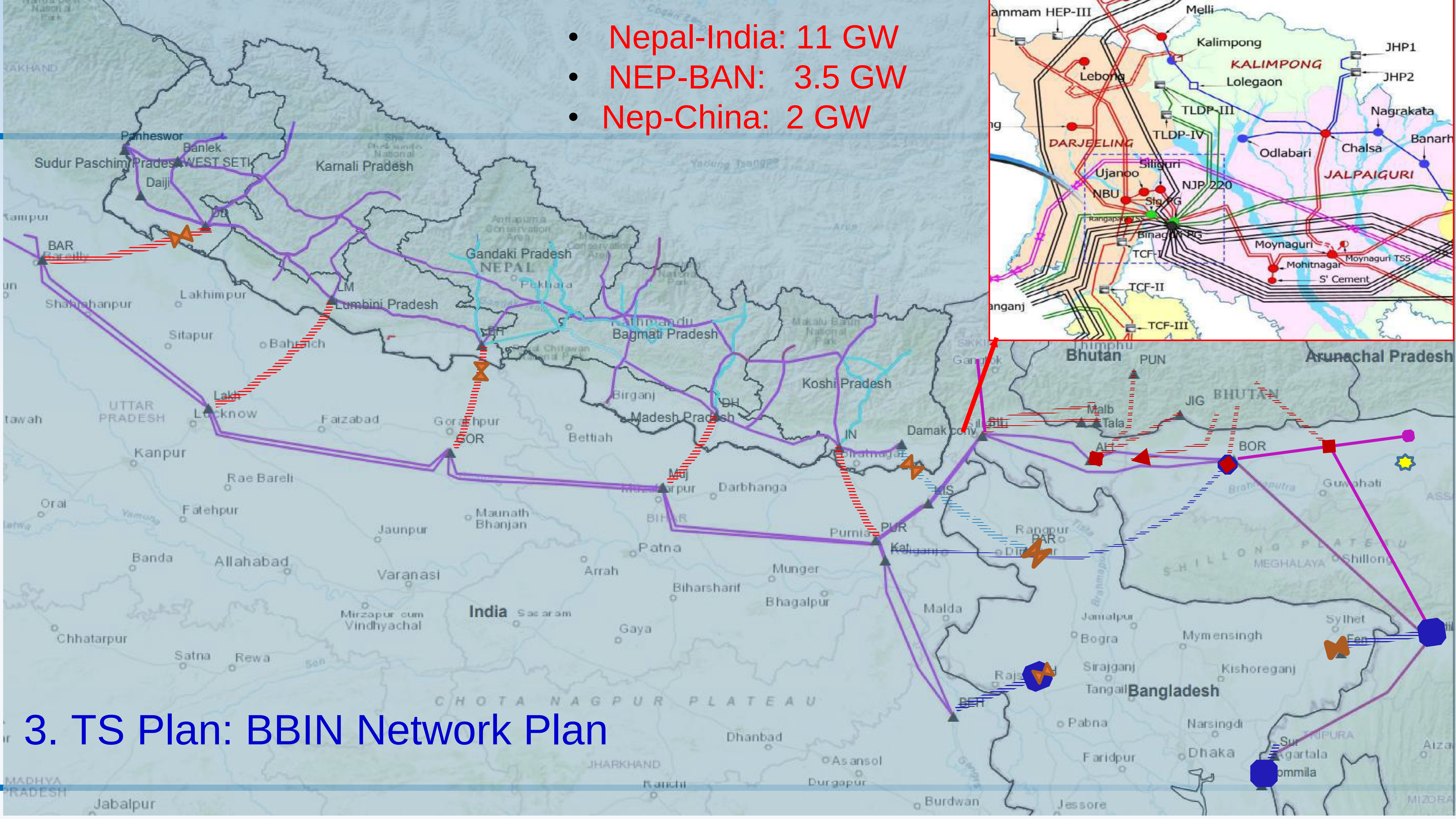
Existing connections and Trade:

- Several bilateral power trade agreements are already in place via Indian Grid
- India-Nepal; India-Bhutan, India-Bangladesh, Nepal-Bangladesh



3. BBIN Grid: A Subset of SAARC Grid

- Nepal-India: 11 GW
- NEP-BAN: 3.5 GW
- Nep-China: 2 GW



3. TS Plan: BBIN Network Plan

3. Transmission Master Plan: Bhutan

Expected Export: 25 GW (more than 80% of Generation)

Export 25 GW (2030-35)

CEA Report:2018

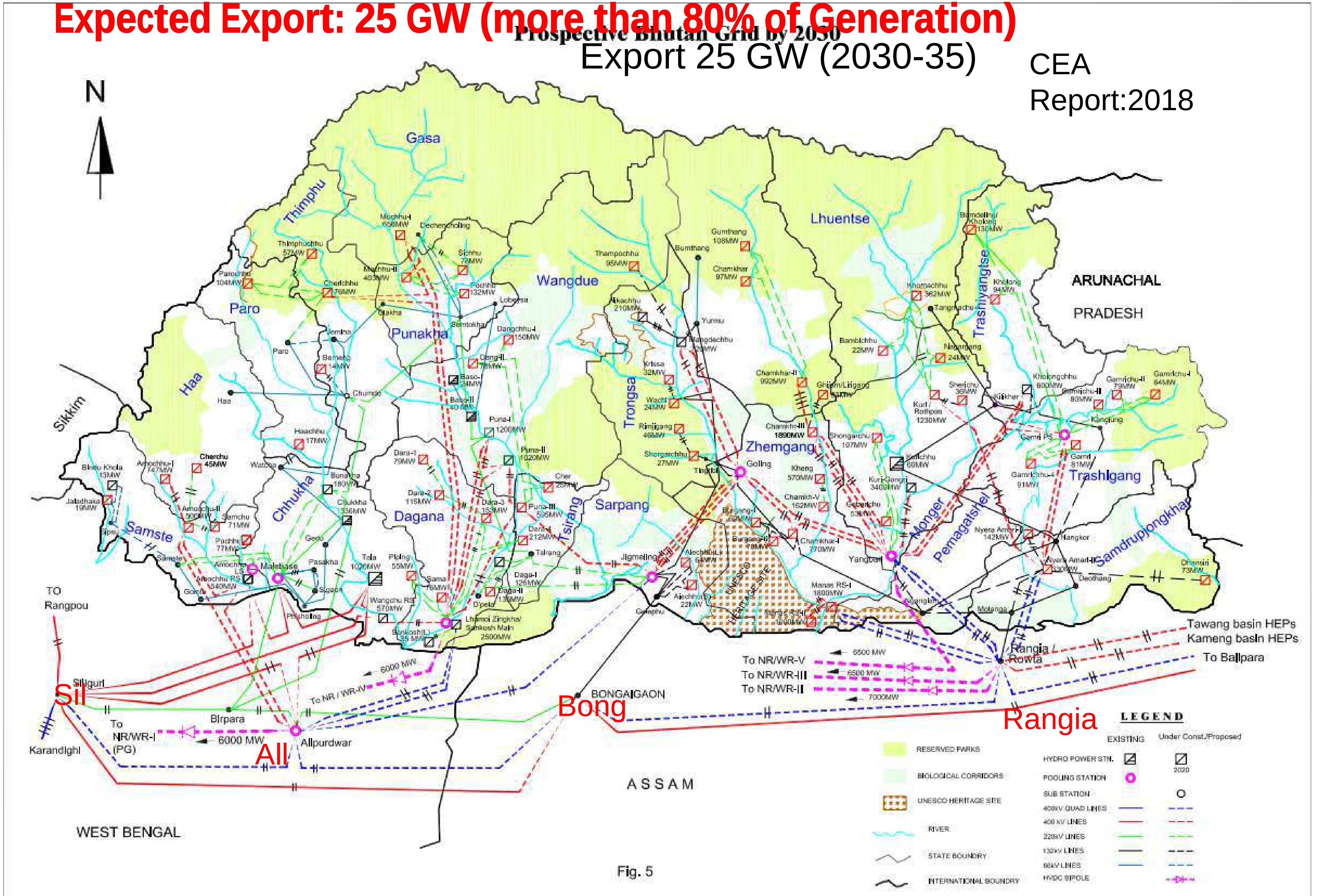


Fig. 5

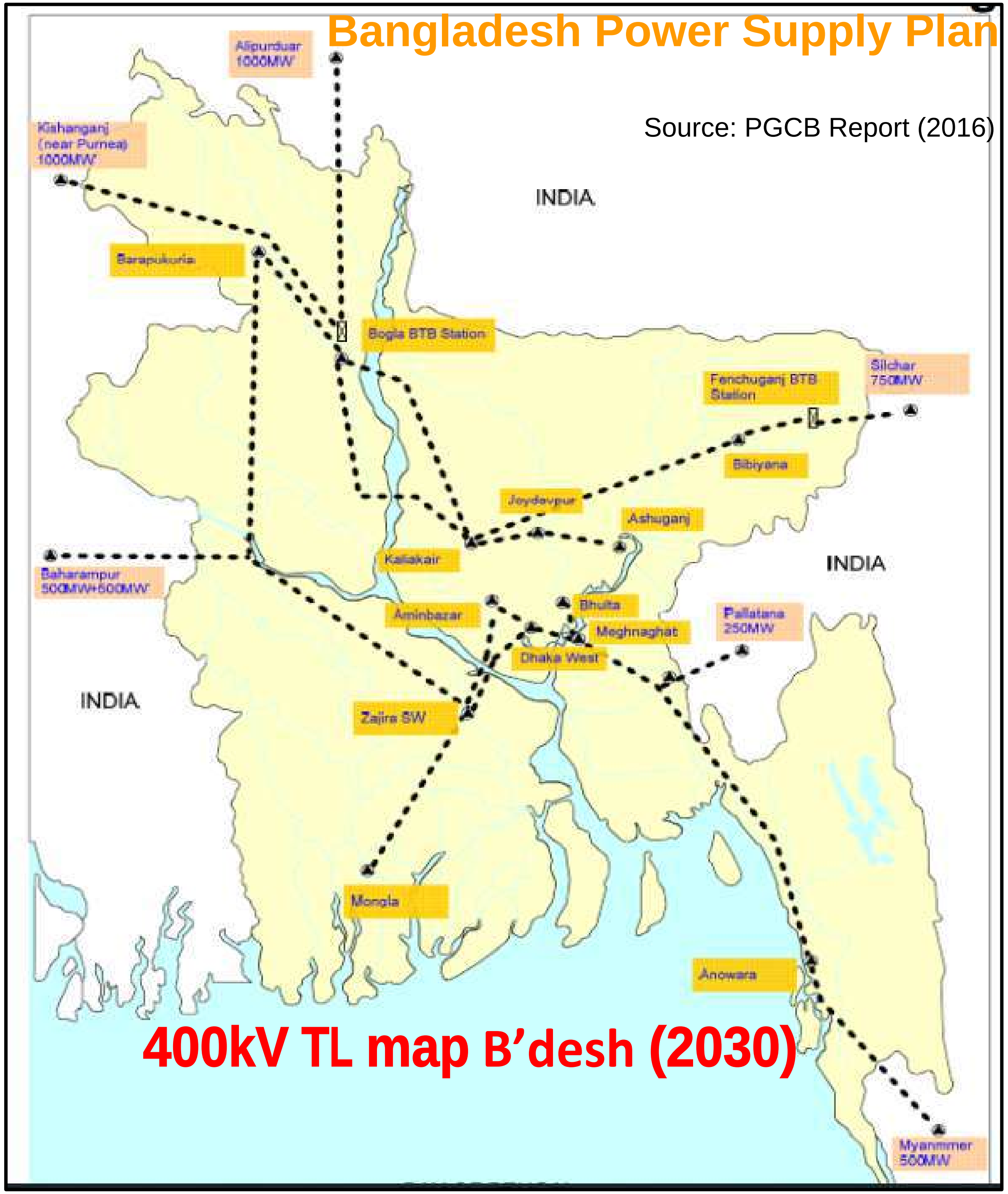
3. Power Supply Plan: Bangladesh

Name of Interconnection	Power Import (MW) by Year 2015	2020	2025	2030
Bheramara – Bahrampur	500	500	1,000	1,000
Myanmar - Bangladesh	0	500	500	500
Palatana - Comilla	0	0	250	250
Shilchar - Fenchuganj	0	0	750	750
Kishanganj - Bogra (Hydro Power from Nepal)	0	0	500	500
Alipurduar - Bogra (Hydro Power from Bhutan)	0	0	500	500
Total	500	1,000	3,500	3,500

	Demand forecast			*Generation Plan*
	Government Policy	Considering GDP: 06%	Considering GDP: 07%	Gen. Capacity Present Proposition
2015	10 GW	8 GW	9 GW	18.2 GW
2020	18 GW	10 GW	13 GW	22.5 GW
2025	25 GW	14 GW	19 GW	29.3 GW
2030	33 GW	18 GW	28 GW	38.3 GW

Bangladesh Power Supply Plan

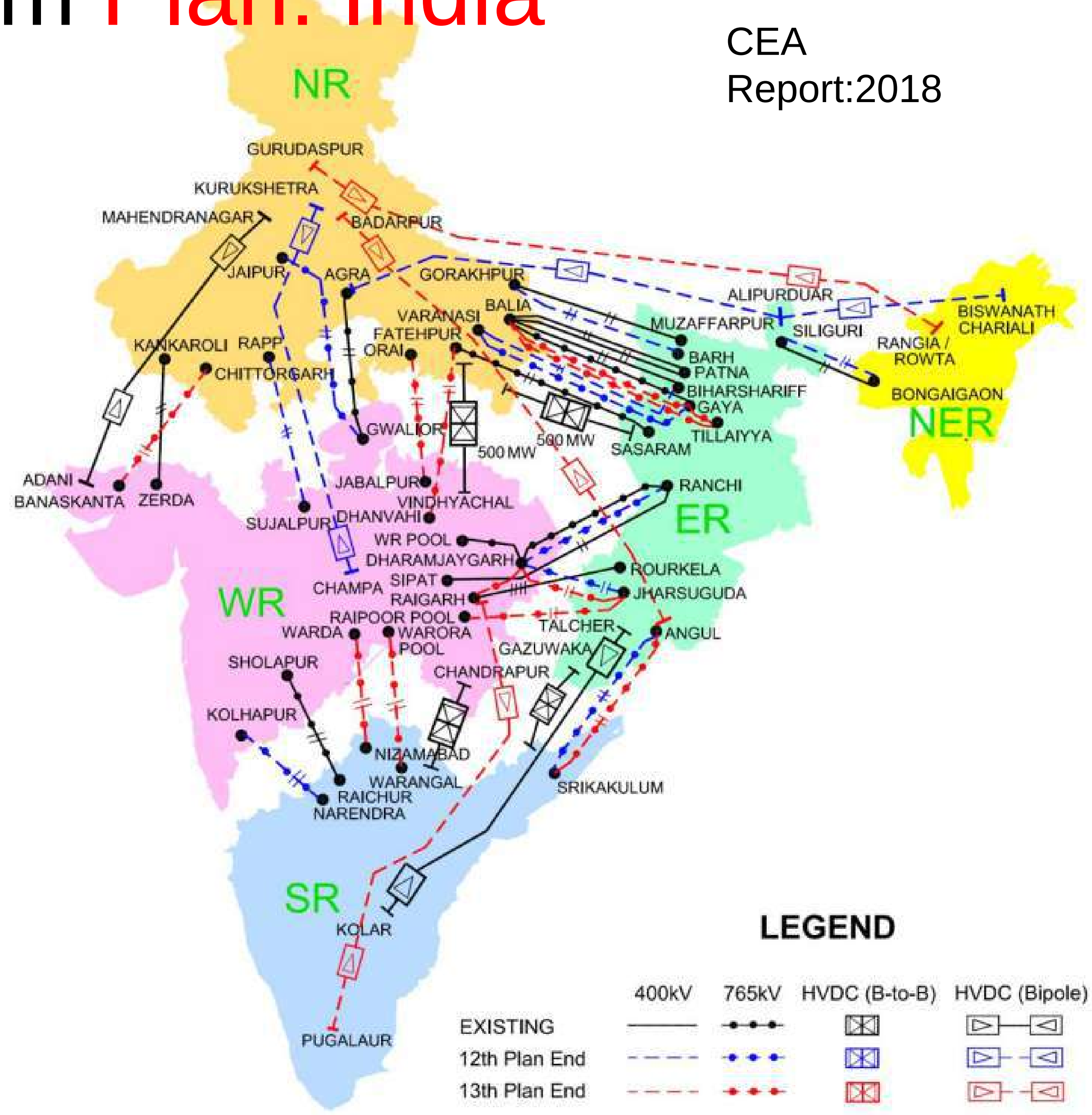
Source: PGCB Report (2016)



400kV TL map B'desh (2030)

3. Transmission System Plan: India

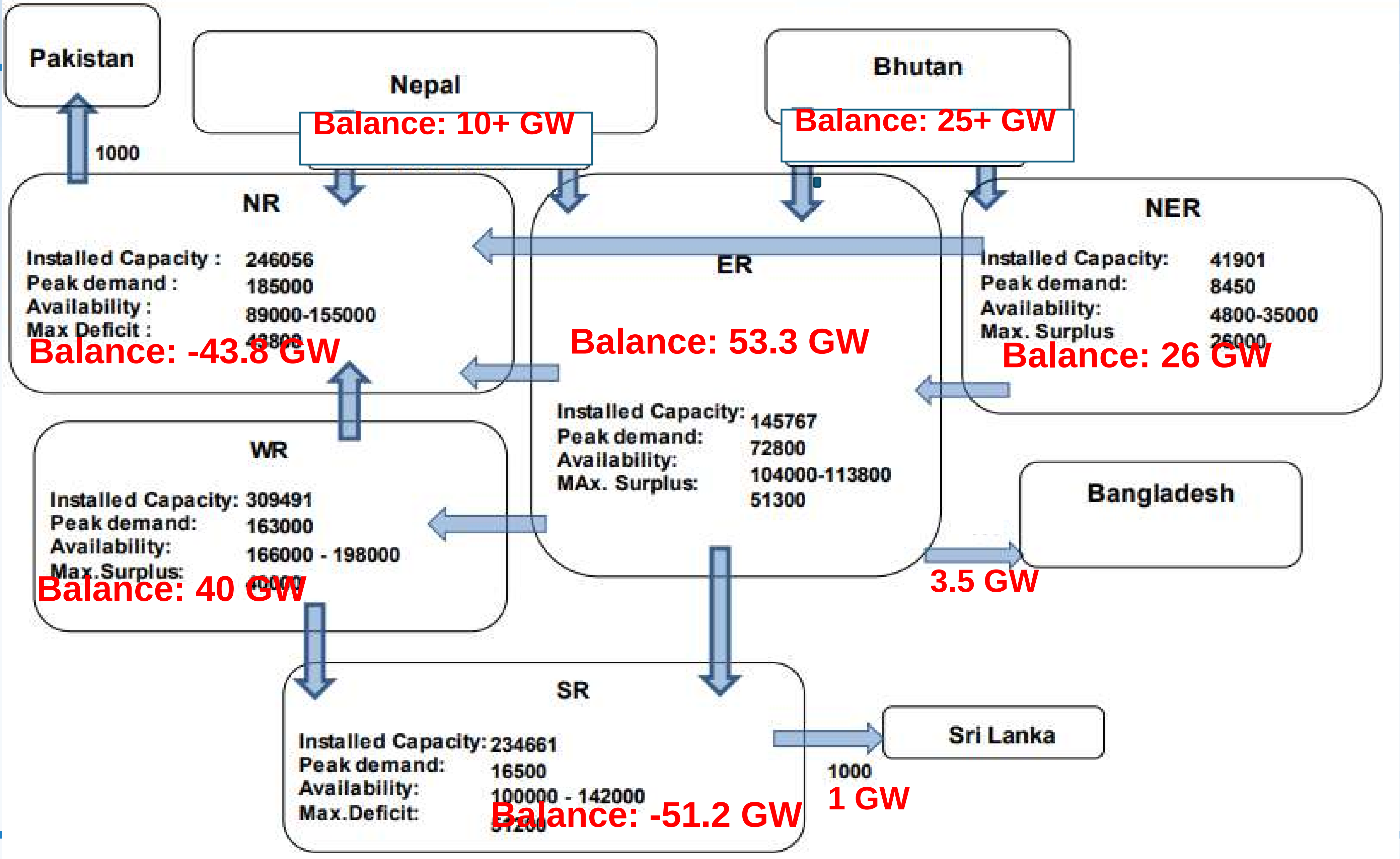
CEA
Report:2018



3. Transmission Grid:

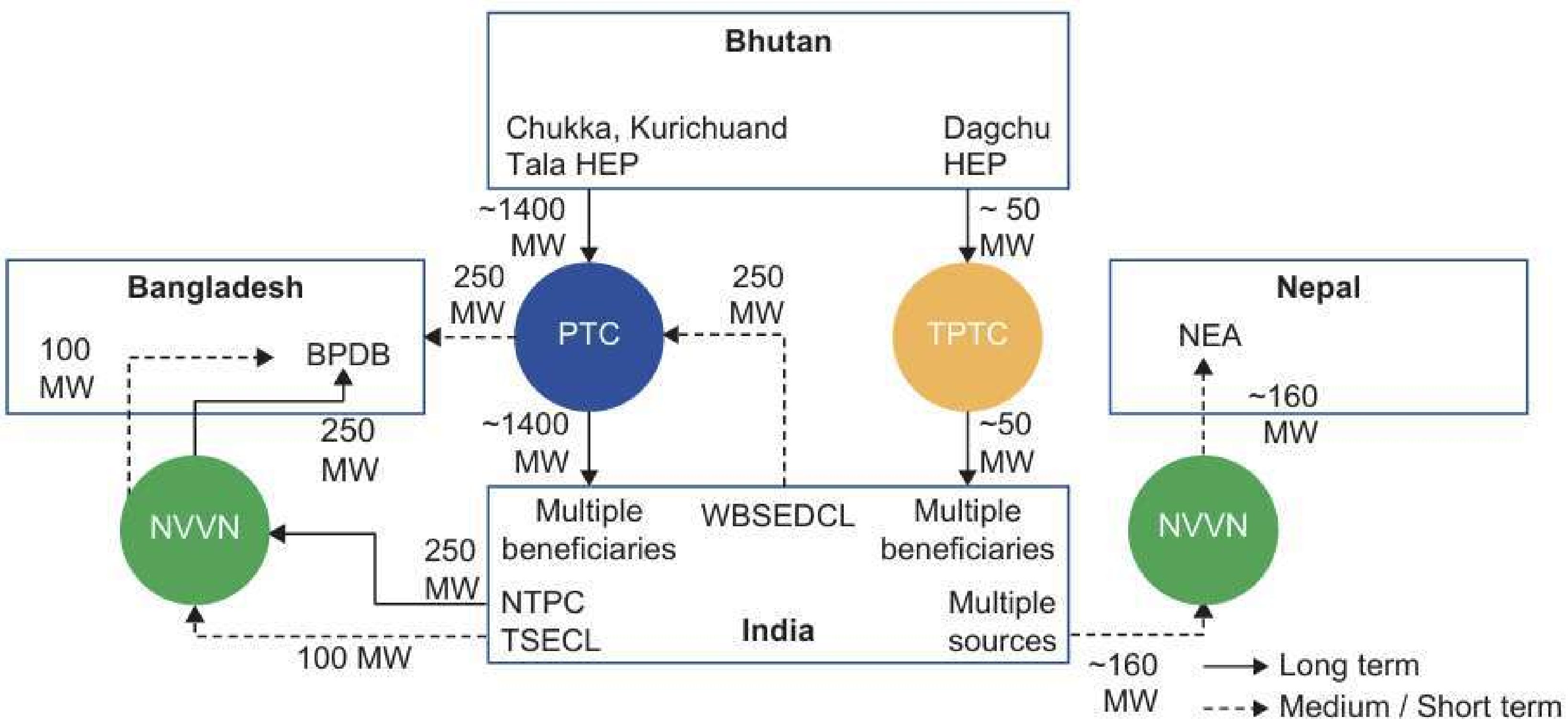
BBIN X-Border Grid

How much X-Border Power can Indian Grid Handle?



3. BBIN Trade Feature

Figure 5: Snapshot of Key Cross-Border Electricity Trade in South Asia



4. Open Access for CBET

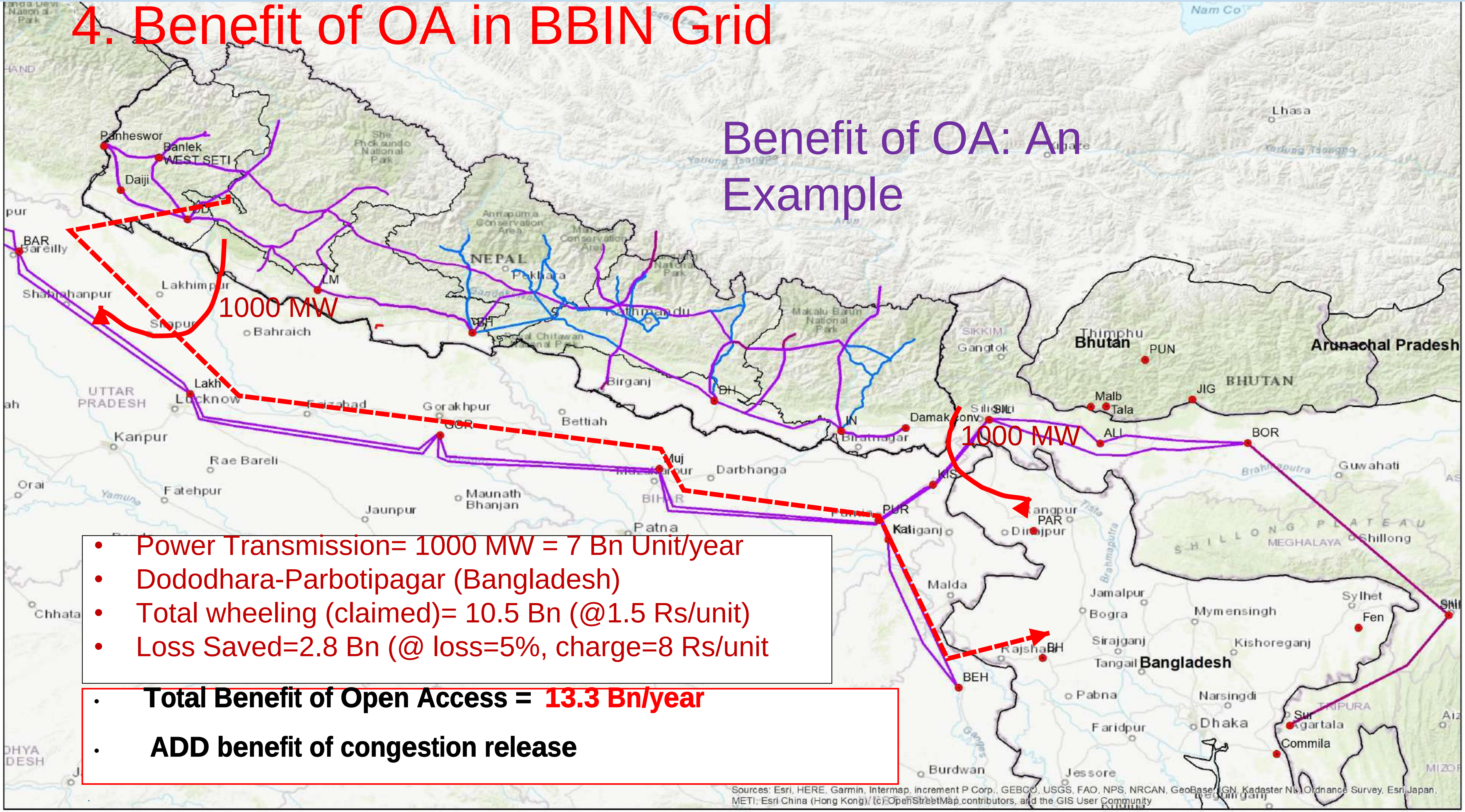
What is OA?

- Transmission Open Access Service allows non-utility entities (e.g., independent power producers, consumers, or traders) to use existing transmission networks for electricity transfer without owning the infrastructure.
- Regulated by energy authorities to promote competition and efficiency in the power sector.

What are the Key Features?

- **Non-Discriminatory Access**: Equal access to transmission infrastructure for all eligible users, regardless of ownership or affiliation.
- **Transparent Pricing**: Standardized and regulated tariffs to ensure fairness.
- **Capacity Allocation**: Available transmission capacity allocated based on predefined rules (e.g., first-come, first-served or auction-based).
- **Grid Reliability**: Ensures compliance with grid codes to maintain system stability.
- **Multiple Supplier and Multiple Buyer:** Competition for Supply

4. Benefit of OA in BBIN Grid



Benefit of OA: An Example

- Power Transmission= 1000 MW = 7 Bn Unit/year
- Dododhara-Parbotipagar (Bangladesh)
- Total wheeling (claimed)= 10.5 Bn (@1.5 Rs/unit)
- Loss Saved=2.8 Bn (@ loss=5%, charge=8 Rs/unit

- **Total Benefit of Open Access = 13.3 Bn/year**
- **ADD benefit of congestion release**

5. Summary