ADB

Technical Assistance Consultant's Report

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Mongolia: Updating the Energy Sector Development Plan

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Prepared by E. Gen Consultants Ltd. Bangladesh in association with MVV decon GmbH, Germany, and Mon-Energy Consult, Mongolia

For Ministry of Energy, Mongolia

Asian Development Bank

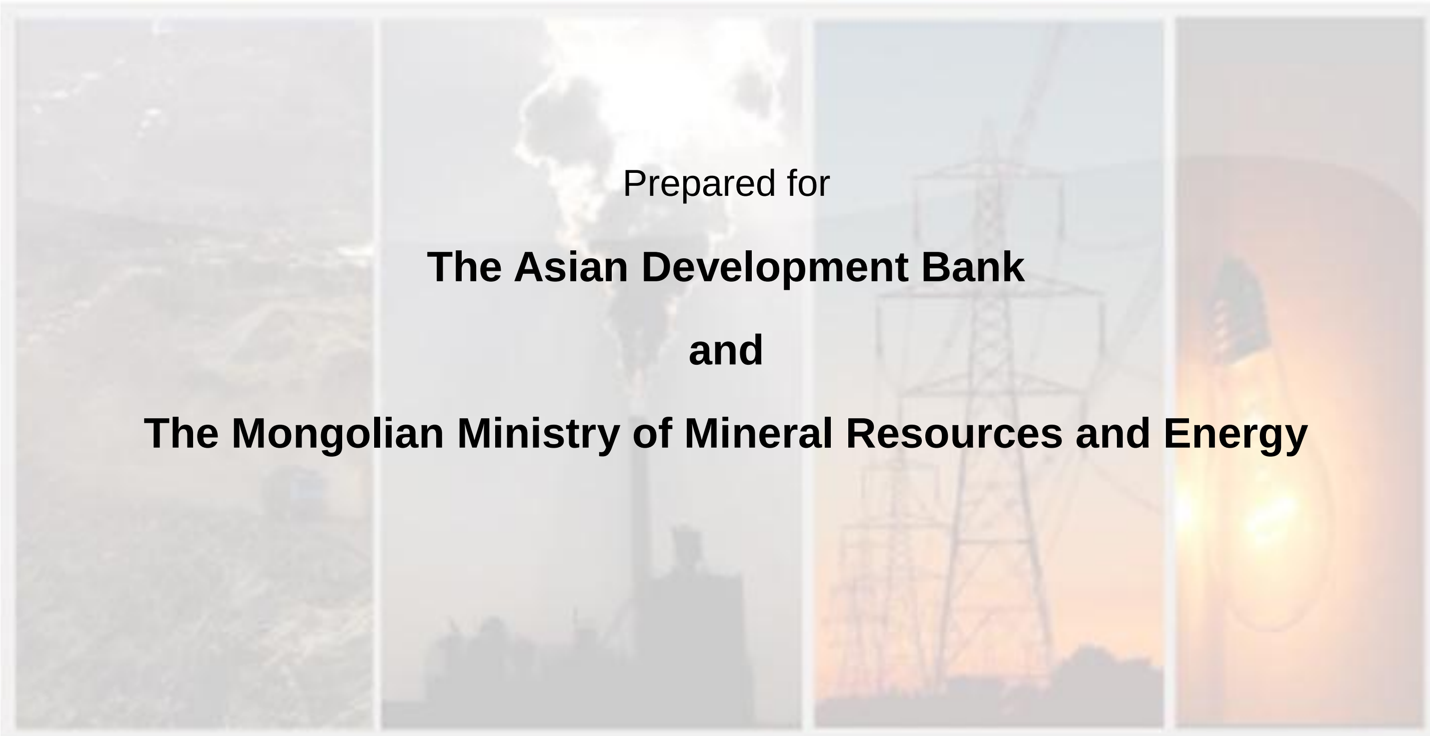
Updating Energy Sector Development Plan

Project Number: TA No. 7619-MON

FINAL REPORT

PART C: Volume - IX of X

ELECTRICITY TRANSMISSION EXPANSION



Prepared for

The Asian Development Bank

and

The Mongolian Ministry of Mineral Resources and Energy

Prepared by

e.Gen Consultants Ltd.

in association with

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ABBREVIATIONS

ADB	–	Asian Development Bank
CES	–	Central Electricity System
EHV	–	Extra High Voltage
MOE	–	Ministry of Energy
MOF	–	Ministry of Finance
NDC	–	National Dispatch Center
O&M	–	Operation and Maintenance
UB	–	Ulaanbaatar
WRES	–	Western Energy System

UNITS OF MEASURE

kWh	-	Kilowatt-hour
MWh	-	Megawatt-hour
MWel	-	Megawatt electric
MWth	-	Megawatt thermal

WEIGHTS AND MEASURES

GW (giga watt)	–	1,000,000,000 calories
GJ (giga joules)	–	1,000,000,000 joules
GW (giga watt)	–	1,000,000,000 watts
kVA (kilovolt-ampere)	–	1,000 volt-amperes
kW (kilowatt)	–	1,000 watts
kWh (kilowatt-hour)	–	1,000 watts-hour
MW (megawatt)	–	1,000,000 watts
W (watt)	–	unit of active power

NOTE

In this report, “$” refers to US dollars.

CONTENTS

I. INTRODUCTION

A. Methodology & Approach

1. An Energy Masterplan focusses primarily on supply expansion plan needs. Typically an Energy Masterplan is developed for electricity supply expansion, after which a detailed Transmission & Distribution Masterplan is developed.

2. The Consultant's analyses of investment requirements for T&D is limited to a high-level determination of the investment required to 1) develop the bulk supply transmission network in the long-term, 2) to augment existing transmission and distribution assets in the medium term, and 3) to replace aging assets in the short to medium term.

3. The bulk supply network delivers energy from power plants to load centres. As a general rule the location of plants should be near to fuel sources, e.g. coal basins, and such are the abundance of such coal deposits in Mongolia that large power plants can be located close to major load centres, and notably close to industrial zones. This means that power plant connections mostly involve short transmission lines connecting to the main grid.

4. Security and adequacy provisions related to the bulk supply network require that the capacity of the bulk supply system can handle the loss of a major transmission element; furthermore the network must be designed in such a way that the power system remains stable under a first contingency fault condition. In practice this means selecting a suitable transmission voltage and network configuration.

5. The highest voltage in use in Mongolia is 220kV. Taking a long term perspective, and considering the development of industrial centres in Mongolia, this voltage will eventually prove to be inadequate. The voltage will require to be upgraded to 400kV or 500kV. The Consultant has undertaken a study of such a scenario.

6. At 220kV and 110kV the detailed assessment of transmission capacity needs should be based on 'loadflow' and 'stability' studies. The length of 220kV and 110kV lines is constrained by technical factors such as transmission line surge impedance and voltage rise under light load conditions. Such technical factors affect operation and are of particular concern where loads are small and separated by large distances. Such operational difficulties have been reported by CRETG.

7. On the other hand, where a transmission network is largely radial in nature, such as the Mongolian transmission network, the demand utilization of substations and lines and projections are a sufficient indicator of the need for and timing of augmentation of the grid. Accordingly for the Energy Masterplan purpose this simplified method has been adopted.

8. The need to replace aging assets is also a driver of investment, and may be a significant driver where a significant portion of the asset base is reaching the end of its service life. Accordingly the age and implied condition has been used to assess the investment needs as 'sustaining' capex.

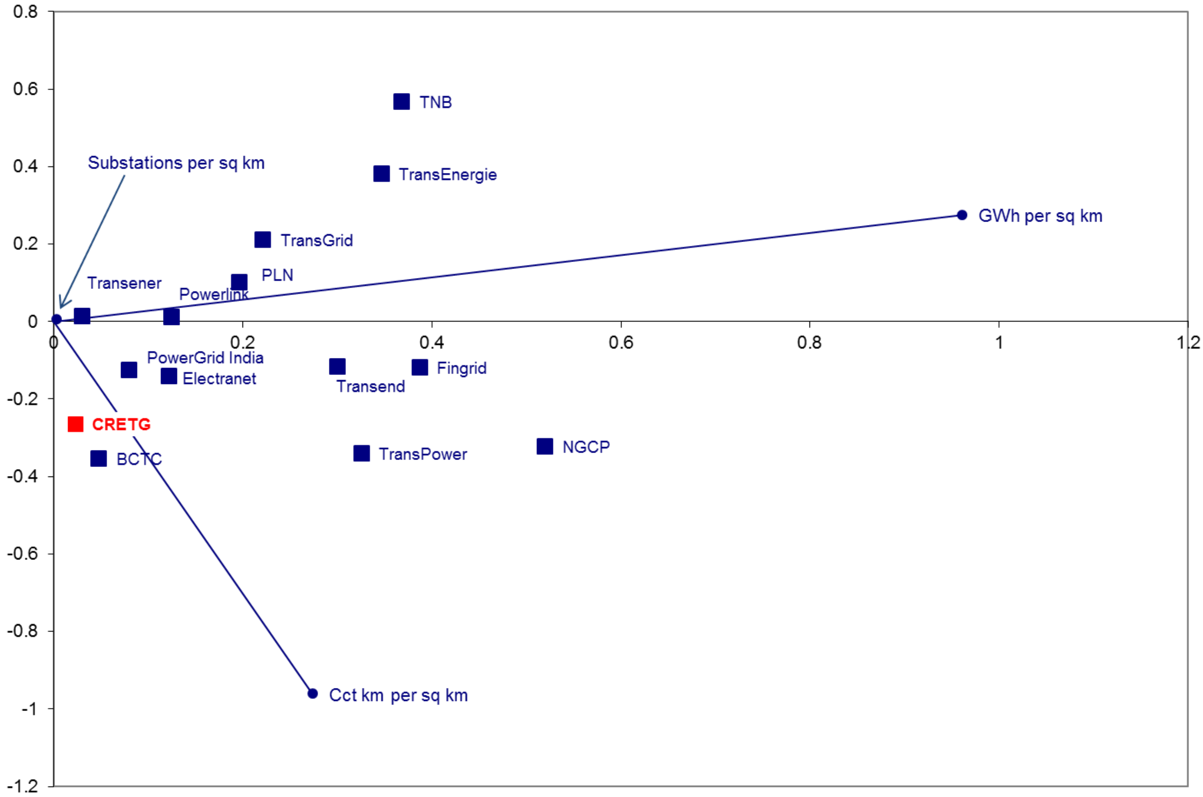
B. Transmission Planning Standards

9. At a fundamental level, the load (energy density) and location determines the voltage levels on economic grounds. The size of substations and distance between substations is a determining factor in the selection of a suitable voltage.

10. The relative cost drivers of the transmission system are indicated by a cluster chart. A cluster chart describes the spatial characteristics of a transmission network in comparison with other transmission networks. The cluster chart shows that the CRETG transmission network is

most similar to that of the British Columbia Transmission Company (BCTC). BCTC's service territory is characterized by long distances between population centres, with small loads at each location, entirely similar to Mongolia. As a result BCTC has a relatively high total length of circuits with similar technical difficulties in operation under light loading conditions.

Figure I-1: Spatial Characteristics of Transmission Networks



Sources: Consultant's analysis; BCTC is a suitable peer transmission utility for the CRETG against which to benchmark practices.

11. In Mongolia the transmission / sub-transmission voltages in use are 220kV, 110kV and 35kV. In BCTC case the voltages in use are 500kV, 230kV, 138kV and 69kV. These latter voltages indicate that the population centre loads in BCTC case are higher than in Mongolia which is expected according to a kWh per capita comparison.

12. In Mongolia, the CRETG 220kV transmission system can be considered as a bulk energy delivery system, delivering energy from generators to major load centres. It is typical to establish a ring system on the outskirts of a major city to cope with the total loss of a 220kV substation or 220kV line. The spare capacity of 220kV substations must be sufficient to cover the first contingency loss of any 220kV substation. Furthermore the first contingency loss of a 220kV line must not result in a loss of load or unacceptable voltage and frequency disturbances to the interconnected power system.

13. The 110kV transmission system can be considered as an 'area' supply designed to deliver bulk energy supply to local areas (which may be widespread areas in a rural setting). Accordingly the 110kV substations are located and sized (MVA capacity) according to energy density considerations. From the standpoint of reliability it is typical to allow sufficient spare capacity of substations to be able to offload the maximum load of a 110kV substation through 110kV and / or 35kV interties.

14. The 35kV system is essentially a 'sub-transmission' voltage. In urban environments such as Ulaanbaatar, the 35kV substations are arranged in a ring(s) connected by 35kV lines that leave and return to 110kV substations. In any case these lines are typically sized to be able to supply

10 / 6kV transformers, with sufficient spare capacity that the loss of a 35kV line can be addressed by load transfers. In the event of the loss of a 35kV substation the station and 6kV feeder network is typically designed so that the station load can be transferred to adjacent substations by 6kV interconnections. This is an ideal arrangement and in rural areas may not be possible due to cost considerations. In rural settings the 35kV lines will generally be radial.

15. The transmission and distribution licensees in Mongolia follow technical planning and design standards when selecting substation plant and equipment. The leads to typical substation configurations:-

1. 220kV substations are mostly designed with ring busses for high reliability;
2. 110kV substations are mostly designed as a single bus configuration; international practice would typically employ a double bus configuration but the additional cost is not justified in Mongolia where 110kV substations have relatively small capacity; and
3. 35kV substations are designed using a single-bus configuration which has acceptable reliability performance; in Ulaanbaatar a ring network is in place.

16. The capacity of substations varies but as a generalization:-

1. 220kV substations in Mongolia typically house 2 x 125MVA power transformers;
2. 110kV substations typically house 1 x 10MVA, 2 x 25MVA, or 2 x 40 / 100MVA power transformers; and
3. 35kV substations typically house 2 x 5MVA or 2 x 12.5MVA power transformers.

17. From an 'N-1' reliability standpoint, there is a fixed relationship between the firm capacity of the 220kV substations and the firm capacity of 110kV substations. Similarly for 110kV and 35kV substations. As mentioned above, with regard to transfer capacity, for similar reasons the ideal relationship between transformation capacities at different voltage levels is often not met where loads are small.

18. Planning standards largely determine the cost of T&D networks, as dictated by the load and location of load. Assessment of new capacity investment needs can therefore be made through consideration of existing and projected substation and line utilization, and the need to add capacity at each voltage level to meet target utilization levels at each voltage level, as defined by planning standards.

19. In addition investment is required to replace transmission and distribution assets that have reached the end of their economic service lives. Obsolescence (the unavailability of spare parts) is also a reason to replace assets and may at times require significant levels of investment if certain items of plant and equipment are present in large quantity.

C. Distribution Planning Standards

Traditional

20. At a fundamental level, the load (energy density) and location determines the voltage levels on economic grounds. The size of substations and distance between substations is a determining factor in the selection of a suitable voltage.

21. In Mongolia the distribution voltages in use are 35kV, 10kV / 6kV and 0.415kV. Substations transform the voltage from 35kV to 10kV / 6kV and distribution feeders leave the substation at the lower voltage level. In Ulaanbaatar the distribution network is mostly built using underground cable. In rural areas pole-mounted distribution transformers transform the voltage to 0.415kV. It is understood that there are 35 / 0.415kV transformers in use, by some accounts around 25% of the line transformers are of this type.

22. Investment in the distribution network is driven by capacity, electricity losses, reliability and

refurbishment needs.

23. Given the vastness of the distribution network, for the purpose of the Energy Masterplan the above categories of investment have been assessed at a high level by recognizing that the capacity at the transmission level must be matched at the distribution network level, wherein the capacities follow a fixed relationship between voltage levels.

24. In the case of refurbishment expenditure the age of assets can be assumed to follow the profile of the age of transmission network assets, as a means to determine an estimate for sustaining capital expenditure.

Micro-Grid Networks

25. In the OECD countries, penetration of distributed generation has not yet reached significant levels but there is a trend towards the establishment of local generation whereby excess power is sold to the local distribution grid.

26. Distributed generation encompasses a wide range of prime mover technologies, such as internal combustion (IC) engines, gas turbines, micro-turbines, photovoltaic, fuel cells and wind power. The benefits include power support at substations with associated reduction in losses and deferral of T&D upgrades. The smaller size of emerging generation technologies also permits generators to be placed optimally in relation to heat loads allowing for use of waste heat. Such applications can more than double the overall efficiencies of a micro-grid system. Emerging technologies have lower emissions and the potential to over-turn traditional economies of scale.

27. However, indiscriminant application of individual distributed generators can cause as many problems as it may solve. Integration of distributed generation requires a system approach where generation and associated local loads as considered as a subsystem or a “micro-grid”. This approach requires local control of distributed generation. During disturbances, the generation and corresponding loads can separate from the distribution system to isolate the micro-grid load (thereby maintaining a high level of service) without impacting the integrity of the wider local grid. Intentional islanding of generation and loads has the potential to provide a higher local reliability than that provided by the power system as a whole.

28. Most current micro-grid implementations combine loads with sources, allow for intentional islanding and try to use the available waste heat. These solutions rely on complex communication and control systems.

Micro-Grid Control

29. Micro-grid controls must be designed so that micro-sources can be added to the system without modification of existing equipment. The controls must ensure that the micro-grid can connect to or isolate itself from the grid in a rapid and seamless fashion, that reactive and active power is independently controlled, and that the dynamic needs of loads are supported.

30. Micro-source controller techniques described below rely on the inverter interfaces found in fuel cells, micro-turbines, and storage technologies. Modern control and communication system design is based on the principle that micro-sources should not need to communicate with other for basic operation function of the micro-grid. Each micro-source controller must be able to respond effectively to system changes without requiring real-time data from the loads or other micro-sources.

31. Operation of the micro-grid assumes that the power electronic controls of include the ability to; regulate power flow on feeders; regulate the voltage at the interface of each micro-source; ensure that each micro-source rapidly pickups up its share of the load when the system islands. In addition to these control functions the ability of the system to island smoothly and to automatically reconnect to the grid is another important operational function. However, the most critical system performance components are the micro-grid controls that regulate the voltage

versus reactive power droop and active power versus frequency droop.

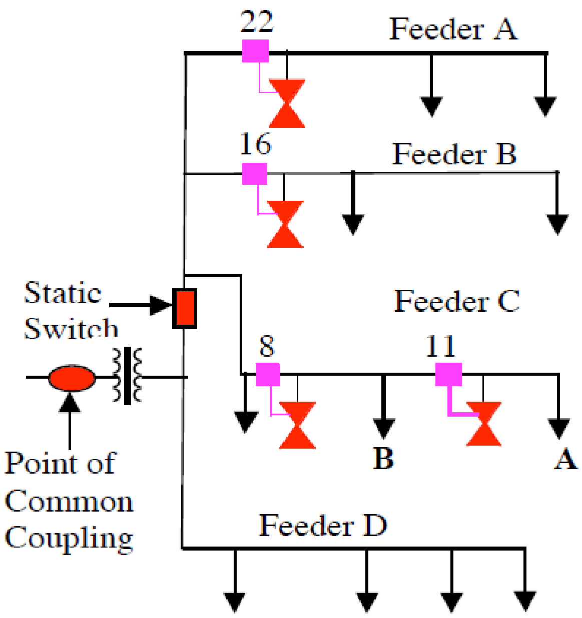
Voltage vs. Reactive Power (Q) Droop

32. Integration of large numbers of micro-sources into a micro-grid is not possible with basic unity power factor controls. Voltage regulation is necessary for local reliability and stability.

33. Without local voltage control, systems with high penetrations of micro-sources could experience voltage and/or reactive power oscillations. Voltage control must ensure that there are no large circulating reactive currents between sources. With small errors in voltage set points, the circulating current may exceed the ratings of the micro-sources. This situation requires a voltage vs. reactive power droop controller that reduces the local voltage set point as the reactive power generated by the micro-source becomes more capacitive, and conversely, as reactive power becomes more inductive, the voltage set point is increased.

34. A basic micro-grid architecture is shown in Figure 2. This system consists of a group of radial feeders, which could be part of a distribution system or part of a building's electrical system. There is a single point of connection to the utility called point of common coupling. Some feeders, (feeders A-C) have sensitive loads, which require local generation. Noncritical load feeders do not have any local generation. In the example a noncritical load feeder feeder D. Feeders A-C can island from the grid using static switches which can separate in less than a cycle. In the example there are four micro-sources at nodes 8, 11, 16 and 22, which are regulated using local voltage and current measurements. When there is a problem with the utility supply, the static switches open, isolating the sensitive loads from the utility. Feeder D loads ride through the event. There must of course be sufficient generation available within the micro-grid system to meet the loads' demand. When the micro-grid is connection to the utility grid, excess power from the local generation sources can be directed to feeder D (or exported).

Figure 2: Micro-Grid Schematic



Micro-Grids in Mongolia

35. Micro-grids are a new concept involving technical challenges. A micro-grid must be designed and tested as a system with adequate attention to the potential adverse effects on customers as the system is proven. In Mongolia, it appears that a pilot of a

micro-grid would be an appropriate way to develop the concept, perhaps by grant from a suitable technology partner. In Mongolia wind turbines appears to be the most favourable local supply sources to operate in a micro-grid, followed by solar PV.

II. LONG-TERM TRANSMISSION EXPANSION

A. EXISTING TRANSMISSION NETWORKS

36. The highest existing voltage in use in the Mongolian transmission network is 220kV. This voltage is used in the CES.

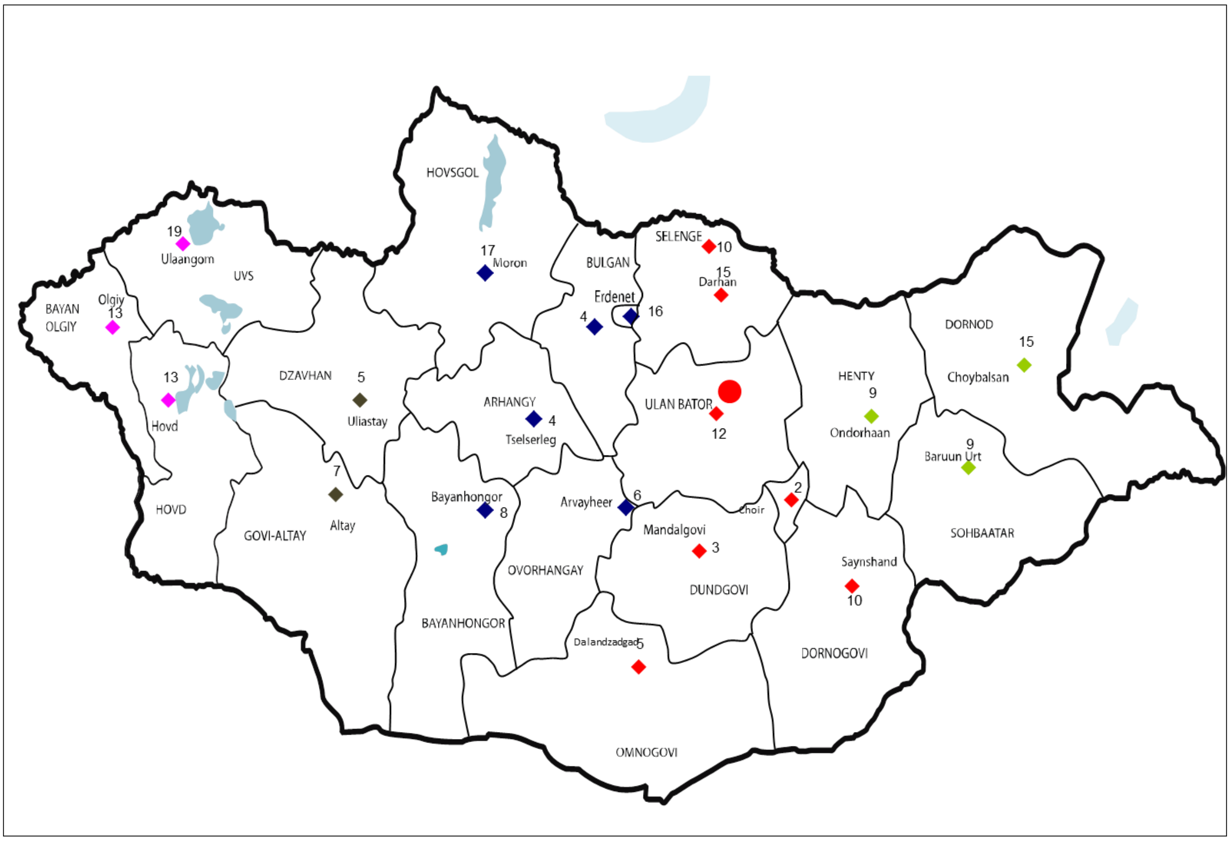
37. In CES the 220kV network has been designed to create a ring between Erdenet, Darkhan and Ulaanbaatar, serving power sourced from Russia (Celedum) via Erdenet. A 220kV double circuit line extends to Baganuur and Choir. A 220kV line was constructed between Ulaanbaatar and Tavan Tolgoi via Mandalgovi in 2012.

38. There are two other small transmission networks, one in WRES and one in ERES.

B. INTEGRATED TRANSMISSION NETWORK

39. Generally speaking load centres coincide with the Aimag centres and the largest towns, notably Ulaanbaatar, Darkhan and Erdenet. With the exception of Ulaanbaatar, the loads are generally low as shown in Figure II-1. The loads are even lower in the AuES, WRES and ERES.

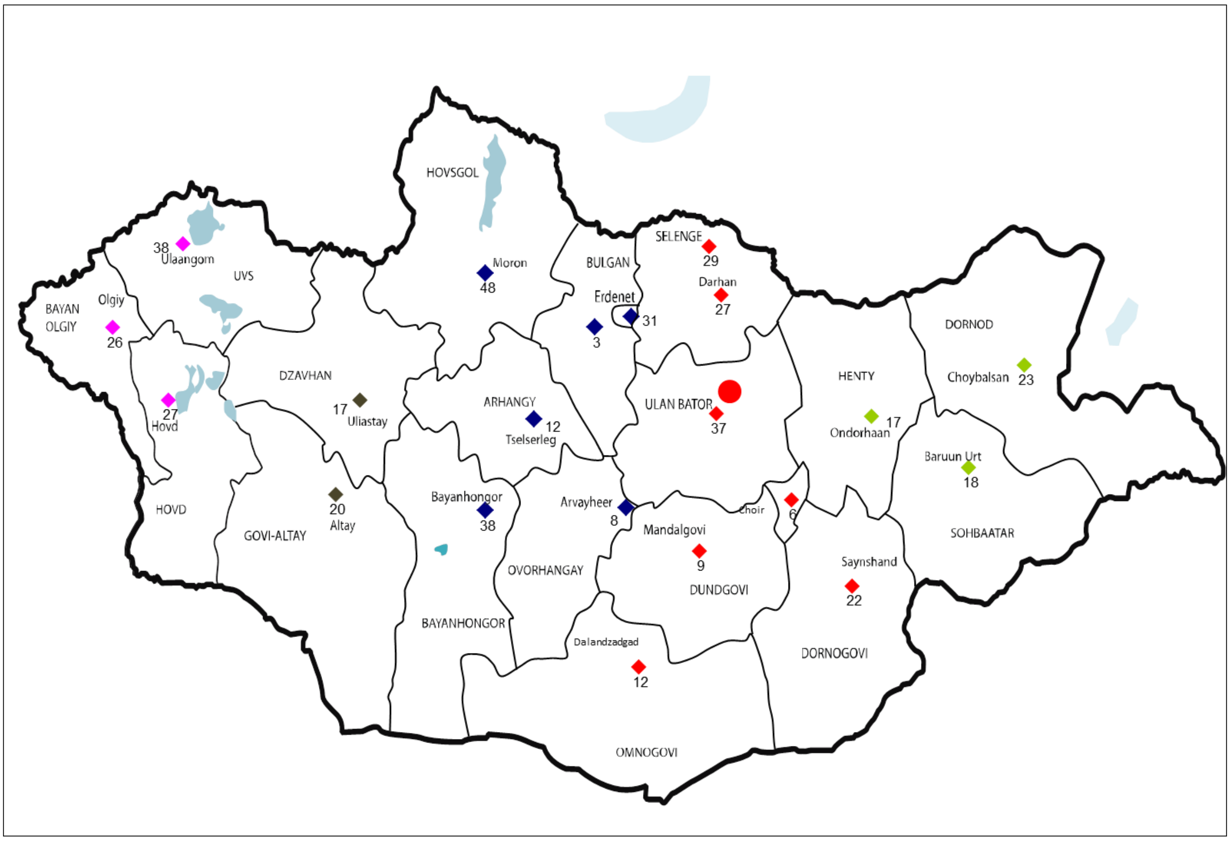
Figure II-1: Aimag Loads in 2013 (MW)



Sources: Consultant's analysis

40. The total load for the Aimags, including Ulaanbaatar was reported at 822MVA. The net load, after deducting Ulaanbaatar was around 200MVA.

Figure II-2: Forecast Aimag Loads in 2025 (MW)



Sources: Consultant's analysis

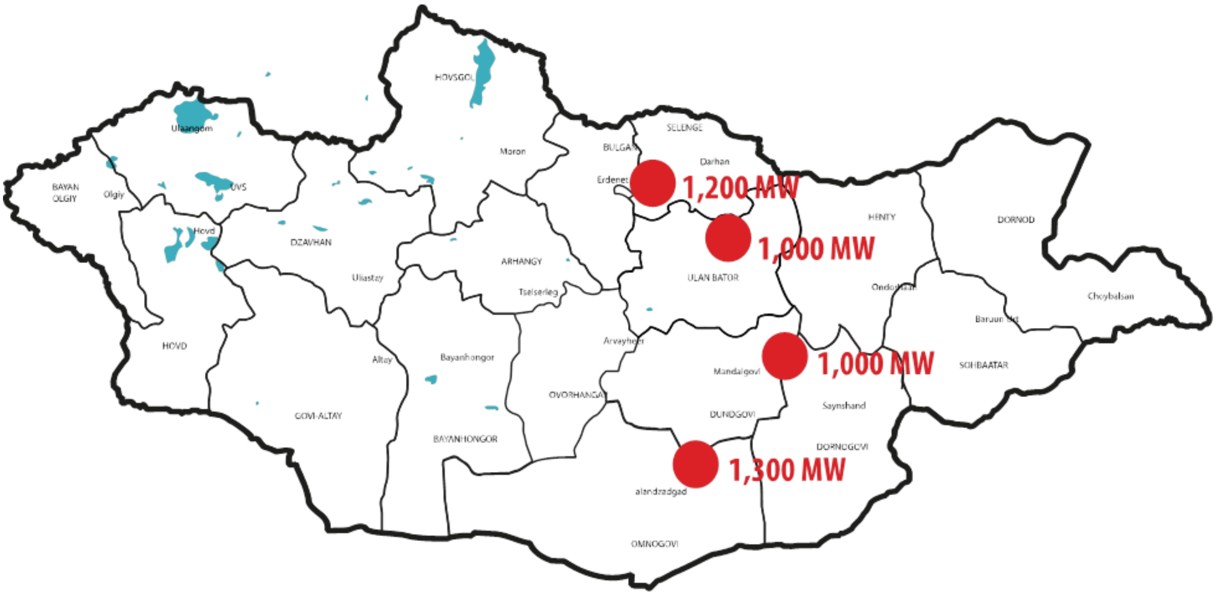
41. The total load for the Aimags, including Ulaanbaatar, is expected to increase to 1,780MVA by 2025. Of this total Ulaanbaatar's forecast load is around 470MVA with a distribution as shown in Figure II-2.

42. Given the forecast loads and the location of loads, the case to develop an integrated transmission network is not to be found in sharing resources between the existing load centres. Across such vast distances an integrated grid would need to develop at 400kV and in such case the transfer of load would need to be of the order of 500 to 1000 MW. The case for the development of an integrated grid is rather to be found in 1) export of bulk power, or 2) the development and interconnection of industrial zones.

43. Expert opinion gathered by the Consultants at various workshops is that there is unlikely to be a significant demand for exported power from either China or Russia within the planning horizon of the Energy Masterplan, i.e. up to 2025. This means that in the short to medium term the demand for export would not support the development of an integrated Mongolian grid. To the north Russia has sufficient capacity and would likely seek to export power to Mongolia from the east or west, as well as through the existing corridor from the north to Erdenet. In the case of China, it is likely that the Chinese would insist on a dedicated transmission line (HVDC) running from a large power plant sited at Shivee Ovoo to industrial load in Beijing area.

44. Industrial zones are part of the vision of Mongolia's development. The vision is based on the development of four major load centres of around 1,000MW each at Ulaanbaatar, the Northern Industrial Zone (Darkhan / Erdenet), Central Industrial Zone (centred at Sainshand or Choir) and the Southern Industrial Zone (centred at Tavan Tolgoi). This scenario is depicted in **Figure II-3**.

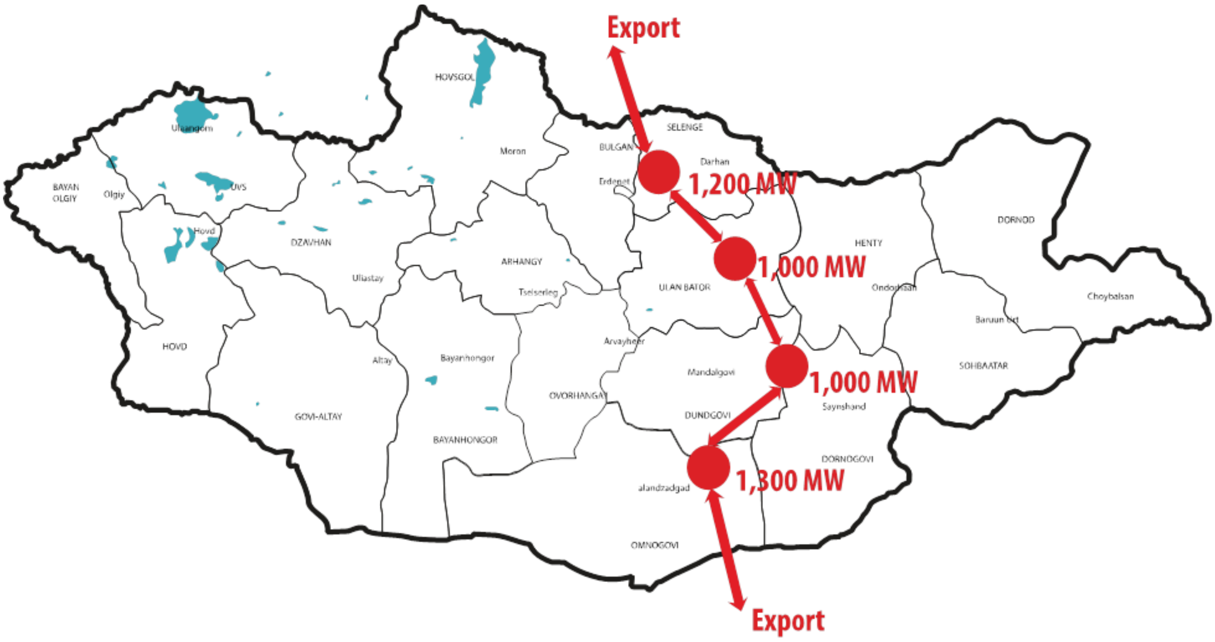
Figure II-3: Industrial Load Centre Development



Sources: Consultant's analysis

45. Consideration of Figure II-3 shows a north-south orientation of power flow. This arrangement suggests a north-south EHV transmission 'backbone'. This orientation is consistent with future transmission grid integration with China and possible strengthening of the connection to Russia.

Figure II-4: Export Model

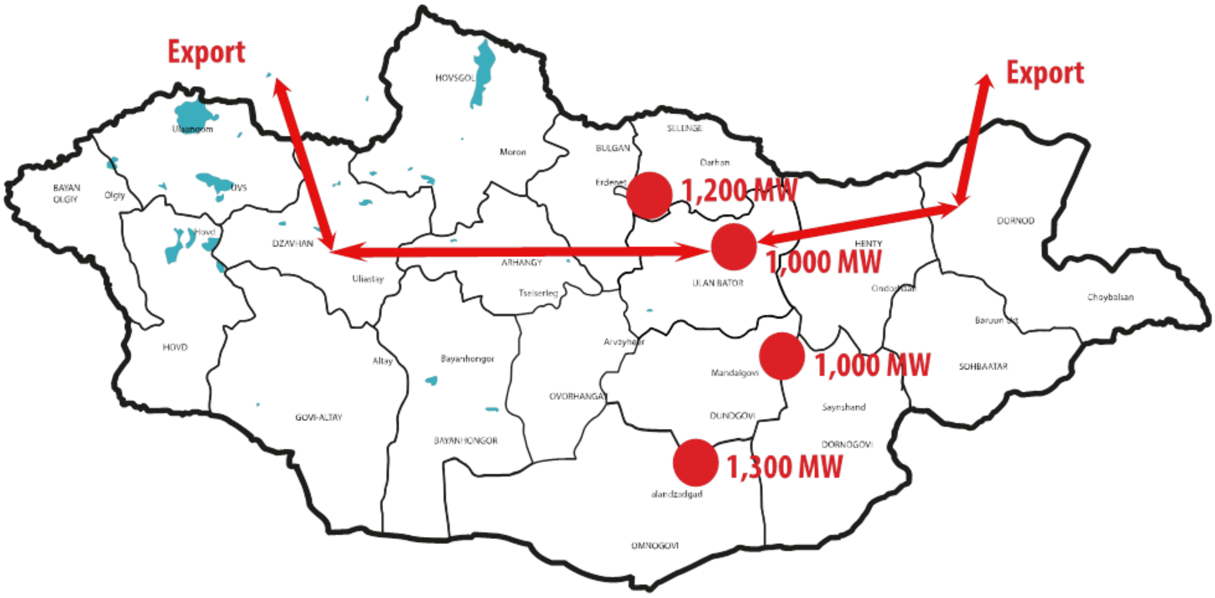


Sources: Consultant's analysis

46. It has been suggested that the time difference between east and west Mongolia is sufficient to consider load transfers from East to West and vice versa, but at the present time it is clear from Figure II-2 that the load centres to the West will remain of small size during the planning horizon and the case to do this for Mongolia alone will not develop before 2025. Taking advantage of time zone differences could offer an advantage in participating in a Russian electricity market but

for reasons mentioned above the case for export does not appear to be strong.

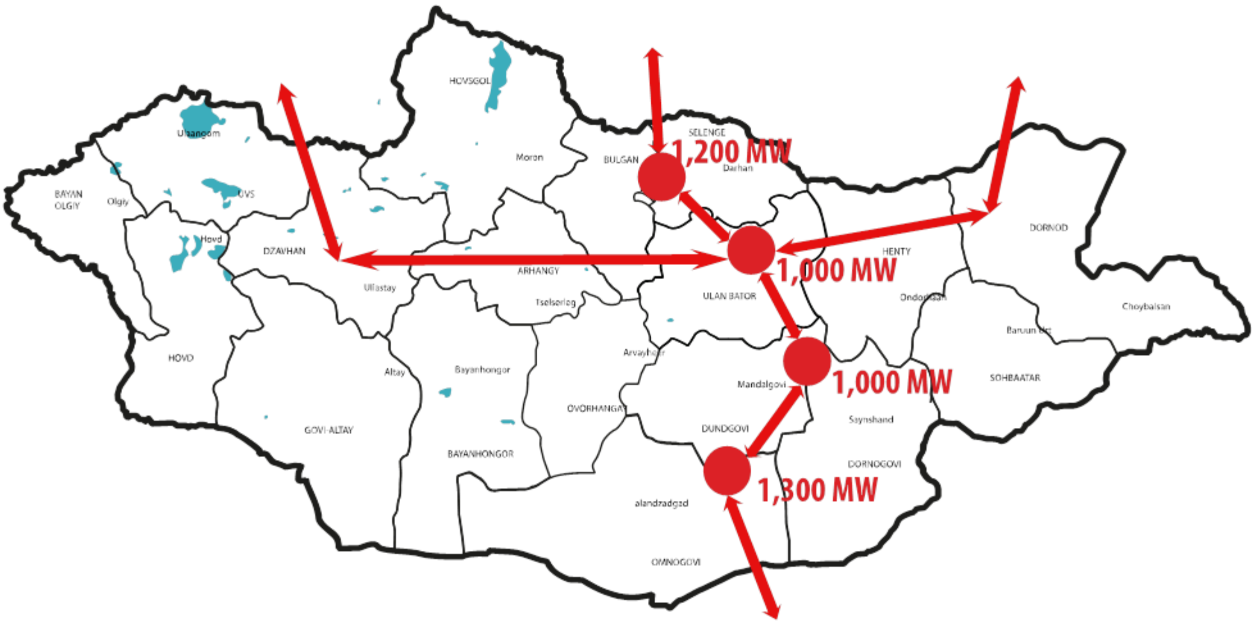
Figure II-5: Time Zone Model



Sources: Consultant's analysis

47. In the long term, a combined approach would see the development of a 400kV north-south transmission network to link the industrial zones and Ulaanbaatar, and an east-west transmission network. Combining all scenarios would result in the following configuration is shown as Figure II-6.

Figure II-6: Pitchfork Zone Model



Sources: Consultant's analysis

48. Such a configuration could be strengthened by creating a ring between UB and the South Gobi region so that UB, the South Gobi and the Central (Sainshand) zones could provide backup to each other, particularly when power plants are established at Sainshand and in the Tavan Tolgoi area. In fact there is a 220kV line in place between Ulaanbaatar and the southern industrial

zone.

49. Through the use of intermediate substations in the east-west network, almost all of the populated areas could be reached by 110kV area grid transmission networks.

50. An important question is what voltage would be required to support the delivery of power between industrial zones, and to the east and west, when the distances are so great. To provide insights to this issue a study of the South-Gobi to Ulaanbaatar transmission interconnection was undertaken.

C. SOUTH-GOBI TRANSMISSION NETWORK STUDY

51. As a proof of concept a set of grid integration studies was performed to determine if it is technically feasible for a power plant based at Tavan Tolgoi to export significant amounts of power to Ulaanbaatar. The establishment of a ring connecting Ulaanbaatar – Tavan Tolgoi – Oyu Tolgoi, Sainshand was modelled.

Figure II-7: Location of Tavan Tolgoi & Power Evacuation Routes

52. Three cases were considered.

1. Case No. 1 was evacuation of power from TT to UB via Mandalgovi at 220kV;
2. Case No. 2 was evacuation of power from TT to Sainshand at 220kV; and
3. Case No. 3 examined evacuation of power from TT to UB or Sainshand at 400kV.

53. Technical feasibility was defined according to a set of technical criteria:-

4. Transmission lines must remain within their thermal loading limits under normal and (N-1) conditions; and
5. Voltage must remain within set technical limits, allowing for additional compensation

devices known as shunt capacitors.

54. In these cases the main issue of concern was the static and dynamic stability of the electrical system created by large power transfers to Ulaanbaatar in particular, following the loss of a power plant in UB. These concerns arise because the distance between Ulaanbaatar and Tavan Tolgoi is around 520km and large power transfers over such a long distance are known to make stable operation difficult to maintain under fault and light loading conditions.

55. Under a worst case scenario the entire Central Electricity System could potentially shut down if a close-in heavy fault was to occur near to say Ulaanbaatar or Tavan Tolgoi. It must be noted however, that a large power transfer to Ulaanbaatar would be needed only if a substantial amount of generation was lost from the Mongolian CHP plants in the CES. In the alternative case of loss of a Tavan Tolgoi unit there would need to be sufficient power available at the TT plant to cover the loss. Such problem would be unlikely in the summer months or at certain times of the day and night when spare capacity was available in Ulaanbaatar.

56. A secondary concern is the stability of the electrical system under a load transfer of up to 450MW from Tavan Tolgoi to the Oyu Tolgoi mining complex, or for a significant load transfer between Tavan Tolgoi and the proposed Central industrial zone at Sainshand.

57. The studies were divided into short term (2014), medium term (2018) and long term (2022) studies. With respect to each of these years, it was assumed that the Tavan Tolgoi plant would export 300 MW, 450MW and 600 MW respectively. It was assumed that an Oyu Tolgoi power plant (OTPP) would maintain a reserve capacity of 150MW above the needs of the Oyu Tolgoi mining complex; furthermore that this reserve block of power would be available to the grid.

58. With regard to the connection of Ulaanbaatar and Tavan Tolgoi via Mandalgovi, the following conclusions were reached:-

- It is technically acceptable to connect a power plant to a double circuit 220kV transmission line connecting the plant and Ulaanbaatar via Mandalgovi, albeit the maximum transfer of power is limited to 50MW under this configuration - under some first contingency fault conditions there is a risk of a voltage collapse;
- The secure transfer of a large amount of power, around 400MW, would require 3 x 220 kV transmission lines from Tavan Tolgoi to Ulaanbaatar via Mandalgovi substation. This maximum load transfer would be required following a loss of generation in Ulaanbaatar but only be feasible at a time of light load conditions (67% of maximum load) in the South Gobi region. This transfer would also require a 200MVAr shunt 220kV capacitor bank at Ulaanbaatar 220kV busbar to provide voltage regulation
- The transfer of up to 450MW of power from ETT to OT is technically acceptable via a double circuit 220kV line;
- In general, based on the stability studies performed, inter-area oscillations are not very well damped and it would be necessary to introduce Power System Stabilisers (PSSs) at the power plants to improve transient stability performance.
- The transmission system required for the short term is also sufficient for the medium term with increased generation at ETT and OT. However, it should be noted that the load demand during this period was assumed to increase, and a 50 MVAr capacitor bank would eventually be required at Mandalgovi 220kV busbar for the system to operate within acceptable voltage limits for various loading and contingency scenarios.
- In the long term, strengthening of the transmission network would be required due to the large amount of generation proposed in the region. The transmission system requires a backbone from Tavan Tolgoi to Ulaanbaatar via Mandalgovi of at least 4 x 220kV lines. The system could evacuate all the power to Ulaanbataar within the operating limits of all equipment under normal and (N-1) conditions with the inclusion of shunt capacitors. However, even with 4 x 220 kV lines and compensation from shunt

capacitors the system remains weak owing to the long distances over which the large amounts of power is transmitted.

- The final scenario examined for the long term was the upgrade of the transmission system in the South Gobi region to 400 kV. The 400 kV network could evacuate all of the available power from the South Gobi to Ulaanbataar with a backbone of only 2 x 400 kV lines. The voltage was maintained on the system with the inclusion of shunt reactors and capacitor banks at selected locations.

59. Under the scenarios described above, fault levels at new busbars on the transmission system remained well below rupturing capacity of most industry standard circuit breakers and associated equipment with the highest fault level being 8 kA at 220 kV.

60. It can be concluded from the studies that significant strengthening of the transmission system is required for evacuation of power from the proposed generation sources in the south of Mongolia to Ulaanbataar. This strengthening has begun with the recent completion of a 220kV line from UB to Tavan Tolgoi via Mandalgovi.

61. At this time, the outlook for the development of a 400kV network linking industrial zones in a north-south corridor is an appropriate vision for the future development of Mongolia's transmission network. However, the timing of such a development is considered to fall under a 15 to 20 year vision. The timing of development of an East-West 400kV transmission corridor falls under a 20 to 30 year vision. In the meantime the strengthening of an Eastern 220kV network is likely in the short to medium term as new coal-fired power plants are developed in coal basins to the east of UB. The details of the 220kV and 400kV case studies are provided as Appendix A.

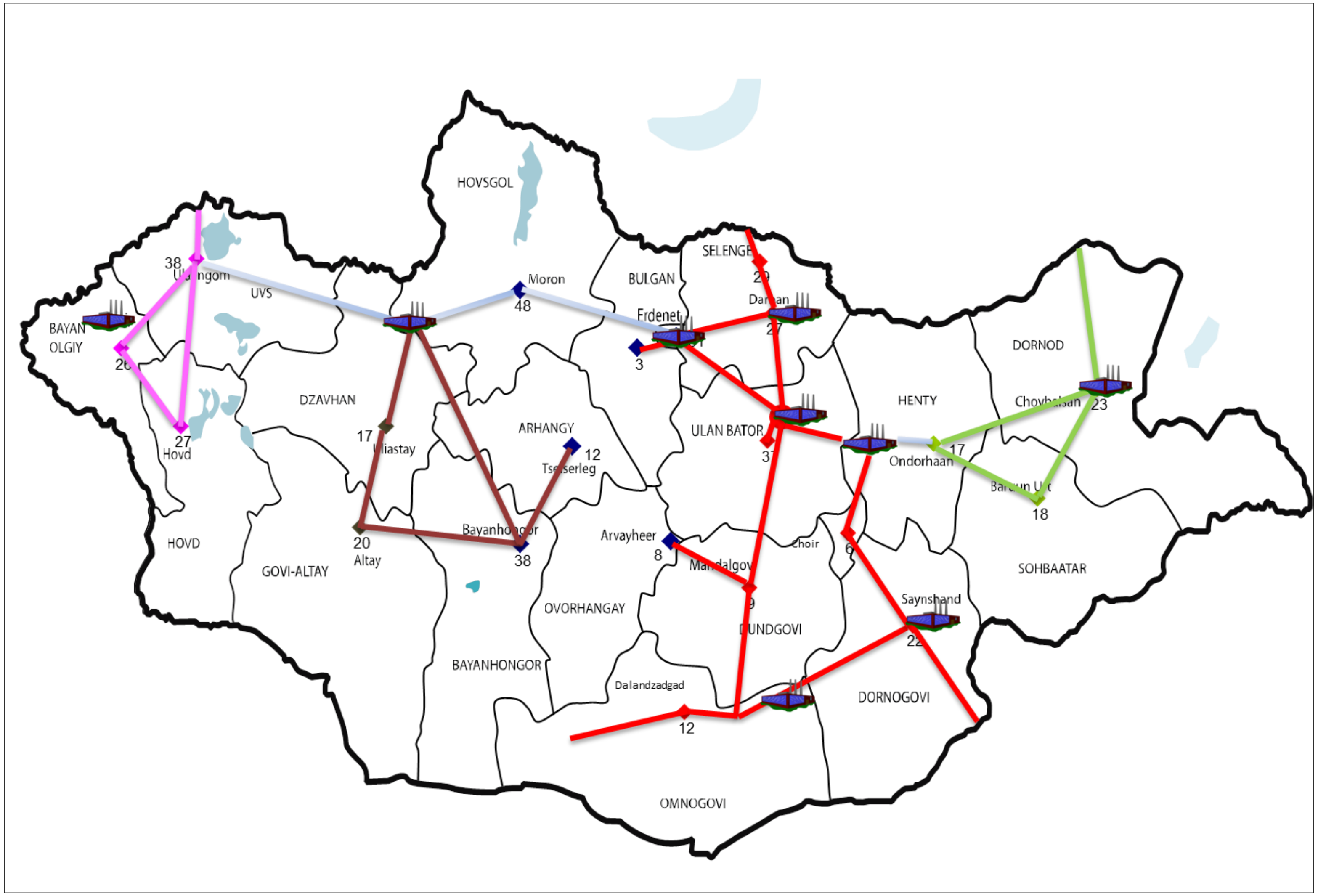
D. SMALL ENERGY REGION INTEGRATION

62. Small Energy Region expansion plans were tabled in a separate report preceding this volume. A possible vision for integration was presented as shown below in Figure II-8.

63. The cost of the development of the integrated transmission grid is considered in Section III below, in a general manner, under the topic of medium term capacity needs.

64. Transmission line costs are not determined for individual lines, according to the line and interconnectors identified in the small Energy Region expansion plan report, as a general costing is sufficient for master-planning purposes. The accurate costing of lines and interconnectors is rightly determined by feasibility studies, in conjunction with associated power plant developments.

Figure II-8: Vision – Integrated Electricity System – 2025



III. MEDIUM TERM T&D NETWORK CAPACITY NEEDS

E. MONGOLIA'S TRANSMISSION NETWORK CHARACTERISTICS

65. The determination of investment needs is based on an observation of the ratios of capacity between voltage levels in the existing Mongolian networks.

Figure III-1: Mongolian Transformation Capacity Ratios

	35kV	110kV	220kV
MVA	2,582	1,375	1,065
LT / HT MVA	1.9	1.3	

Sources: Consultant's analysis

Figure III-2: Mongolian Cct kms by Voltage

	35kV	110kV	220kV
Circuit kms	4,298	3,342	1,509

Sources: Consultant's analysis

Figure III-3: Mongolian Cct km and Capacity

	35kV	110kV	220kV
MVA / km	0.60	0.41	0.71
km / MVA	1.66	2.43	1.42

Sources: Consultant's analysis

Figure III-4: Mongolian Cct km LT / HT

	<35kV	35kV	110kV	220kV
line km	13,367	6,684	3,342	1,509
LT / HT route km	2.0	2.0	2.2	

Sources: Consultant's analysis

Figure III-5: Mongolian Cct km per CB

	35kV	110kV	220kV
CB count	184	161	30
Cct km per CB	9	21	50

Sources: Consultant's analysis

66. In general the above ratios are typical of a transmission network covering a vast service territory.

Figure III-6: Mongolian LT / HT CB Ratio

	35kV	110kV	220kV

CBs	184	161	30
LT / HT CB ratio	1.1	5.4	

Sources: Consultant's analysis

F. MONGOLIA'S TRANSMISSION NETWORK UTILIZATION

67. The Mongolian power transformer utilization in 2013 is generally low.

Figure III-7: Mongolian Power Transformer Utilization – 2012

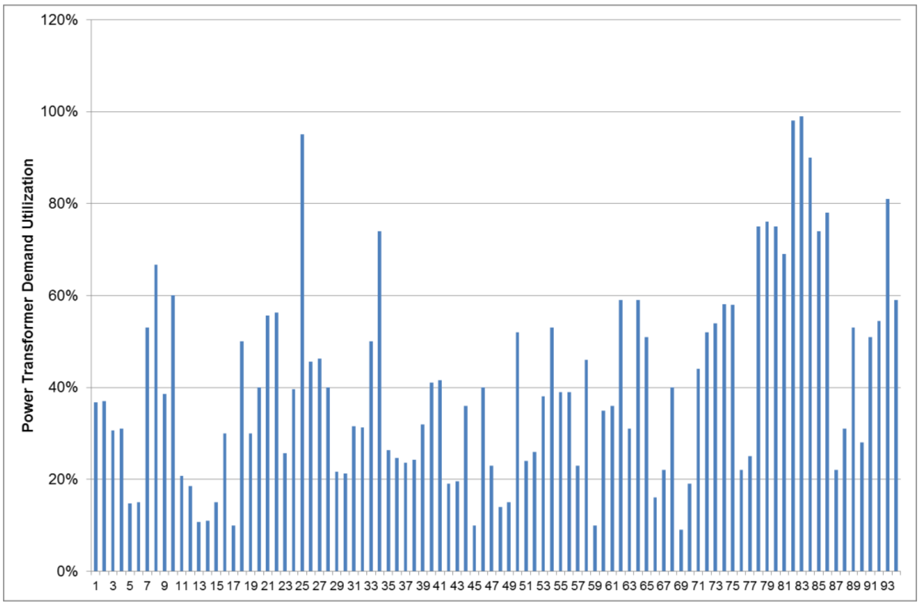
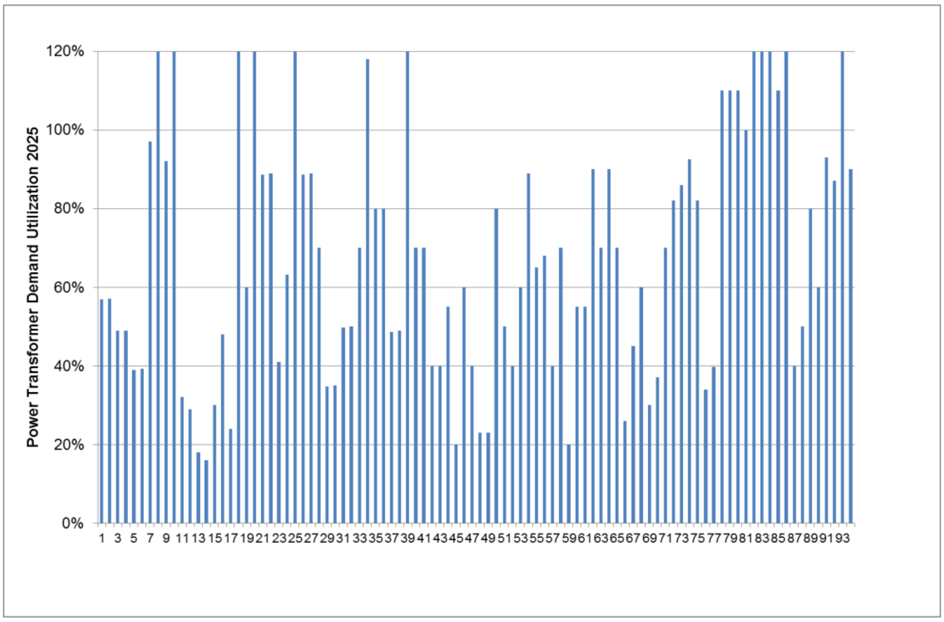


Figure III-8: Mongolian Power Transformer Utilization – 2025

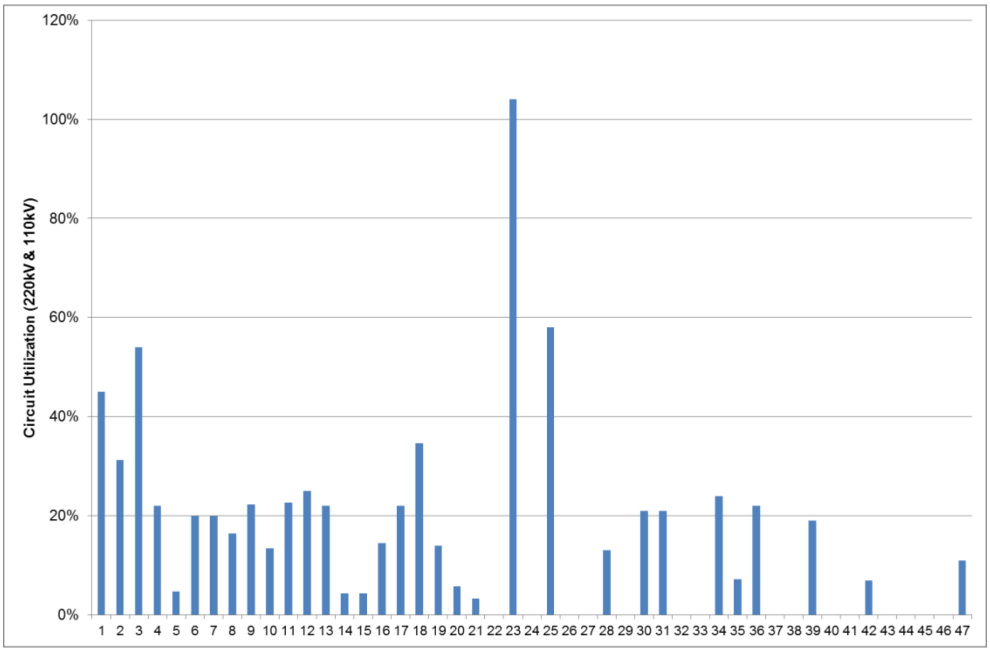


Sources: Consultant's analysis

68. The power transformer utilization will increase by 2025, with some transformers expected to exceed an acceptable level of utilization.

69. Similarly the Mongolian EHV transmission line utilization in 2013 is generally low.

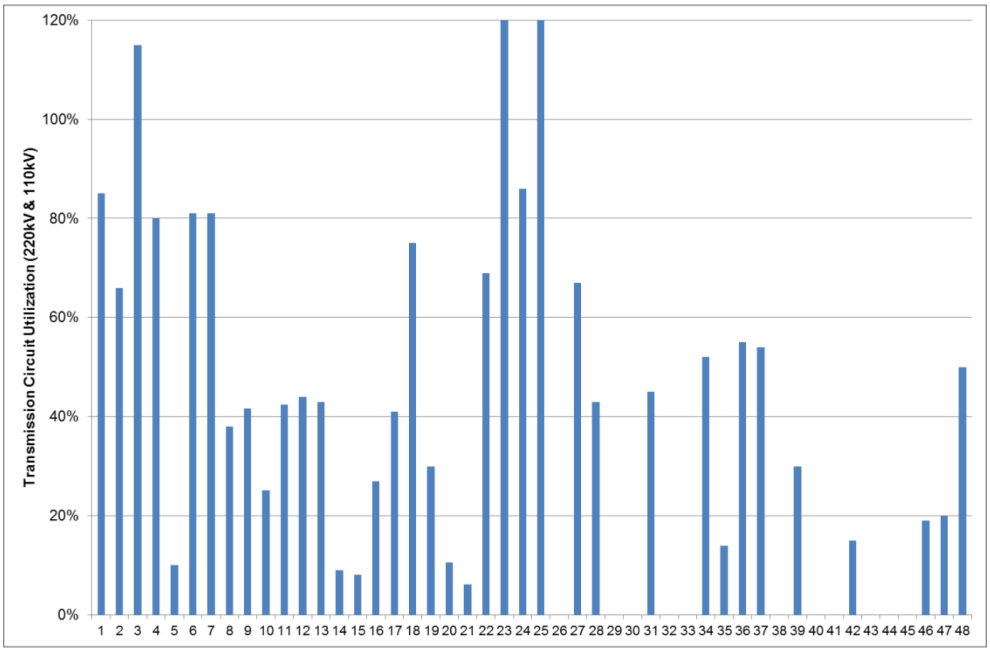
Figure III-9: Mongolian Transmission Line Utilization – 2012



Sources: Consultant's analysis

70. By 2025, the EHV transmission line utilization will in general remain at acceptable levels.

Figure III-10: Mongolian Transmission Line Utilization – 2025



Sources: Consultant's analysis

G. AIMAG TRANSMISSION CAPACITY EXPANSION NEEDS

71. The medium term is considered as the period from 2013 to 2025. As described in Section

D above investment needs that follow have been determined according to existing and forecast utilization levels and compliance with planning standards.

72. Using load forecast data from Volume III, and demand utilization data provided by the CRETG via the Ministry of Energy, we have established the incremental capacity required by the Aimags (excluding UB) by 2025, to maintain an N-1 planning standard.

Figure III-11: Aimag Incremental Capacity Need by 2025

	2013	2025	Firm Capacity (N-1) 2013	N-1 Utilization 2013	Estimated Load 2025	N-1 Utilization 2025 without augmentation	Incremental Capacity Required by 2025 for N-1
	MVA	MVA	MVA	%	MVA	MVA	MVA
Arhangai	4	12	5	87%	12	235%	20
Ulgii-Bayan	13	26	-	-	-	-	-
Bayanhongor	8	38	6	134%	38	598%	70
Bulgan	4	3	16	22%	3	21%	-
Darkhan-Uul	15	27	67	171%	128	191%	190
Dornod	15	23	-	-	-	-	-
Dornogovi	10	22	27	36%	22	80%	20
Dundgovi	3	9	5	67%	9	178%	10
Govi-Altai	7	20	-	-	-	-	-
Govisumber	2	6	132	2%	6	4%	-
Hentii	9	17	26	35%	17	65%	10
Hovd	13	27	-	-	-	-	-
Huvsgul	17	48	11	147%	48	426%	80
Omnogovi	5	12	71	8%	12	18%	-
Orkhon	16	31	272	60%	249	91%	225
Uvurhangai	6	8	23	24%	8	35%	-
Seleng	10	29	49	21%	29	58%	10
Sukhbaatar	9	18	10	93%	18	177%	25
Tov	12	37	33	37%	37	111%	40
Uvs	19	38	-	-	-	-	-
Zavkhan	5	17	-	-	-	-	-
Total	203	468	755		635		700

Sources: Consultant's analysis

73. It can be seen from Figure III-11 that the total incremental capacity required outside of Ulaanbaatar is around 700MVA. This incremental capacity calculation assumes that large power plants associated with Oyu Tolgoi and Tavan Tolgoi are serviced by existing local transmission capacity.

74. Using the information in the above tables and charts, the capacity expansion needs can proceed from the requirement for 700MVA capacity increase at each voltage level, 220kV, 110kV and 35kV. The costs of the capacity are based on current benchmarks for expenditure ($ / MVA relationship) and tested against current Mongolian prices. The costs are treated on average basis for the purposes of developing an annual investment profile.

Figure III-12: 220kV Capacity Expansion Needs

	MVA	$m	CB Bays	$m	Route km	$m
2013	54	2.7	2	1.1	76	14.9
2014	54	2.7	2	1.1	76	14.9
2015	54	2.7	2	1.1	76	14.9
2016	54	2.7	2	1.1	76	14.9
2017	54	2.7	2	1.1	76	14.9
2018	54	2.7	2	1.1	76	14.9
2019	54	2.7	2	1.1	76	14.9
2020	54	2.7	2	1.1	76	14.9
2021	54	2.7	2	1.1	76	14.9
2022	54	2.7	2	1.1	76	14.9
2023	54	2.7	2	1.1	76	14.9
2024	54	2.7	2	1.1	76	14.9
2025	54	2.7	2	1.1	76	14.9
	700	35	20	14	992	193

Sources: Consultant's analysis

Figure III-13: 110kV Capacity Expansion Needs

	MVA	$m	CB Bays	$m	Route km	$m
2013	70	4.3	9	2.3	182	14.6
2014	70	4.3	9	2.3	182	14.6
2015	70	4.3	9	2.3	182	14.6
2016	70	4.3	9	2.3	182	14.6
2017	70	4.3	9	2.3	182	14.6
2018	70	4.3	9	2.3	182	14.6
2019	70	4.3	9	2.3	182	14.6
2020	70	4.3	9	2.3	182	14.6
2021	70	4.3	9	2.3	182	14.6
2022	70	4.3	9	2.3	182	14.6
2023	70	4.3	9	2.3	182	14.6
2024	70	4.3	9	2.3	182	14.6

	MVA	$m	CB Bays	$m	Route km	$m
2025	70	4.3	9	2.3	182	14.6
	904	56	114	31	2,366	189

Sources: Consultant's analysis

Figure III-14: 35kV Capacity Expansion Needs

	MVA	$m	CB Bays	$m	Route km	$m
2013	104	7.5	31	2.6	279	7.8
2014	104	7.5	31	2.6	279	7.8
2015	104	7.5	31	2.6	279	7.8
2016	104	7.5	31	2.6	279	7.8
2017	104	7.5	31	2.6	279	7.8
2018	104	7.5	31	2.6	279	7.8
2019	104	7.5	31	2.6	279	7.8
2020	104	7.5	31	2.6	279	7.8
2021	104	7.5	31	2.6	279	7.8
2022	104	7.5	31	2.6	279	7.8
2023	104	7.5	31	2.6	279	7.8
2024	104	7.5	31	2.6	279	7.8
2025	104	7.5	31	2.6	279	7.8
	1,356	98	403	33	3,631	102

Sources: Consultant's analysis

75. A similar ratio method is used to predict distribution network investment needs. Again the costs are treated on average basis for the purposes of developing an annual investment profile.

Figure III-15: 6 / 10kV Capacity Expansion Needs

	MVA	$m	CB Bays	$m	Route km	$m
2013	156	12	311	5	156	12
2014	156	12	311	5	156	12
2015	156	12	311	5	156	12
2016	156	12	311	5	156	12
2017	156	12	311	5	156	12
2018	156	12	311	5	156	12
2019	156	12	311	5	156	12
2020	156	12	311	5	156	12
2021	156	12	311	5	156	12

	MVA	$m	CB Bays	$m	Route km	$m
2022	156	12	311	5	156	12
2023	156	12	311	5	156	12
2024	156	12	311	5	156	12
2025	156	12	311	5	156	12
	2,033	159	4,038	69	2,033	159

Sources: Consultant's analysis

Figure III-16: 415V Capacity Expansion Needs

	Route km	$m
2013	239	2.4
2014	239	2.4
2015	239	2.4
2016	239	2.4
2017	239	2.4
2018	239	2.4
2019	239	2.4
2020	239	2.4
2021	239	2.4
2022	239	2.4
2023	239	2.4
2024	239	2.4
2025	239	2.4
	3,102	31

Sources: Consultant's analysis

76. The total T&D capacity investment is summarized as follows:-

Figure III-17: Summary – Total T&D Capacity Needs ($m)

	220kV $m	110kV $m	35kV $m	10/6kV $m	LV $m	Total $m
2013	19	21	18	17	2.4	78
2014	19	21	18	17	2.4	78
2015	19	21	18	17	2.4	78
2016	19	21	18	17	2.4	78
2017	19	21	18	17	2.4	78
2018	19	21	18	17	2.4	78
2019	19	21	18	17	2.4	78

	220kV	110kV	35kV	10/6kV	LV	Total
	$m	$m	$m	$m	$m	$m
2020	19	21	18	17	2.4	78
2021	19	21	18	17	2.4	78
2022	19	21	18	17	2.4	78
2023	19	21	18	17	2.4	78
2024	19	21	18	17	2.4	78
2025	19	21	18	17	2.4	78
	242	276	233	227	31	1,009

Sources: Consultant's analysis

H. ULAANBAATAR T&D CAPACITY (AUGMENTATION) NEEDS

77. Ulaanbaatar's capacity needs are estimated as follows.

Figure III-18: UB Incremental Capacity Need by 2025

Installed Capacity	Load 2013	N-1 Utilization 2013	Estimated Load 2025	N-1 Utilization 2025 without augmentation	Incremental Capacity Required by 2025 for N-1
MVA	MVA		MVA		MVA
1,649	619	75%	1,312	159%	1,800

Sources: Consultant's analysis

78. Noting that the Aimag capacity need was 700MVA, and Ulaanbaatar's capacity need is 1,800MVA, Ulaanbaatar's T&D capacity costs are simply scaled up to estimate the requirement.

Figure III-19: UB Incremental Capacity Need by 2025

	Distribution (Ulaanbaatar)	Transmission (Ulaanbaatar)			
	New Capacity	New Capacity			
	less than 35kV	35kV	110kV	220kV	Total
	USD$m	USD$m	USD$m	USD$m	USD$m
2013	51	-	-	-	51
2014	51	20	24	21	117
2015	51	20	24	21	117
2016	51	20	24	21	117
2017	51	20	24	21	117
2018	51	20	24	21	117
2019	51	20	24	21	117
2020	51	20	24	21	117
2021	51	20	24	21	117

	Distribution (Ulaanbaatar)	Transmission (Ulaanbaatar)			
	New Capacity	New Capacity			
	less than 35kV	35kV	110kV	220kV	Total
	USD$m	USD$m	USD$m	USD$m	USD$m
2022	51	20	24	21	117
2023	51	20	24	21	117
2024	51	20	24	21	117
2025	51	20	24	21	117
	664	246	291	256	1,457

Sources: Consultant's analysis

IV. MEDIUM TERM T&D NETWORK REPLACEMENT NEEDS

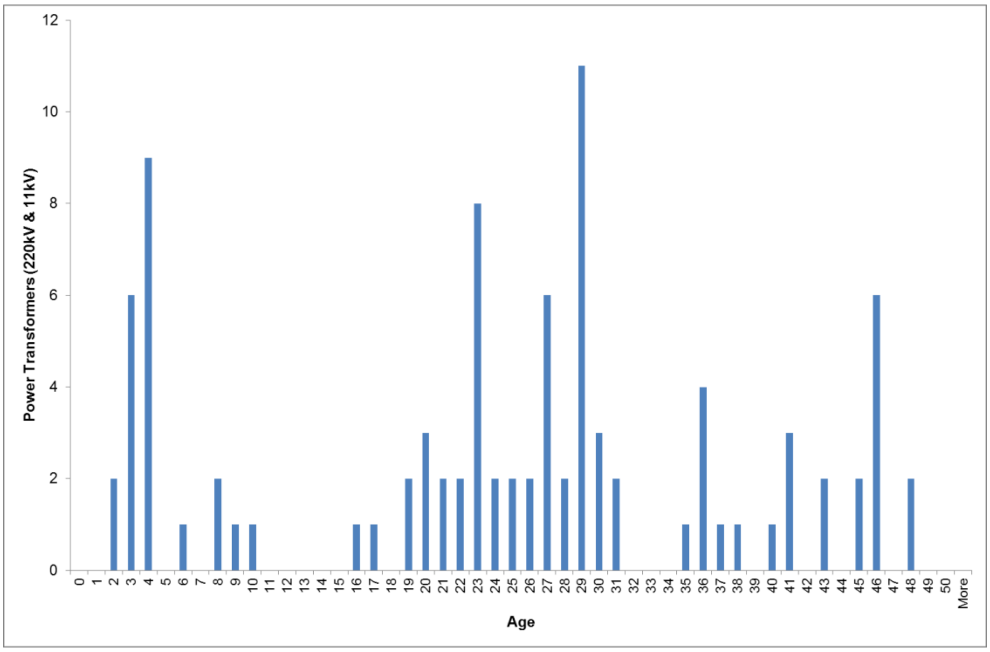
I. TRANSMISSION & DISTRIBUTION REPLACEMENT NEEDS

79. Transmission asset replacement needs are determined according to the age profile of major plant items, namely power transformers, circuit breakers and transmission lines. Distribution asset replacement needs are determined as a proportion of the existing assets, assuming an average life expectancy of 30 years.

J. TRANSMISSION POWER TRANSFORMERS

80. Total installed capacity of transmission power transformers is 4,470 MVA installed power transformers. The capacity-weighted average age profile is 24 years. The total count of transformers is 94, of which 9 are overdue for replacement based on age considerations.

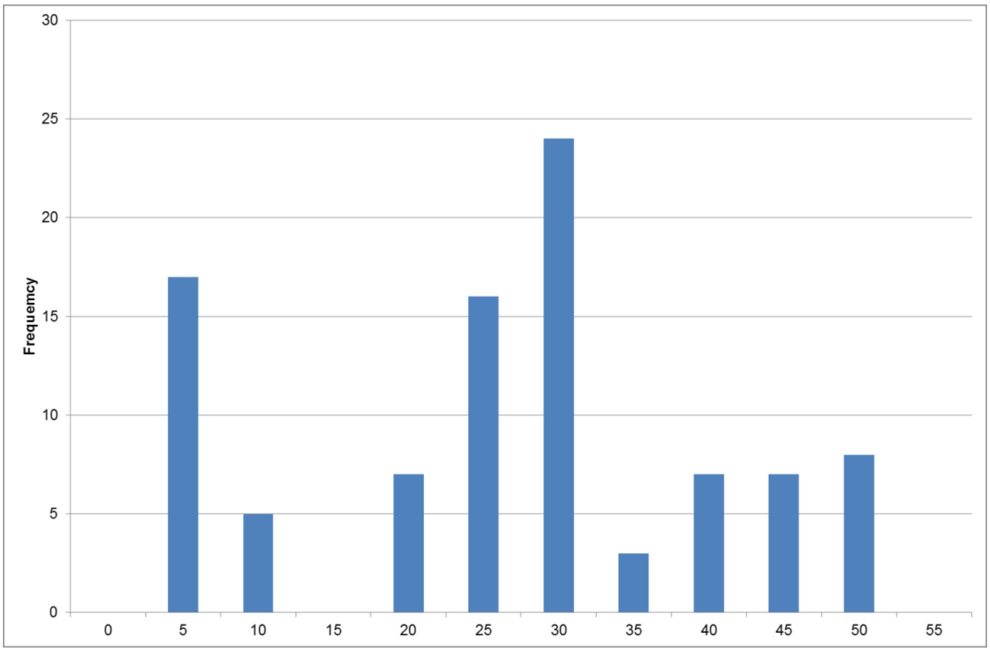
Figure IV-1: Power Transformer Age Profile (220kV & 110kV)



Sources: Consultant's analysis

81. The age profile shows that a significant number of transformers were installed around 25 to 30 years ago. This shows that towards the end of the planning horizon to 2025, many of these transformers will become due for replacement. Within the planning horizon around 20 power transformers will need replacement.

Figure IV-2: Power Transformer Age by Frequency (220kV & 110kV)



Sources: Consultant's analysis

82. Replacement costs of power transformers are estimated on annual basis as follows:-

Figure IV-3: Power Transformer Replacement

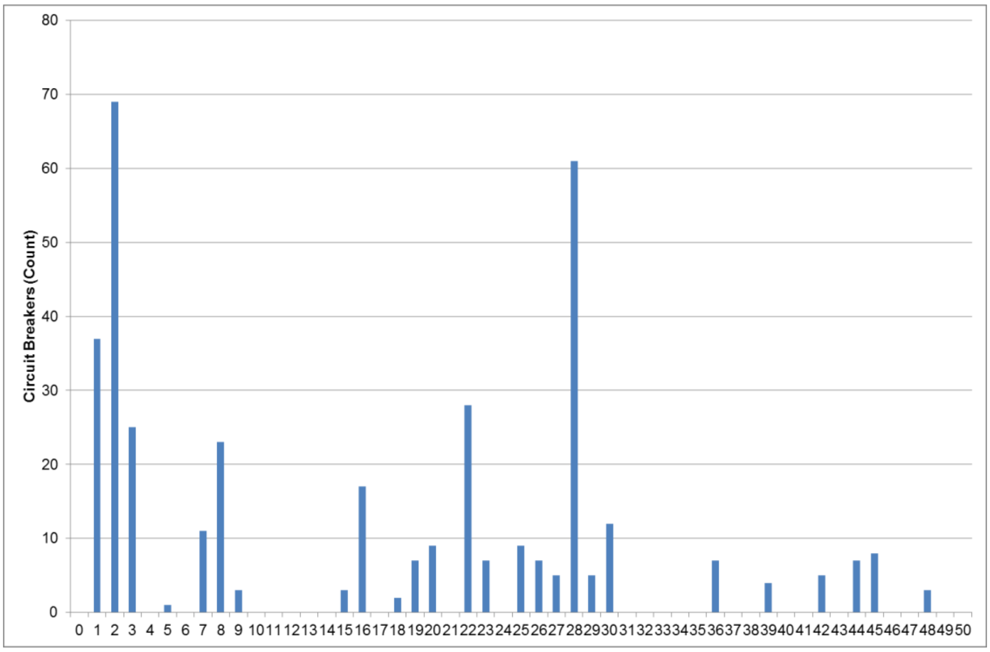
	110kV			220kV		
	Count	MVA	USD$m	Count	MVA	USD$m
2013	0	0	0	0	0	0.0
2014	10	75	4.7	0	0	0.0
2015	10	75	4.7	0	0	0.0
2016	2	2	0.1	2	63	3.2
2017	2	80	5.0	2	250	12.5
2018	0	0	0.0	1	125	6.3
2019	0	0	0.0	0	0	0.0
2020	0	0	0.0	0	0	0.0
2021	0	0	0.0	0	0	0.0
2022	0	0	0.0	2	250	12.5
2023	4	26	1.6	0	0	0.0
2024	8	122	7.6	4	189	9.5
2025	2	13	0.8	0	0	0.0
	38	393	24.4	11	877	43.9

Sources: Consultant's analysis

K. TRANSMISSION CIRCUIT BREAKERS

83. There are 375 EHV circuit breakers. The average age is 16 years. The expected life of an EHV circuit breaker is 35 years. Of the 375 CB's around 10% need replacement immediately and a further 90 should be replaced between 2013 and 2025.

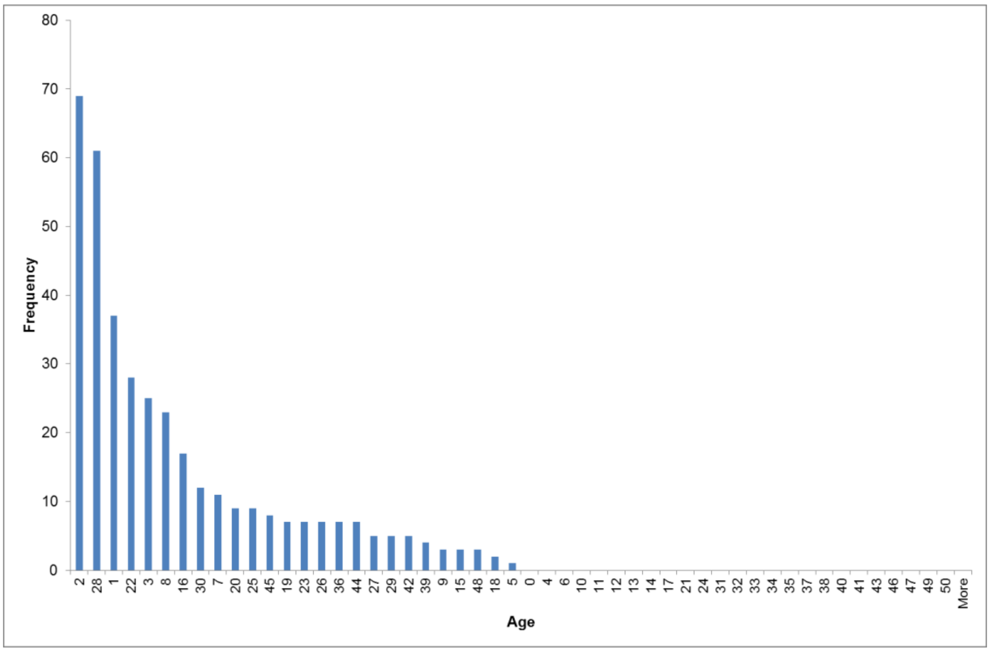
Figure IV-4: Transmission Circuit Breaker Age Profile (220kV & 110kV)



Sources: Consultant's analysis

84. The age profile indicates that many CB's were installed around 25 to 30 years ago, consistent with the power transformer statistics.

Figure IV-5: Transmission Circuit Breaker Age by Frequency (220kV & 110kV)



Sources: Consultant's analysis

85. Replacement costs of EHV circuit breakers are estimated on annual basis as follows:-

Figure IV-6: Transmission Circuit Breaker Replacement

	35kV		110kV		220kV	
	Count	USD$	Count	USD$	Count	USD$
2013	0	-	0	-	0	0
2014	8	0.7	3	0.8	0	0
2015	8	0.7	3	0.8	0	0
2016	8	0.7	3	0.8	0	0
2017	5	0.4	7	1.8	0	0
2018	5	0.4	7	1.8	0	0
2019	5	0.4	7	1.8	0	0
2020	5	0.4	7	1.8	0	0
2021	5	0.4	7	1.8	0	0
2022	5	0.4	7	1.8	0	0
2023	5	0.4	7	1.8	0	0
2024	5	0.4	7	1.8	0	0
2025	5	0.4	7	1.8	0	0
	69	6	72	19	-	-

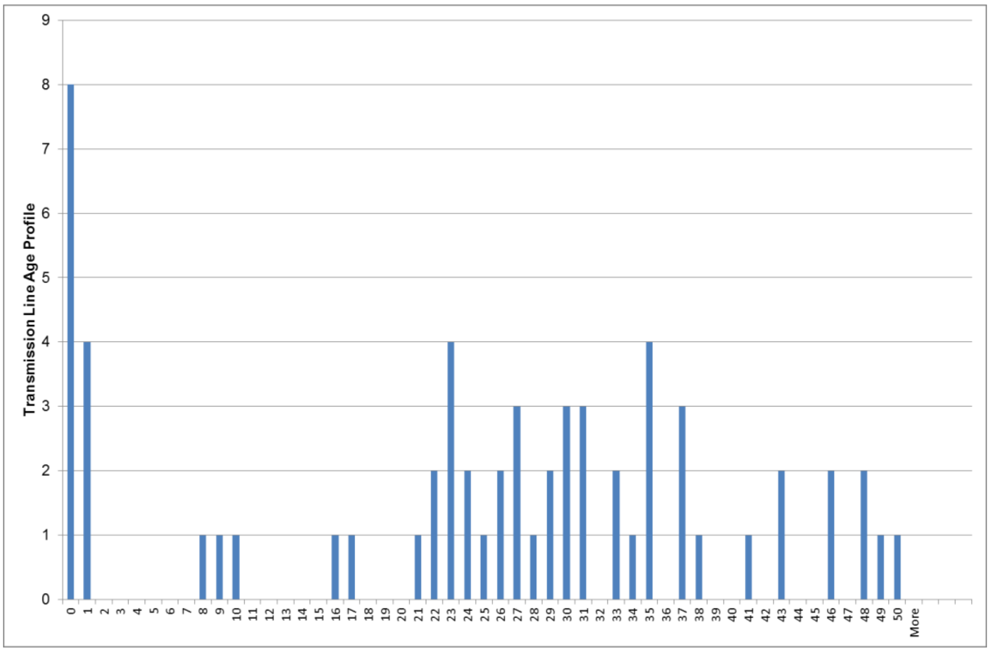
Sources: Consultant's analysis

L. TRANSMISSION LINES

86. There are 52 EHV transmission lines. There are 1,500km of 220kV lines, and 3,342km of 110kV lines. The average age of lines is 28 years. The expected life of a transmission line in Mongolian conditions is 50 years.

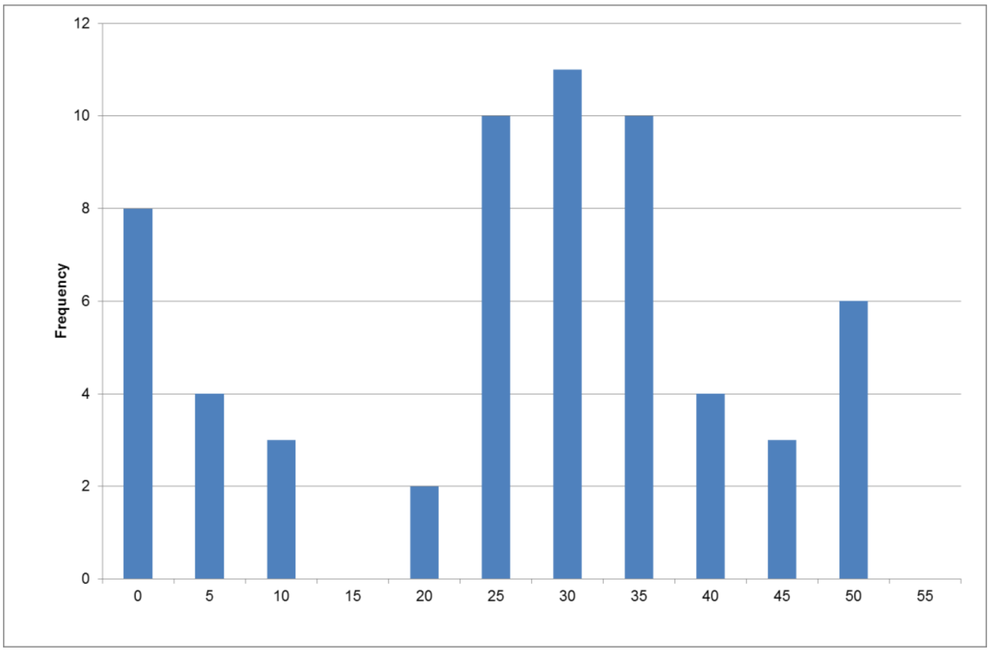
87. Again the age profile indicates that many transmission lines were installed around 25 to 30 years ago, consistent with the power transformer statistics.

Figure IV-7: Transmission Line Age Profile (220kV & 110kV)



Sources: Consultant's analysis

Figure IV-8: Transmission Line Age by Frequency (220kV & 110kV)



Sources: Consultant's analysis

88. Replacement costs of EHV transmission lines are estimated on annual basis as follows:-

Figure IV-9: Transmission Line Replacement

	110kV		220kV	
	Circuit km	USD$m	Circuit km	USD$m
2013	-	-	-	-
2014	178.2	11.0	-	-
2015	178.2	11.0	-	-
2016	178.2	11.0	-	-
2017	72.5	4.5	-	-
2018	362.8	22.5	-	-
2019	135.6	8.4	-	-
2020	97.3	6.0	-	-
2021	37.4	2.3	-	-
2022	120.4	7.5	-	-
2023	124.3	7.7	-	-
2024	-	-	-	-
2025	107.4	6.7	-	-
	1,592.1	98.7	-	-

Sources: Consultant's analysis

M. SUMMARY - TRANSMISSION NETWORK

89. Asset replacement needs are determined according to the age profile of major plant items, namely power transformers, circuit breakers and transmission lines.

Figure IV-10: Total Transmission Replacement Expenditure

	35kV	110kV	220kV	Sub-total
	USD$m	USD$m	USD$m	USD$m
2013	-	-	-	-
2014	4	16	-	20
2015	4	16	-	20
2016	4	12	3	19
2017	4	11	13	28
2018	4	24	6	35
2019	4	10	-	14
2020	4	8	-	12
2021	4	4	-	8
2022	4	9	13	26
2023	4	11	-	15

	35kV	110kV	220kV	Sub-total
	USD$m	USD$m	USD$m	USD$m
2024	4	9	9	23
2025	4	9	-	13
	48	142	44	234

Sources: Consultant's analysis

N. DISTRIBUTION NETWORK REPLACEMENT

90. Distribution network replacement costs for whole of Mongolia are set at the equivalent value of new capacity needs.

Figure IV-11: Distribution Network Replacement

Distribution (whole Mongolia)	
	Replacement
	less than 35kV
	USD$m
2013	20
2014	20
2015	20
2016	20
2017	20
2018	20
2019	20
2020	20
2021	20
2022	20
2023	20
2024	20
2025	20
	260

V. CONCLUSION

O. SUMMARY OF T&D INVESTMENT NEEDS

Figure V-1: Distribution Investment Needs

	Distribution (Ulaanbaatar)	Distribution (Aimags excl UB)	Distribution (whole Mongolia)	
	New Capacity	New Capacity	Replacement	
	less than 35kV	less than 35kV	less than 35kV	Sub-Total
	$m	$m	$m	$m
2013	51	20	20	91
2014	51	20	20	91
2015	51	20	20	91
2016	51	20	20	91
2017	51	20	20	91
2018	51	20	20	91
2019	51	20	20	91
2020	51	20	20	91
2021	51	20	20	91
2022	51	20	20	91
2023	51	20	20	91
2024	51	20	20	91
2025	51	20	20	91
	664	258	260	1,183

Sources: Consultant's analysis

Figure V-2: Transmission Investment Needs

	Transmission (Ulaanbaatar)			Transmission (Aimags excl UB)			Transmission (whole Mongolia)			
	New Capacity			New Capacity			Replacement			
	35kV	110kV	220kV	35kV	110kV	220kV	35kV	110kV	220kV	Sub -Total
	$m	$m	$m	$m	$m	$m	$m	$m	$m	$m
2013	-	-	-	-	-	-	-	-	-	-
2014	20	24	21	18	21	19	4	16	-	144
2015	20	24	21	18	21	19	4	16	-	144
2016	20	24	21	18	21	19	4	12	3	143

	Transmission (Ulaanbaatar)			Transmission (Aimags excl UB)			Transmission (whole Mongolia)			
	New Capacity			New Capacity			Replacement			
	35kV	110kV	220kV	35kV	110kV	220kV	35kV	110kV	220kV	Sub -Total
2017	20	24	21	18	21	19	4	11	13	152
2018	20	24	21	18	21	19	4	24	6	158
2019	20	24	21	18	21	19	4	10	-	138
2020	20	24	21	18	21	19	4	8	-	136
2021	20	24	21	18	21	19	4	4	-	132
2022	20	24	21	18	21	19	4	9	13	150
2023	20	24	21	18	21	19	4	11	-	139
2024	20	24	21	18	21	19	4	9	9	147
2025	20	24	21	18	21	19	4	9	-	137
	246	291	256	215	255	224	48	142	44	1,719

Sources: Consultant's analysis

Figure V-3: Total T&D Investment

	Distribution	Transmission	Total
	$m	$m	$m
2013	91	-	91
2014	91	144	235
2015	91	144	235
2016	91	143	234
2017	91	152	243
2018	91	158	249
2019	91	138	229
2020	91	136	227
2021	91	132	223
2022	91	150	241
2023	91	139	230
2024	91	147	238
2025	91	137	228
	1,183	1,719	2,902

Sources: Consultant's analysis

91. The average T&D investment requirement is around USD$230m per annum.

APPENDIX A – INTEGRATED GRID CASE STUDIES

VI. APPENDIX A - INTEGRATED GRID CASE STUDIES

P. 220kV & 400kV Case Studies

92. Case studies were undertaken to investigate the thermal evacuation of power generation from Tavan Tolgoi to load centres in Ulaanbaatar, Oyu Tolgoi and Sainshand Industrial park.

93. The case studies were based on typical security and adequacy criterion. Security is defined according to a set of technical criteria:-

- Transmission lines must remain within their thermal loading limits under normal and (N-1) conditions; and
- Voltage must remain within set technical limits, allowing for additional compensation devices known as shunt capacitors.

94. Technical stability studies included:-

1. Steady state studies including:
    i. Load flow studies;
    ii. Fault level studies;
    iii. Contingency analysis (Reliability study); and
    iv. Voltage stability.
2. Dynamic stability studies including Transient Stability.

95. Steady-state studies were divided into three phases according to short term, medium term and long term planning considerations.

Q. Load Flow

96. A load flow analysis was performed to investigate the thermal evacuation of power generation from Tavan Tolgoi to load centres in Ulaanbaatar, Oyu Tolgoi and Sainshand Industrial park. The loading on the equipment was determined to ensure that no equipment was overloaded. The thermal evacuation was considered under various loading conditions and the under the worst case system scenario which was at minimum local load. The following methodology was followed for the load flow studies:-

1. Load flow analysis at the minimum and maximum demand conditions;
2. Verify that thermal loadings on lines and transformers are below 100%; and
3. Verify that Busbar (busbar) voltage levels are within acceptable limits.

R. Contingency (Reliability)

97. In the event of an outage on equipment at substations and surrounding lines, it is important to verify that despite this outage, all other equipment operates within acceptable limits. The worst case contingency considered was an N-1 operating scenario with a 67% regional load. The contingency analysis was performed as follows:-

1. Switch out one device to model an N-1 operating scenario;

2. Verify that thermal loadings on lines and transformers are below 100%; and
3. Verify that busbar voltage levels are within acceptable limits.

S. Short Circuit Study

98. The fault current analysis was performed to verify that faults that occurred on the busbar are within the rupturing capacity of the associated busbar circuit breakers. Three phase short circuits at the busbar were considered as the worst case. The fault levels were calculated according to IEC 60909 for all 220kV busbar.

T. Voltage Stability

99. The voltages of the busbars to remain within the following limits:

100. Under normal conditions:-

- Maximum voltage -1.05 p.u
- Minimum voltage - 0.95 p.u

101. Under N-1 contingency conditions, minimum voltage - 0.90 p.u

102. Voltage stability analysis was performed to ensure that these limits are complied with. Various compensation devices were evaluated in cases where voltage limits where exceeded.

U. Transient Stability Studies

103. Transient stability refers to the ability of synchronous generators operating on the power system to maintain synchronism with each other following a transient disturbance. These disturbances could typically be in the form of line or bus short circuits and the possible associated loss of a transmission line/s.

104. In this study, the analysis of transient stability is investigated via transient short circuits at selected busses on the new Southern Mongolian transmission system with the associated tripping of a transmission line thereafter (N-1) condition following the transient disturbance).

105. The complexity of the Mongolian central power system is not of interest to this study. Instead, the stability of the newly envisioned Southern Mongolian power system relative to the Mongolian system is of interest. Thus, the central Mongolian system has been equivalenced at the 220 kV Ulaanbaatar bus with the correct steady fault level and X/R ratio. The existing fault level and X/R ratio at the Ulaanbaatar 220 kV bus is given in Table VI-1. The equivalent system also has an inertia equivalent to the sum of the inertias of the generators on the existing Ulaanbaatar central system. This inertia has been assumed to be of reasonable size at around 65 s (relative to the new generators being integrated).

Table VI-1: Ulaanbaatar 220kV Busbar Fault Level & X/R Ratio

Bus	UB-220	
I"k	A	4304.4
S"k	MVA	1640.18
X	ohm	32.374
R	Ohm	2.215

Bus	UB-220	
Z	Ohm	32.450
Angle	deg	86.09
X/R		14.62

V. Study Details

106. As it is planned for ETT to connect to a transmission line between Ulaanbaatar and Tavan Tolgoi, the main issue of concern is the static and dynamic stability of the electrical system created by the connection under large power transfer scenarios. This is because the distance between Ulaanbaatar and Tavan Tolgoi is around 520km and large power transfers over such a long distance is known to make stable operation difficult to maintain under fault conditions. Under a worst case scenario the entire Central Electricity System could potentially shut down if a close-in heavy fault was to occur near to say Ulaanbaatar or Tavan Tolgoi. It must be noted however, that a large power transfer to Ulaanbaatar would only occur if a substantial amount of generation was lost from the Mongolian CHP plants in the CES or from Russia import to the CES.

Figure VI-2: Location of Tavan Tolgoi & Power Evacuation Routes

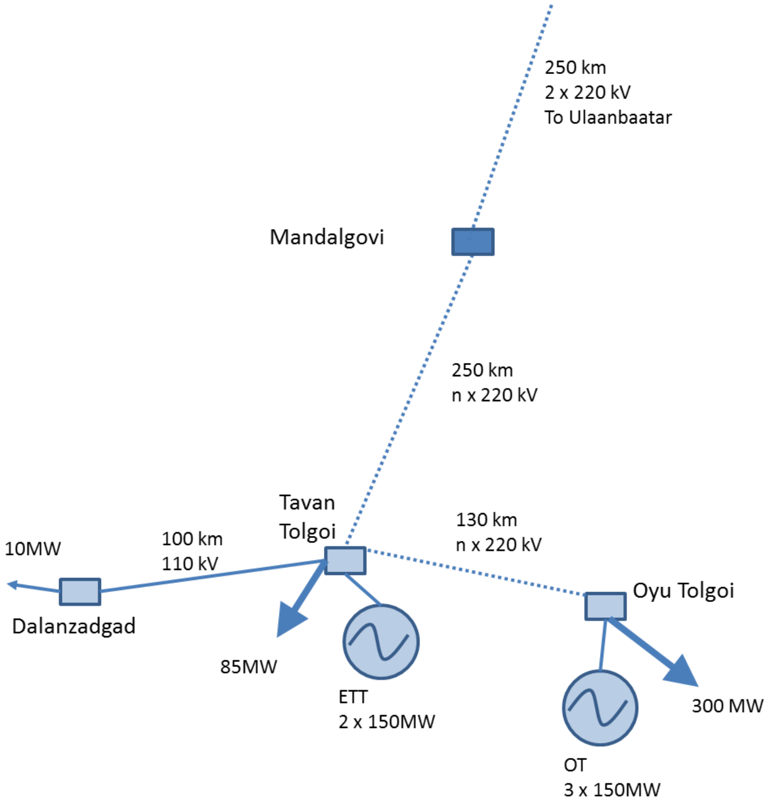
Three cases were considered.

1. Case No. 1 was evacuation of power to UB via Mandalgovi at 220kV;
2. Case No. 2 was evacuation of power to Sainshand at 220kV; and
3. Case No. 3 examined evacuation of power to UB or Sainshand at 400kV.

W. Case no. 1 – Evacuation of Power to UB via Mandalgovi

107. The model for Case no. 1 is shown as Figure VI-3.

Figure VI-3: Transmission Topology for Case 1



Results and Analysis

Load Flow

108. The thermal loading on the transmission system is detailed in Table VI-4. The thermal loading is investigated under high and low local load conditions.

Table VI-4: Percentage Line Thermal Loading

Lines	Loading Percentage (%)	
	Min Demand	Max Demand
Ulaanbaatar – Mandalgovi 220kV	56	59
Mandalgovi - Tavan Tolgoi 220kV	61	48
Tavan Tolgoi - Oyu Tolgoi 220 kV	49	34
Tavan Tolgoi – Dalanzadgad 110kV	5	8

109. The thermal loading of all lines in the region are well within their limits for both loading conditions. Three 220 kV lines connect Ulaanbaatar SS to Mandalgovi SS and Ulaanbaatar SS to Mandalgovi SS. A double circuit line was found to overload under N-1 scenarios, hence a

three line circuit configurations was examined. Furthermore Mandalgovi 220 kV busbar experienced excessive low voltage levels under this condition.

Contingency (Reliability)

110. The main contingencies assessed are on the triple circuit line from Ulaanbaatar SS to Mandalgovi SS and the double circuit from Tavan Tolgoi SS to Oyu Tolgoi SS. Three main contingencies where considered. The loading and voltage levels in the system were assessed for the following outages:

1. Single circuit outage on Ulaanbaatar – Mandalgovi line;
2. Single circuit outage on Mandalgovi – Tavan Tolgoi line; and
3. Single circuit outage on Tavan Tolgoi – Oyu Tolgoi line.

111. The system was found to be N-1 contingent under the above mentioned operating scenarios. All busbar voltage and thermal loading of lines are within acceptable limits.

Voltage Stability

112. The voltages on various busbar in the transmission system are detailed in Table VI-5. Mandalgovi busbar experienced under voltages for the low local load, hence an additional 50 MVAr capacitor bank is placed at the 220 kV Mandalgovi busbar. The results in Table VI-5 are with the capacitor bank in service.

Table VI-5: Voltage Levels on Busbars

Busbars	Voltage Level (p.u)	
	Min Demand	Max Demand
Ulaanbaatar 220kV BB	1.00	1.00
Mandalgovi 220kV BB	1.00	0.99
Tavan Tolgoi 220kV BB	0.99	1.00
Oyu Tolgoi 220kV BB	0.99	0.97
Dalanzadgad 110kV BB	1.03	1.02

113. Three 220 kV lines are sufficient to thermally evacuate the generation scenario for 2018 case. With the inclusion of the capacitor bank, the voltage levels on the various busbar are within the accepted limits for both loading conditions.

Fault levels

Table VI-6 below specifies the fault level on busbar in the southern region network.

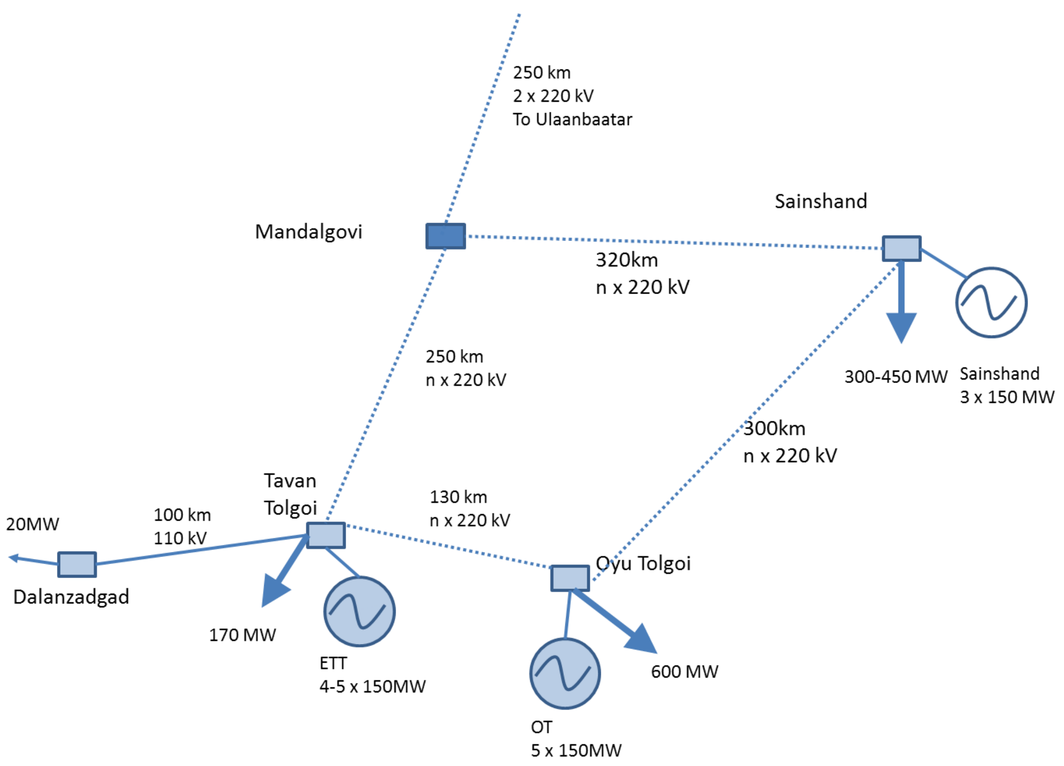
Table VI-6: Busbar Fault Levels

Busbars	Fault level (kA)
Ulaanbaatar 220kV BB	5.92
Mandalgovi 220kV BB	4.24

Busbars	Fault level (kA)
Tavan Tolgoi 220kV BB	4.93
Oyu Tolgoi 220kV BB	4.82
Dalanzadgad 110kV BB	1.32

X. Case no. 2 – Evacuation of Power to Sainshand

Figure VI-7: Case No. 2 Topology



Results and Analysis

Load flow

114. Load flow studies were conducted in order to verify that the loading of the transmission lines were within their specified technical limits. The results tabulated in Table VI-8 were obtained with all the Power Plant generators in service at maximum and minimum demand.

Table VI-8: Percentage Line Thermal Loading

Lines	Loading Percentage (%)	
	Min Demand	Max Demand
Ulaanbaatar – Mandalgovi 220kV	51	42

Lines	Loading Percentage (%)	
	Min Demand	Max Demand
Mandalgovi - Tavan Tolgoi 220kV	49	43
Tavan Tolgoi - Oyu Tolgoi 220kV	59	32
Oyu Tolgoi - Sainshand 220kV	14	25
Sainshand - Mandalgovi 220kV	51	32

115. The results in Table VI-8 show that the maximum loading of the lines are well below their operating limits under maximum and minimum demand conditions.

Voltage Stability

116. The voltage levels on the 220 kV busbar are shown in Table VI-9. Voltage levels were once again beyond acceptable limits which resulted in the inclusion of shunt capacitor banks specified in Table VI-10. The voltage levels in Table VI-9 are with the shunt capacitors in service.

Table VI-9: Busbar Voltage Levels

Busbars	Voltage (p.u.)	
	Min Demand	Max Demand
Ulaanbaatar 220kV BB	0.953	1.000
Mandalgovi 220kV BB	0.995	1.006
Tavan Tolgoi 220kV BB	0.997	0.999
Oyu Tolgoi 220kV BB	0.987	0.972
Sainshand 220kV BB	0.995	0.987

117. The voltage levels on the busbar in Table VI-9 are all within acceptable limits due to the operation of strategically placed switchable shunt capacitor banks. The location and size of the capacitor banks are shown in Table VI-10.

Table VI-10: Capacitor Bank Size & Location

Capacitor Banks	
Location	Capacity (MVAr)
Ulaanbataar	250
Mandalgovi	200

118. Steady state voltage stability was of great concern at minimum demand as this required a large amount of power to be evacuated back to Ulaanbataar. The long lengths of the 220 kV lines from Tavan Tolgoi to Ulaanbataar and Sainshand to Ulaanbataar also caused significant voltage drops, hence the requirement for four parallel lines between Ulaanbataar and Tavan Tolgoi. The inclusion of shunt capacitors further controlled the voltage levels.

Short Circuit analysis

119. Steady state fault levels in Table VI-11 were simulated using the IEC-60909 method.

Table VI-11: Busbar Fault Levels

Busbars	Fault Level	
	MVA	kA
Ulaanbaatar 220 kV BB	2784	7.307
Mandalgovi 220 kV BB	2609	6.848
Tavan Tolgoi 220 kV BB	2868	7.529
Oyu Tolgoi 220 kV BB	2771	7.271
Sainshand 220 kV BB	1640	4.305

120. The increased fault levels are all within reasonable limits and will be well within the operating limits of standard circuit breakers and associated equipment.

Contingency analysis (N-1)

121. The contingency cases in Table VI-12were considered.

Table VI-12: Contingency Cases

Case Number	Contingency
1	Ulaanbaatar – Mandalgovi 220kV
2	Mandalgovi - Tavan Tolgoi 220kV
3	Tavan Tolgoi - Oyu Tolgoi 220kV
4	Tavan Tolgoi - Dalanzadgad 110kV
5	Sainshand - Oyu Tolgoi 220 kV
6	Sainshand - Mandalgovi 220kV

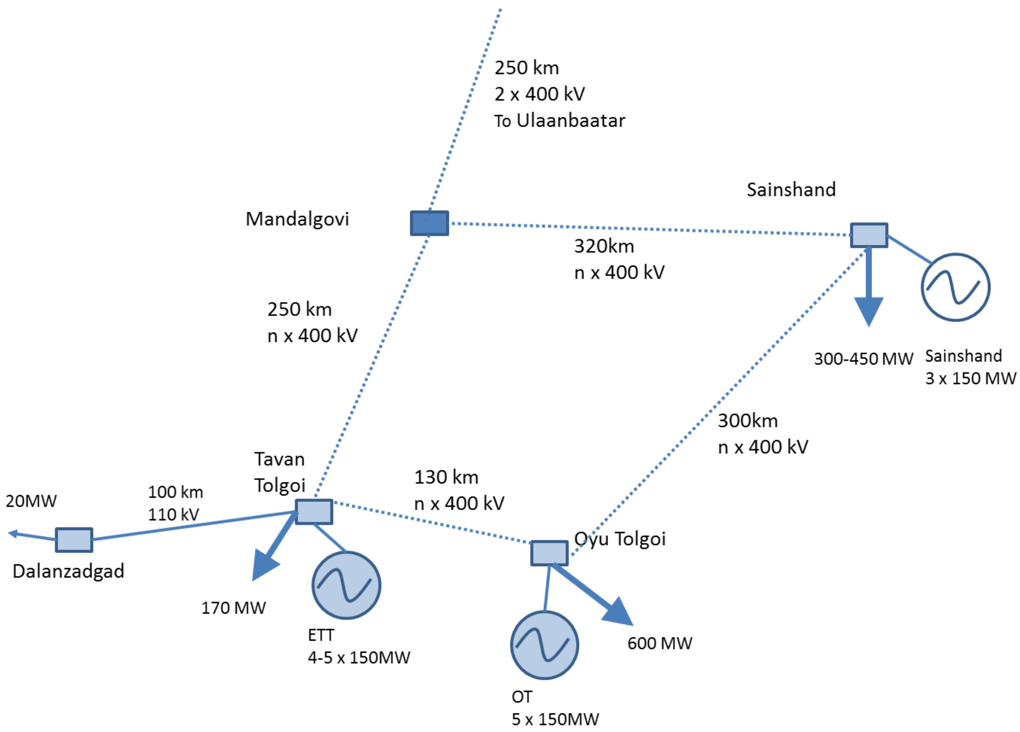
122. All transmission lines and busbar were within their operational limits under all the specified

contingency cases.

Y. Case no. 3 – Evacuation of Power to UB / Sainshand via 400kV

123. Figure VI-13 presents an alternative solution to operate the transmission system at 400 kV. The transmission system depicted in the Figure VI-13 below is designed to be N-1 contingent. All the lines in the system are double circuit lines.

Figure VI-13: Case No. 3 Topology



Results

Load flow

124. The thermal loading on the transmission system is detailed in Table VI-14. The thermal loading is investigated under high and low local load conditions.

Table VI-14: Percentage Line Thermal Loading

Lines	Loading Percentage (%)	
	Min Demand	Max Demand
Ulaanbaatar – Mandalgovi 400 kV	46.21	28.44
Mandalgovi - Tavan Tolgoi 400 kV	28.02	21.99
Mandalgovi – Sainshand 400 kV	18.83	14.43
Sainshand - Oyu Tolgoi 400 kV	15.05	14.35
Tavan Tolgoi - Oyu Tolgoi 400 kV	15.03	8.82

Lines	Loading Percentage (%)	
	Min Demand	Max Demand
Tavan Tolgoi – Dalanzadgad 110 kV	10.84	15.77

125. Under both loading scenarios, the thermal loading of the lines are within acceptable levels. The highest loading is observed on the Ulaanbaatar – Mandalgovi line under minimum demand condition.

Contingency (Reliability)

126. The thermal loading and voltage levels in the system are assessed for the following outages:

1. Single circuit outage on Ulaanbaatar – Mandalgovi line
2. Single circuit outage on Mandalgovi – Tavan Tolgoi line
3. Single circuit outage on Mandalgovi – Sainshand line
4. Single circuit outage on Sainshand – Oyu Tolgoi line
5. Outage on Tavan Tolgoi – Oyu Tolgoi line

127. The system was found to be N-1 contingent under the above mentioned contingency scenarios. All busbar and thermal loading of lines are well within acceptable limits. In many cases the system may also be operated at N-2 contingency.

Voltage Stability

128. The voltages on various busbar in the transmission system are detailed in Table VI-15 with the applicable shunt reactors and capacitors in service.

Table VI-15: Busbar Voltage Levels

Busbars	Voltage (p.u.)	
	Min	Max
Ulaanbaatar 400 kV BB	0.97	1.02
Mandalgovi 400 kV BB	1.04	1.04
Sainshand 400kV BB	1.04	1.04
Tavan Tolgoi 400 kV BB	1.02	1.02
Tavan Tolgoi 110 kV BB	1.00	0.99
Oyu Tolgoi 400 kV BB	1.01	1.01
Dalanzadgad 110 kV BB	0.97	0.95

129. In order to sustain voltage levels within acceptable limits, a 30 MVAr shunt capacitor bank is needed to support the voltage at the Ulaanbaatar 400 kV busbar under minimum demand conditions. Conversely, under high load demand a 270 MVAr shunt reactor is needed to decrease the voltage levels at Mandalgovi 400 kV busbar. The shunt compensation equipment is switch in and out of the system when it is required depending on the loading scenario on the

system. With the inclusion of the shunt compensation, the voltage levels on the various busbar are within the accepted limits for both loading conditions.

Fault levels

Table VI-16 below specifies the fault level on busbar in the southern region network.

Table VI-16: Busbar Fault Levels

	Fault level (kA)
Ulaanbaatar 400 kV BB	5.18
Mandalgovi 400 kV BB	7.13
Sainshand 400 kV BB	7.70
Tavan Tolgoi 400 kV BB	9.09
Tavan Tolgoi 400 kV BB	12.88
Oyu Tolgoi 400 kV BB	9.72
Dalanzadgad 110 kV BB	1.40

Z. Stability Studies

130. The parameters used for the generators in the new Southern Gobi are given in Table VI-17.

131. The excitation system to be used at Tavan Tolgoi is the Brushless Rotating Excitation type and thus the standard IEEE Type 1 (AC1A) excitation system is used. The parameters used for the excitation system at Tavan Tolgoi and Oyo Tolgoi are given in Table VI-18.

132. Power System Stabilisers have been included in the model with generic parameters as shown in Table VI-19. The IEEE type 2 (PSS2A) excitation system has been used.

Table VI-17: Generator Parameters

Description	Value	
Unit Name	Tavan Tolgoi	
Manufacturer	Siemens	
Rated Output	179.5	MVA
Rated Power Factor	0.85	
Rated Stator Voltage	15.75	kV
Rated Stator Current	6580	A
Generator Type	GENROE	
Total Mass Inertia Constant (H) H	2.8	MW.s/MVA
Damping constant D	0.0	pu

Description		Value	
Reactances (Unsaturated)			
Direct-Axis Synchronous	Xd	1.95	pu
Quad-Axis Synchronous	Xq	1.85	pu
Direct-Axis Transient	X'd	0.23	pu
Quad-Axis Transient	X'q	0.445	pu
Direct-Axis Sub-Transient	X''d	0.172	pu
Quad-Axis Sub-Transient	X'q	0.19	pu
Armature Leakage	Xl	0.136	pu
Time Constants			
Direct-Axis Transient (Open Loop)	T'do	10.16	s
Direct-Axis Sub-Transient (Open Loop)	T"do	0.041	s
Quad-Axis Transient (Open Loop)	T'qo	2.5	S
Quad-Axis Sub-Transient (Open Loop)	T''qo	0.15	S
Saturation Parameter			
S(1.0)		0.112	pu
S(1.2)		0.553	pu

Table VI-18: Excitation System Parameters (Type: AC1A)

Parameter	Value	Unit	Description
Tr	0.02	[s]	Measurement Delay
Tb	4	[s]	Filter Delay Time

Parameter	Value	Unit	Description
Tc	20	[s]	Filter Derivative Time Constant
Ka	200	[pu]	Controller Gain
Ta	0.01	[s]	Controller Time Constant
Te	0.34	[s]	Exciter Time Constant
Kf	0.05	[pu]	Stabilization Path Gain
Tf	0.75	[s]	Stabilization Path Delay Time
Kc	0.05	[pu]	Rectifier regulation constant
Kd	0.05	[pu]	Exciter Armature reaction Factor
E1	6.12	[pu]	Saturation Factor 1
Se1	0.15	[pu]	Saturation Factor 2
E2	3.8	[pu]	Saturation Factor 3
Se2	0.05	[pu]	Saturation Factor 4
Ke	1	[pu]	Exciter Constant
Vrmin	-5.3	[pu]	Controller Minimum Output
Vrmin	5.9	[pu]	Controller Maximum Output

Table VI-19: PSS Parameters (Type: IEE2ST)

Parameter	Value	Unit	Description
Ics1	**1**	**[1-6]**	**1st Input Selector**
Ics1	0	[1-6]	2nd Input Selector
K1	10	[pu]	Signal 1 transducer gain
T1	0.01	[pu]	Signal 1 transducer time constant
K2	0	Unit	Signal 2 transducer gain
T2	0	[s]	Signal 2 transducer time constant
T3	5	[s]	First washout derivate time constant
T4	5	[pu]	First washout integrate time constant
T6	0.02	[s]	First Lead/Lag delay time constant
T5	0.3	[pu]	First Lead/Lag derivative time constant
T8	0.05	[pu]	Second Lead/Lag delay time constant
T7	0.5	[pu]	Second Lead/Lag derivative time constant

Parameter	Value	Unit	Description
T10	0	[pu]	Three Lead/Lag delay time constant
T9	0	[pu]	Three Lead/Lag derivative time constant
Kd	0.01	[pu]	Derivator Factor
Lsmin	-0.2	[pu]	Signal pss minimum
Vcl	0.92	[pu]	Lower voltage output limiter
Lsmax	0.2	[pu]	Signal pss maximum
Vcu	1.08	[pu]	Upper voltage output limiter

AA. Results

133. The critical clearance times for Tavan Tolgoi and Oyu Tolgoi Power Stations are given in Table VI-20.

134. Rotor angles and bus voltages for a transiently stable case are given in Figure VI-21 and Figure VI-22 respectively. Rotor angles and bus voltages for transiently unstable cases are given in

135. Figure **VI-23** and Figure VI-24.

136. It should be noted that the critical clearance times noted during the studies are very short in comparison to industry norms. Typically, the relay pick-up, delay and circuit breaker operating time are in the region of 100-150 ms.

Table VI-20: Critical Clearance Times

Faulted bus	Voltage	Contingency (line)		Critical clearance time
	kV	From	To	Ms
Tavan Tolgoi	220	Tavan Tolgoi	Mandalgovi	65
Oyu Tolgoi	220	Oyu Tolgoi	Tavan Tolgoi	55

Figure VI-21: TT and OT Rotor Angles (transiently stable)

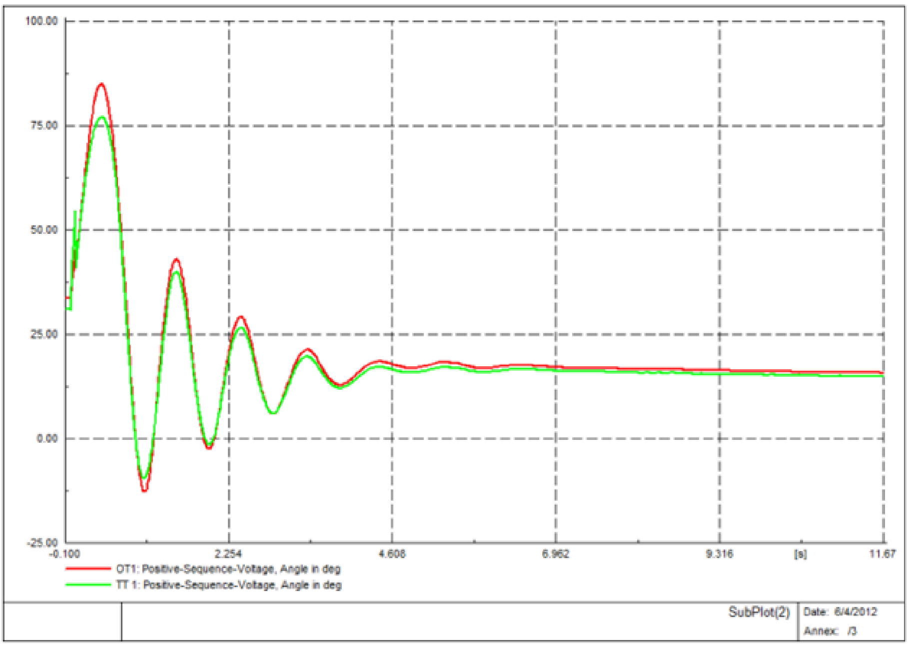


Figure VI-22: Bus Voltages (transiently stable)

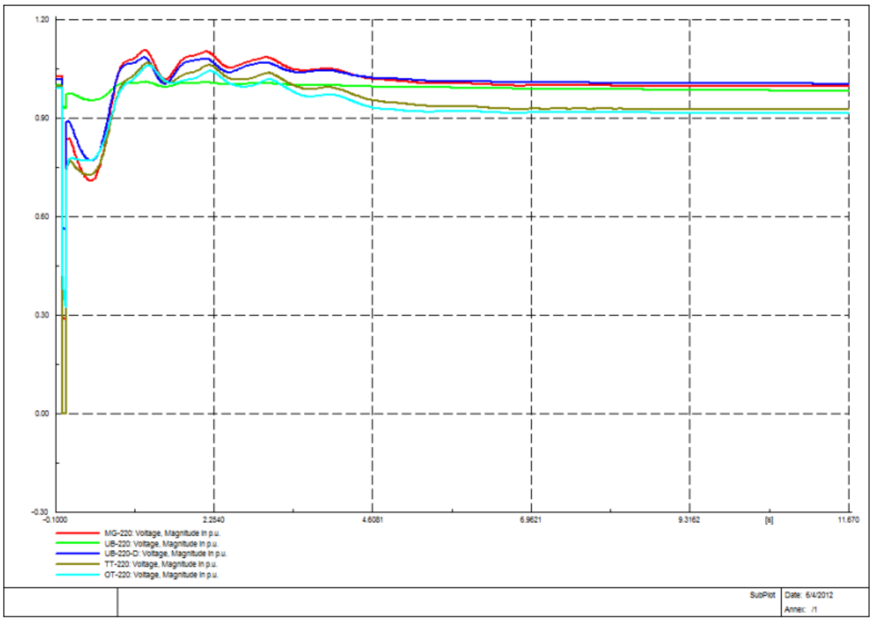


Figure VI-23: TT and OT Rotor Angles (transiently unstable)

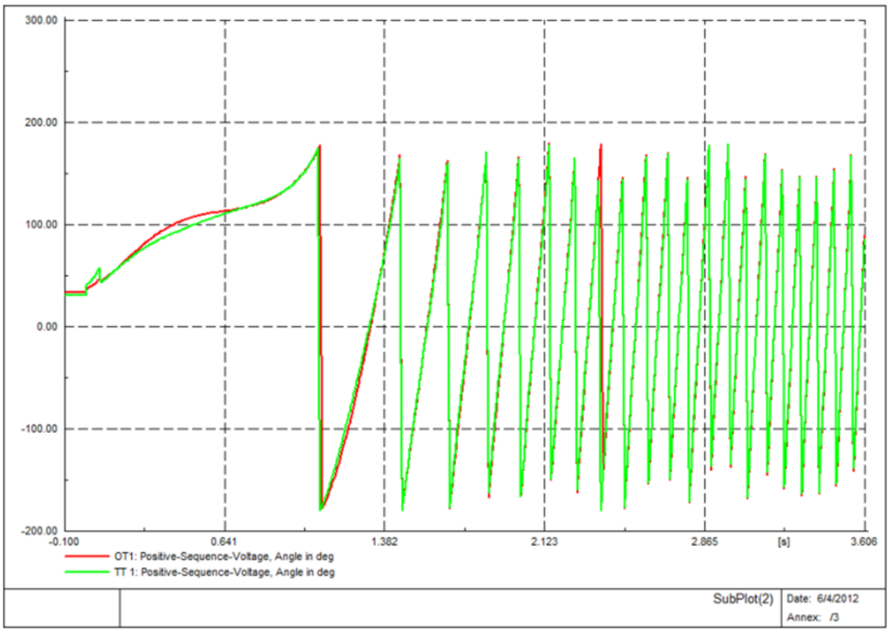


Figure VI-24: Bus Voltages (transiently unstable)