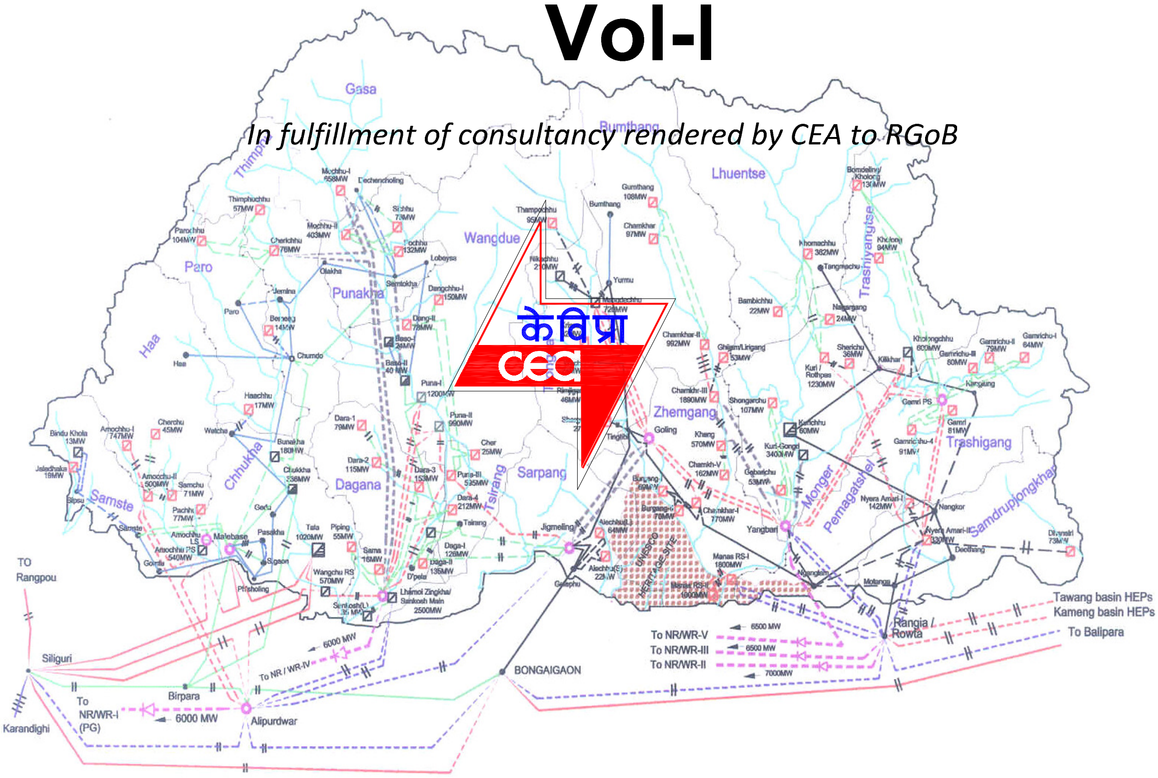
National Transmission Grid Master Plan (NTGMP) for Bhutan

Vol-I

In fulfillment of consultancy rendered by CEA to RGoB



Central Electricity Authority

System Planning & Project Appraisal Division,
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New Delhi, India.

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ACKNOWLEDGEMENTS

Royal Government of Bhutan has desired evolving a National Transmission Grid Master Plan (NTGMP) in their Himalayan country pari passu with the development of over 10,000 MW hydro power by 2020.

We thank RGoB for appointing Central Electricity Auhthority (CEA) as Consultant for preparation of NTGMP for Bhutan. We have been inspired and encouraged continuously by the power sector officials of Bhutan during the preparation of the NTGMP. We enriched our knowledge and experience during joint site visits at various prospective project sites, potential grid points, existing installations, etc. in Bhutan and also through extensive interactions and exchange of ideas with various stake holders in power sector of Bhutan.

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Abbreviations

RGoB	Royal Government of Bhutan
BPC	Bhutan Power Corporation
DVC	Damoder Valley Corporation
DGPC	Druk Green Power Corporation
HEP	Hydro Electric Project
PHEP-I	Punatsangchhu–I HEP
PHEP-II	Punatsangchhu–II HEP
MHEP	Mangdechhu HEP
HTLS	High Temperature Low Sag Conductor
p.f.	Power factor
S/S	Sub-station
MVA	Mega Volt ampere
MW	Mega Watt
Mvar	Mega volt ampere reactive
ATS	Associated Transmission System
LILO	Loop in Loop out
S/C	Single circuit
D/C	Double circuit on the same Tower
S/C on D/C	Single circuit on Double circuit Tower
HVDC	High Voltage Direct Current
EHVAC	Extra High Voltage Alternating Current
NR	Northern Region of India
WR	Western Region of India
WB	West Bengal
PS	Pooling Station
NTGMP	National Transmission Grid Master Plan
NTG	National Transmission Grid
ERS	Emergency Restoration System
TM	Twin Moose
LB	Left Bank
RB	Right Bank
AIS	Air Insulated Sub-station
GIS	Gas Insulated Sub-station
SIL	Surge Impedance Loading (MW)
PL	Price Level
INR	Indian Rupees

Chapter-1

INTRODUCTION

1.1 Royal Government of Bhutan (RGoB) has embarked on developing its huge hydro power potential at various basins in the country. Over 10,000 MW potential has been planned to be harnessed by 2020 from thirteen hydro projects viz. Punatsangchhu-I, Punatsangchhu-II, Mangdechhu,Nikachhu, Sankosh (Main & Left Bank), Kuri-Gongri, Wangchhu, Bunakha, Kholongchhu, Chamkarchhu-I, Amochhu and Bindu Khola HEPs. With this endeavour, Bhutan has aimed to prepare a National Transmission Grid Master Plan (NTGMP) by 2020 in the country to meet its load growth and to export huge surplus to India.

1.2 RGoB and CEA signed MoU on December 22, 2009 in New Delhi appointing CEA as the consultant for the preparation of NTGMP for Bhutan. Accordingly, CEA has undertaken the consultancy work and carried out the NTGMP exercise at the right earnest.

1.3 The first draft NTGMP study report was tabled by CEA in December 2010 for the 2020 hydro scenario on the basis of detailed system studies, considering load-generation and system data furnished by Bhutan and inputs gathered during the first joint site visit from 19-5-10 to 28-5-10 in Bhutan. On this report, a presentation was given by CEA to the senior power sector officials of Bhutan on 29th November, 2010 in Delhi. Anticipating higher load growth, Bhutan had desired to enhance their load demand from 978MW to 1500MW by 2020. In order to optimize Right of Way requirements (RoW) in the long term perspective (2030), resulting in minimum impact on Biological/Reserved park and environment, Bhutan had also desired for studying 2030 scenario to identify the requirement of overall RoWs for major trunk transmission corridors needed by the time for evacuation and transmission of power from additional HEPs expected by 2030, and 2020 NTGMP would be a subset of 2030 scenario.

1.4 Subsequently, Bhutan furnished the list of new 75 HEPs (basin-wise) for 2030 scenario with total installed capacity of 25054 MW. Out of this potential, capacity addition program for 2020 time frame is revised to 10334 MW from 14 HEPs. With an existing installed capacity of 1480 MW, total hydro capcity by the end of 2030 and 2020 will be 26534 MW and 11814 MW respectively.

1.5 With the above hydro development program and inputs gathered during second joint site visit to Bhutan from 15-02-2011 to 22-02-2011 and considering feedback of Bhutan on the first study report, the second draft NTGMP study report considering 2030 and 2020 power scenario in Bhutan was submitted by CEA to RGoB in October, 2011. Road map for development of strong and reliable NTGMP, optimizing RoW requirements for EHVAC & HVDC corridors was prepared and it was then presented by CEA to the power sector officials of RGoB, BPC, DGPC and other stakeholders including environment ministry of Bhutan in the 2-days workshop held on Nov 3-4, 2011 at Paro in Bhutan.

1.6 In the workshop, a new development within Bhutan was highlighted about a large geographical area in the south-eastern part of Bhutan (Zhemgang and Pemagatsel districts) being declared as a UNESCO National Heritage Site. In effect, it was noted that trunk AC & HVDC transmission corridors (viz. Yangbari-Jigmeling corridor) that were planned for bringing power from eastern to the western side of Bhutan and also for evacuation of Manas RS I & II (2800 MW) HEPs would be inaccessible as these corridors are falling in the Heritage Site. Further, the environment/forest department, GoB highlighted major constraints in the availability of RoWs in the Yangbari-Chamkarchuu-Goling and Goling-Jigmeling corridors due to involvement of biological parks. Thus, identification of alternative appropriate corridors not falling in the National Heritage site and redoing of NTGMP exercise for 2030 and 2020 scenario added a new dimension in the system planning. However, considering the above aspects and feedback of Bhutan, the NTGMP has been finalized and prepared after carrying out a comprehensive system study.

1.7 During the NTGMP exercise, grid scenarios for 2020 and 2030 time frames have been evolved considering twin moose conductor in 400 kV transmission system, as desired by Bhutan. In certain corridors, multiple number of 400 kV D/C twin moose conductor lines are required to evacuate power from HEPs to pooling points within Bhutan, accessing multiple numbers of right-of-ways in those corridors. To save right-of-ways using HTLS conductor, CEA shared its views that HTLS technology having much higher ampacity over ACSR moose conductor and high operating conductor temperature, has been extensively opted in India to built 400kV transmission systems in hilly terrains for evacuation of power from HEPs of Satluz basin and Chanrabhaga basin in Himachal Pradesh by 1016-1019. In the opinion of Bhutan, 400kV transmission lines using twin moose conductor would be the choice for 2020 scenario, but for 2030 scenario use of HTLS conductor could be one possible option. Accordingly, for Bhutan National Grid by 2020, twin moose conductor has been exclusively used in 400 kV transmission system. In the 2030 scenario, HTLS conductor in certain corridors has been considered to optimize right-of-ways as an alternative Grid Plan for 2030.

1.8 The NTGMP report has been prepared in two volumes, Volume-I and Volume-II. Volume-I contains 10 chapters of the main report and Volume-II contains Annexures and Exhibits. Given in annexures are various existing/approved/under construction system data, list of existing HEPs, list of HEPs by 2030, list of 2020 HEPs, load forecast data, generation despatches of various hydro stations, ATS for HEPs for 2030, short circuit study results, estimated costs etc. Results of load flow case studies, continegency analysis, sensitivity study, etc are given in Exhibits.

Chapter-2

BACKGROUND

2.1 Bhutan has total installed generating capacity of 1480 MW (apart from macro/micro hydel stations) comprising of Tala (1020MW), Chukha (336MW), Kurichu (60MW) and Bosochhu-I (24MW) & II (40MW) HEPs. In addition, Dagachhu (126MW) HEP, a Run of the River (RoR) scheme in western Bhutan is being developed under public-private-partnership with Tata (26% share) from India and Druk Green Power Corporation (DGPC) and NPPF from Bhutan as partners, and it is targeted to be commissioned by 2013.

2.2 The peak load demand of Bhutan is expected to be around 372 MW during 2012, out of which 331 MW load is in Western Bhutan and 41 MW in Eastern/Central Bhutan. The transmission voltage of Bhutan is 400kV, 220kV, 132kV and 66kV. The entire 220kV and 400kV transmission system networks are in the western part, and it was largely developed as associated transmission systems for Chukha (336MW) and Tala (1020MW) HEPs. Electricity generated from these HEPs is mostly exported to India. During winter when hydro generation in Bhutan is inadequate to meet its load demand, Bhutan imports power from India.

2.3 In the eastern part of Bhutan, Kurichu (60MW) HEP and its 132kV evacuation system caters to the local consumer and industrial load presently and the surplus power is transmitted to India through 132kV Gelephu (Bhutan) – Salakati (India) line. In order to establish West-East interconnection, LILO of 132kV Gelephu-Tintibi (Lodrai point for LILO) line at Jigmeling is being implemented by BPC to form the 132kV Tintibi-Jigmeling S/C line as East-West link.

2.4 The first draft NTGMP study report, considering 2020 hydro power development scenario in Bhutan, was tabled in December 2010 with the load-generation and system data furnished by Bhutan and inputs gathered during first joint site visits from 19-5-10 to 28-5-10 in Bhutan. In this exercise, project specific ATS, various alternatives for Bhutan grid, transmission strengthening for reliable supply to load centers, system requirements for export of huge surplus to India, etc. were evolved and 400kV transmission was considered as backbone for Bhutan National grid. On this report, a presentation was given to the senior power sector officials of Bhutan on 29-11-2010 in Delhi. Bhutan had envisaged higher load growth in their country and enhanced the load demand from 978MW to 1500MW by 2020. In order to optimize the overall Right of Way requirements (RoW) in the long term perspective that is by 2030 with an objective of having minimum impact on Biological/Reserved park and environment, Bhutan had desired for studying its 2030 power scenario to identify the major transmission corridors needed by the year 2030, considering evacuation of additional HEPs likely to materialize by the time. NTGMP for 2020 time frame would be a subset of 2030 scenario. Accoringly, additional inputs for carrying out the necessary studies for 2030 and 2020 time frames were to be submitted by Bhutan.

2.5 Subsequently, Bhutan furnished the list of basin-wise prospective HEPs for 2030 scenario, revised hydro capacity addition program for 2020 time frame, etc. RGoB identified about 25054MW hydro power potential to be harnessed by 2030 from about 75 new hydro projects. Out of this, 10334 MW hydro power development from fourteen HEPs has been envisaged during 2020, revising the earlier schedule of 11442 MW. Balance 14720 MW capacity is envisaged to be added during 2020-2030.

2.6 During 2020, 6234MW out of 10334 MW new capacities is envisaged to be added in Western Bhutan and 4100 MW in Eastern Bhutan. Two HEPs i.e. Nikachhu (210MW), an upstream project of Mangdechhu HEP in eastern Bhutan, and Bindu Khola (13MW) in western Bhutan were included under the revised 2020 power development programme. Further, installed capacity of Kholongchhu was revised from 486MW to 600MW. Based on the updated data, inputs gathered from second joint site visit in Bhutan from 15-02-2011 to 22-02-2011 and considering RGoB's observations on the first study report, a comprehensive and long exercise to evolve Bhutan grid Plan was carried out for 2030 and 2020 time frames. With (n-1) criteria (including 400kV tower outage), major transmission AC & HVDC corridors, RoW requirements and major power pooling points within Bhutan were identified for 2030. Accordingly, detailed transmission planning exercise was carried out corresponding to 2020 scenario to derive the NTGMP for Bhutan in a holistic manner, utilizing the findings of 2030 studies.

2.7 The second draft NTGMP study report considering 2030 and 2020 power scenario in Bhutan was submitted by CEA to RGoB in October, 2011. Major high capacity transmission corridors, potential pooling points, composite evacuation system for a cluster of basin-wise HEPs, transmission reinforcements in India for transfer of Bhutan surplus, etc. were determined. An elaborate system planning exercise for NTGMP by 2020 was done and road map for development of strong and reliable NTGMP for Bhutan by 2020, identifying and optimizing RoW requirements for AC & HVDC corridors was prepared. The report was then presented to the power sector officials of RGoB, BPC, DGPC and other stakeholders including environment ministry of Bhutan in the 2-days Workshop held on 3-4 Nov’2011 in Bhutan. The draft NTGMP was discussed thread bare and some corridor issues for transmission system development in Bhutan emerged as explained in the following paragraph.

2.8 For evacuation of power from HEPs in eastern Bhutan, Yangbari-Jigmeling corridor was identified to be developed as trunk transmission lines to facilitate power transfer to Alipurduar (India) via Jigmeling. However, in the workshop, Bhutan informed that:

i. A large land area in the south-eastern part of Bhutan (Zhemgang and Pemagatsel districts) has been declared as UNESCO National Heritage Site and this area would be inaccessible for getting any RoW for transmission system development. The Yangbari-Jigmeling corridor was earlier identified to be built as high power density lines for transfer of power from eastern to western side of Bhutan and it is now falling in the proposed Heritage site. Appropriate alternative corridors were required to be identified and studied for power evacuation from HEPs in eastern Bhutan.

ii. Manas RS hydro projects (Stage-I & II) of 1800MW and 1000 MW capacity being envisaged in 2030 time frame are lying in this area, and harnessing of this hydro power development and its evacuation has added a new dimension to determine new corridors for associated AC and HVDC transmission systems.

iii. Further, the environment/forest department, GoB highlighted major constraints to the availability of RoWs in the Yangbari-Chamkarchuu-Goling and Goling-Jigmeling corridors due to involvement of biological parks. Development of multiple numbers of 400kV transmission lines in these corridors has become a serious problem for HEPs in eastern Bhutan.RGoB opted for limited use of RoWs in these corridors.

iv. The installed capacity of Sankosh HEP in western Bhutan was revised from 4060 MW to 2585 MW (including main and right bank power houses).

v. The installed capacity for Kuri-Gongri HEP in eastern Bhutan was yet to be firmed-up. However, RGoB desired to consider its capacity as 1800 MW and alternatively, 3400 MW.

vi. Further, due to severe land procurement/acquisition problems, Bhutan desired not to set-up any HVDC station within Bhutan for transfer of their surplus power to India in 2020 secnario.

2.9 In view of above changes in scenario, NTGMP exercise for 2030 and 2020 time frames needed a comprehensive review. Accordingly, revised system studies and analysis for 2030 and 2020 are carried out to re-firm up system requirements within and outside Bhutan. The long term requirements for developing transmission corridors/highways for AC & HVDC lines, nodal pooling points, HVDC converter stations in Bhutan and India are inter-alia firmed up corresponding to 2030 scenario. Considering 2030 system study as a base, various case studies for 2020 scenario including peak load,minimum load, full hydro despatch, minimum hydro despatch, high hydro despatch, reactive power compensation, credible contingency analysis, system strengthening, etc. are carried out. Accordingly, detail system requirements to develop an integrated National Grid in Bhutan by 2020, phasing for implementation and estimated costs has been derived, aimimg to reliable power supply to the load centers of Bhutan and to export huge surplus to India.

Chapter-3

SYSTEM DATA

3.1 Existing Power System Data

The following system data furnished by Bhutan in respect of their Hydro Capacity addition by 2030 and revised hydro generation scenario for 2020 time frame, and existing and planned transmission systems constitutes the basic input file to carry out system study for NTGMP of Bhutan.

(i)	Existing Hydro Generating Stations	*Annex-I*
(ii)	New Hydro Generating Projects by 2020	*Annex-II*
(iii)	New Hydro Generating Projects beyond 2020 and upto 2030	*Annex-III*
(iv)	Existing Transmission Lines (66kV and above)	*Annex-IV*
(v)	Planned/Under construction Transmission Systems	*Annex- V*
(vi)	Existing Sub-stations (66kV and above)	*Annex-VI*
(vii)	Planned/Under construction/Proposed sub-stations	*Annex-VII*

3.2 Prospective Hydro Projects in Bhutan.

3.3 HEPs by 2030 Time Frame:

RGoB has envisaged to harness over 25054 MW hydro power potential by 2030 from about 75 new hydro projects identified at different hydro basins. The list of projects is given at Annex-II & III

3.4 HEPs by 2020 Time Frame:

Out of the above HEPs, Bhutan has embarked upon to develop 10334 MW by 2020 from fourteen HEPs after revising capacity addition programme for 11650 MW from ten HEPs. Out of 10334 MW, 6234 MW would be developed in Western Bhutan and 4100 MW in Eastern Bhutan. The list of the fourteen HEPs is given at Annex-II. Thus, additional 14720 MW hydro power development is envisaged during the 2020-2030 time period.

In the revised programme, two additional HEPs viz. Nikachhu (210MW), an upstream project on Mangdechhu HEP in eastern Bhutan, and Bindu Khola (13MW) in western Bhutan are included under the 2020 power scenario. Further, installed capacities of the ten HEPs have been revised and updated list of 2020 Projects is given below.

Sl. No.	Name of HEP	Initial Installed capacity (MW)	Revised capacity with addl. projects (MW)	Year of commissio-ing	DPR
1.	Punatsangchhu-I	1200(6x200)	1200(6x200)	2015	WAPCOS
2.	Punatsangchhu-II	**990(6x165)**	**1020(6x170)**	2017	WAPCOS
3.	Mangdechhu	720(4x180)	720(4x180)	2017	NHPC
4.	Sankosh Main HEP	**4000**	**2500**	2020	THDC*
5.	Sankosh LB HEP	**60**	**85**	2020	THDC*
6.	Kuri-Gongri	**1800**	1800/**3400**	2020	NHPC*
7.	Wangchhu	**600**	**570(4x142.5)**	2019	SJVNL
8.	Bunakha Reservoir	180(3x60)	180(3x60)	2020	THDC
9.	Kholongchhu	**486**	**600(4x150)**	2018	SJVNL
10.	Chamkarchhu-I	**670**	**770(4x192.5)**	2018	NHPC
11.	Amochhu RS	**600**	**540(4x135)**	2018	NTPC
12.	Nikachhu	210	**210**/140	2020	DGPC*
13.	Bindu Khola	13	13	2020	DGPC*
14.	Dagachhu	**114**	**126(2x63)**	2020	DGPC & Tata
	Total	**11420**	**10334**		

**DPR under preparation or being revised*

3.5 The topological map of Hydro Projects:

The topological map depicting the location of the existing hydro stations, new HEPs by 2020, and HEPs being envisaged during 2020-2030 is shown in Fig.1.

TOPOLOGICAL MAP OF BHUTAN

(SHOWING TENTATIVE LOCATIONS OF HEPs BY 2030)

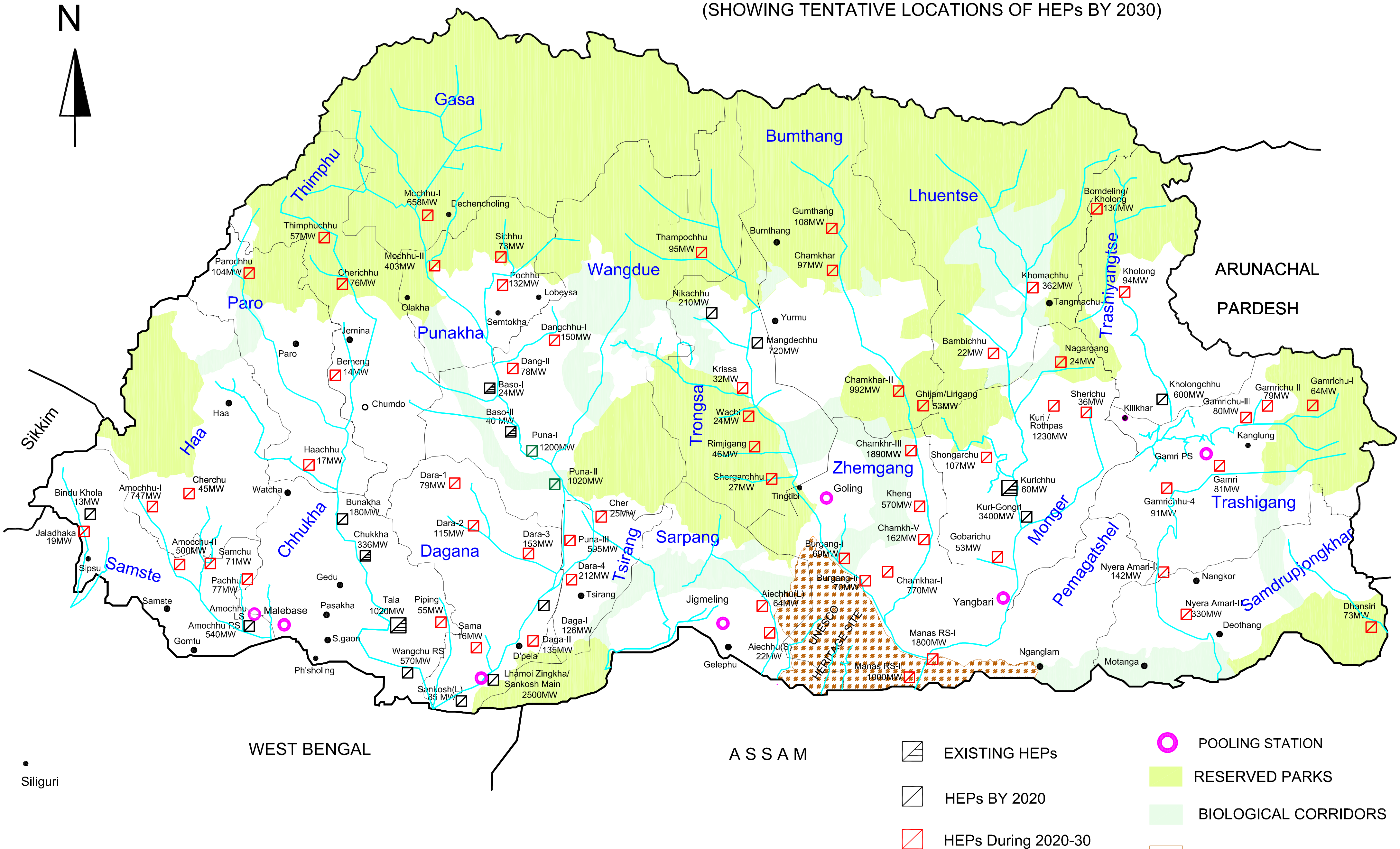


Fig. 1

3.6 The year-wise growth in installed generating capacity in Bhutan is shown at Fig. 2.

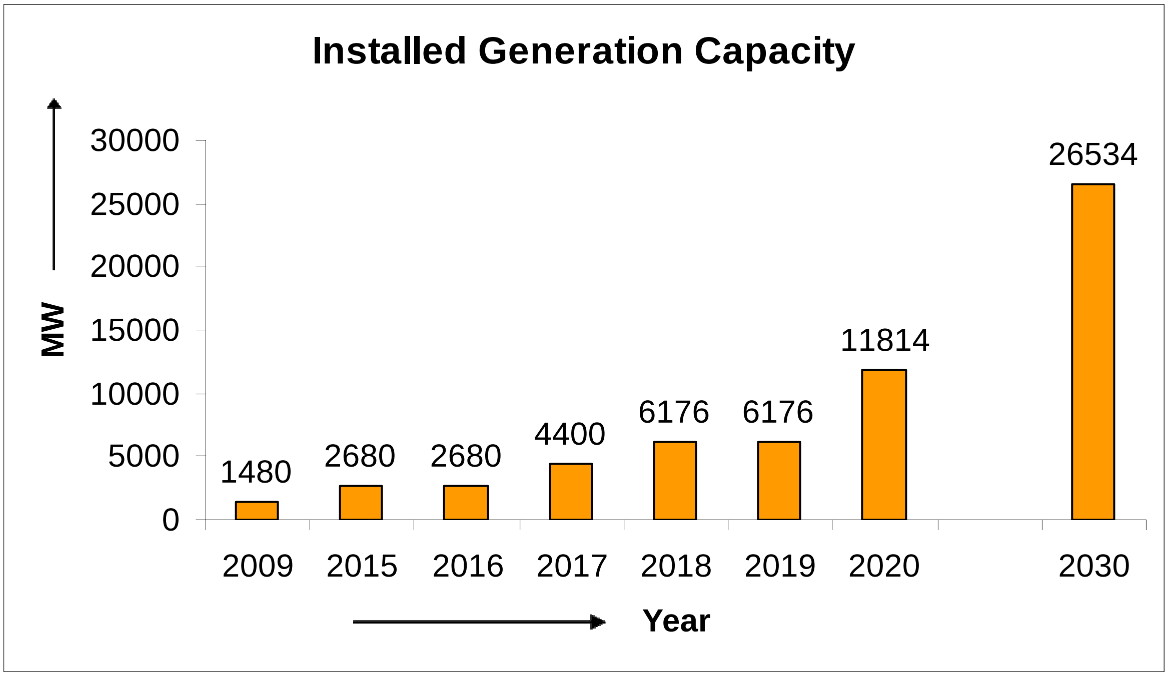


Fig. 2

3.7 Generation Dispatches

Considering 0.5% auxiliary consumption, the following generation dispatches at hydro stations in Bhutan are worked out to carry out various case studies for 2030 and 2020 scenario.

3.7.1 Dispatch for 2030 scenario

Full hydro dispatch at peak load condition for 2030 scenario is given at Annex-IX.

3.7.2 Dispatch for 2020 scenario

(i) Full hydro dispatch for peak load condition for 2020 scenario is given at Annex-IX

(ii) Generation Dispatch during minimum hydro & light load conditions is given at Annex-IX

(iii) High hydro Dispatch during during high monsoon periods at Annex-IX.

(iv) 10% additional dispatch over normal peak load dispatch during high monsoon period at Annex-IX.

3.8 Load Forecast

3.9 Load Growth in Bhutan by 2030

The demand forecast in Bhutan for 2020 was initially 978 MW and subsequently revised to 1500 MW. As per the year-wise load forecast data furnished by Bhutan upto 2020 time frame, and an average load growth is worked out to about 15%. Accordingly, load demand (MW) during 2030 is estimated to about 2500MW.The corresponding sub-station wise load growth by 2030 scenario has been worked out as shown at Annex-VIII.

3.10 Load Growth in Bhutan by 2020

The load growth was initially estimated to be 978 MW by 2020 of which 857 MW demand is in Western Bhutan and 121 MW is in eastern/central Bhutan. Subsequently, anticipating higher industrial load growth, Bhutan increases it to 1500 MW. Keeping this in view, year wise sub-stations' loads are increased on pro-rata basis for 2020 condition as shown at Annex-VIII. The revised demand of Western Bhutan becomes 1314 MW and that of Eastern/Central Bhutan is 186 MW. The revised load demand for 2020 and for the year 2030 in Bhutan is shown in Fig.3.

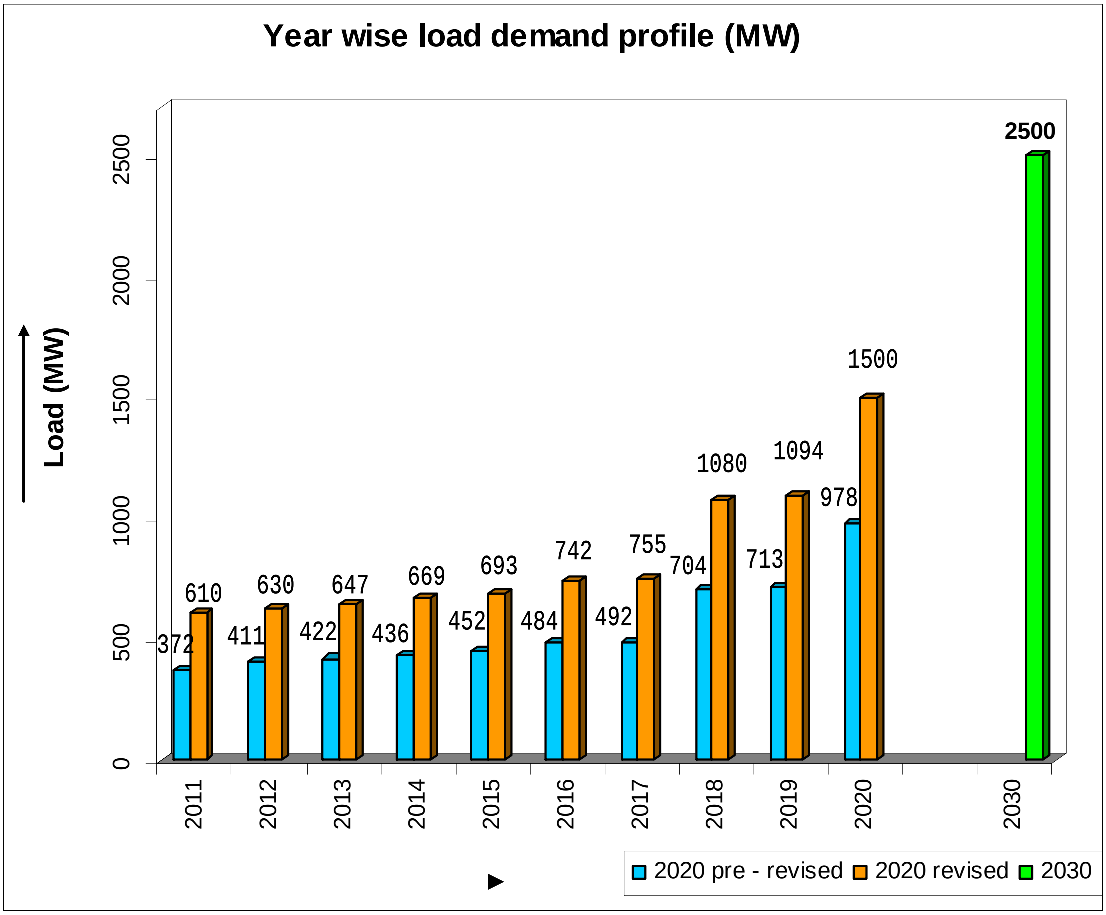


Fig.3

3.11 Route length of Transmission lines

The route length (km) of the existing/approved lines as furnished by Bhutan is given at Annex-IV, whereas lengths of various new transmission lines are measured tentatively as per the scale of the topogological map. However, keeping in view the physical terrain being hilly in nature in Bhutan, about 30% more in length over the scale of measurements is considered. Accordingly, route length of various project specific transmission system is shown at Annex-X.

3.12 Load power factor

In view of the Bhutan load being primarily industrial and domestic in nature, load power factor is considered as 0.9 lag during peak and minimum load conditions.

Chapter-4

Existing Transmission System Scenario in Bhutan

The transmission networks in Bhutan comprises the Western and Eastern grids operating in isolation due to no interconnecting line between the two regions.

4.1 The transmission network in the western part of Bhutan is relatively large compared to eastern grid and having 400kV, 220kV and underlying 66kV systems supplying the load centers. The 220kV lines have been developed primarily for evacuation of power from Chukha HEP and Bosochhu-II (Rurichhu) HEPs. For Chukha HEP, three 220kV circuits from Chukha to Indian border at Birpara S/S (one D/C line on the same tower and one S/C line) were established. Also, the 220kV Rorichhu-Semtokha, Semtokha-Chukka, and Rorichhu-Tsirang (operating at 66kV) lines become part of the Western grid system.

4.2 The 400kV system development in Bhutan came into being for evacuation of power from Tala HEP. The 400kV Tala-Siliguri (India) 2xD/C Twin moose lines along with 400/220, 220//66kV sub-station at Malbase by LILOing one circuit of 400kV Tala-Siliguri lines, was constructed. The 220kV single circuit Chukha-Birpara line was LILOed at 400/220/66kV Malbase sub-station. The 220kV D/C line from Malbase to Singhigaon meets industrial loads at Pasakha/Phuntosholing areas. The underlying 66kV wide spread network is well interconnected to the 220kV system in the western Bhutan and is supplying electricity to the load centers.

4.3 In the eastern part only 132kV transmission network exists having altogether seven nos. 132kV S/C lines and it was primarily developed for evacuation of power from Kurichu HEP(60 MW). After meeting load demand of eastern Bhutan, exportable surplus power available from Kurichhu is transferred to DVC & West Bengal in India through 132kV Gelephu-Salakati (Assam) link. The construction of the 132kV

Deothang - Rangia (Assam) S/C line has also been completed (yet to be charged) to facilitate evacuation.

4.4 Under the on-going construction work, 220kV sub-station each at Jigmeling and Dagapela, 220kV Dagachhu HEP- Jigmeling D/C line with LILO of one circuit at 220kV Tsirang S/S, and LILO of one circuit of 220kV Dagachhu-Tsirang D/C line at Dagpela are being established by BPC in the central/southern Bhutan to facilitate power evacuation from upcoming Dagachhu HEP (126MW) and to meet local load demand. Further, the existing 132kV Tintibi – Gelephu S/C line is being LILOed (at Lodrai location) at Jigmeling. The LILO portion of about 10km is planned to be constructed as 220kV D/C line with Zebra conductor and operated at 132kV. With this LILO, a 132kV West-East interconnection within Bhutan is going to be established at initial phase with formation of 132kV Tintibi-Jigmeling S/C and Jigmeling-Gelephu S/C lines. At Jigmeling, a 220/132 kV, 2x63 MVA along with a 132/33 kV 1x15 MVA capacity substation is proposed to be established by BPCL to meet the initial load requirement of about 100 MW from this sub-station.

4.5 Bulk of power generated at the existing Chukha (336 MW), Kurichhu (60 MW) and Tala (1020MW) HEPs in Bhutan, is exported to India. The associated transmission systems are given in Annex-IV**.** Bhutan is exporting its surplus power from Chukha through 220kV Chukha-Birpara(India) D/C line; Tala power is being exported through 400kV Tala-Siliguri(India) 2xD/C line, one ckt of which is LILOed at 400/220/66kV Malbase S/S in Bhutan; Kurichu power is normally exported to India through 132kV Gelephu-Salakati (India) S/C line.

4.6 Total circuit kilometer of 66kV to 400kV transmission lines that are existing and under construction/planned (excluding Punatsangchhu I & II transmission lines) in Bhutan are shown at Fig.4.

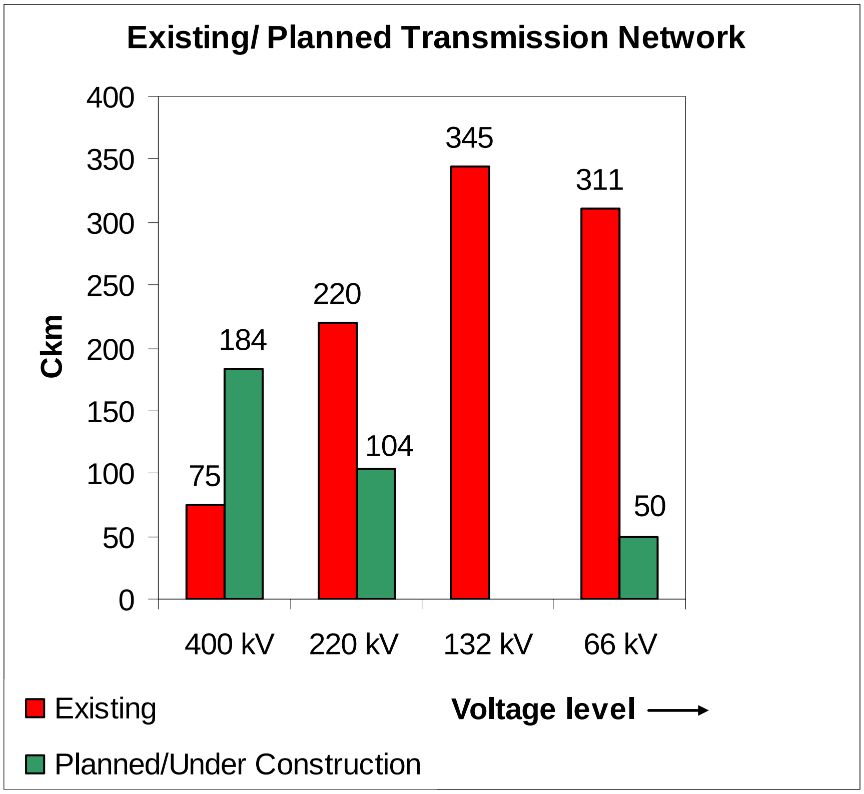

Existing/ Planned Transmission Network
Ckm
400
350
300
250
200
150
100
50
0
75
184
220
104
345
311
50
400 kV
220 kV
132 kV
66 kV
Existing
Planned/Under Construction
Voltage level

Fig. 4

Chapter-5

System Planning Guidelines

5.1 Planning Approach

In the process of evolving evacuation systems for various HEPs and during finalization of evacuation system Punatsangchhu-I and Punatsangchhu-II HEPs, close interactions were held with the officials of RGoB and BPC about selection/using of high ampacity low sag conductors (viz. HTLS), AAAC, ACSR conductor, light towers, more than two bundle conductors, etc. in 400kV transmission in Bhutan.

5.1.1 Subsequently, RGoB and BPC shared their experiences gained from visiting HLTS conductor manufacturers and installations in foreign countries with a view that HTLS conductor is being used mostly in special cases for short lengths such as river or sea crossing, or for re-conductoring a line, and nowhere HTLS conductor is being used as a regular conductor. Excessive temperature rise and voltage drop during (n -1) contingency were issues of concern with HTLS conductor apart from issues related to careful handing, jointing and repair and maintenance. Therefore, the idea of using HTLS conductor was not pursued.

5.1.2 Later, during review of transmission systems for PHEP-I & PHEP-II HEPs, AAAC conductor, was thought of and it was proposed to use triple and quad conductor configurations to reduce the number of corridors. Bhutanese side was of the view that quad and triple conductor towers would be very heavy and may not be prudent to be adopted in the fragile Himalayan terrain of Bhutan. It was also opined that Bhutan would not have a strong meshed grid and shut down of a hydro station due to tower outage would have significant impact on the reliability of supply to Bhutan and India. Further, for tower outage in plains, ERS can be used for temporary and fast restoration of the line but, in hilly terrain it is difficult to use the ERS. In view of above, BPC had proposed the following criteria in general for system planning while the Punatsangchhu transmission system was firmed-up:

- D/C line with twin Moose ACSR for the 400kV transmission system is the preferred option due to difficult hilly terrain and O&M related issues.
- Within Bhutan, contingency of tower outage needs to be considered.
- Necessary environmental clearances for the multiple transmission corridors would be taken care by BPC.

5.1.3 According to the topological condition, Bhutan is having widespread biological/ reserved parks, difficult hilly terrain and serious environmental concern. Considering these aspects, the following strategies towards evolving transmission systems for NTGMP of Bhutan were followed,

- Meeting the requirements of adequacy, security and reliability
- Amenable to development in stages
- Cost economy
- Right of way (RoW) optimization
- Ease of operation and maintenance
- Minimum environmental impact

5.1.4 With the above objectives, the following norms are generally followed to carry out the transmission planning exercise for NTGMP.

- Planning for development of integrated National transmission grid in Bhutan.
- (n-1) contingency including tower outage in hilly terrain.
- Power transmission at 400kV, 220kV,132kV and 66kV AC voltage and ±800kV for HVDC Transmission.
- Twin Moose ACSR conductor in hilly terrain and quad moose and/or twin moose conductor at plain for power transmission at 400kV with in Bhutan border.
- 0.5 % auxiliary consumption at hydro stations

5.2 System Planning Methodology & Software

Load flow studies have been carried out to plan and determine the system requirement of NTGMP for 2030 and 2020 scenarios in Bhutan, using PSSE software (vers. 26) and Desktop computer in CEA. The methodology for power flow study in an electrical network and various numerical algorithms are given at Appendix-3.

The base case PSSE input files prepared to carry out load flow studies for 2020 and 2030 peak load condition are given at Annex- XVI.

5.3 Transmission line loading capacity

Thermal loading limit of a transmission line is generally decided by design practice on the basis of ambient temperature, maximum permissible conductor temperature, wind velocity, solar radiation intensity, solar radiation absorption co-efficient, conductor emissivity, etc. EHV transmission lines are planned in Bhutan for operation at maximum conductor temperature of 85ºC, and it is presumed that the ambient temperature in Bhutan normally lies within 35ºC. Among the ACSR conductors, Moose conductor is considered in 400kV; Zebra is in 220kV; Panther is in 132kV; Wolf/Dog is in 66kV transmission lines. The approximate values of ampacity (thermal loading capacity) of the above conductors at ambient temperature of 30ºC, 35ºC, 40ºC are given at Appendix-1.

Permissible line loading depends on many factors such as length of the line, current carrying capacity, voltage regulation, stability etc. For shorter line, a line may be loaded to the extent of thermal loading limit, whereas loading limit in long lines are generally governed by its Surge Impedance Loading (SIL). The line loading as function of length of the line is given at Appendix-2.

Chapter-6

Transmission System Exercise for 2030 Scenario

In order to evacuate power from various hydro projects in Bhutan and to export Bhutan surplus to India, load flow studies are carried out to identify long term requirements of RoWs for developing major transmission corridors and associated pooling stations within Bhutan, considering load- generation scenario for 2030.

6.1 Generation Scenario by 2030

Bhutan has identified about 75 nos. new HEPs of large to small generation capacity by 2030 at various hydro basins of their Himalayan terrain. The list of basin-wise HEPs including the existing ones with their installed capacity is given at Annex-II & III. Altogether, 26534 MW hydro potential would be harnessed by 2030, in which 12198 MW capacities is envisaged in Western Bhutan and 14336 MW in Eastern Bhutan. The overall capacity addition scenario by 2020 and beyond (upto 2030) is given in Table-1.

Table-1: Generation Capacity addition in Bhutan by 2030

Existing I.C.	Capacity addition by 2020	I.C. at the end of 2020	Capacity addition during 2020-2030	I.C. at the end of 2030
1480 MW	10334 MW (fourteen HEPs)	11814 MW	14720 MW (sixtyone HEPs)	26534 MW

The new HEPs are well distributed over the five major river basins viz. Wangchhu, Amochhu, Punatsangchhu, Mangdechhu and Drangmechhu basins. The largest basin is Drangmechhu in eastern Bhutan where about 7900 MW hydro potential will be harnessed. Major HEPs in this basin are Kuri-Gongri, Kholongchhu, Khomachhu, Kuri/Rothpasang, Manas-RS I & II, etc. At Wangchhu basin in the western Bhutan, Wangchhu HEP is a new project to be developed by 2020 in addition to the existing

Tala and Chukha HEPs. At Amochhu basin in the western Bhutan, major HEPs identified are Amochhu-RS, and Amochhu-I & II projects. There is about 5900 MW hydro potential identified at Mangdechhu basin in the eastern Bhutan, where major HEPs are Mangdechhu, Nikachhu, Chamkarchhu and Chamkarchhu-I/II/III/IV/V,Kheng, etc.At Punatsangchhu basin in the eastern Bhutan, about 7600 MW hydro potential has been identified and the major HEPs are Sankosh, Punatsangchhu-I, II & III, Mochhu-I & II, Dagachhu, etc.

6.2 Joint Site visits in Bhutan

In order to identify prospective sites for nodal Pooling points and transmission corridors, two site visits were performed jointly by CEA team and power sector officials of Bhutan during 19-5-10 to 28-5-10 and 15-02-2011 to 22-02-2011. The visits had also given opportunities of close interactions with the field engineers, enabling to gather knowledge about the nature of hilly terrain, RoW problems, huge areas occupying with biological/reserved parks, availability of lands for creating pooling/sub-stations, density of population, scope of expansion of the existing infrastructure/sub-stations, etc. The information has greatly influenced to identify the prospective locations for nodal pooling stations and to identify major corridors for bulk power transmission within Bhutan, considering that minimum damages to environment and forests are done and alignment through the protected national parks and sanctuaries are avoided. The detail findings of the above site visits are given at Annex-XII.

The prospective locations for pooling stations in western Bhutan are identified at Jigmeling (east-south zone), Lhamoizingkha/Sankosh (west-south), and Punatsangchhu-III (west zone), where hydro generations from western basins will be mostly pooled. In eastern part of Bhutan, Goling, Yangbari, Nyera Ameri and Gamri are the preferred locations for setting up of pooling stations where hydro generations from various basins shall be pooled.

6.3 Load - Generation position by 2030

Load demand was originally estimated to grow to 978MW by 2020. Anticipating higher industrial load growth it was augmented to 1500MW. Presuming @15% growth per year, load of Bhutan is estimated to be 2500 MW by 2030.

For the 2030 scenario, hydro generation dispatches for peak load condition, has been worked out with a total dispatch of about 26394 MW as given at Annex-IX. There will be huge surplus in Bhutan to be exported to India after meeting its internal requirement of 2500MW. In order to conserve environment in Bhutan, it is aimed to minimize RoW access for building trunk transmission corridors to meet internal load growth as well as to facilitate export of surplus to India. As entire surplus of Bhutan needs to be catered through the Chicken-neck area in the northern part of West Bengal (WB) in India, where severe RoW problems persist, ± 800 kV HVDC transmission technology is considered to provide right solution for bulk power transmission over long distance from Bhutan to deficit regions (NR/WR) in India.

6.4 System Studies for 2030 scenario

Transmission planning studies have been carried out for 2030 scenario using PSSE software to determine major bulk power transmission corridors, RoW requirements, nodal pooling stations, generation specific evacuation system for 75 HEPs at various basins, etc.

6.4.1 For power evacuation, step-up voltage for HEPs is considered at 400kV or 220kV or 132kV or 66kV level depending on the installed capacity of the projects. The 400kV transmission system is considered to be the backbone for 2030 Bhutan grid. In order to optimize size of the pooling station at Yangbari and to contain short circuit level with in accepatable level, new poling station at Nyera Amari is contemplated and evacuation of a couple of HEPs (by 2030) in eastern Bhutan has been pooled at this point, considering transmission to be inter-basin in nature. The details of ATS for the HEPs are given at Annex-VIII. Transmission grid plan for the 2030 scenario is given at Figs. 5 & 5A.

6.4.2 Generations of Sankosh Main (2500MW) and LB (85 MW) hydro projects, which are located at Lhamoizingkha (in the vicinity of Sankosh HEP), about 15km from the Indian border, will be evacuated over 400kV system and pooled at Alipurduar

(India) through 2xD/C 400kV Lhamoizingkha/Sankosh-Alipurduar Quad moose conductor lines for further transmission. Matching with the time line of Sankosh projects, a separate ± 800kV 6000MW Alipurduar-NR/WR HVDC bipole line is contemplated to be developed corresponding to 2020 scenario by upgrading 3000MW converter module (rectifier) to 6000MW at Alipurduar with setting up of a new inverter module 6000MW in NR/WR and associated new ±800kV DC bi-pole line for export of 6000MW Bhutan power.

6.4.3 At the downstream of Punatsangchhu-I/II HEPs, Punatsangchhu-III and many HEPs at the same basin are envisaged and generation from such projects will be primarily pooled at Lhamoizingkha as an intermediate pooling station. Further, generations from Mochhu-I & II HEPs located at far west-north area and its adjoining downstream and upstream HEPs, are proposed to be evacuated over 400kV 2xS/C triple moose conductor lines and pooled at Lhamoizingkha/Sankosh station. A ± 800kV 6000MW Sankosh/Lhamoizingkha -NR/WR bipole line with 6000MW converter module (rectifier) at Lhamoizingkha and 6000MW inverter module at NR/WR would be developed for export to India by 2030.

6.4.4 Generations from Amochhu-I & II HEPs at Amochhu basin will be pooled at Alipurduar over 400kV lines, whereas evacuation of upcoming Amochhu-RS project by 2020 is planned to be made by LILO of one circuit of the 400kV Tala-Pugli - Siliguri D/C line, passing nearby the project and it would enable to utilize the margin available in the Tala transmission system.

6.4.5 The above power scenario will provide the key inputs for determining the detailed system requirements for NTGMP by 2020 in Bhutan.

Prospective Bhutan Grid by 2030

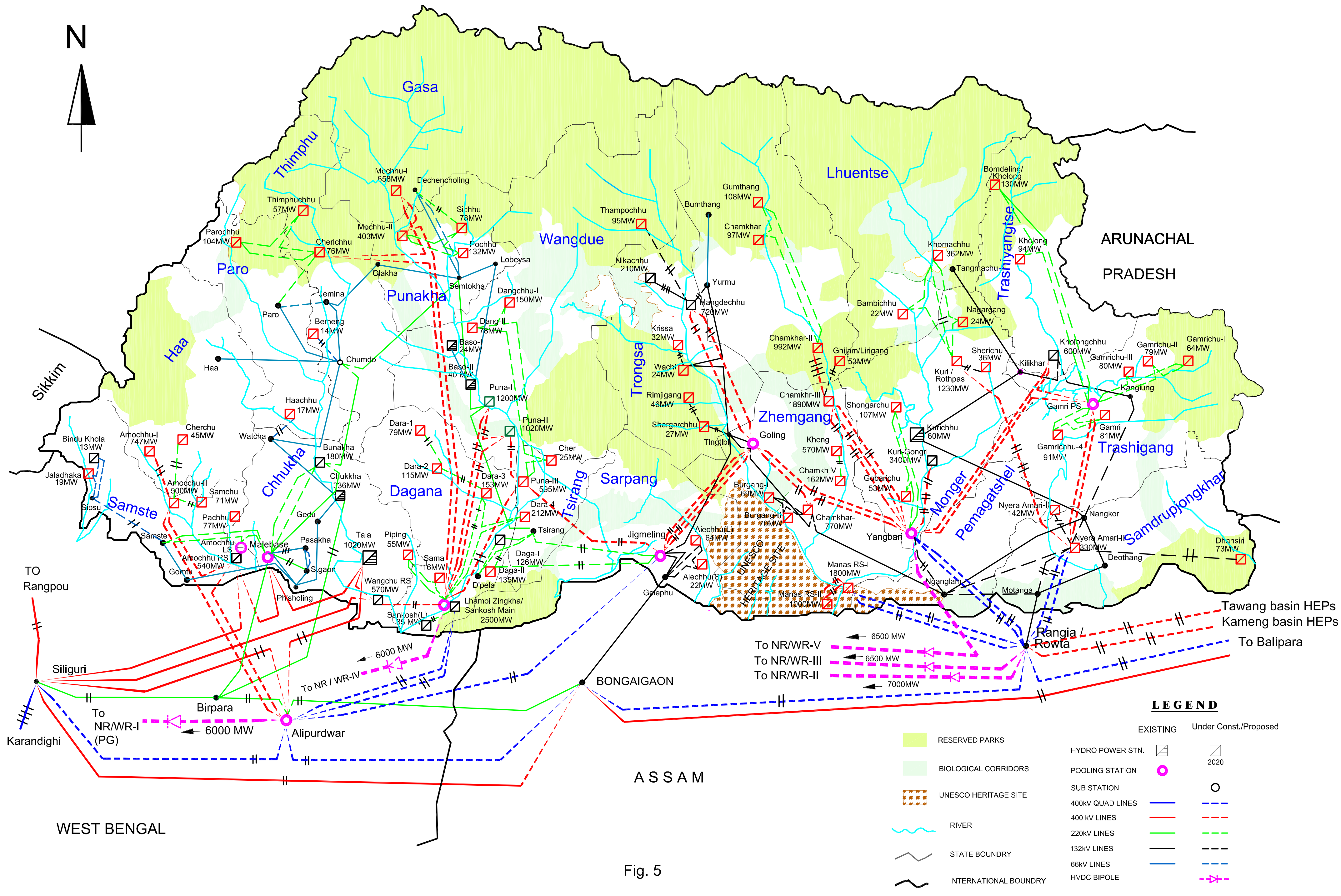


Fig. 5

Prospective Bhutan Grid by 2030
(plain Map)

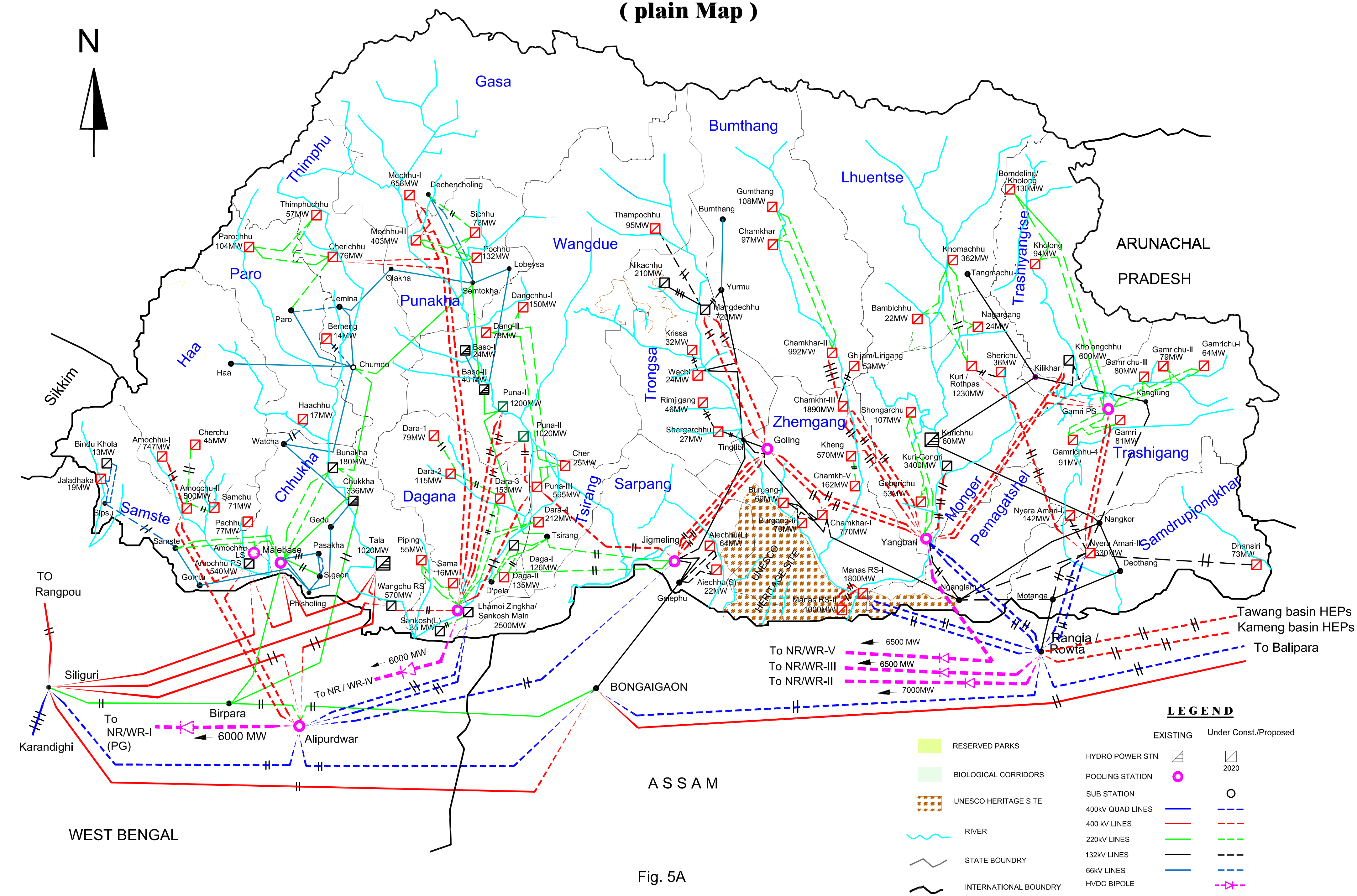


Fig. 5A

6.4.6 In the Eastern Bhutan, generations from MHEP, Nikachhu, Chamkharchhu-I HEPs and some of the upstream and down stream HEPs at Mangdechhu basin are considered to be pooled at Jigmeling via intermediate pooling station at Goling by 2xD/C 400kV twin moose lines from MHEP. Generations from other HEPs at the same basin viz. Gumthang, Chamkharchhu, Kheng,Ghijam and Chamkharchhu-I, II,I II, IV & V HEPs would be pooled at Yangbari by 3xD/C 400kV twin moose lines. About 4000 MW from Kuri-Gongri, Kolonchhu, Shongarchhu, and Gabraichhu HEPS at Drangmechhu basin will be also pooled at Yangbari over a number of 400kV D/C twin moose lines. At Yangbari, a 400/220kV and 220/132kV EHVAC sub-station is proposed to be established as a pooling station for power evacuation as well as to meet the local demand.

In view of huge hydro power development scenario in eastern Bhutan, Nyera Amari location having Nyera Amari I & II HEPs, is considered to be another potential pooling point to reduce the size of Yangbari PS. Generations from Kuri/Rothpasang and Khomachhu HEPs at Drangmechhu basin would be pooled at Nyera Amari over 2xD/C 400kV twin moose lines from Kuri/Rothpass HEP. From the same basin, power from Bomdeling, Gamrichhu-I,II,III & IV,and Gamri HEPs will be pooled at an intermediate 400/220kV Gamri pooling station over 220kV transmissiopn lines and thereon to Nyera Amari PS through 400kV D/C line.

6.4.7 Due to non-accessibility of RoWs in the north-east Bhutan on account of a large area of land being declared as National Heritage site, there is severe RoW problems in Yangbari-Goling and Goling-Jigmeling corridors. Huge quantum of power being pooled at Yangbari/Nyera Amari by 2030 is considered to be evacuated and exported to India through transmission corridors in Assam of NER, after meeting a small load demand locally. The Yangbari PS would be connected to Rangia/Rowta (Assam) by 2xD/C 400kV quad moose lines. By 2020 time frame, a ±800kV, 6000/7000MW Rangia/Rowta-NR/WR HVDC bipole line, depending upon capacity of Kuri-Gongri HEP (1800 or 3400 MW), would be developed for part evacuation of Bhutan power and for part evacuation of power from HEPs at Tawang and Kameng basins in Arunachal Pradesh in NER.

6.4.8 Generations from Manas–I & II HEPs (by 2030) with installed capacity of about 2800MW was initially envisaged to be evacuated through Bhutan corridors and pooled at Yangbari for further transmission. In addition, about 7700 MW potential from HEPs (by 2030) at Drangmechhu basin was also enviasaged to be pooled at Yangbari. Accordingly, two ± 800kV 6500 MW HVDC bi-pole station/lines from Yangbari to NR/WR were considered in conjunction with a large 400kV EHVAC sub-station at Yangbari. Manas I & II are located within the National Heritage site and it was gathered during close interaction with RGoB & other stake holders in power sector of Bhutan that no corridors within Bhutan will be available to pool power of Manas HEPs at Yangbari. As an alternative, generations of Manas-I & II HEPs are proposed to be directly pooled at Rangia/Rowta (Assam) through high capacity 400kV lines and thereon to NR/WR through ± 800kV HVDC bi-pole line from Rangia/Rowta. In view of Yangbari PS being a major power hub in eastern Bhutan, and many generations being pooled there, one ± 800kV, 6500MW Yangbari-NR/WR (India) bi-pole line is envisaged for 2030 scenario in conjunction with 400kV Yangbari-Rangia/Rowta 2xD/C Quad moose lines to be developed under 2020 scenario. In order to reduce the size of Yangbari PS, another 400 kV pooling station at Nyera Amri in eastern Bhutan has been considered. Generations from a cluster of HEPs in eastern Bhutan are proposed to be pooled at Nyera Amari for further injection at Rangia/Rowta (Assam) for evacuation through 400 kV Nyera Amari-Rangia/Rowta 2xD/C quad moose lines. It is studied that altogether, two ± 800kV, 6500/7000MW bipole systems would be required to be developed at Rangia/Rowta ultimately by 2030 to cater to the evacuation requirements of Bhutan as well as Arunachal power .

6.4.9 Evacuation of upcoming Chamkarchhu-I HEP will be made by constructing a 400kV Yangbari-Goling D/C line with LILO at Chamkharchhu-I. An additional 400kV Yangbari-Goling D/C line (2nd D/C) is envisaged to be established to facilitate evacuation of Kholongchhu and Kuri-Gongri HEPs.

6.4.10 Goling pooling station will cater to the requirement of power evacuation from Mangdechhu, Nikachhu, Thampochhu, Krissa, Wachi, Rimjigangchhu, and Chamkarchhu-I HEPs. Initially, by 2020 time frame, a 400kV switching station only at Goling is proposed to facilitate evacuation of Mangdechhu, Nikachhu, Chamkarchhu-I and Kolongchhu HEPs. Whenever, other HEPs at Mangdechhu basin will materialize, a 400/132kV sub-station facility at Goling with a 132kV D/C link between Goling and Tintibi may be created to pool generation from smaller HEPs at the same basin and it will provide a well-knit 132kV grid interconnection with the eastern grid in the longer time frame.

6.4.11 From Jigmeling (close to Indian border) which is a nodal power hub in Bhutan for pooling and de-pooling of power, high power density 1xD/C 400kV quad moose conductor line would enable to transfer bulk power to Alipurduar (WB) in India for further transmission over ± 800kV 6000 MW HVDC bipole line and underlying 400kV EHVAC systems from Alipurduar to NR/WR. The Jigmeling is a central grid station that will have strong connectivity between the Western and Eastern grids in Bhutan through 400kV Punatsangchhu-Jigmeling D/C line and provides supply to the load centers in the south-eastern Bhutan including Gelephu area.

6.4.12 A composite evacuation system for Mangdechhu, Nikachhu and Chamkharchhu-I and a cluster of HEPs at Mangdechhu basin has been evolved for 2030 scenario, Accordingly, construction of 400kV Mangdechhu-Goling-Jigmeling 2xD/C lines with Goling switching station and Jigmeling pooling point are planned and its development is envisaged in a phased manner. Initially, single circuit will be strung in the MHEP - Goling section of the 400kV Goling – Jigmeling 2xD/C line and second circuit stringing would be taken up under Nikachhu HEP. The existing 132kV Tintibi -Gelephu line presently interconnecting to Jigmeling, will be the only western- eastern interconnector. By the time 2020 or so, it would be very old and weak link and this corridor/RoW is proposed to be utilized for construction of an additional 400kV D/C line with twin moose conductor from Goling to Jigmeling (3rd D/C). The power flow results corresponding to 2030 time frame is given at Exhibit-I.

6.5 Identification of Major Transmission corridors and prospective Nodal Pooling Points within Bhutan by 2030.

6.5.1 Major High Density Transmission Corridors within Bhutan by 2030

From the results of the system studies carried out for 2030 time frame, major high density transmission corridors and nodal pooling stations are evolved as following:

- **EHV Transmission Corridors**

(i) Mochhu-Sankosh corridor for 400 kV 2xS/C lines with triple moose conductor (to materialize beyond 2020)

(ii) Punatsangchhu-III – Lhamozinkha /Sankosh corridor for 1XD/C line (to materialize beyond 2020)

(iii) 400kV Amochhu-I – Amochhu-II – Alipurduar corridor with 1XD/C line (to materialize beyond 2020)

(iv) 400 kV Mangdechhu-Goling-Jigmeling corridor for 2xD/C lines (to materialize by 2020)

(v) Jigmeling-Punatsangchhu-II corridor for 400 kV 1xD/C line (to materialize by 2020)

(vi) 400 kV Kuri-Gongri-Yangbari corridor for 3xD/C lines(to materialize by 2020)

(vii) 400 kV Kholongchhu-Yangbari corridor for 2xS/C on D/C tower lines(to materialize by 2020)

(viii) 400kV Yangbari-Goling corridor for 2xD/C lines (to materialize by 2020)

(ix) 400kV Goling –Jigmeling corridor for 3rd D/C line (to materialize by 2030)

(x) Manas-RS I/II –Rangia/Rowta corridor for 2xD/C lines (to materialize beyond 2020)

(xi) 400kV Yangbari-Rangia/Rowta 2xD/C lines (to materialize by 2020)

(xii) 400kV Gamri PS- Nyera Amari 2x(S/C on D/C) lines (to materialize beyond 2020)

(xiii) 400kV Chamkharchhu III-Yangbari 400 kV 3X D/C lines with one D/C LILO at Kheng (to materialize beyond 2020)

(xiv) 400kV Kuri/Rothpass – Nyera Amari 2xD/C corridor (to materialize beyond 2020)

- **HVDC Transmission Corridors in Bhutan and India**

  (i) ± 800 kV, 6000 MW HVDC Alipurduar-NR/WR-I (India) HVDC bipole corridor (India) (to materialize by 2020)

  (ii) ± 800 kV, 7000 MW Rangia/Rowta-WR/NR-II (India) HVDC bi-pole corridor (to materialize by 2020)

  (iii) ± 800 kV, 6500 MW Rangia/Rowtai-WR/NR-III (India) HVDC 2nd bi-pole corridors (to materialize beyond 2020)

  (iv) ± 800 kV, 6000 MW HVDC Sankosh/Lhamozingha – NR/WR IV HVDC bipole corridor (to materialize beyond 2020)

  (v) ± 800 kV, 6500 MW Yangbari-WR/NR-V (India) HVDC bi-pole corridor (to materialize beyond 2020)

6.5.2 Prospective EHVAC & HVDC Pooling Stations in Bhutan by 2030

The following pooling stations or sub-stations are identified to be developed in Bhutan by 2030. In view of difficulty to get adequate land for establishment of AIS in hilly terrains in Bhutan and to conserve environment, these sub-stations/pooling stations are proposed to be developed as GIS stations.

- 400/220kV GIS and 220/132kV GIS at Jigmeling (to materialize by 2020)
- 400/220kV and 220/132kV GIS at Yangbari (to materialize by 2020)
- 400/132kV GIS at Goling PS (to materialize by 2020)
- 400kV GIS (by 2020) and ±800kV,6000MW HVDC Station at Lhamozingkha / Sankosh (beyond 2020)
- ±800kV, 6500MW HVDC converter Station and 400kV GIS expansion at Yangbari PS (to materialize beyond 2020)
- 400/220kV Punatsangchhu-III GIS (to materialize beyond 2020)
- 400kV GIS at Nyera Amari (to materialize beyond 2020)
- 400kV GIS at Gamri PS (to materialize beyond 2020)
- 220/66kV Paro GIS

6.5.3 Corridor Optimization using HTLS conductors

In order to optimize right-of-way requirements in a corridor in Bhutan, use of HTLS conductor(s) in EHV transmission system provides a right solution to reduce the requirement of multiple number of 400 kV D/C twin moose conductor lines in a corridor. With the use of such conductor(s) on the same tower structure of conventional moose conductor, power density in a corridor increases phenomenally due to its inherent characteristics of high current carrying capacity (more than two fold relative to ACSR moose conductor) and high operating conductor temperature. In this perspective, Chairperson, CEA in a DO letter dated 19.3.2012 to Director General, DoHPS, Deptt. of Energy, RGoB shared the views on using HTLS conductor in India and highlighted that HTLS technology has been extensively opted in hilly areas in India to develop 400kV transmission systems for power evacuation from HEPs (3000 MW) of Satluj basin and from HEPs (4000 MW) of Chanderbhaga basin in Himachal Pradesh by 2016-19. Bhutan should go for use of HTLS conductor to save RoWs particularly in their 2030 scenario. In this context, Director General, DoHPS, RGoB was of the view conveyed in April 18, 2012 that HTLS technology in Bhutan should not be considered for 2020 scenario, but it could be a possible option for 2030 scenario. Bhutan desired to have an alternative 2030 scenario with possible choice of HTLS system in addition to the scenario with the conventional transmission system.

In the light of above, corridors with multiple numbers of 400kV D/C lines with twin moose conductor have been identified in the 2030 grid scenario, where use of HTLS conductor could be the right option to save RoWs. For example, in Chamkharchhu-III – Yangbari corridors requiring three corridors for 3xD/C 400kV lines with twin moose conductor, one 400kV RoW may be saved by constructing 2xD/C 400kV twin HTLS conductor lines. Three 400kV D/C twin moose conductor lines from Goling to Jigmeling using three 400kV RoWs are required for 2030 scenario of which two D/C lines are planned during 2020 and the third one by 2030 to facilitate evacuation of HEPs in eastern Bhutan. The requirement of the third corridor may be eliminated by reconductoring the 2xD/C 400kV lines with the HTLS conductor. Out of the three 400kV Rows to be used for evacuation of Kuri-Gongri HEP (3400MW) by 3xD/C 400kV twin moose lines, 2xD/C lines using HTLS conductor would cater to the evacuation requirement saving one RoW in the corridor. Evacuation of Mochhu-I & II and other adjoining HEPs of Punatsangchhu basin is envisaged by 400kV Mochhu-Sankosh 2xS/C lines with triple moose conductor. Instead of using triple moose conductor, 400kV transmission system may be built in this corridor with the HTLS conductor. A prospective 2030 grid map showing 400kV & 220kV corridors that may be developed with the HTLS conductor lines is shown in Fig. 6.

Corridors with HTLS Conductors for 2030 Scenario

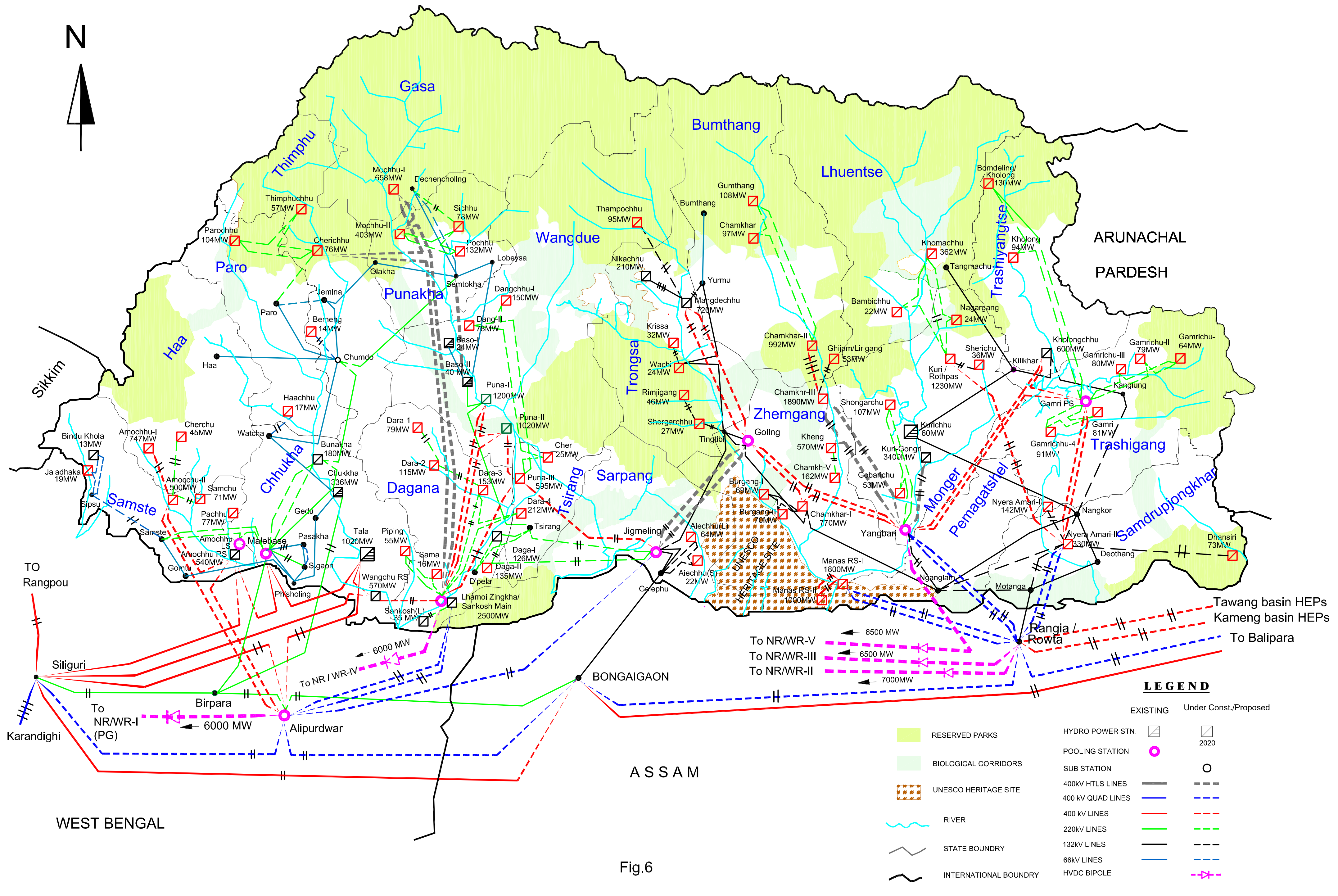


Fig.6

Chapter-7

National Transmission Grid Master Plan by 2020

In the light of power system studies for 2030, the transmission grid plan for 2020 time frame has been reviewed and revised by detailed system studies, considering the revised load-generation scenario furnished by RGoB, additional input gathered during the second site visit in Bhutan, and the feedbacks given by RGoB. The existing/on-going transmission system of Bhutan is shown in Fig. 7.

7.1 Revised Hydro Power Development Scenario for 2020

RGoB has revised its hydro power development programme from 11777 MW to 10334 MW for 2020 against total hydro potential of 25054 MW identified corresponding to 2030 time frame. Out of the upcoming 14 HEPs by 2020, installed capacity of 9 HEPs was revised in the intervening period and 2 HEPs i.e. Nikachhu HEP (210MW) at Mangdechhu basin and, Bindu Khola (13MW) HEP in Western Bhutan, have been scheduled from 2030 to 2020 scenario. The revised list of HEPs is given in Annex-II.

7.2 Load Generation Scenario by 2020

According to the load forecast of Bhutan, it is initially estimated to 978 MW by 2020. Anticipating higher industrial load growth, Bhutan has increased its load demand from 978 MW to 1500MW. Considering hydro capacity addition of 10334MW by 2020 and the enhanced load demand, power flow studies are carried out with an objective that the NTGMP for 2020 will exclusively fit into the 2030 grid scenario with minimum impact on the environment in Bhutan.

The project specific generation dispatche for 2020, including existing HEPs, is worked out as given at Annex-IX and the total dispatches amounts to 11724 MW. The sub-station-wise load demand is given at Annex-VIII. It has emerged that Bhutan will have huge surplus to export to in India after meeting its load growth corresponding to 2020 time frame. Generations from the HEPs, excepting Bunakha, Sankosh LB and Bindu Khola HEPs, are stepped up to 400kV, whereas evacuations for Bunakha and Sankosh LB HEPs are considered at 220kV level and Bindu Khola at 66kV.

According to the system studies, ATS for new HEPs, grid strengthening in western and eastern grids, reactive power compensation, system requirements for export of power to India, etc. are determined.

7.3 Major Pooling Stations and Transmission Corridors by 2020

7.3.1 By 2020, four major pooling stations are planned of which two stations are in western Bhutan i.e. **Jigmeling and Lhamoizingkha/Sankosh** and the other two are in eastern Bhutan i.e. **Yangbari and Goling**. These pooling stations may be established as GIS stations in order to optimize land requirements and also to conserve environment. The existing 400/220/66kV Malbase S/S in western Bhutan would be utilized as a pooling point for Bunakha HEP.

7.3.2 The proposed Jigmeling PS is in eastern/southern part of Bhutan, and close to Indian border, where generation from Mangdechhu, Nikachhu and Chamkharchhu-I HEPs would be pooled via intermediate switching station at Goling. For evacuation of above HEPs, Mangdechhu-Goling-Jigmeling 2XD/C is evolved for implementation in a phased manner depending on the time schedule of the above projects. The proposed Jigmeling PS being a potential load center and nodal grid point to connect western and eastern grids in Bhutan, should be developed as a 400/220kV GIS sub-station. Already, a 220/132kV sub-station at Jigmeling is being implemented by BPC.

7.3.3 At Lhamoizingkha, about 14km from Indian border, Sankosh main dam PH (2500MW) and Sankosh Barrage PH (85MW) are scheduled to come in 2020 and its generation will be evacuated at 400kV and pooled at Alipurduar EHV & HVDC station (India) by creating an additional 400 kV Lhamoizingkha/Sankosh- Alipurduar quad moose D/C line(2nd). The main dam PH is in the left bank of the Sankosh river and adequate land of gentle hilly terrain is also available in this bank for construction of switchyard/pooling station where the 400kV Punatsangchhu-I - Lhamoizingkha twin moose 2xD/C lines (Punatsangchhu system) will be terminated.

7.3.4 For evacuation of Wangchhu HEP at 400kV, the existing 400kV Tala transmission system will be utilized and there will be no requirement of RoW, except for LILO of one circuit of 400kV Tala-Khogla/Pugli-Siliguri lines (except the line being LILOed at Amochhu).

7.3.5 A common pooling station at Yangbari has been identified and generation from Kuri-gongri, Kolongchhu and Chamkharchhu-I HEPs will be pooled there over 400kV lines. It would also serve the long term system requirements for 2030 scenario when huge hydro potential at Drangmechhu basin would be harnessed for evacuation through Yangbari. Accordingly, adequate quantum of land at Yangbari is to be acquired. This pooling station would provide an alternative feed to the load centers of the eastern grid at 132kV level. For de-pooling of power from Yangbari, establishment of 400kV Yangbari-Goling 2xD/C twin moose lines (one D/C via Chamkharchhu-I) and 400kV Yangbari-Rangia/Rowta (Assam) 2xD/C quad moose conductor lines are considered in NTGMP. Power to be injected at Rangia/Rowta (Assam) from Yangbari will be transmitted by a ±800kV 6000/7000 MW HVDC bipole to be developed from Rangia/Rowta to deficit regions (NR/WR) of India. The capacity of the converter stations may be either 6000 MW or 7000 MW according to the 1800 MW or 3400 MW installed capacity of Kuri-Gongri HEP. This HVDC bi-pole will be utilized for transmission of Bhutan power and hydro power to be harnessed at Tawang and Kameng basins by 2020.

7.3.6 While the installed capacity for Kuri-Gongri HEP has been identified 1800MW, Bhutan subsequently desired that this capacity may undergo revision and a case study considering 3400 MW potential should be studied. Accordingly case studies are carried out.

7.3.7 The Grid map of NTGMP for 2020 is shown in Figs. 8 & 8A. Case studies on power flows during peak condition, considering 1800MW and 3400MW installed capacity at Kuri-Gongri are given at Exhibit-II & XVIII respectively.

Existing / Planned Transmission System in Bhutan

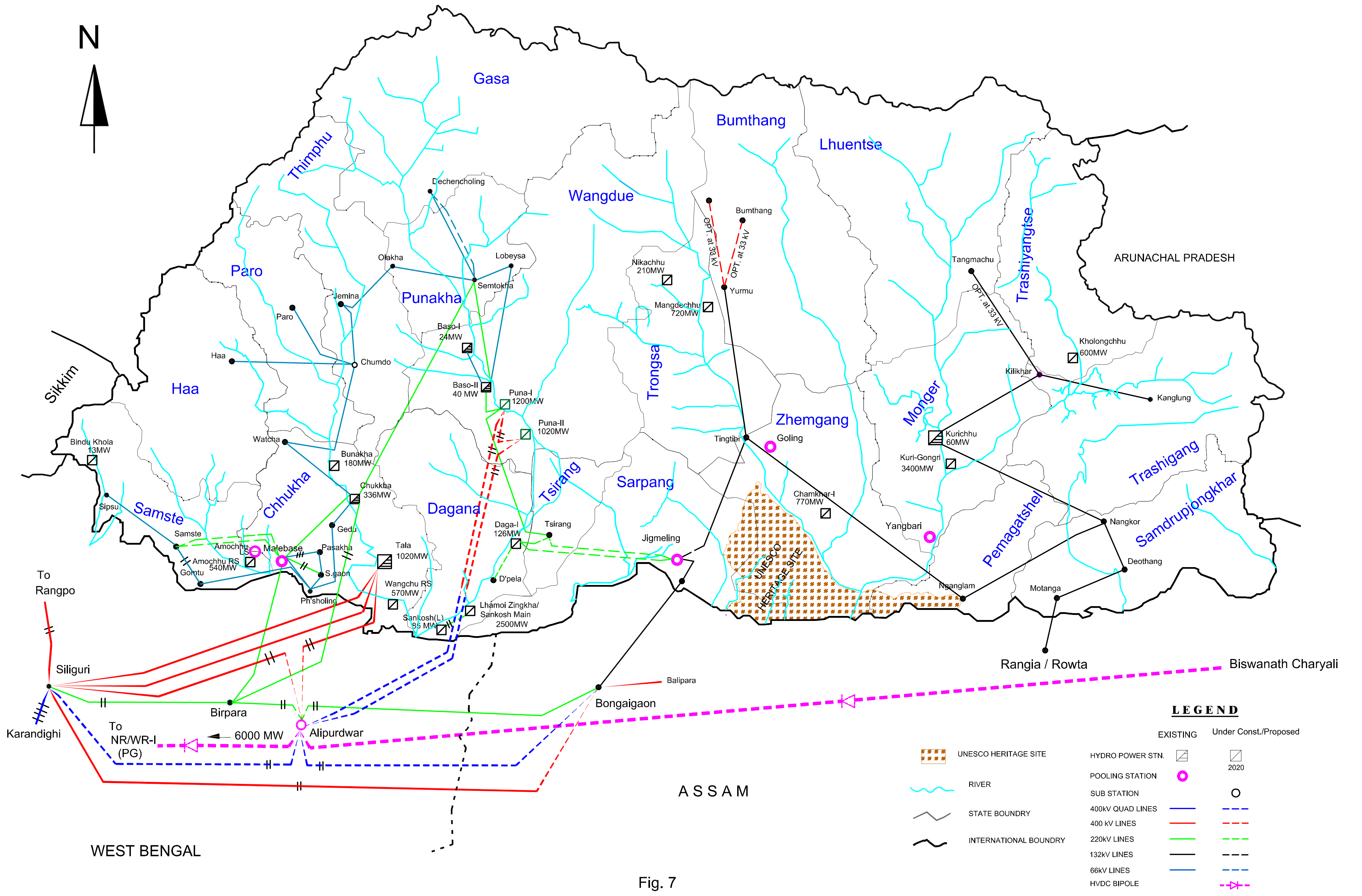


Fig. 7

7.4 Associated Transmission System (ATS) for HEPs by 2020

Punatsangchhu-I (1200MW) and Punatsangchhu-II (1020 MW) (15km downstream of Puna-I) HEPs, located in the western Bhutan are under various stages of development and targeted to be commissioned by 2015 and 2017 respectively. Already, the approved/planned ATS for these HEPs as given below is under execution phase.

7.4.1 Punatsangchhu-I (1200MW)

- 400kV Punatsangchhu-I - Sankosh/Lhamoizingkha Twin Moose 2xD/C (one D/C routing via Punatsangchhu-II HEP)
- Sankosh- Alipurduar Quad Moose D/C line (Bhutan portion)
- 400/220kV, 4X105MVA ICT at Punatsangchhu-I
- LILO of 220kV Bosochhu-II – Tsirang S/C line at Punatsangchhu-I.
- 1X80MVAr 420 kV Bus Reactor at Punatsangchhu-I

7.4.2 Punatsangchhu II HEP (1020MW)

- Loop-in-loop-out (LILO) of one D/C line of 400kV Punatsangchhu-I-Lhamoizingkha 2XD/C lines at Punatsangchhu-II HEP.

However, for improving reliability of evacuation for the HEP, Bhutan desired to inter-alia include the 400 kV Punatsangchhu-II - Jigmeling D/C line (envisaged earlier as part of evacuation for Mangdechhu HEP) under Punatsangchhu-II. It is observed from system study that this line also forms a strong interconnection between the eastern and western grids of Bhutan and gets fairly loaded during (n-1) continegency. Accordingly, the above ATS for Punatsangchhu-II HEP is modified as follows.

The revised ATS for Punatsangchhu II HEP (1020MW):

- 400kV step-up voltage
- Loop-in-Loop-out(LILO) of one 400 kV D/C Punatsangchhu-I - Sankosh/Lhamo Zingkha line at Punatsangchhu-II
- 400 kV Punatsangchhu-II - Jigmeling D/C line

- 1x80 MVAr 420 kV Bus Reactor at Punatsangchhu-II HEP.

7.4.3 Sankosh HEP (2585MW)

Sankosh HEPs in Bhutan is located in the south/west area of Bhutan and is about 14km inside from the Indian border and is scheduled to be implemented during 2020. It comprises of main dam Power House with 2500 MW installed capacity to be evacuated at 400kV and the downstream Right Bank Power House with installed capacity of 85 MW to be evacuated at 220kV. Generation from RB PH will be pooled at Main PH over a 220kV D/C line for evacuation. In view of reduction in installed capacity from 4060 MW to 2585 MW at Sankosh and land procurement problem at Sankosh site, HVDC option for power evacuation is not considered and instead, ATS is evolved with 400 kV EHV transmission. Generation from Sankosh will be pooled at Alipurduar by creating a second 400kV Lhamoizingkha/Sankosh-Alipurduar Quad moose conductor line (1st D/C line is being developed matching with Punatsangchhu-I/II). Further, matching with the time line of Sankosh, an independent ± 800kV, 6000 MW HVDC bipole line from Alipurduar (WB) to NR/WR with 6000 MW converter station each at Alipurduar and NR/WR is proposed to be developed, withdrawing the LILO of Biswanath Chariyali-Agra HVDC line at Alipurduar converter station (LILO is presently being implemented to facilitate evacuation of Punatsangchhu-I/II and Mangdechhu HEPs).

The ATS for Sankosh is considered as given below.

- 400kV step-up voltage
- 400kV Lhamoizingkha/Sankosh-Alipurduar Quad moose conductor D/C line (2nd)
- Bussing of 400kV Punatsangchhu- Lhamoizingkha 2xD/C line at Sankosh HEP
- Bussing of 400kV Lhamoizingkha-Alipurduar D/C line(1st) at Sankosh HEP
- 400/220kV, 200MVA ICT at Sankosh GIS switchyard

- 220kV D/C interconnection between Main Dam PH (2500MW) and Regulating Dam PH (85MW)
- 2x80MVAr, 420kV Bus Reactors at Sankosh main dam PH

7.4.1 Wangchhu HEP (570MW)

The Wangchhu HEP is envisaged to be set-up by 2019. Generation would be stepped up at 400kV and would be evacuated through the existing 400kV Tala transmission system.

The ATS for the project is considered as follows:

- 400kV step-up voltage
- LILO of one ckt. of 400 kV Tala-Khogla/Pugli-Siliguri lines (except the line being LILOed at Amochhu) at Wangchhu HEP
- 1x63MVAr 420 kV Bus Reactor at Wangchhu

7.4.2 Amochhu RS HEP (540MW)

This project is located in the western part of Bhutan. Power generated will be stepped up to 400kV and evacuated through LILO of the existing 400kV Tala-Siliguri D/C line (i.e. 400kV Tala- Pugli line), passing very close to the project site.

For supply of construction power, a separate 220/11kV 20MVA sub-station (Amochhu load station) near to the project site would be established by LILO of the 220 kV Malbase-Samtse line. This sub-station may be expanded and utilized for meeting local load growth in future.

The ATS for the project is as follows:

- 400kV step-up voltage
- LILO of one circuit of 400 kV Tala-Silliguri via Pagli D/C line at Amochhu
- 1x63 MVAr 420 kV Bus Reactor at Amochhu HEP
- Establishment of 220/11 kV , 20 MVA Amochhu S/S

- LILO of 220 kV Malbase-Samtse line at Amochhu LS

7.4.6 Bunakha HEP (180MW)

The HEP is proposed to be located about 30km upstream of the existing Chukha HEP. Generation would be stepped up at 220kV and pooled at the existing 400/220kV Malbase S/S primarily by 220 kV Bunakha-Malbase 2xS/C lines for further evacuation. From Bunakha, 2xS/C 220kV lines are considered to meet (n-1) contingency.

The ATS is proposed as follows:

- 220kV step-up voltage
- LILO of the existing 220kV Chukha-Semtokha S/C line at Bunakha
- 220 kV Bunakha-Malbase 2xS/C lines
- Augmentation of 400/220kV ICT at Malbase with an additional 4x67 MVA Transformer.

7.4.7 Mangdechhu HEP (720MW)

Mangdechhu HEP (MHEP) is located in east/north side of Bhutan and scheduled to set-up during 2017-18. Further, Nikachhu HEP is an upstream project, about 7/8km away from Mangdechhu and is proposed to be established in 2020. Generation at MHEP is evacuated at 400kV voltage and pooled at Jigmeling by two nos. 400kV MHEP-Goling-Jigmeling S/C on D/C tower lines. A 400kV switching station at Goling is also envisaged to facilitate evacuation of Chamkharchhu-I and in the longer time frame (2030), it would be transformed into a 400/132kV sub station. Second circuit stringing in MHEP-Goling corridor will be implemented under Nikachhu project.

At Jigmeling, a 220/132 KV, 2X 63 MVA S/S is being constructed and it is to be upgraded with a 4X167MVA,400/220kV GIS facility so that generations from HEPs in eastern Bhutan (viz. MHEP, Nikachhu, Chamkharchhu-I,Kolongchhu HEPs) could be pooled for further dispersal. After meeting industrial load demands at Jigmeling/Gelephu, surplus would be exported to India at Alipurduar HVDC/EHVAC station (West Bengal) through 400kV 1xD/C quad moose lines.

For a cluster of HEPs to be developed in the same basin beyond 2020, evacuations are proposed to be made at 132kV level using Mangdechhu as a sub-pooling point. Further Mangdechhu and Nikachhu would serve the local load demand through the132kV Yurmu sub-station to be connected by a 132kV D/C line from Mangdechhu.

Accordingly, the MHEP evacuation system is,

- 400kV step-up voltage
- 400kV Mangdechhu- Goling 2x (S/C on D/C) tower line with twin moose conductor (stringing of 2nd circuit in each line under Nikachhu HEP)
- 400kV Goling – Jigmeling 2x (S/C on D/C) twin moose tower lines
- 400kV Jigmeling - Alipurduar D/C Quad moose line (Bhutan portion).
- 400/220kV, 4X167MVA Jigmeling pooling station (GIS).
- 1X80 MVAr, 420kV Bus Reactor at Mangdechhu
- 1X80 MVAr, 420kV Bus Reactor at Jigmeling
- 132kV Mangdechhu-Yurmu D/C line
- 400/132kV, 4X67 MVA ICT (1st) at Mangdechhu

7.4.8 Nikachhu HEP (210/140 MW)

The project is located at the upstream of Mangdechhu HEP.It was earlier envisaged to come beyond 2020 time frame. DPR is not yet prepared. The installed capacity was originally 210MW. But, Bhutan has informed in April, 2012 that the capacity may be 140 MW. The 400kV Mangdechhu-Goling-Jigmeling corridor will be utilized to pool power at Jigmeling via Mangdechhu and Goling. Accordingly, its evacuation requirement is studied considering generation to be stepped up at 400 kV or alternatively at 132kV for evacuation.

The ATS for evacuation at 132kV is considered as below:

- 132kV Step-up voltage
- 132kV Nikachhu-MHEP 2xD/C lines
- Augmentation of 400/132 kV ICT with an additional 3x67MVA (2nd) at MHEP
- Second circuit stringing on 400kV Mangdechhu-Goling 2x(S/C on D/C tower lines.

Alternatively,

- 400kV step-up voltage
- LILO of one circuit of the 400kV Mangdechhu-Goling-Jigmeling lines.
- Second circuit stringing in 400kV Mangdechhu-Goling 2x(S/C on D/C) lines

7.4.9 Chamkarchhu-I HEP (770MW)

The Chamkarchhu-I HEP is located at Zhemgang District and targeted to be implemented during 2018. DPR has been prepared by NHPC. The installed capacity of the project as per the data furnished by Bhutan was 670 MW. But it is noted from DPR submitted by NHPC that the capacity of the project is 770MW (4x192.5 MW). Accordingly, evacuation system is re-evolved taking into consideration the RoW/ corridor problems in the National Heritage site in Bhutan.Generation is targeted to be pooled at Jigmeling and/or Yangbari for further transmission.

The evacuation system has been evolved as given below:

- 400kV step-up voltage
- 400kV Yangbari-Goling 1xD/C (out of 2xD/C line)
- LILO of 400kV Yangbari-Goling D/C at Chamkarchhu-I
- 400/132, 4x67 MVA ICT at Chamkharchhu-I HEP
- 400kV Goling GIS switching station with provision of space for future expansion/upgradation to a 7x67MVA 400/132kV sub-station and four 132kV line bays.

- 2X80 MVAr 420 kV bus reactors at Goling
- 1X80 MVAr bus reactors at Jigmeling
- LILO of 132 kV Nganglam - Tintibi D/C line at Chamkharchhu-I
- Second circuit stringing in each circuit of the 400kV Goling-Jigmeling 2X(S/C on D/C) lines

7.4.10 Kuri-Gongri HEP (1800MW/3400 MW)

The Kuri-Gongri HEP is one of the very large hydro projects in eastern Bhutan which is targeted for implementation during 2020. DPR is not yet prepared. Orginally, installed capacity was envisaged to be 1800MW. But, Bhutan has informed that plant capacity may be also 3400 MW and accordingly, case studies for determining ATS are carried out for 1800 MW and 3400 MW capacity.

Generation will be stepped up at 400kV and injected at Yangbari over 400kV lines as a sub-pooling point and thereon to 400kV EHVAC and HVDC station at Rangia/Rowta in Assam for landing in NR/WR. By 2020 time frame, a ±800kV, Rangia/Rowta-NR/WR HVDC bipole line with converter capacity 6000MW (for Kuri-Gongri 1800 MW) or 7000 MW (for Kuri-gongri 3400 MW) is contemplated for evacuation of Bhutan power and for part evacuation of Arunachal HEPs at Tawang and Kameng basins in NER.

The ATS for Kuri-Gongri (1800MW) is determined as follows:

- 400kV step-up voltage
- 400kV Kuri-Gongri- Yangbari 2xD/C twin moose lines and an additional D/C (3rd) for evacuation of Kuri-Gongri 3400 MW)
- 400 kV Yangbari - Rangia/Rowta 2x D/C Quad Moose Lines (Bhutan portion)
- 400/132kV,4X67 MVA Yangbari GIS
- 2X80 MVAr, 420kV Bus Reactors at Yangbari.
- 132 kV Yangbari - Nganglam D/C line

7.4.11 Kholongchhu HEP (600MW)

The installed capacity of the project is revised from 486 MW to 600 MW. In the system studies carried out for 2020 & 2030 scenario, 400kV Kholongchhu-Yangbari 2XS/C lines is considered to pool power to Yangbari for further transmission. In order to provide reliable supply to the eastern Bhutan, creation of 400/132kV ICT with LILO of the existing 132kV Kilikhar-Kanglung line is also considered.

Accordingly, ATS for Kholongchhu HEP is,

- 400kV step-up voltage
- Kholongchhu - Yangbari twin moose 2x (S/C on D/C) tower lines
- 400/132/33 kV 4x67 MVA ICT at Kholongchhu
- 400 kV Yangbari – Goling D/C (2nd D/C line)
- 1x80 MVAr, 420 kV bus reactor at Kholongchhu.
- LILO of 132 kV Kilikhar-Kanglung S/C at Kholongchhu

7.4.12 Bindu Khola HEP (13 MW)

- 66kV Bindu Khola - Sipsu 66 kV D/C line

7.5 System Strengthening in Bhutan

System studies are carried out to identify the system strengthening requirements in entire Bhutan. The reinforcement plan including reactive power compensation, are determined as follows:

7.5.1 System Strengthening in Western Bhutan

The transmission system in western Bhutan is comprising 400kV, 220kV and underlying 66kV lines. To meet the anticipated load growth/demand upto 2020 in Bhutan, it is observed from the load flow studies that creation of 220 kV/66 kV substation at Chumdo by LILO of the existingv220 kV Chukha-Semtokha S/C line would enable to cater to the load growth around Paro/Jemina/Haa areas being fed through 66kV lines, and improve voltage stability and reliability of power supply.

Further, for meeting load demand at Dechecholing area, an additional 66 kV line from Semtokha is needed.

The load of 66kV Paro S/S supplying power to the Bhutan international airport is considered to be a load of higher priority. Accordingly, a new 66 kV line from Jemina to Paro is proposed for second in-feed to Paro, which would enable to secure power supply in case of outage or maintenance of the 66 kV Paro-Chumdo line.

Power supply to the 66kV Phuntosholing and Pasakha sub-stations having industrial loads is presently made from 400/220/66kV Malbase S/S and 220/66kV Singhigoan S/S. The existing multi-circuit 66kV line from Malbase to Pasakha is a critical line, and in case of its outage, power supply to industrial loads at Pasakha would be largely affected. An additional 66 kV Singhigaon-Pasakha D/C line (2nd & 3rd circuit) would therefore provide reliable power supply to these areas even during line contingencies.Alternatively,reconductoring by higher capacity conductor may be made in this corridor.

Thus, in addition to the evacuation systems envisaged for HEPs in the western Bhutan (viz. Bunakha, Amochhu, Wangchhu and Sankosh HEPs), the following network expansion/augmentation in 220kVand 66kV system would be required:

220 kV System

- LILO of 220 kV Chukha-Simtokha S/C line at 220 kV Chumdo substation.
- Upgradation of 66kV Chumdo GIS to 220 kV level with 2x50 MVA, 220/66kV transformers.

66 kV System

- Simtokha-Dechecholing S/C line(2nd ckt.)
- Jemina-Paro S/C line
- Singhigaon-Pasakha D/C line (2nd and 3rd ckt)
- Additional 1x50 MVA,220/66kV transformer at Singhigoan
- Additional 1x50 MVA,220/66kV transformer at Malbase
- Additional 3x50 MVA, 220/66kV transformers at Samste.

7.5.2 System Strengthening in Southern-Central-Northern Bhutan

Jigmeling and Gelephu areas are major load centers in southern/central Bhutan and both the places are close by. Load growth at Jigmeling is estimated to 440 MW and at Gelephu 31 MW as per the load forecast made by Bhutan. The existing Gelephu 132/66/33kV S/S is presently supplying demand of about 5MW through the 132kV Tintibi-Gelephu S/C line. The projected load demand of Gelephu will be met primarily from Jigmeling where a 400/220kV GIS (220/132kV S/S under implementation by BPC) is proposed to be developed under Mangdechhu HEP.

BPCL has already undertaken the construction of a 10 kms 220 kV D/C line with zebra conductor up to Lodrai (enroute to Tintibi-Gelephu 132kV line) for LILO of the 132 kV Tintibi-Gelephu S/C line to establish 132kV Tintibi-Jigmeling east-west link and Jigmeling-Gelephu line. The LILO portion is intended to be operated at 132kV. It is observed from system studies that during 2020 time frame, there is rush in power flow from Tintibi to Jigmeling and this section of the Tintibi-Jigmeling-Gelephu 132kV link gets critically overloaded to the extent of 90/95 MW and may not be sustainable, if load growth takes place as estimated. It is recommended that the Tintibi-Jigmeling line being fairly old by 2020, may be kept out of service, and utilizing that line bay at Jigmeling, an additional 132kV line may be established from Jigmeling to Gelephu forming two 132kV line to provide reliable supply to Gelephu areas. In view of above, the following system strengthening in Southern/Central Bhutan is hereby proposed:

- 132kV Jigmeling-Gelephu S/C (2nd Circuit)

In the northern part of Bhutan, the 132 kV Tintibi- Yurmo/Bhumthang S/C line (132 kV line upto Yurmo point) is presently being operated at 33 kV level to supply power to Bhumthang and its adjourning areas. With the load growth in these areas and to facilitate supply of start-up-power to upcoming Mangdechhu and Nikachhu HEPs, Tintibi – Yurmo line needs to be operated at 132 kV with creation of a 132/33 kV, 2x20 MVA substation at Yurmo. Under Mangdechhu HEP, 132kV D/C interconnection to 132kV Yurmu S/s has been proposed. Accordingly, system strengthening requirement in this part of Bhutan shall be as following:

- Operation of the existing 132 kV Tintibi – Yurmu line (being presently operated at 33kV) at the designed voltage level of 132 kV.
- Establishment of a 132/33 kV, 2x20 MVA GIS substation at Yurmu.

7.5.3 System Strengthening in Eastern Bhutan

In order to meet load growth in the eastern Bhutan, LILO of the existing 132kV Nanglam-Tintibi line at Yangbari PS has been considered as part of ATS of Chamkharchhu-I. Further, construction of a 132kV Yangbari-Nganglam D/C line is envisaged under ATS of Kuri-Gongri HEP. With a 132kV S/C on D/C tower line from Nganglam to Motanga, a 132kV ring i.e. Nganglam- Nangkor – Deothang – Motanga-Nganglam will be established to provide reliable power supply to the load centers in eastern Bhutan. Further, with setting up of Kholongchhu HEP where provision of a 400/132kV ICT along with LILO of the existing 132kV Kilikhar-Kanglung line has been kept, a 132kV ring i.e. Nangkhor-Kurichhu-Kilikha-Kholongchhu-Kanglung-Nangkhor will be established by creation of a new 132kV Kanglung-Nangkor S/C on D/C line. The ring will make a very strong 132kV grid for supply to each load center in the eastern Bhutan under any credible contingency. In view of above, the following system strengthening is proposed.

- 132kV Nganglam-Motanga S/C on D/C tower line
- 132kV Nangkor-Kanglung S/C on D/C tower line
- Augmentation of 132/33 kV transformation capacity with 2x50 MVA ICTs at Motanga
- Augmentation of 132/33 kV transformer at Deothang with 1x5 MVA transformer.

The above system strengthening shall be implemented matching with the commissioning of Kuri-Gongri and Kholongchhu projects.

7.5.4 Reactive Power Compensation

With load power factor presumed to be 0.9 at grid sub-stations, low bus voltages are observed at various 66kV/132kV sub-stations during peak load condition corresponding to 2020 scenario. In order to improve and maintain bus voltages within permissible limits at load centers, switchable capacitive shunt compensation is required. From the system studies, 365 MVAr is the total quantum of compensation (MVAr) is determined at the specific 66kV and 132kV sub-station as following.

Table-2: Reactive Power Compensation

Sl.No	**Name of the 66kV/132kV Sub-station buses**	**Capacitive compensation (MVAr)**
1	Semtokha 66kV	20
2	Dechencholing 66kV	15
3	Lobesa 66kV	10
4	Paro 66kV	10
5	Gomtu 66kV	13
6	Singhigaon 66kV	40
7	Pasakha 66kV	70
8	Olakha 66kV	10
9	Samtse 66kV	60
10	Jigmeling 132kV	60
11	Gelephu 66kV	10
12	Motanga 132kV	20
13	Nganglam 132kV	15
14	Phuentsoling 66kV	12
	Total	365

National Transmission grid Master Plan for Bhutan by 2020

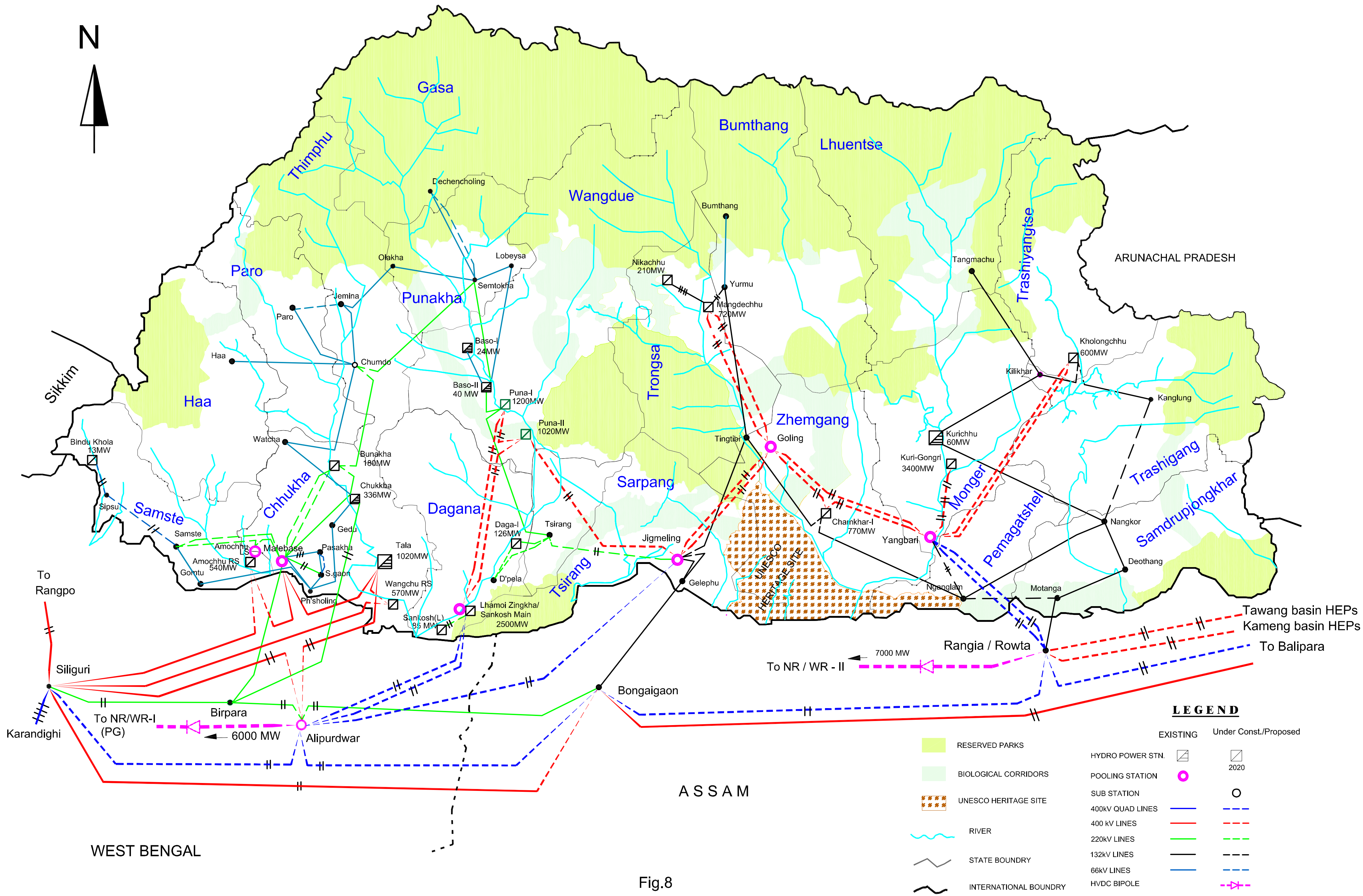


Fig.8

National Transmission grid Master Plan for Bhutan by 2020
(Plain Map)

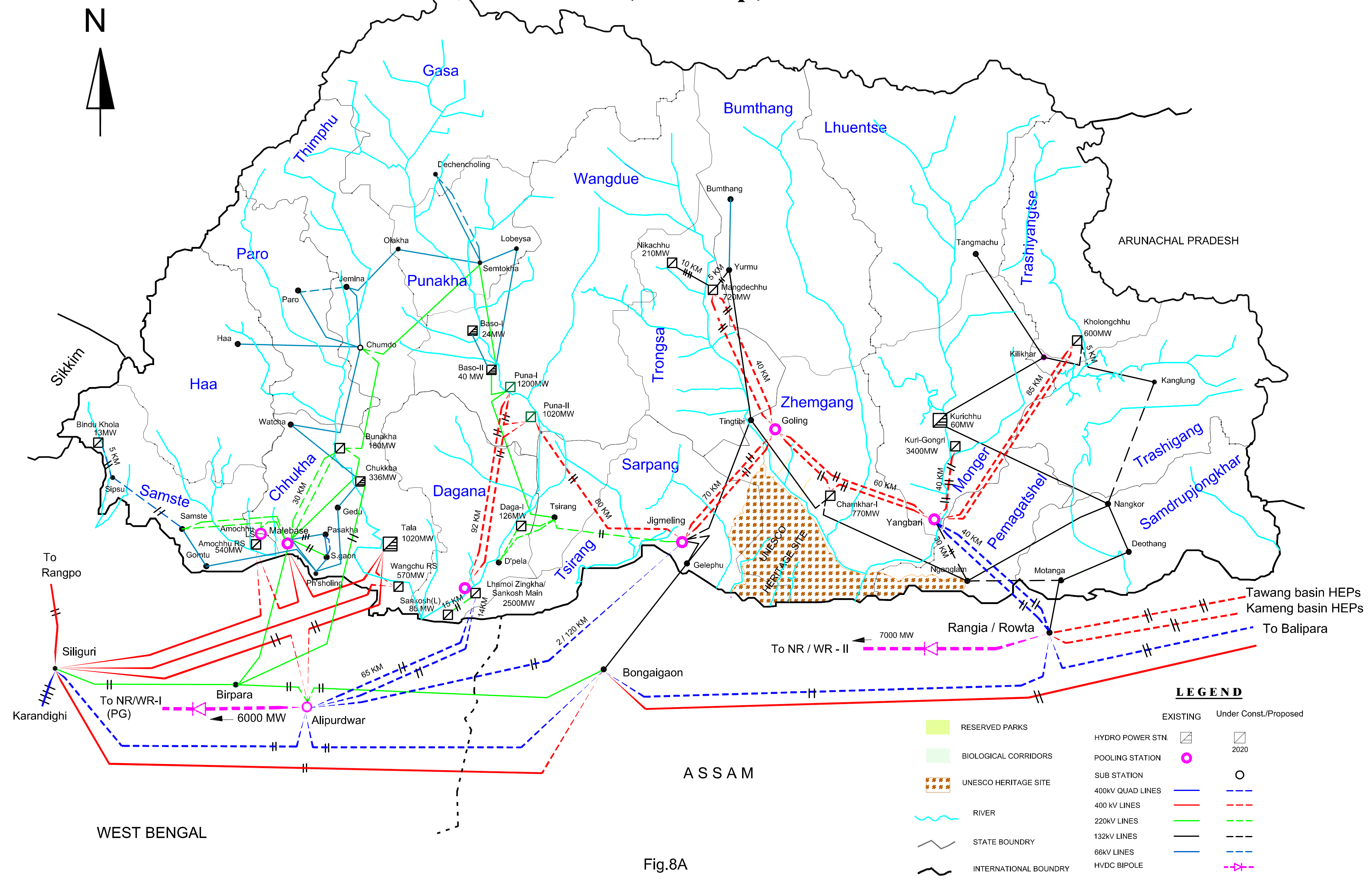


Fig.8A

Chapter-8

Indian Grid Reinforcements for import of Bhutan surplus by 2020

The installed hydro generating capacity in Bhutan is targeted to reach 11814 MW by 2020. After meeting the load growth to the the tune of 1500 MW, huge surplus power will be exported to India. Accordingly, grid reinforcements in India would be made in a phased manner, matching with the commissioning schedule of various upcoming HEPs.

8.1 Indian Grid Strengthening for import of Bhutan surplus by 2015-17.

Among the upcoming HEPs in Bhutan, Punatsangchhu-I, Punatsangchhu-II and Mangdechhu HEPs are under various stages of development and targeted to be commissioned during 2015-17. The major generation from these HEPs would be exported to India, after meeting the load demand within Bhutan.

For power evacuation from Punatsangchhu-I HEP, the two numbers 400kV D/C Twin moose lines from Punatsangchhu-I have been planned to be constructed upto Lhamoizingkha/Sankosh (Indian border) with one D/C via Punatsangchhu-II HEP. From Sankosh, one 400kV high capacity D/C line (quad moose conductor) upto the Indian pooling point at Alipurduar would be constructed and each of these circuits would be initially inter-connected to a D/C twin moose line of Punatsangchhu HEP, till the time 400kV switchyard of Lhamozinkha/Sankosh HEP gets established.

At Alipurduar, an HVDC station with ±800kV, 3000MW converter module and 2x315MVA, 400/220kV EHVAC sub-station is planned to be constructed for import of power from Punatsangchhu-I & II. The ±800kV,6000MW Bishwanath Chariyali (NER)- Agra(NR) HVDC bi-pole line with 3000MW converter module each at Bishwanath Chariyali (Rectifier end) and Agra (inverter end), which is being developed as part of NER-NR/WR interconnector project for power evacuation from HEPs in NER, would be LILOed at Alipurduar. An additional 3000MW converter module at Agra making total terminal capacity of 6000MW is planned to facilitate import of power from Bhutan. Accordingly, the transmission System reinforcements in India at the initial stage would be as hereunder:

- New 2x315MVA, 400/220kV AC & HVDC sub-station with ±800kV, 3000MW converter module at Alipurduar.
- Extension of ± 800 kV HVDC station with 3000 MW inverter module at Agra
- LILO of ±800kV Bishwanath Chariyali – Agra HVDC Bi-pole line at Alipurduar for parallel operation of the HVDC converter station at Alipurduar.
- LILO of Bongaigaon – Siliguri 400kV D/C Quad line (M/s. Sterlite) at Alipurduar
- LILO of Tala-Siliguri 400kV 1xD/C line at Alipurduar.
- LILO of Birpara-Salakati 220kV D/c line at Alipurduar
- Sankosh/Lhamoizingkha – Alipurduar 400kV 1xD/C Quad moose line (Indian portion)
- Earth Electrode line at Alipurduar HVDC terminal
- Earth Electrode line at Agra HVDC Terminal

Accordingly, the existing and planned cross-border interconnections with Bhutan during 2015-17 are shown in Fig.7.

8.2 Indian Grid Strengthening for import of Bhutan surplus by 2020

Mangdechhu, Nikachhu, Chamkarchhu-I, Kuri-Gongri, and Kholongchhu HEPs in eastern part of Bhutan are envisaged to be developed during 2017-2020. Power generations from these HEPs are proposed to be pooled at Jigmeling (via Goling) and thereon to Alipurduar (WB) over a 400kV D/C quad moose conductor line, after meeting the internal load demand of Bhutan. Exportable surplus power to be available at Jigmeling for export to India is in the order of 1500-1900 MW under normal peak operating condition. Further from Sankosh/Lhamoizingha, about 4200-4400 MW is being injected to Alipurduar over 400kV 2xD/C quad moose lines. In order to transfer such a huge quantum of power from Alipurduar to NR/WR (deficit regions) of India, it is planned to develop a new and independent ±800kV, 6000MW HVDC bi-pole line from Alipurduar to a suitable de-pooling point in NR or WR of India (based upon the regional load generation scenario) with augmentation of converter terminal capacity from 3000MW to 6000MW at Alipurduar, and a 6000MW new converter station (inverter terminal) at the de-pooling point. Subsequently, LILO of ±800kV, 6000MW Bishwanath Chariyali (NER) - Agra (NR) HVDC line at Alipurduar would be removed restoring the direct HVDC bi-pole line from Bishwanath Chariyali (NER) to Agra(NR).

A large land area in the south-eastern part of Bhutan (Zhemgang and Pemagatsel districts) has been recently declared as UNESCO National Heritage Site and this area would be inaccessible for getting any RoW for transmission system development. The Yangbari-Jigmeling corridor was a potential corridor for high power density lines to transfer power from eastern to western side of Bhutan and it would not be available as the corridor is falling in the proposed Heritage site. Further, due to biological/reserved parks spread over wide geographical area in eastern Bhutan, there is a limitation to get adequate RoWs for bulk power power transmission from Yangbari (used as a power-hub) to western Bhutan and thereon to Indian grid.

In view of above, power injected at Yangbari PS from HEPs in eastern Bhutan is pooled at 400kV EHVAC & HVDC station at Rangia/Rowta in Assam over 400 kV Yangbari- Rangia/Rowta 2xD/C Quad moose conductor lines. A ±800kV, Rangia/Rowta-NR/WR HVDC bipole line with converter capacity 6000MW (for Kuri-Gongri 1800 MW) or 7000 MW (for Kuri-gongri 3400 MW) is contemplated for evacuation of Bhutan power and for part evacuation of Arunachal HEPs at Tawang and Kameng basins in NER. Thus, the transmission grid reinforcements shall cover the following:

- Construction of 400kV Jigmeling-Alipurduar Quad moose D/C line (Indian portion).

- Construction of 400 kV Yangbari- Rangia/Rowta 2xD/C Quad moose conductor lines (Indian portion).

- Establishment of a new ±800kV, 6000MW HVDC bi-pole line from Alipurduar to a suitable de-pooling point in NR/WR and redoing of ±800kV Bishwanath Chariyali (NER)- Agra(NR) HVDC line by removing its LILO at Alipurduar.

- ±800kV, Rangia/Rowta-NR/WR HVDC bipole line with converter capacity 6000MW (for Kuri-Gongri 1800 MW) or 7000 MW (for Kuri-gongri 3400 MW) each at Rangia/Rowta and NR/WR.

Chapter-9

System Study Results for 2020 and 2030

9.1 Load Flow Case Studies

The details of the load flow study results and contingency analysis are given at the following Exhibits.

i. Case Study with full Hydro Dispatch for 2030 Power Scenario in Bhutan Exhibit-I

ii. Case Study with full Hydro Dispatch for 2020 Scenario with load growth of 1500 MW (Kuri Gongri 1800 MW)- Exhibit-II

iii. Single line diagram with Full Hydro dispatch with load growth of 1500 MW (Kuri Gongri 1800 MW) for 2020 Scenario Exhibit III

iv. Outage of 400 kV Punatsangchhu-I-Lhamoizingkha D/C linen - Exhibit-IV

v. Outage of 400 kV Punatsangchhu-II-Lhamoizingkha D/C line - Exhibit-V

vi. Outage of 400 kV Tala-Alipurduar D/C line- Exhibit-VI

vii. Outage of 400 kV Alipurduar-Siliguri D/C line - Exhibit-VII

viii. Outage of 400 kV Amochhu-Siliguri line- Exhibit-VIII

ix. Outage of 400 kV Wangchuu-Siliguri line - Exhibit-IX

x. Outage of one ckt of 400 kV Sankosh-Alipurduar D/C line- Exhibit-X

xi. Outage of one pole of ±800 kV,6000 MW Alipurduar-Agra/NR/WRBi-pole lineExhibit-XI

xii. Outage of 220 kV Bunakha-Malbase S/C line - Exhibit-XII

xiii. Outage of 400 kV Yangbari-Goling D/C line - Exhibit-XIII

xiv. Outage of 400 kV Goling -Jigmeling D/C line - Exhibit-XIV

xv. Outage of one ckt of 400 kV Jigmeling-Alipurduar D/C line - Exhibit-XV

xvi. Outage of one D/C of 400 kV Yangbari-Rangia 2XD/C line - Exhibit-XVI

xvii. Outage of one pole of ± 800 kV Rangia –NR/WR Bi-pole line - Exhibit-XVII

xviii. Case Study with full Hydro Dispatch for 2020 Scenario with load growth of 1500 MW (Kuri Gongri 3400 MW)- Exhibit-XVIII

xix. Single line diagram with Full Hydro dispatch for 2020 Scenario with load growth of 1500 MW (Kuri Gongri 3400 MW)- Exhibit XI

xx. Case Study with full Hydro Dispatch with load growth of 978 MW - Exhibit-XX

xxi Base Case with 10 % high Hydro Dispatch in monsoon for 2020 scenario Exhibit-XXI

xxii Case study for minimum hydro dispatch with minimum load for 2020 scenario Exhibit- XXII

xxiii. Case study for peak hydro dispatch with minimum load during monsoon for 2020 scenario Exhibit- XXIII

xxiv Case study for minimum hydro dispatch with maximum load for 2020 scenario Exhibit- XXIV

9.2 Sensitivity Studies on NTGMP for 2020 scenario

The following case studies have been additionally carried out to meet the adequacy & reliability of the proposed NTGMP plan for 2020 scenario.

9.2.1 Case Study with 10% higher generation dispatches during high hydro season

Considering 10% additional dispatch at hydro stations during high monsoon season (i.e. exceeding 10% of the full dispatch), system study has been carried out for peak load condition to examine the adequacy and reliability of the Master Plan. It is observed from the results of the studies that the Bhutan grid would have no transmission constraints to cater to the internal load demand within Bhutan by 2020 and also to export additional surplus to India. The base case power flows is given at Exhibit-XXI.

9.2.2 Case study for pre-revised load of 978 MW by 2020

Presuming 978 MW demand to grow by 2020 as per the original load forecast made by Bhutan, a case study with full hydro-despatch has been carried out and the power flow results is given at Exhibit-XX. It is observed that the proposed NTG grid is sufficient to cater to the system requirement.

9.2.3 Light load condition with minimum hydro generation

The sub-station wise light load forecast (1125 MW) of Bhutan and minimum hydro dispatches are depicted at Annexure-VIII & IX respectively for 2020 scenario. A case study is carried out and power flows in the network is given at Exhibit-XXII. It is observed there will not be any grid problem in Bhutan.

9.2.4 Peak hydro dispatch with minimum load during monsoon

A case study is carried out considering light load and peak hydro dispatch at hydro stations for 2020 scenario and corresponding power flows in the network is given at Exhibit-XXIII. It is observed there will not be any grid problem in the proposed NTG of Bhutan.

9.2.5 Peak load condition with minimum hydro generation

A case study is carried out considering maximum load and minimum hydro dispatch (winter scenario) for 2020 scenario and corresponding power flows in the network is given at Exhibit-XXIV.

9.3 Fault Analysis

The perspective transmission planning exercise for Bhutan has been carried out corresponding to 2030 scenario. Considering the 2030 grid configuration with all hydro machines in operation, short circuit studies using PSSE software has been carried out for three phase to ground fault to enable designing of various electrical equipments and protection systems. Accordingly, from the study results, fault level/current (kA) at various 400 kV, 220 kV, 132 kV and 66 kV buses in Bhutan as given at Annex-XI observed to be lying within 50kA.

Chapter-10

COST ESTIMATE

Investment requirement for implementation of the proposed NTGMP in Bhutan by 2020 has been tentatively worked out considering high transportation costs for materials/equipments in hilly terrains, high labour costs, etc. The PL is taken on the basis of 1st Qtr. 2012. ATS for Punatsangchhu-I being in implementation stage is not considered in the cost estimates. In case of transmission lines crossing the Bhutan border, cost of Bhutan portion has been considered in the cost estimates. The tentative investments needed for development of ATS for various HEPs and system strengthening including reactive power compensation are worked out to about Nu 42590 Million (4259 crores INR) and Nu 3130 Million (313 crores INR) respectively, resulting in total investment requirement of about Nu 45720 Million (4572 crores INR) as given below.

Table 3: Estimated Cost

Estimated investment required for developing NTGMP by 2020

Sl No	System head	Rs. (Crore)
1	ATS for HEPs	4259
2	System Strengthening works	313
Total*		**4572**

**excluding the Cost of ATS for Punatsangchhu-I HEP*

The detailed break-up of estimated costs for project specific evacuation system and system strengthening works in Bhutan corresponding to 2020 are given at Annex-XIII & XIV respectively. A summary of item-wise cost break-up in respect of the proposed 400kV, 220kV, 132kV, 66kV lines and 400/220/132kV sub-station works (including PS/Switching station is given at Annex-XV.

CONCLUSIONS

- The NTGMP for 2020 has been finalized considering the latest data/inputs furnished by Bhutan. As per the latest load-generation scenario, hydro capacity addition by 2020 is 10334 MW and with existing HEPs of 1480 MW, total installed capacity by the end of 2020 amounts to 11814 MW. After meeting the peak load demand of 1500MW in Bhutan, surplus will be exported to India.
- The master plan for 2020 is evolved in holistic manner with a background of the perspective grid plan scenario evolved by system studies for 2030 time frame, considering RoW inaccessibility in the wide area of east-south Bhutan being declared as a National Heritage Site. In the NTGMP exercise, RoW requirements is optimized keeping in view the long term requirements of corridors, resulting in minimum impact on Biological/Reserved park, and environment.
- The long term (for 2030 scenario) requirements of major 400kV trunk transmission corridors, 400kV nodal pooling stations within Bhutan, HVDC transmission corridors and terminal/converter stations, ATS for basin based HEPs, etc have been identified as given in para 6.4.1 & 6.5 ,which have been considered as key inputs to review and revise the NTGMP for 2020.
- ACSR Moose conductor in 400 kV transmission system developments is considered.
- System requirements has been evolved considering (n-1) contingency including tower outage.
- In 2020 time frame, 400kV EHVAC transmission for evacuation and transfer of power from HEPs in Bhutan has been exclusively adopted as backbone of NTG in the country.
- ATS for Punatsangchhu-II HEP has been revised with an additional 400kV Punatsangchhu-II-Jigmeling D/C line.

- System strengthening and reactive power compensation requirements at 132kV and 66kV levels have been determined to meet the 2020 load demand, maintaining voltage near nominal values.
- In the time frame of Punatsangchhu I & II and Mangdechhu HEPs scheduled to materialize by 2015-17, exportable surplus power from these HEPs would be pooled at Alipurduar HVDC & EHVAC station by LILO of the ±800kV,6000MW Biswanath Chariyali (NER) - Agra(NR) HVDC bi-pole line in India for supply to the Northern/Western Regions of India. At Alipurduar, a 3000MW HVDC converter terminal (Rectifier end) along with 2x315MVA 400/220kV AC sub-station is being set up with a number of interconnecting EHV 400kV transmission lines.
- In the time frame of Chamkarchhu-I, Kuri-Gongri, Kholongchhu, Amochhu RS and Nikachhu HEPs i.e. beyod 2017, an independent ±800kV, 6000MW HVDC bi-pole line from Alipurduar to a suitable de-pooling point in WR/NR along with an additional 3000MW HVDC converter module at Alipurduar (Rectifier terminal), and a new 6000MW converter module (inverter terminal) at a siuitable de-pooling point would be developed. With this, the LILO of the ±800kV Biswanath Chariyali (NER) - Agra (NR) HVDC bi-pole line at Alipurduar would be removed.
- During high hydro season, adequacy of the proposed NTG has been tested with 10% additional dispatch at HEPs over normal peak load dispatch.
- Three phase to ground fault levels at 400kV, 220kV & 132kV buses corresponding to 2030 scenario are not exceeding 50kA.
- Tentative total estimated cost is about Nu 45720 million (excluding costs of ATS of Punatsangchhu-I).

RECOMMENDATIONS

NTGMP of Bhutan will provide the road map for building a strong and reliable National Grid in Bhutan by 2020. Aiming to achieve this objective, the following grid development Plan are being recommended.

1. Evacuation Systems for HEPs coming up by 2020

i) **<u>Punatsangchhu –I (1200 MW)</u>**

- 400kV Punatsangchhu-I - Sankosh/Lhamoizingkha Twin Moose 2XD/C (one D/C routing via Punatsangchhu-II HEP)
- 400kV Lhamoizingkha (Sankosh) -Alipurduar D/C Quad Moose line
- 400/220kV, 4X105MVA ICT at Punatsangchhu-I
- LILO of 220kV Bosochhu-II – Tsirang S/C line at Punatsangchhu-I.
- 1X80MVAr Bus Reactor at Punatsangchhu-I

ii) **<u>Punatsangchhu –II (1020 MW)</u>**

- 400kV step-up voltage
- Loop-in-Loop-out(LILO) of one 400 kV D/C Punatsangchhu-I -Sankosh/Lhamo Zingkha line at Punatsangchhu-II
- 400 kV Punatsangchhu-II - Jigmeling D/C line
- 1x80 MVAr 420 kV Bus Reactor at Punatsangchhu-II HEP.

iii) **<u>Sankosh (2500+85 MW)</u>**

- 400kV step-up voltage
- 400kV Lhamoizingkha/Sankosh-Alipurduar Quad moose conductor D/C line (2nd)
- Bussing of 400kV Punatsangchhu- Lhamoizingkha 2xD/C line at Sankosh HEP
- Bussing of 400kV Lhamoizingkha-Alipurduar D/C line(1st) at Sankosh HEP
- 400/220kV, 200MVA ICT at Sankosh GIS switchyard
- 220kV D/C interconnection between Main Dam PH (2500MW) and Regulating Dam PH (85MW)
- 2x80MVAr, 420kV Bus Reactors at Sankosh main dam PH

iv) **Wangchhu (570 MW)**

- 400kV step-up voltage
- LILO of one circuit of 400 kV Tala-Khogla/Pugli-Siliguri lines (except the line being LILOed at Amochhu) at Wangchhu HEP
- 1x63 MVAr Bus Reactor at Wangchhu

v) **Amochhu RS (540 MW)**

- 400kV step-up voltage
- LILO of one circuit of 400 kV Tala-Silliguri via Pagli D/C line at Amochhu
- 1x63 MVAr 420 kV Bus Reactor at Amochhu HEP
- Establishment of 220/11 kV , 20 MVA Amochhu S/S
- LILO of 220 kV Malbase-Samtse line at Amochhu LS

vi) **Bunakha (180MW)**

- 220kV step-up voltage
- LILO of the existing 220kV Chukha-Semtokha S/C line at Bunakha
- 220 kV Bunakha-Malbase 2xS/C lines
- Augmentation of 400/220kV ICT at Malbase with an additional 4x67 MVA Transformer

vii) **Mangdechhu (720MW)**

- 400kV step-up voltage
- 400kV Mangdechhu- Goling 2x (S/C on D/C) tower lines with twin moose conductor (stringing of 2nd circuit in each line under Nikachhu HEP)
- 400kV Goling – Jigmeling 2x (S/C on D/C) twin moose tower lines
- 400kV Jigmeling - Alipurduar D/C Quad moose line (Bhutan portion).
- 400/220kV, 4X167MVA Jigmeling pooling station (GIS).
- 1X80 MVAr, 420kV Bus Reactor at Mangdechhu
- 1X80 MVAr, 420kV Bus Reactor at Jigmeling
- 132kV Mangdechhu-Yurmu D/C line
- 400/132kV, 4X67 MVA ICT (1st) at Mangdechhu

viii) **Nikachhu HEP (210/140 MW)**

- 132kV Step-up voltage
- 132kV Nikachhu-MHEP 2xD/C lines
- Augmentation of 400/132 kV ICT with an additional 3x67MVA (2nd) at MHEP
- Second circuit stringing on 400kV Mangdechhu-Goling 2x(S/C on D/C tower lines.

Alternatively,

- 400kV step-up voltage
- LILO of one circuit of the 400kV Mangdechhu-Goling-Jigmeling lines.
- Second circuit stringing in 400kV Mangdechhu-Goling 2x (S/C on D/C) lines

ix) **Chamkarchhu-I HEP (770MW)**

- 400kV step-up voltage
- 400kV Yangbari-Goling 1xD/C (out of 2xD/C line)
- LILO of 400kV Yangbari-Goling D/C at Chamkarchhu-I
- 400/132, 4x67 MVA ICT at Chamkharchhu-I HEP
- 400kV Goling GIS switching station (with provision of space for future expansion/upgradation to a 4x67MVA 400/132kV sub-station and four 132kV line bays).
- 2X80 MVAr 420 kV bus reactors at Goling
- 1X80 MVAr bus reactors at Jigmeling
- LILO of 132 kV Nganglam - Tintibi D/C line at Chamkharchhu-I
- Second circuit stringing in each circuit of the 400kV Goling-Jigmeling 2X(S/C on D/C) lines

x) **Kuri-Gongri (1800/3400MW)**

- 400kV step-up voltage
- 400kV Kuri-Gongri- Yangbari 2xD/C twin moose lines and an additional D/C (3rd) for evacuation of Kuri-Gongri 3400 MW)
- 400 kV Yangbari - Rangia/Rowta 2x D/C Quad Moose Lines (Bhutan portion)
- 400/132kV,4X67 MVA Yangbari GIS
- 2X80 MVAr, 420kV Bus Reactors at Yangbari.
- 132 kV Yangbari - Nganglam D/C line

xi) **Kholongchhu (600 MW)**

- 400kV step-up voltage
- Kholongchhu - Yangbari twin moose 2x (S/C on D/C) tower lines
- 400/132/33 kV 4x67 MVA ICT at Kholongchhu
- 400 kV Yangbari – Goling D/C (2nd D/C line)
- 1x80 MVAr, 420 kV bus reactor at Kholongchhu.
- LILO of 132 kV Kilikhar-Kanglung S/C at Kholongchhu

xii) **Bindu Khola (13 MW)**

- 66kV Bindu Khola - Sipsu 66 KV D/C line

2 Transmission System Strengthening at 400kV 220kV,132kV and 66kV levels

➢ ***System Strengthening in Western Bhutan***

220 kV System

- LILO of 220 kV Chukha-Simtokha S/C line at 220 kV Chumdo GIS substation.
- Upgradation of 66kV Chumdo S/S to 220 kV (GIS) level with 2x50 MVA, 220/66kV transformers.

66 kV System

- Semtokha-Dechecholing S/C line (2nd ckt.)
- Jemina-Paro S/C line
- Singhigaon-Pasakha D/C line (2nd and 3rd ckt)
- Additional 1x50 MVA,220/66kV transformer at Singhigoan
- Additional 1x50 MVA,220/66kV transformer at Malbase
- Additional 3x50 MVA, 220/66kV transformers at Samste.

➢ ***System Strengthening in Eastern Bhutan***

132 kV System

- 132kV Nganglam-Motanga S/C on D/C tower line
- 132kV Nangkor-Kanglung S/C on D/C tower line
- Augmentation of 132/33 kV transformation capacity with 2x50 MVA ICTs at Motanga
- Augmentation of 132/33 kV transformer at Deothang with 1x5 MVA transformer.

- ***System Strengthening in Southern/Central/Northern Bhutan***

<u>132 kV System</u>

- 132kV Jigmeling-Gelephu S/C (2^{nd} Circuit)

3 Sub-station wise Capacitive Reactive Power Compensation

Sl.No	Name of the 66kV/132kV Sub-station buses	Capacitive compensation (MVAR)
1	Semtokha 66kV	20
2	Dechencholing 66kV	15
3	Lobesa 66kV	10
4	Paro 66kV	10
5	Gomtu 66kV	13
6	Singhigaon 66kV	40
7	Pasakha 66kV	70
8	Olakha 66kV	10
9	Samtse 66kV	60
10	Jigmeling 132kV	60
11	Gelephu 66kV	10
12	Motanga 132kV	20
13	Nganglam 132kV	15
14	Phuentsoling 66kV	12
		365

4 In view of difficulty to get adequate land for establishment of AIS in the hilly terrain in Bhutan, identified pooling stations or sub-stations are recommended to be developed as GIS stations. Accordingly, GIS cost at Goling, Yangbari and Jigmeling are considered in the cost estimate.

5 For development and future extension of 400 kV pooling points at Jigmeling, Lhamoizingkha, Yangbari and Goling, adequate quantum of lands need to be acquired.

6 The environmental clearances for construction of newly proposed transmission lines passing through Biological corridors/Reserved parks in Bhutan would be required to be obtained.

7 Sharing of common transmission system/elements for multiple projects should be derived on commercial terms and price recovery mechanism should be in place before execution of those works.

APPENDIX-1

APPROXIMATE AMPACITY (A) OF ACSR OVERHEAD CONDUCTORS

Conductor Name, Nom Area (mm^2), OD (mm) & Configuration	**Amb. Temp (^0C)**	**Ampacity (A) Max Conductor Temp (^0C)**			**Weight (kg/km)**
		75^0C	**85^0C**	**90^0C**	
Moose	30	855	**975**	1030	2004
A=520 mm^2 (Al), D=31.77mm	35	780	**915**	975	
54/3.53 mm Al, 7/3.53mm St	40	700	**850**	915	
Zebra	30	850	**905**	904	1621
A=420 mm^2 (Al), D=28.62mm	35	805	**855**	856	
54/3.18 mm Al, 7/3.18mm St	40	620	**750**	805	
Panther	30	495	**560**		974
A=200 mm^2 (Al), D=21.0mm	35	455	**525**		
30/3.00 mm Al, 7/3.00mm St	40	415	**490**		
Wolf	30	415	**470**		726
A=150 mm^2 (Al), D=18.13mm	35	380	**440**		
30/2.59 mm Al, 7/2.59 mm St	40	345	**410**		
Dog	30	320	**360**		394
A=100 mm^2 (Al), D=14.15mm	35	295	**340**		
6/4.72 mm Al, 7/1.57mm St	40	270	**320**		

Air Density (kg/m^3)=1.0588kg/m^3

Abs. viscosity in air (kg/m hr)=0.072027 kg/m hr

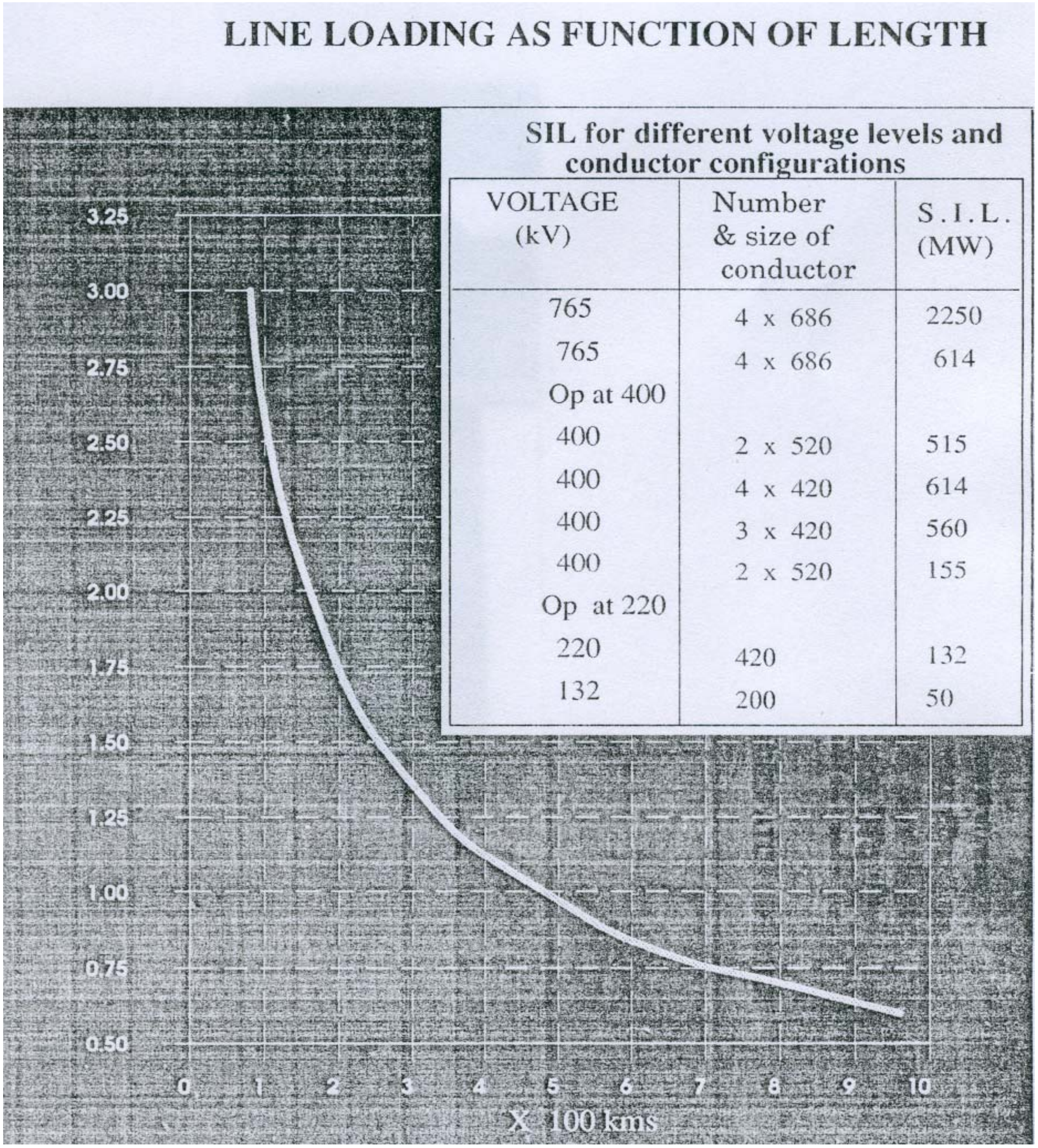
Wind Velocity (m/hr) = 2000m/hr

Solar Radiation = 1045 w/m^2

Solar absorption co-eff. = 0.8

Thermal emissivity Const = 0.45

APPENDIX-2



SIL for different voltage levels and conductor configurations

VOLTAGE (kV)	Number & size of conductor	S.I.L. (MW)
765	4 x 686	2250
765 Op at 400	4 x 686	614
400	2 x 520	515
400	4 x 420	614
400	3 x 420	560
400 Op at 220	2 x 520	155
220	420	132
132	200	50

Ref. Manual on Transmission Planning Criteria, CEA

APPENDIX-3

LOAD FLOW SOLUTION TECHNIQUES

Power flow problem is to determine value for all state variables of an interconnected power system by solving an equal number of power flow equations. Under steady state conditions, load flow techniques enable us to calculate the bus voltages (state variables) as well as branch power flows in the network.

1. Framing of Bus Admittance matrix (Ybus)

Performance of an interconnected network comprising n no. of buses with elements of generation, loads, network data, voltage control devices etc., is described by (n-1) independent nodal equations. The performance equations with a nominal II-model of network are derived by Kirchoff Current Law (KCL) and can be written in matrix notation as below:

$$\mathbf{I_{bus} = Y_{bus} V_{bus}} \qquad (1)$$

Where, $\mathbf{V_{bus}}$ = bus voltage vector with dimension (n x 1)
$\mathbf{I_{bus}}$ = impressed bus current with dimension (n x 1)
$\mathbf{Y_{bus}}$ = Bus admittance matrix with dimensions (n x n).

Elements of $\mathbf{Y_{bus}}$ are known as driving point/self admittance ($\mathbf{Y_{ii}}$) and transfer/mutual ($\mathbf{Y_{ij}}$) admittance. $\mathbf{Y_{ii}}$ is a diagonal term for and equals algebraic sum of all admittances terminating to the i-bus. $\mathbf{Y_{ij}}$ is an off diagonal term between i and j-nodes and equals the negative of the sum of all admittances connected directly between the nodes. The impressed current at i-bus is

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j , \qquad i = 1,2,3 \ldots n \qquad (2)$$

In matrix form,

$$\begin{vmatrix} I_1 \\ I_i \\ I_n \end{vmatrix} = \begin{vmatrix} Y_{11} \ldots & Y_{1j} \ldots & Y_{1n} \\ Y_{i1} \ldots & Y_{ij} \ldots & Y_{in} \\ Y_{n1} \ldots & Y_{nj} \ldots & Y_{nn} \end{vmatrix} \cdot \begin{vmatrix} V_1 \\ V_i \\ V_n \end{vmatrix} \qquad (3)$$

The admittance matrix, $\mathbf{Y_{bus}}$ in equation(3) is a symmetric matrix ,except when phase shifting transformer and non-linear loads are involved. For a system of n-buses only n(n+1)/2 terms need to be stored due to $\mathbf{Y_{bus}}$ symmetry. If the network is large, the matrix is very sparse (may be as high as 90%), and sparsity techniques are adopted to minimize memory requirements and only non-zero elements are stored.

The complex Power injected (**S**) by the source into the i-bus (load may be taken as negative generation) is

$$S_i^* = P_i - j\,Q_i = V_i^* I_I = V_i^* \sum_{j=1}^{n} Y_{ij} V_i \qquad (4)$$

Assuming $V_i = |V_j| \angle \delta_j$ and $Y_{ij} = |Y_{ij}| \angle \theta_{ij}$, real and reactive power component at i-bus are,

$$P_i = |V_i| \sum_{j=1}^{n} |V_j| \, |Y_{ij}| \, Cos(\theta_{ij} + \delta_j - \delta_i) \quad (5)$$

$$Q_i = -|V_i| \sum_{j=1}^{n} |V_j| \, |Y_{ij}| \, Sin(\theta_{ij} + \delta_j - \delta_i) \quad (6)$$

These are non-linear algebraic equations due to **Sin/Cosine** terms and product of voltage terms. For n- bus system, 2n equations are obtained. From equ. (5) and (6) it is seen that each bus is characterized by 4-variables, P_i, Q_i, $|V_j|$ and δ_i . If two variables are specified other two variables can be solved.

2.Bus Classification

Depending upon variables being specified, the buses are classified as below:

Bus-type	Parameter specified/unspecified
PQ bus/load bus	**P,Q** - known **and** **|V|,** δ - unspecified
PV bus/generator bus/ voltage control bus	**P,|V|** - known and **Q ,** δ - unspecified
Slack bus/Swing bus/ reference bus	**|V|** δ - known and **P,Q** - unspecified

The slack bus considered as a large generating station bus which facilitates working out system losses. In n-bus system comprising a slack bus (no state variable), n_v nos. are PV buses (n_v state variables) followed with (n - (n_v+1)) nos. are PQ buses i.e 2(n-n_v –1) state variables, and there would be 2(n-1)- n_v number of power flow equations which would be require to be solved.

3. Iterative Numerical Techniques to Solve Non-linear Algebraic Equations

- Gauss-Seidel (GS) Method and Gauss Method
- Newton-Raphson (NR) Method
- Decoupled Newton Method
- Fast Decoupled Load Flow (FDLF)

3.1 GS Method – It solves the power flow equation in rectangular co-ordinates until difference in bus voltages from one iteration to another are sufficiently small.

All buses except slack-bus (only PV bus) are assumed PQ buses.The slack bus voltage being specified there are (n-1) bus voltages whose starting values (magnitude and angles) are assumed. During each iteration voltages at buses i = 1…n (except slack bus) are sequentially updated by the following equation:

$$V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - j\,Q_i}{V_i^*} - \sum_{i=1,\, j \neq i}^{n} Y_{ij} V_j \right] \qquad i = 1 \ldots\ldots n, \quad i \neq \text{slack bus} \quad (7)$$

Iterations are continued until difference in voltages in successive iterations is within specified tolerance.

If instead of updating voltages at every step of an iteration, updating is carried out at the end of a complete iteration, the process is known as the Gauss iterative method. It is much slower to converge and may sometimes fail to do so.

3.2 NR-Method– It solves the power flow equations until ∇**P** and ∇**Q** mismatches at all buses fall within specified tolerance and load flow solution must satisfy the following non-linear algebraic equations during the iterative process of computation:

$$f(|V_j|, \angle\delta) = P_{specified} - P_{calculated} = \nabla P < \in \text{ (tolerance value= .01,say)}$$

and,

$$f(|V_j|, \angle\delta) = Q_{specified} - Q_{calculated} = \nabla Q < \in$$

The Taylor's series expansion for non-linear equations, **f(x)** is

$$f(x) = f(x_0) + \partial f(x_0)/\partial x + \text{Higher order terms} \quad (8)$$

Linearized equation in martix form, $[\nabla f(x)] = [J][\nabla x]$ (9)

Where,
- $f(x)$ = a set of defining functions(non-linear)
- x = a set of unknown variables
- x_o = solution of **x** at $x = x_o$
- ∇x =state vector update
- $\nabla f(x)$ = $f(x)$specified – $f(x_0)$calculated
- $J = \partial f(x_0)/\partial x$ = Jacobian matrix (matrix of partial derivatives)

Equation (9) being a set of linear algebraic equations can be solved by the method traingularization and back substitution. It is to be noted that guess for **x** should be near to the final solution.

In power system, the defining functions are real and reactive power component of complex power at i- bus and equation (4) can be expressed in rectangular co-ordinate form and polar co-ordinate form and accordingly, a set of linearized equations as given below are formed with Taylor's series:

3.2.1 Rectangular co-ordinate form

$$P_i = \sum_{j=1}^{n} [\, e_i (e_j G_{ij} - f_j B_{ij}) + f_i (f_j G_{ij} + e_j B_{ij} \,] \quad (10)$$

$$Q_i = \sum_{j=1}^{n} [\, f_i (e_j G_{ij} - f_j B_{ij}) - e_i (f_j G_{ij} + e_j B_{ij} \,] \quad (11)$$

where, $V_i = e_i + j f_i$ and $Y_{ij} = G_{ij} + j B_{ij}$

Assuming all the buses as PQ buses, the linearized equation in matrix form is,

$$\begin{vmatrix} \nabla \mathbf{P} \\ \nabla \mathbf{Q} \end{vmatrix} = \begin{vmatrix} \partial \mathbf{P}/\partial \mathbf{f} & \partial \mathbf{P}/\partial \mathbf{e} \\ \partial \mathbf{Q}/\partial \mathbf{f} & \partial \mathbf{Q}/\partial \mathbf{e} \end{vmatrix} \begin{vmatrix} \nabla \mathbf{f} \\ \nabla \mathbf{e} \end{vmatrix} = [\,\mathbf{J}\,] \begin{vmatrix} \nabla \mathbf{f} \\ \nabla \mathbf{e} \end{vmatrix}$$

where,

$$[\,\mathbf{J}\,] = \begin{vmatrix} \partial \mathbf{P}/\partial \mathbf{f} & \partial \mathbf{P}/\partial \mathbf{e} \\ \partial \mathbf{Q}/\partial \mathbf{f} & \partial \mathbf{Q}/\partial \mathbf{e} \end{vmatrix}$$ = Jacobian matrix which is a highly sparse matrix like $\mathbf{Y_{bus}}$.

3.2.2 Polar/Hybrid Co-ordinate form

Complex Power $\mathbf{S_i = P_i + j\,Q_i = V_i\,I_i^*}$ (12)

When, $\mathbf{V_{i=}|V_j|\angle\delta}$, $\mathbf{Y_{ij} = G_{ij} + j\,B_{ij}}$ **and,** $\delta_{ij} = \delta_i - \delta_i$

Real and reactive component of power become,

$$\mathbf{P_i} = |\mathbf{V_j}| \sum_{j=1}^{n} [\,\mathbf{V_j}\,(\mathbf{G_{ij}}\,\mathbf{Cos}\,\delta_{ij} + \mathbf{B_{ij}}\,\mathbf{Sin}\,\delta_{ij}\,] \quad (13)$$

$$\mathbf{Q_i} = |\mathbf{V_j}| \sum_{j=1}^{n} [\,\mathbf{V_j}\,(\mathbf{G_{ij}}\,\mathbf{Sin}\,\delta_{ij} - \mathbf{B_{ij}}\,\mathbf{Cos}\,\delta_{ij}\,] \quad (14)$$

From equation (12),

$$\nabla \mathbf{P_i} = \sum \partial \mathbf{P_i}/\partial\delta_j \;\; \nabla\delta_j + \sum \partial \mathbf{P_i}/\partial|\mathbf{V_j}| \;\; \nabla|\mathbf{V_j}| = \sum \mathbf{H_{ij}} \;\; \nabla\delta_j + \sum \mathbf{N_{ij}} \;\; \nabla|\mathbf{V_j}| \quad (15)$$

$$\nabla \mathbf{Q_i} = \sum \partial \mathbf{Q_i}/\partial\delta_j \;\; \nabla\delta_j + \sum \partial \mathbf{Q_i}/\partial|\mathbf{V_j}| \;\; \nabla|\mathbf{V_j}| = \sum \mathbf{J_{ij}} \;\; \nabla\delta_j + \sum \mathbf{L_{ij}} \;\; \nabla|\mathbf{V_j}| \quad (16)$$

Linearized equation in matrix form :

$$\begin{vmatrix} \nabla \mathbf{P} \\ \nabla \mathbf{Q} \end{vmatrix} = \begin{vmatrix} \partial \mathbf{P}/\partial\delta & \partial \mathbf{P}/\partial|\mathbf{V}| \\ \partial \mathbf{Q}/\partial\delta & \partial \mathbf{Q}/\partial|\mathbf{V}| \end{vmatrix} \begin{vmatrix} \nabla\delta \\ \nabla\,|\mathbf{V}| \end{vmatrix} = \begin{vmatrix} \mathbf{H} & \mathbf{N} \\ \mathbf{J} & \mathbf{L} \end{vmatrix} \begin{vmatrix} \nabla\delta \\ \nabla\,|\mathbf{V}|/|\mathbf{V}| \end{vmatrix} = [\,\mathbf{J}\,] \begin{vmatrix} \nabla\delta \\ \nabla\,|\mathbf{V}|/|\mathbf{V}| \end{vmatrix} \quad (17)$$

where,

$$[\,\mathbf{J}\,] = \begin{vmatrix} \mathbf{H} & \mathbf{N} \\ \mathbf{J} & \mathbf{L} \end{vmatrix} = \begin{vmatrix} \partial \mathbf{P}/\partial\delta & \partial \mathbf{P}/\partial|\mathbf{V}| \\ \partial \mathbf{Q}/\partial\delta & \partial \mathbf{Q}/\partial|\mathbf{V}| \end{vmatrix} \quad (18)$$

The slack bus does not enter the Jacobian as **P** and **Q** are unspecified and $|V|$**,** δ are fixed. From equ. (18) it may be seen that the Jacobian elements corresponding to each bus is a 2 x 2 sub-matrix. When two buses i and j are not connected to each other , the corresponding 4-elements in the sub-matrix become zero. Therefore, the Jacobian matrix is as sparse as Y_{bus} matrix.

In the iterative process, when there are **Q** limits provided at a PV buses and limit violation takes place, corresponding PV bus is made PQ bus and in subsequent computation if Q comes back to the prescribed limit, he bus is switched back to a PV bus. Likewise in a PQ bus, violation of voltage limitation (if provided) makes it a PV bus fixing thereby voltage at the limiting value and in subsequent computation, it switches back to PQ bus if voltage comes within the limit.

3.3 Decoupled Newton Method

Power transmission system operating in steady state does have strong interdependence between **P-** δ and **Q - |V|** and have very week coupling between coupling **P - |V|** and **Q -** δ. Accordingly, the sub-matrices **[N]** and **[J]** can be neglected and decoupled linear Newton equations become

$$\begin{vmatrix} \nabla P \\ \nabla Q \end{vmatrix} = \begin{vmatrix} H & 0 \\ 0 & L \end{vmatrix} \begin{vmatrix} \nabla \delta \\ \nabla |V|/V \end{vmatrix} \qquad (19)$$

where,

$$H_{ij} = L_{ij} = |V_j|\ |V_j|\ (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}),\ i \neq j \qquad (20)$$

$$H_{ii} = -B_{ii} |V_j|^2 - Q_i \quad \text{and} \quad L_{ii} = -B_{ii} |V_j|^2 + Q_i \qquad (21)$$

Updating **[H]** and [**L]** matrices in each iteration, decoupled equation (19) can be solved.

3.4 Fast Decoupled Load Flow (FDLF) Method

The following assumptions are considered to be valid in power system :

(i) $\cos \delta_{ij} \cong 1$
(ii) $\sin \delta_{ij} \cong 0$ **(very small)**
(iii) **Since** $G_{ij} << B_{ij}$, $B_{ij} >> G_{ij} \sin \delta_{ij}$
(iv) $Q_i << B_{ij} |V_j|^2$

With these assumptions, the [H] and [L] sub-matrices of equation(19) get simplified as

$$H_{ij} = L_{ij} = -|V_j|\ |V_j|\ B_{ij} \quad \text{for } i \neq j \qquad (22)$$

$$H_{ii} = -B_{ii} |V_j|^2 = L_{ii} \quad \text{for } i = j \qquad (23)$$

The modified set of linearized equations become,

$$[\nabla P] = [V\ B'\ V]\ [\nabla \delta] \tag{24}$$

$$[\nabla Q] = [V\ B''\ V]\ [\nabla V/V] \tag{25}$$

where,

B' = -B* (comprising one bus less than **B**) and **B" = -B**** (comprising two bus less than **B**)

Because of presence of variable **V**, Jacobian are not constant matrices. Further, the effects of the elements not affecting real powers predominantly in **B'** e.g transformer taps, shunts , the effects of resistance from **B'** and phase angle shifter from **B"** can be ignored. Dividing (24) and (25) by $|V_j|$ with setting $|V_j| = 1$ p.u, the linearized FDLF equations can be written as

$$[\nabla P/V] = [B']\ [\nabla \delta] \tag{26}$$

$$[\nabla Q/V] = [B'']\ [\nabla V] \tag{27}$$

[**B'**] and [**B"**] are real, sparse, symmetrical and have the structure of [**H**] and [**L**] respectively. In FDLF, the matrices are factorized only once and stored only once before iteration begins. Hence, this leads to a very fast solution also.

4. Comparative Analysis of various iterative methods

FDLF Method - Requires 60% of storage of NR method, about 5-times faster than NR iterations and provides reliable convergence.

NR Method- Faster solution speed compared to GS method provides reliable convergence, higher storage requirements compared to GS and initial guess crucial for convergence.

GS Method- Least storage requirement, poor convergence(unreliable),worse in speed for large (even moderate) system due to week convergence, sensitive to selection of slack bus, convergence problem in radial network and dependence on acceleration factor.

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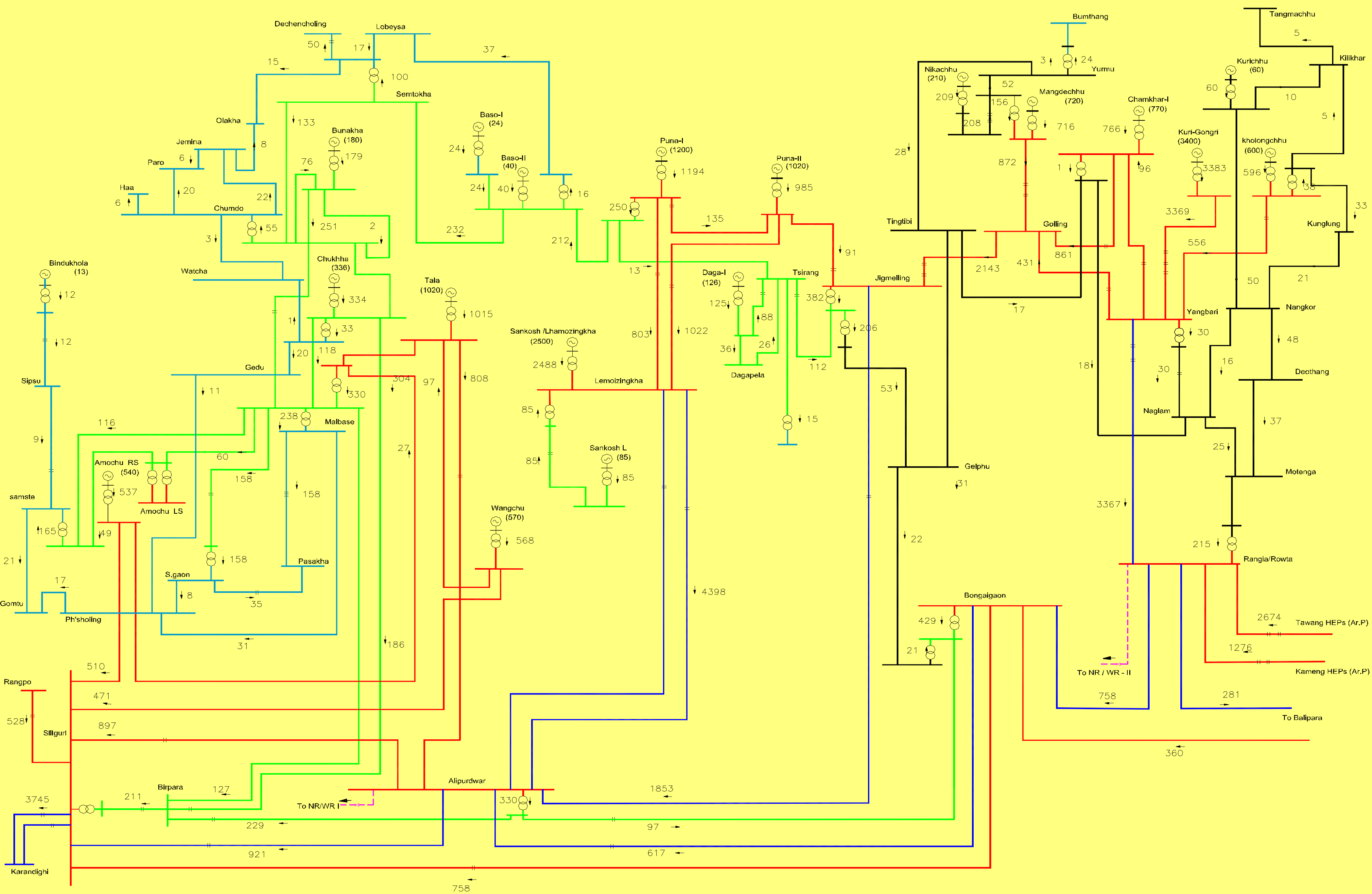
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Lobeysa
Semtokha
Olakha
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Bunakha (180)
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Baso-II (40)
Chukhha (336)
Tala (1020)
Gedu
Malbase
Bindukhola (13)
Sipsu
samste
Gomtu
Ph'sholing
Amochu RS (540)
Amochu LS
S.gaon
Pasakha
Rangpo
Siliguri
Birpara
Karandighi
To NR/WR I
Alipurdwar
Wangchu (570)
Sankosh /Lhamozingkha (2500)
Lemoizingkha
Sankosh L (85)
Puna-I (1200)
Puna-II (1020)
Daga-I (126)
Tsirang
Dagapela
Jigmelling
Tingtibi
Gelphu
Bongaigaon
To NR / WR - II
Nikachhu (210)
Mangdechhu (720)
Bumthang
Yurmu
Golling
Chamkhar-I (770)
Kuri-Gongri (3400)
Yangbari
Naglam
kholongchhu (600)
Kurichhu (60)
Tangmachhu
Kilikhar
Kunglung
Nangkor
Deothang
Motenga
Rangia/Rowta
Tawang HEPs (Ar.P)
Kameng HEPs (Ar.P)
To Balipara