P/21-113141-001

Afghanistan's NEPS Transmission System
Power System Analysis

Final Report

Prepared for

Advanced Engineering Associates International

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September, 18, 2007

P/21-113141

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Contents

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Executive Summary

Afghanistan is planning to import power from its three northern neighboring countries of Tajikistan, Turkmenistan and Uzbekistan. To facilitate the import of power, a"220 kV Grid System" referred to as "North East Power System" (NEPS) is currently under implementation.

NEPS (see figure 1) is designed to receive power from Turkmenistan, Tajikistan and Uzbekistan and transmit it to the main load center in "Greater Kabul Area" and in the process also supply power to the various communities along the way. NEPS primarily consists of 220 kV double circuit transmission lines between Mazar e Sherif, Naibabad, Pul e Kumri and Chimtala (Kabul).

There are also plans to construct 220 kV transmission lines from Pul e Kumri to Kunduz to receive power from Tajikistan and to install a 100 MW power plant in Sheberghan. Naibabad switchyard is planned to receive power from Uzbekistan, Andkhoy substation to receive power from Turkmenistan and the Kunduz substation to receive power from Tajikistan.

Steady state (load flow) studies were performed to verify that it is technically possible to import power from the three neighboring countries to the main load center in the "Greater Kabul" area over NEPS, and to determine the maximum power that can be imported under normal conditions and under contingency conditions. The contingency condition is defined as a condition when any one segment of the transmission system is opened because of a fault in that segment or if one of the two transformers at the Chimtala substation is not in service because of a problem in that transformer. The transformers in the Chimtala substation convert the transmission system voltage from 220 kV to 110 kV and feed the Greater Kabul area.

Studies were also done to observe the impact of the proposed 100 MW power plant in Sheberghan on the "System" and the effect of light load conditions on the "System" when the local consumption is low and therefore the demand for imported power will also be low.

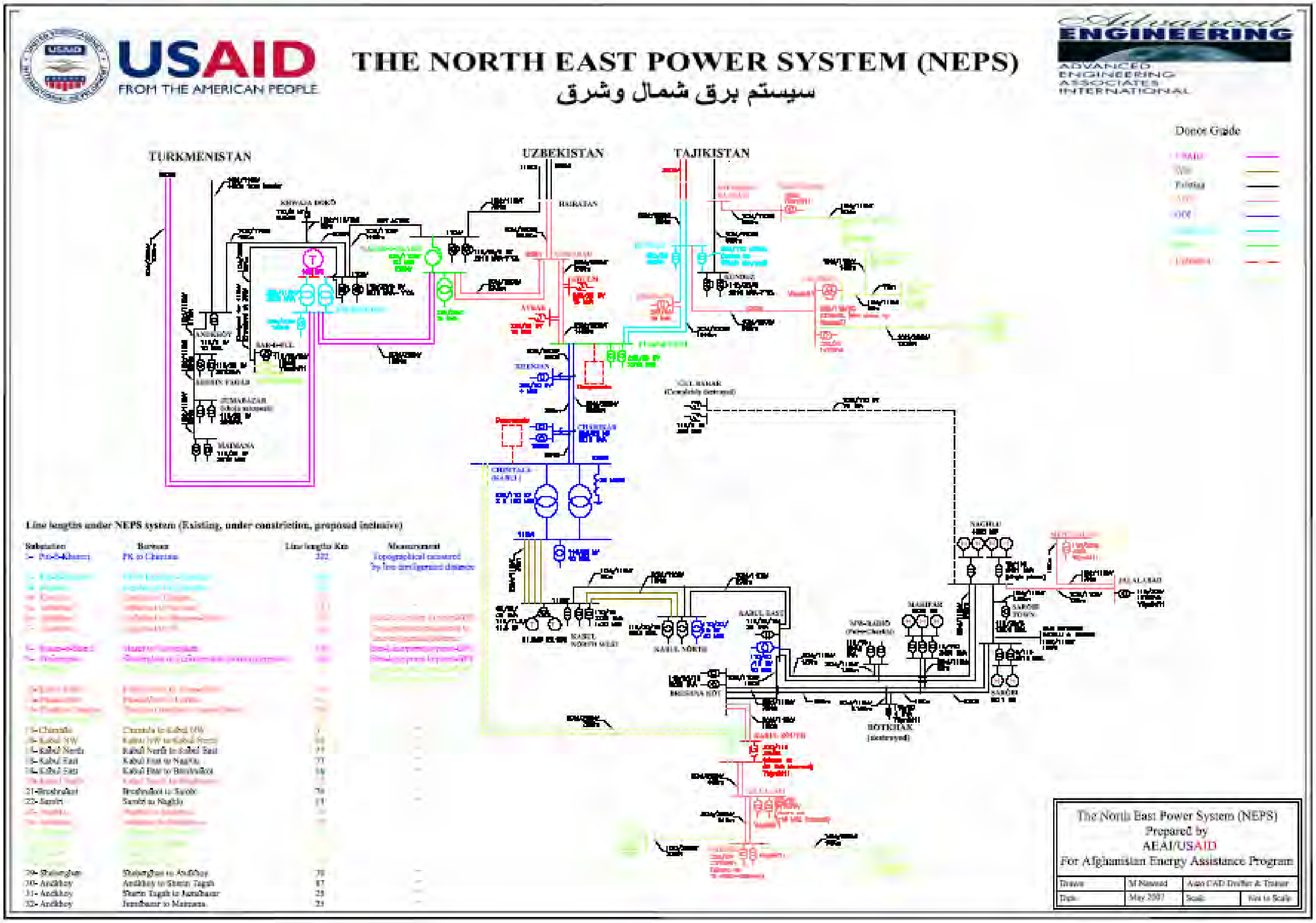
Studies were done to gauge the impact of intermediate loads along the transmission line. The loads and the generation in the Kabul area were adjusted as needed to study the maximum import capability and the effects of light load.

The steady state study identified that because the distance between the power sources in the northern neighboring countries and the main load center in Kabul is large, the power import is constrained by the voltage drops along the line lengths.

Reactive compensation was used, to compensate for these voltage drops to the extent possible, to maximize the power import to Kabul area and keep the Voltage profile in the "System" within the internationally practiced range of +/- 5% under normal conditions and +/- 10% under contingency conditions as defined earlier.

The study is carried out in four parts. The first part covers the import of power from Turkmenistan, the second covers the import of power from Uzbekistan and the third covers the import of power from Tajikistan. The last part was a test case of the dynamic behavior of the system (transient stability), for one of the Turkmenistan supply options.

Figure 1 North East Power System



The Load Flow Study was done such that the three power sources from Turkmenistan, Uzbekistan and Tajikistan are not paralleled in the Afghanistan Grid. This is because the Turkmenistan, Uzbekistan and Tajikistan Systems are currently not synchronized and to parallel their sources in Afghanistan would require an agreement from these three countries and a comprehensive study would have to be done based on a system model that includes the system details in these three countries in addition to Afghanistan.

The study results then has to be vetted and approved by the three countries. This process is politically charged, complicated and will take a long time. In a meeting held in Ashgabad Turkmenistan representative warned that their system should not be paralleled with other countries systems in Afghanistan.

TURKMENISTAN SOURCE

Four options were studied to import power from Turkmenistan:

Option 1

This option is indicated in figure 2 and models a single 500 kV circuit from Serder substation in Turkmenistan to a new substation near Andkhoy in Afghanistan. At this substation a power transformer steps down the incoming 500 kV power supply to 220 kV. A double circuit is taken from this substation to Sheberghan and from Sheberghan to Naibabad. Each circuit has bundled conductors.

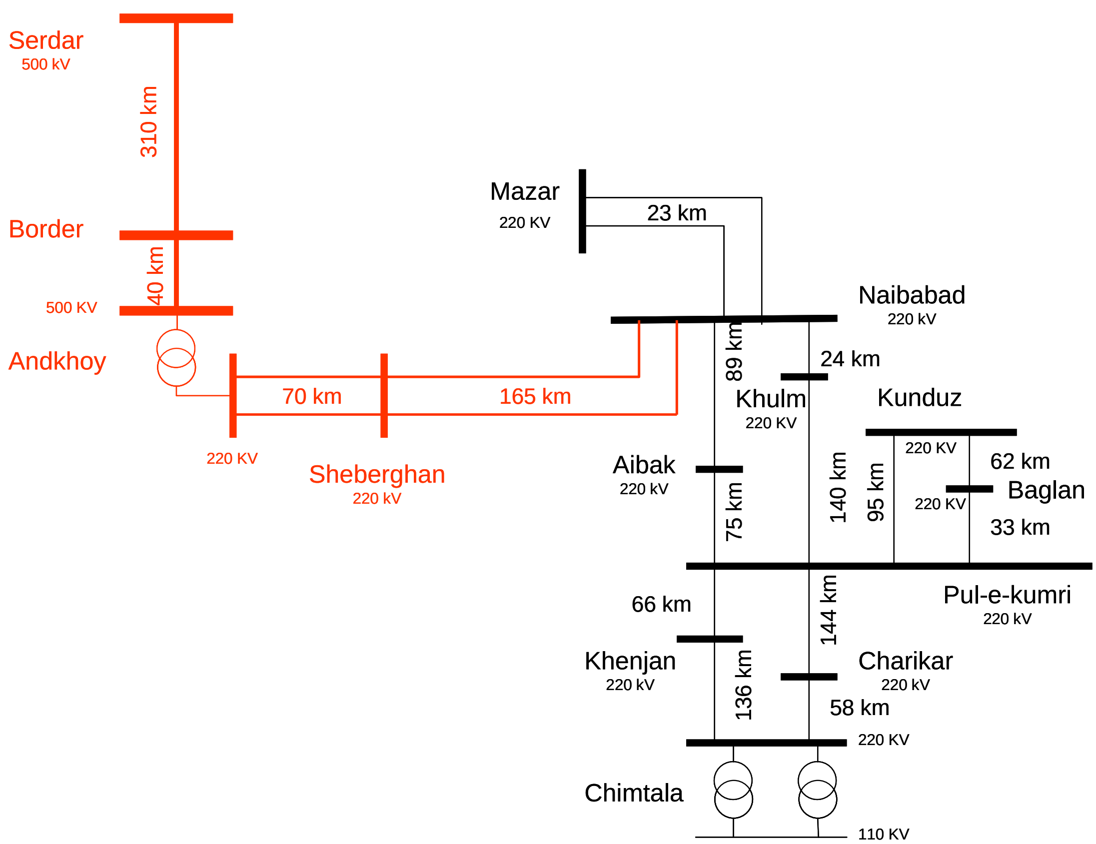


Figure 2 Turkmenistan Source Option 1

Option 2

This option is indicated in figure 3 and models a single 500 kV circuit from Serder substation in Turkmenistan to a new substation in Afghanistan near the border north of Andkhoy. At this substation a power transformer steps down the incoming 500 kV power supply to 220 kV. A double circuit is taken from this substation to Sheberghan and from Sheberghan to Mazar e Sherif. Each circuit has a bundled conductor.

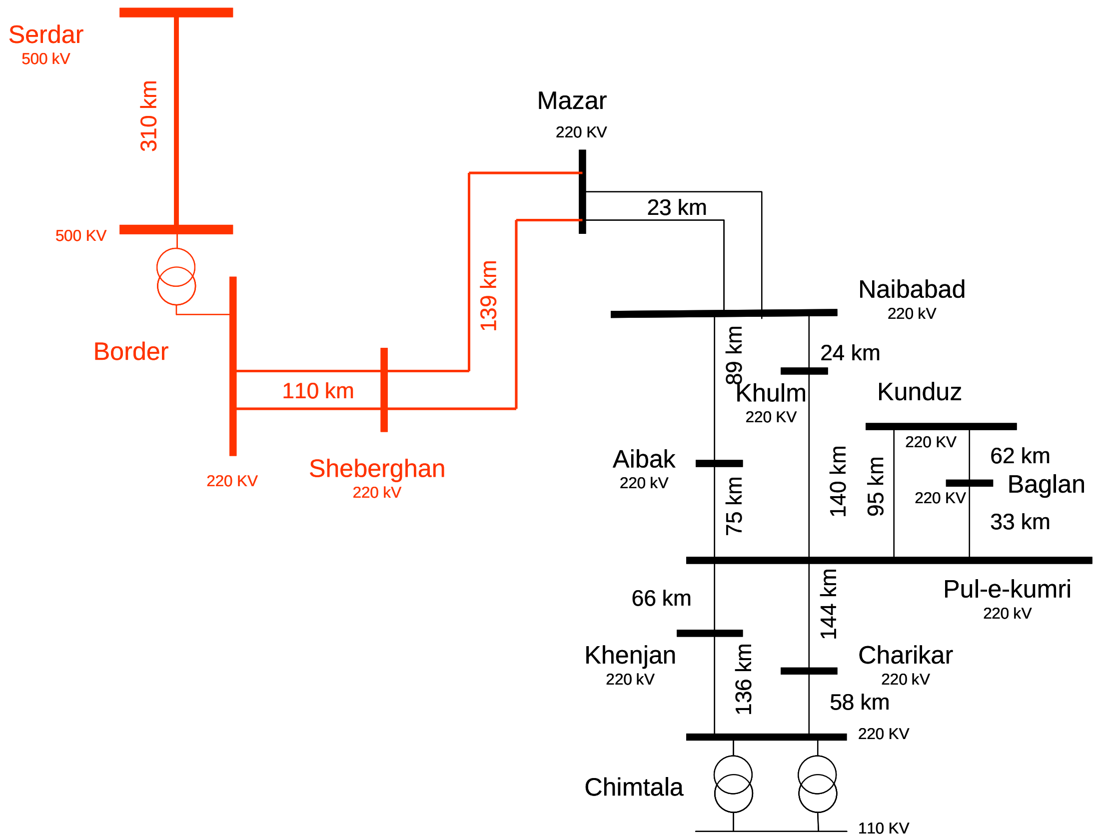


Figure 3 Turkmenistan Source Option 2

Option 3

This option is indicated in figure 4 and models a single 500 kV circuit from Serder substation to Naibabad. At Naibabad a step down power transformer steps down the voltage to 220 kV.

Option 4

This option is indicated in figure 5 and models a single 500 kV circuit from Serder substation to a new substation in Afghanistan near the border. At this substation a power transformer steps down the 500 kV to 220 kV. A single 220 kV circuit is taken from this substation to Naibabad. A bundled conductor matching the 500 kV circuit conductors is used for this circuit

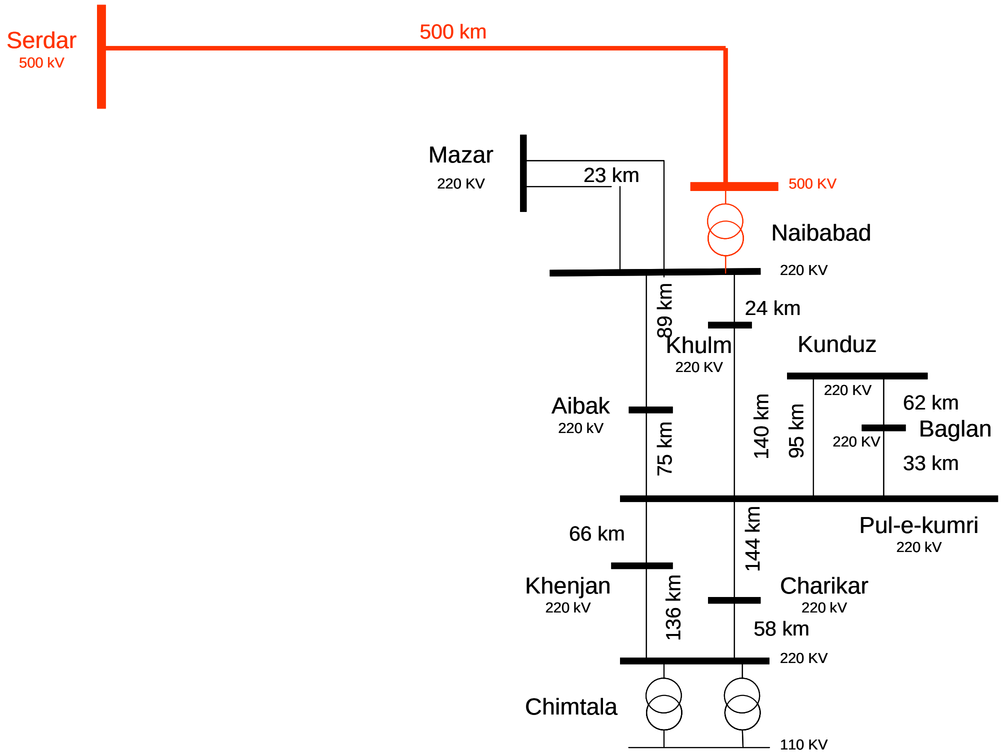


Figure 4 Turkmenistan Source Option 3

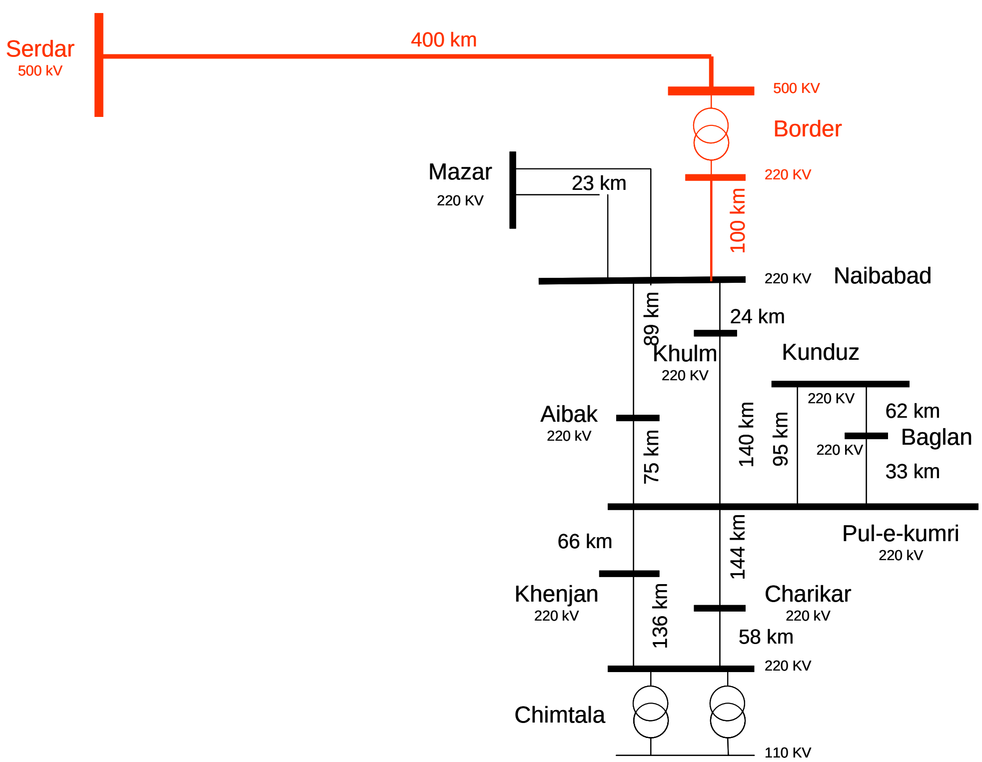


Figure 5 Turkmenistan Source Option 4

Results Summary

Steady State

Table 1 summarizes the steady state analysis results for all the Turkmenistan options.

Option 1 and 2 provide the maximum power import capability with option 1 having a slight advantage in both the import capability and system losses. Under option 1, a maximum of 248 MW can be imported into the 110 kV bus in Chimtala under normal conditions with no load supplied at the intermediate substations. With loads in the intermediate substations at Mazar, Sheberghan, Khulm, Aybak, Pul e Kumri, Kenjan and Charikar supplied the transfer limit decreases to 201.2 MW. Both these options provide a means to connect the Sheberghan Power Plant power output to NEPS

The worst contingencies are noted to be the loss of one transformer in Chimtala when the maximum power that can be transferred is limited to 139.6 MW and the loss of the line Pul-e-kumri - Charikar line when the transfer limit is noted to be 206.6 MW.

It should be noted that to facilitate the reduced power transmission capability under contingency conditions load shedding should be implemented by suitable relay devices.

TURKMENISTAN SOURCE
Power Transfer Limit to Chimtala 110 kV Bus (MW)

Case	Option 1	Option 2	Option 3	Option 4
Normal	248.0	245.8	226.8	208.8
Normal with Single Conductor Andk Naibabad	230.8	NA	NA	NA
Normal with Loads in 220 kV (*)	201.2	199.4	193.2	172.4
Contingency Pul E Kumri - Charikar	206.6	205.6	186.2	179.8
Contingency Naibabad-Pul E Kumri	219.4	217.0	203.2	194.2
Contingency Mazar E Sharif - Naibabad	NA	241.2	NA	NA
Contingency Sheberghan - Mazar E Shariff	NA	226.6	NA	NA
Contingency Sheberghan - Naibabad	226.0	NA	NA	NA
Contingency Border - Sheberghan	NA	234.8	NA	NA
Contingency Andkhoy Sheberghan	241.6	NA	NA	NA
Contingency Loss a Transformer in Chimtala	139.6	129.5	133.9	141.3
Transfer with 100 MW Generation in Sheberghan with Loads 220 kV (*)	239.2	248.4	NA	NA
Transfer with 100 MW Generation in Sheberghan w/o Loads 220 kV	202.6	203.6	NA	NA
System Wide Losses (MW)	46.1	47.4	33.3	33.6
Required Shunt Capacitor Compensation (MVAR)	145.0	150.0	150.0	150.0
Required Shunt Reactor Compensation (MVAR) (**)	470.0	440.0	600.0	470.0

* Condition where all the substations along the 220 kV line are loaded.

** Up to 240 MVAR are required in Serder, Turkmenistan

Table 1 Turkmenistan Source Steady State Results

Transient Stability

The previous analysis simulated the system behavior under steady state conditions , assuming that the system will survive the transient period (first 20 seconds) after a contingency occurs.

In order to study the transient behavior of the system a worst case scenario of a three phase fault at different parts of the system was studied for Turkmenistan Option 1. The results are tabulated below. It should be realized that three phase faults are rare. Generally single phase to ground faults have greater chances of occurring and these types of faults are less onerous. It is recommended that further studies be done to study these cases in detail when the Turkmenistan System details are available and a comprehensive study can be performed.

Event 1, the loss of the Serder –Andkhoy line: The System becomes unstable since there is insufficient generation in Afghanistan to balance the load. The system is likely to experience a black out and has to be reestablished gradually.

Event 5, the loss of Pul e Kumri-Charikar line: in order to survive the transient period the System requires five additional MVAR of reactive compensation and 48 MW of load shedding in Kabul. Similar load shedding is also required for Event 6.

Event 8, the loss of the 220 kV lines from Pul e Kumri to Khulm and from Pul e Kumri to Charikar for a bus fault at Pul e Kumri. The system will become unstable and is likely to experience black out. The system has to be reestablished gradually. However it should be noted that the bus faults are rare.

TURKMENISTAN SOURCE OPTION 1 TRANSIENT STABILITY ANALYSIS RESULTS		
Event Number	Description	Comments
1	Loss of Serdar - Border 500 kV line	Unstable
2	Loss of 220 kV circuit Sheberghan - Naibabad	Stable
3	Loss of 220 kV circuit Andkhoy -Sheberghan	Stable
4	Loss of line Naibabad - Pul - E- Khumri	Stable
5	Loss of line Pul-E-Khumri - Charikar	Unstable even with tripping of load. Aditional 5 MVAr required at Pul_E-Khumri to have stable system but with load shedding of 20 % on buses 104 (24 MW) 102 (13 MW) 101 (11 MW)
6	Loss of Chimtalah - Charikar	Unstable unless load shedding of 20% at buses 104 (24 MW) 102 (13 MW) 101 (11)
7	Loss of one Chimtalah Transformer	Stable
8	Fault in Pul-E-Kumri bus with Loss of line Pul-E-Kumri - Charikar and Pul-E-Khumri - Khulm	Unstable

Table 2 Transient Stability Results for Afghanistan Option 1

UZBEKISTAN SOURCE

Three options were studied to bring power from Uzbekistan to Afghanistan.

Option 1

This option is indicated in figure 6 and models the import of power over a 220 kV transmission line from Surkhan substation in Uzbekistan to Naibabad and the existing 110 kV transmission line from Amu substation in Uzbekistan to Mazar e Sherif.

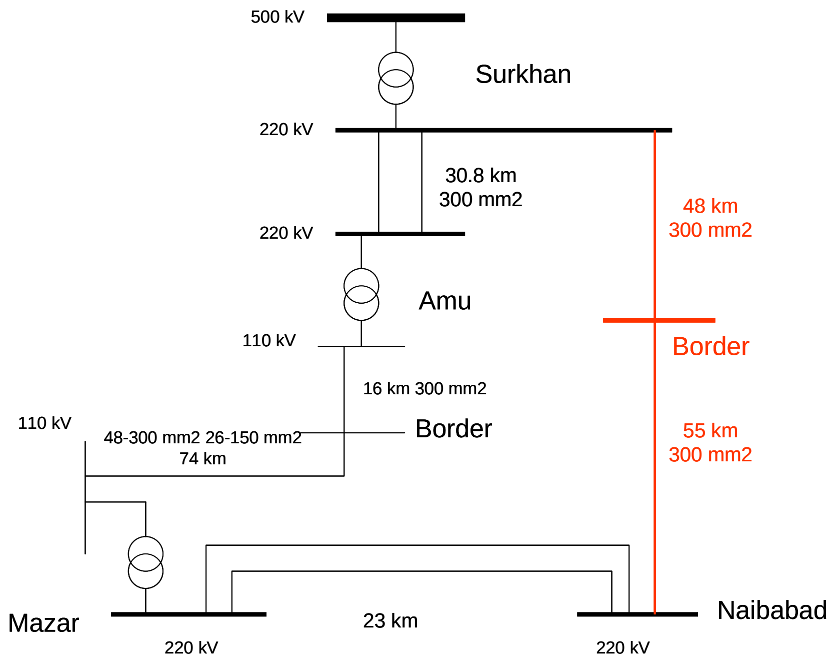


Figure 6 Uzbekistan Source Option 1

Option 2

This option is indicated in figure 7 and models the import of power over a 220 kV double circuit transmission line from Surkhan substation to Naibabad switchyard in Afghanistan.

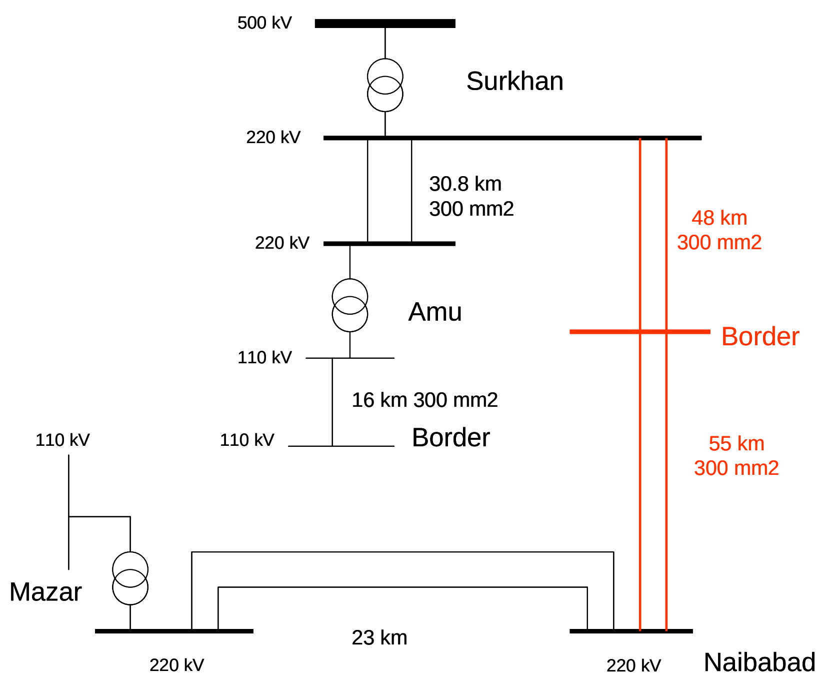


Figure 7 Uzbekistan Source Option 2

Option 3

This option is indicated in figure 8 and models the import of power over a 220 kV transmission line from Amu substation in Uzbekistan to Naibabad and the existing 110 kV transmission line from Amu substation in Uzbekistan to Mazar e Sherif.

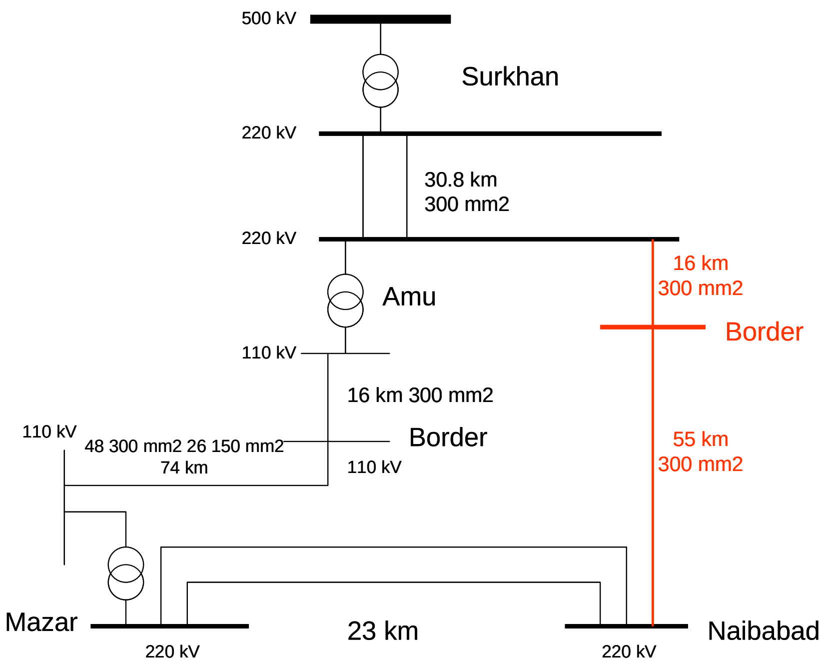


Figure 8 Uzbekistan Source Option 3

Results Summary

<u>Steady State</u>

Table 3 summarizes the steady state analysis results for all the Uzbekistan options.

Option 2 provides the maximum power import capability. Under this option a maximum of 242 MW can be imported into the 110 kV bus in Chimtala under normal conditions and no additional load in the intermediate 220 kV substations. With loads in the intermediate 220 kV substations the transfer limit decreases to 220.2 MW.

The worst contingencies are the loss of one transformer in Chimtala when the maximum load that can be transferred is limited to 144.7 MW and the loss of the Pul-e-kumri Charikar line with a transfer limit of 200.8 MW. To facilitate the reduced power transmission capability under contingency conditions load shedding should be implemented by suitable relay devices.

<u>Transient Stability</u>

Transient stability analysis for Uzbekistan source was not included in the scope of work.

UZBEKISTAN SOURCE Power Transfer Limit to Chimtala 110 kV Bus (MW)			
Case	**Option 1**	**Option 2**	**Option 3**
Normal	230.4	242.0	231.4
Normal with local loads (*) and Sheberghan-Naibabad Line	208.8	220.2	220.6
Normal without local loads (*) and Sheberghan-Naibabad Line	256.0	263.8	259.0
Contingency Pul E Kumri - Charikar	193.2	200.8	194.6
Contingency Naibabad-Pul E Kumri	209.8	219.0	208.2
Contingency Surkhan Naibabad 220 kV	63.6	227.4	NA
Contingency Amu Border 220 kV	NA	NA	79.6
Contingency Amu Surkhan 220 kV	226.0	NA	229.8
Contingency Border Mazar 110 kV	227.4	242.0	228.6
Contingency Loss a Transformer in Mazar	226.6	247.4	233.8
Contingency Loss a Transformer in Chimtala	143.5	144.7	144.6
System Wide Losses (MW)	44.0	40.4	42.2
Required Shunt Capacitor Compensation (MVAR)	145.0	145.0	145.0
Required Shunt Reactor Compensation (MVAR)(**)	35.0	80.0	40.0

* Condition where all the substations along the 220 kV are loaded

** Up to 80 MVAR are required in Surkhan, Uzbekistan

Table 3 Uzbekistan Source Steady State Results

TAJIKISTAN SOURCE

Tajikistan proposed interconnection scheme is shown in figure 9. The interconnection point in Tajikistan will be the Sangtuda 220 kV substation. Two new 220 kV circuits will go from Sangtuda to the border and from there to Kunduz and to Pul-e-kumri.

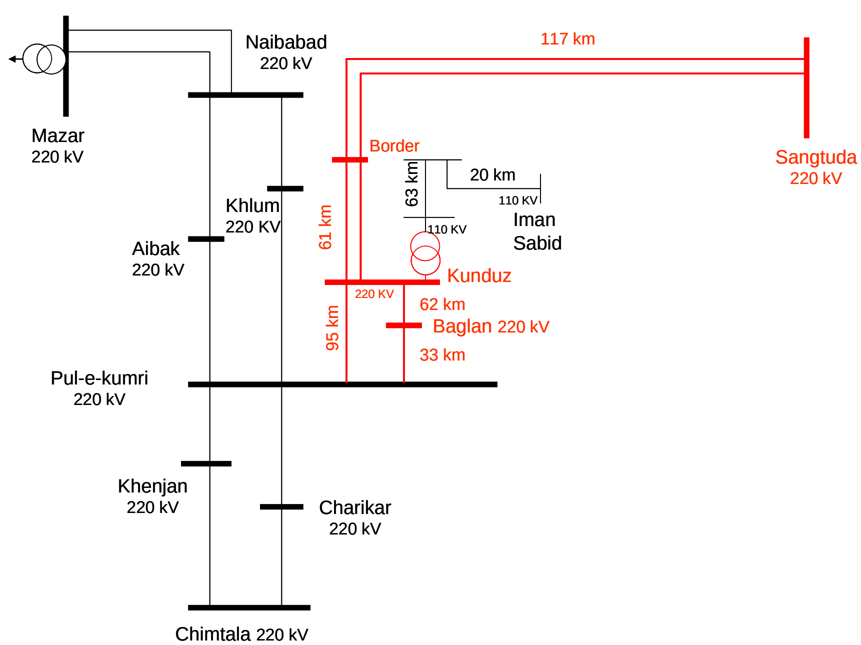


Figure 9 Tajikistan 220 kV Source Option

A special case was analyzed in which the existing 110-35 kV interconnection between Geran (in Tajikistan) and Kunduz is upgraded to 110 kV and is used to reinforce the 220 kV circuits as shown in figure 10.

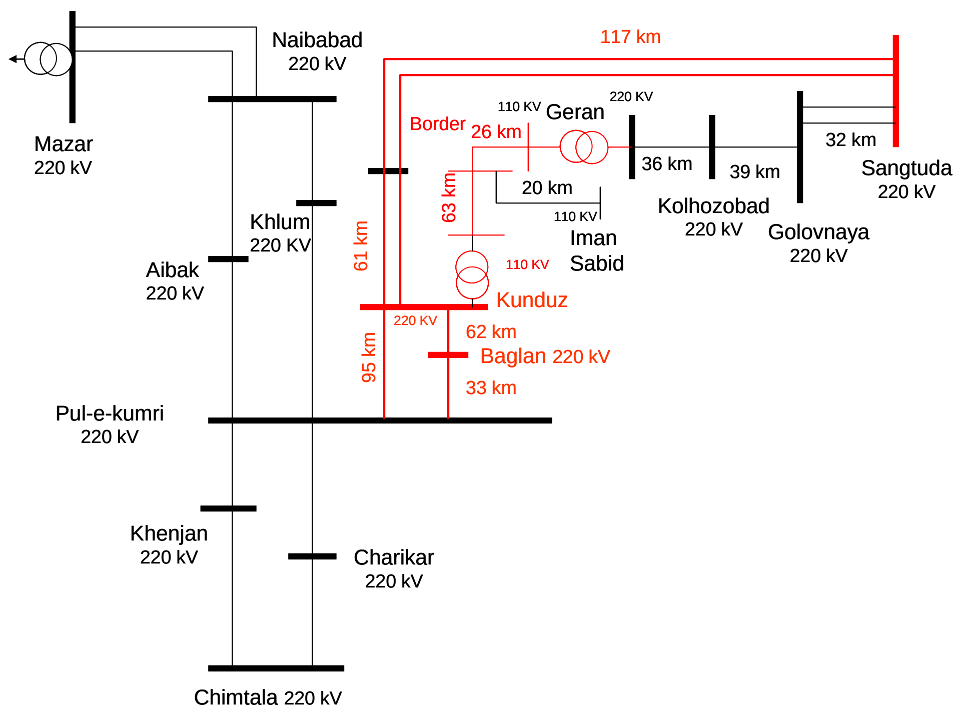


Figure 10 Tajikistan 220 kV and 110 kV Source Option

Results Summary

<u>Steady State</u>

Table 4 summarizes the steady state analysis results for the Tajikistan 220 kV source study cases.

Under normal conditions the transfer limit to Kabul area is 229.6 MW. This transfer can be increased to 241.2 MW if Taluqan load is isolated from the Kunduz area. If the loads in Mazar and Sheberghan areas are connected to Naibabad and supplied from Tajikistan, the transfer limit to Kabul will be reduced to 216 MW. This case includes 100 MW generation in Sheberghan. If the reinforced Geran - Kunduz 110 kV is available the transfer limit increases to 235.6 MW.

The worst contingencies are the loss of one transformer in Chimtala when the maximum load that can be transferred is limited to 149.2 MW and the loss of the Pul-e-kumri Charikar line when the transfer is limited to 188.2 MW. To facilitate the reduced power transmission capability under contingency conditions load shedding should be implemented by suitable relay devices.

TAJIKISTAN SOURCE Power Transfer Limit to Chimtala 110 kV Bus (MW)	
Case	**Option 220 kV Source**
Normal Conditions	229.6
Normal with Taluqan Load Out	241.2
Contingency Pul E Khumri - Charikar	188.2
Contingency Naibabad-Pul E Khumri	226.8
Contingency Kunduz-Pul E Khumri	208.0
Contingency Kunduz- Baghlan	209.2
Contingency Shekanbandar-Kunduz	211.0
Contingency Sangtuda Shekanbandar	194.8
Contingency Loss a Transformer in Chimtala	149.2
Normal with Mazar, Line Sheberghan-Naibabad	216.0
Normal with Mazar, Line Sheberghan-Naibabad no 220 kV Loads (*)	270.0
Contingency Santugda Sherkanbandar with Mazar, Line Sheberghan-Naibabad	181.0
Normal with Mazar, Line Sheberghan-Naibabad and Geran Kunduz 110 kV	235.6
kV	204.2
System Wide Losses (MW)	64.2
Required Shunt Capacitor Compensation (MVAR)	230.0
Required Shunt Reactor Compensation (MVAR) (**)	85.0

* Condition where all the substations along the 220 kV are loaded

* Up to 75 MVAR are required in Sangtuda, Tajikistan

Table 4 Tajikistan 220 kV Source Steady State Results

Transient Stability

Transient stability analysis for Tajikistan source was not included in the scope of work.

TRANSFER CAPABILITY SUMMARY

Table 5 summarizes the transfer limit for the 3 options:

Power Transfer Limit to Chimtala 110 kV Bus (MW)		
Source	**Normal**	**Contingency**
Turkmenistan	248.0	139.6
Uzbekistan	242.0	144.7
Tajikistan	229.6	149.2

Table 5 Transfer Capability Summary

RECOMMENDATIONS

The load flow study summarized above was performed with out taking the system details of Turkmenistan, Uzbekistan and Tajikistan into consideration as these details were not available at the time of this study. It is recommended that the load flow studies and the transient stability analysis be repeated when this data becomes available. Generally the source characteristics will have an impact on transient stability.

This study focused on estimating the maximum loads that could be imported over NEPS within the acceptable voltage limits. Further studies may be performed to study the system behavior and determine actual compensation requirements under different operating scenarios based on such factors as economic dispatch, hydro generation schedules etc. With the system model developed for this study such studies would be relatively simple.

Section

1

Introduction

This report summarizes the results of the Power System Analysis of the Afghanistan's North East Power Systems (NEPS) transmission network conducted by Siemens PTI for Advanced Engineering Associates International as part of the USAID program for the reconstruction of Afghanistan.

The scope of work includes:

- Validate and confirm the steady state model for the NEPS system
- Include new transmission lines in 220 kV to NW Afghanistan
- Develop the interconnection models for 3 independent sources: Turkmenistan, Uzbekistan and Tajikistan
- Load flow analysis
- Short circuit analysis
- Contingency analysis
- Active and reactive power margin studies (PV and QV analysis)
- Define NEPS transfer limit to Kabul and need for NEPS system upgrades
- Transient Stability Preliminary Analysis
- Report

Additionally Siemens PTI supply a license of the power system analysis software PSSE V30 and provide training in Kabul for the software use.

Section

2

NEPS Transmission System

2.1 Afghanistan Existing Power System

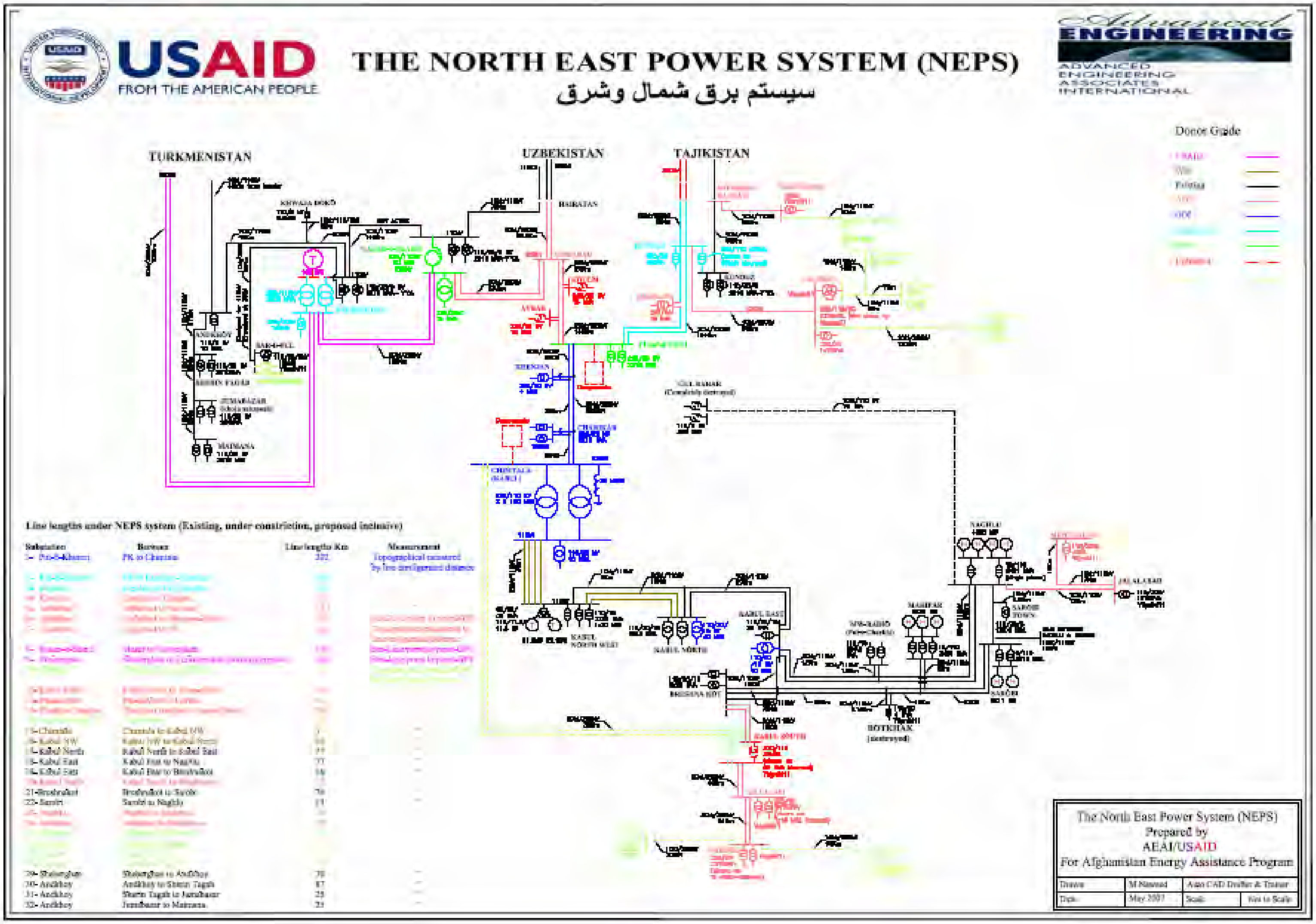
Different regions of Afghanistan are currently supplied power by the following isolated transmission networks:

- Kabul and South East: a 110 kV transmission network that supplies the capital city and a portion of the south east section of the country. Electricity is provided from local hydro and thermal generation.
- North West: a 110 kV transmission network which imports power from Turkmenistan to the Jawzjan province in Afghanistan.
- North Central: a 110 kV transmission network which imports power from Uzbekistan to the Balkh province in Afghanistan.
- North East: a 110/35 kV transmission network which imports power from Tajikistan to the Kunduz province in Afghanistan.
- Western: a 110 kV transmission network which imports power from Iran and Turkmenistan to the Baghis Province in Afghanistan.
- South East: a 110 kV transmission network in the Kandahar Province. Power is provided hydro and thermal facilities.

2.2 Future Transmission System

The Afghanistan Energy Assistance Program coordinated by USAID is developing the expansion of the Afghanistan Transmission Network by creating a new 220 kV network as shown in fig 1.1. This network is generally known as the North East Power System (NEPS) and will traverse the provinces of Faryab, Jawzjan, Balkh, Kunduz, Takhar, Baghlan, Parwan and Kabul

Figure 1.1 North East Power System



The main transmission link of NEPS will be the 220 kV double circuit lines between Kabul and the border regions of neighboring countries in Northern Afghanistan.

The new 220/110 kV Chimtala substation will be the interconnection point of the 220 kV lines with the existing Kabul 110 kV network. Two 160 MVA transformers will supply power to the 110 kV transmission lines that will interconnect Chimtala with Kabul North West substation and the rest of the existing 110 kV system.

The next major substation in the new transmission system is the 220 kV Pul-E-Kumri substation located north of Kabul. A 220 kV double circuit transmission line will interconnect Pul-E-Kumri with Chimtala. One of the circuits will have an intermediate distribution substation at Khenjan and the other at Charikar. These lines have single Squab conductors.

Pul-E-Kumri will be the interconnection point for the North East and North West areas. Kunduz (North East) will be linked to Pul-E-Kumri through a 220 kV double circuit transmission line. At present Kunduz is supplied power from from Tajikistan (at 110/35 kV)

The Naibabad – Pul-E-Kumri double circuit 220 kV transmission line will interconnect Kabul with the North West area. This line will have bundled Squab conductors. Naibabad will be the main node for the possible interconnection with Turkmenistan or Uzbekistan systems and is discussed later in this report.

The last section on the 220 kV transmission lines under construction will be the double circuit 220 kV single conductor line from Naibabad to Mazar-E-Sharif substation where power is currently supplied from Uzbekistan at the 110 kV voltage level.

2.3 System Data

Appendix A includes all the system data that was used for modeling the Afghanistan transmission system. The data is organized in the following categories:

- Bus Data
- Line Data
- Load Data
- Generator Data
- Area Data
- Owner Data

Section

3

Planning Criteria

The following planning criteria were used for the Afghanistan power system analysis:

3.1 Steady State

3.1.1 Voltage Range

- Normal Conditions: all the elements in the systems are in service
  - Between 0.95 P.U. to 1.05 P.U.
- Emergency: a single element in the system out of service
  - Between 0.90 P.U. to 1.10 P.U.

3.1.2 Thermal Overloads

Under normal and contingency conditions lines should not be loaded over their normal thermal ratings.

3.1.3 Reliability

The Load Flow Studies were carried out under the criteria that the system should withstand the loss of a single element with minimal load interruption while maintaining the voltage and thermal criteria.

3.2 Transient Stability

3.2.1 Transient Period

The transient behavior of the power system was simulated for a period of 20 seconds. The simulation starts in normal conditions and then a 3 phase fault is applied in selected elements.

Fault is cleared by the protection system in 4 cycles.

3.2.2 Frequency

The frequency, during the transient period, should no be lower than 48 Hz or higher than 52 Hz.

3.2.3 Voltage

The voltage, during the transient period, should no be lower than 0.7 pu or higher than 1.2 pu.

3.3 Other Considerations

The following considerations were included in the definition of the study cases:

3.3.1 Load

The analysis main objective was to define the maximum amount of power that can be transferred from the Turkmenistan, Uzbekistan and Tajikistan to Kabul. To facilitate this study load was adjusted in Kabul area until the transfer limit was reached. In principle the goal was to achieve a net transfer of 300 MW into the Kabul area at the Chimtala 220 kV substation.

The transfer limit was checked considering, as first approach, that no load will be supplied to any 220 kV substations between the source and Kabul. Sensitivity cases were run to test the effect of intermediate loads over the power transfer capability to Kabul.

Additionally the system performance was checked under light load condition which was defined as the load in the Kabul area that will reduce the power transfer to the Chimtala substation to 50 MW.

3.3.2 Reactive Compensation

Shunt Compensation (capacitors or reactors) was included in each case in order to maximize the power transfer to Kabul.

In the initial stage of the analysis the series compensation was also tested as an option to increase the transfer capability of the NEPS system. However this option did not prove to be an effective solution and therefore was discarded.

3.3.3 Contingencies

The transfer limit was also checked under contingencies, such as a fault in a single segment in the transmission line system, or in the Chimtala Transformers resulting in its isolation.

Reactive compensation was maintained the same for both the normal and the contingency conditions.

3.3.4 Generation Expansion

The impact of a new 100 MW generation facility in Sheberghan was also analyzed.

3.3.5 Single Source

The Load Flow Study was done such that the three power sources from Turkmenistan, Uzbekistan and Tajikistan are not paralleled in the Afghanistan Grid. This is because the Turkmenistan, Uzbekistan and Tajikistan Systems are currently not synchronized and to parallel their sources in Afghanistan would require an agreement from these three countries and a comprehensive study would have to be done based on a system model that includes the system details in these three countries in addition to Afghanistan.

The study results then has to be vetted and approved by the three countries. This process is politically charged, complicated and will take a long time. In a meeting held in Ashgabad Turkmenistan representative warned that their system should not be paralleled with other countries systems in Afghanistan.

3.3.6 Study Cases Definition

Study cases were defined for all the supply alternatives: Turkmenistan, Uzbekistan and Tajikistan.

Several interconnections options were analyzed for each alternative.

For each option the following cases were analyzed:

Maximum Transfer Limit:

- Normal Conditions
- Contingency
- With load supplied to intermediate 220 kV substations
- With Sheberghan 100 MW generation

Light Load:

- With both Naibabad – Chimtala circuits in operation
- With one Naibabad – Chimtala circuit in operation

Section

4

Turkmenistan Source

This section of the report describes the main results and findings in the power system analysis of the different interconnection options for the Turkmenistan Source. Siemens PTI software PSSE 30.1 was used for load flow, contingency and active and reactive power margin and transient stability studies.

4.1 Interconnection Options

The following four options were analyzed for the import of power from the Turkmenistan source to Kabul:

Option 1

This option is indicated in figure 4.1 and models a single 500 kV circuit from Serder substation in Turkmenistan to a new substation near Andkhoy in Afghanistan. At this substation a power transformer steps down the incoming 500 kV power supply to 220 kV. A double circuit is taken from this substation to Sheberghan and from Sheberghan to Naibabad. Each circuit has bundled conductors.

In summary this option has 350 km of single circuit 500 kV line and 235 km of doubled circuit bundled conductor 220 kV line. A 500 MVA 500/220 kV transformer is installed in Andkhoy substation.

Option 2

This option is indicated in figure 4.2 and models a single 500 kV circuit from Serder substation in Turkmenistan to a new substation in Afghanistan near the border north of Andkhoy. At this substation a power transformer steps down the incoming 500 kV power supply to 220 kV. A double circuit is taken from this substation to Sheberghan and from Sheberghan to Mazar e Sherif. Each circuit has a bundled conductor. The final connection to Naibabad is through the double circuit single conductor line, Mazar e Sheriff Naiababad under construction.

In summary this option has 310 km of single circuit 500 kV line and 249 km of double circuit bundled conductor 220 kV line. A 500 MVA 500/220 kV transformer is installed in border substation.

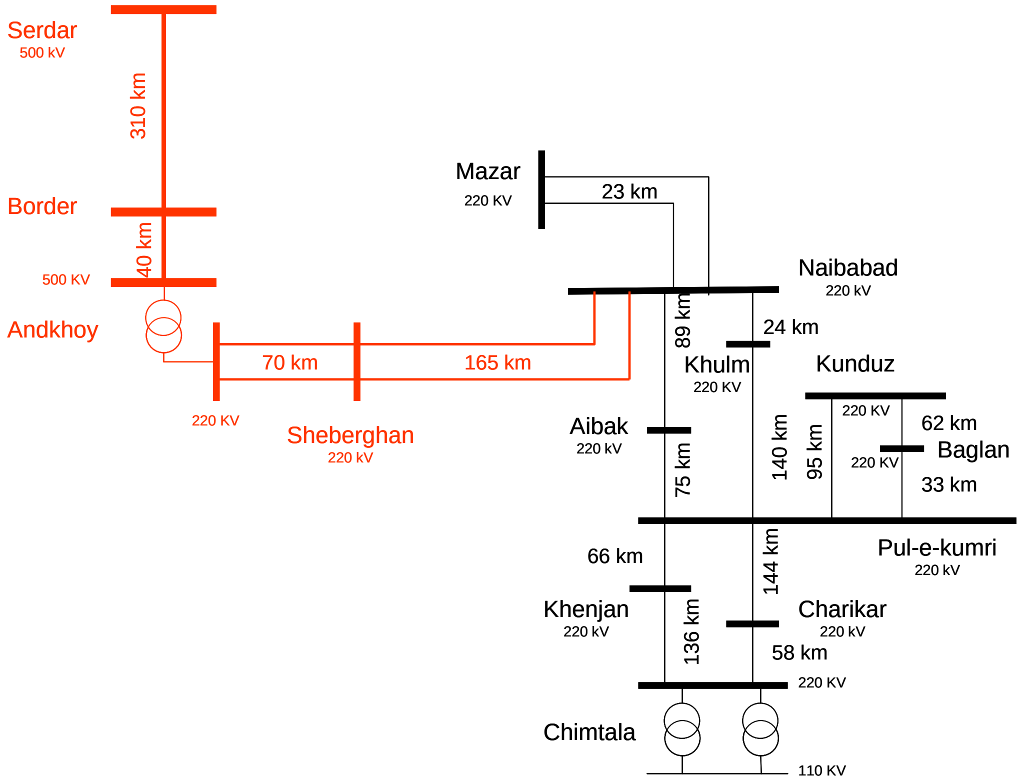


Figure 4.1 Turkmenistan Source Option 1

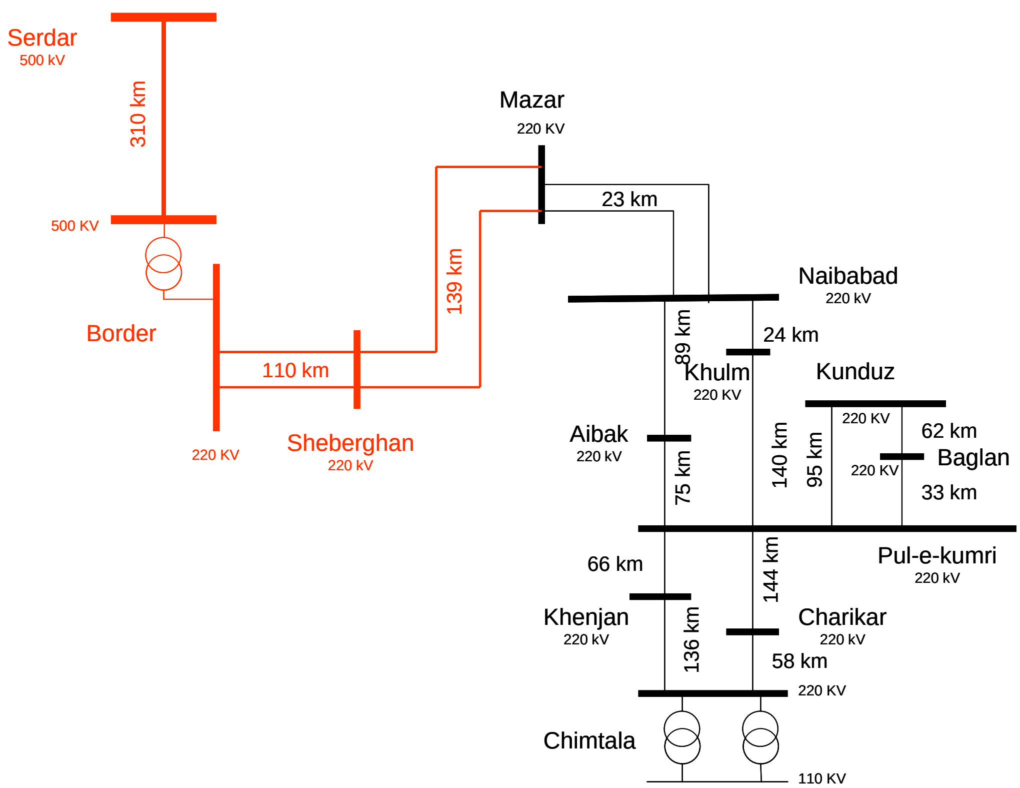


Figure 4.2 Turkmenistan Source Option 2

Option 3

This option is indicated in figure 4.3 and models a single 500 kV circuit from Serder substation to Naibabad. At Naibabad a power transformer steps down the voltage to 220 kV.

In summary this option has 500 km of single circuit 500 kV line and one 500 MVA 500/220 kV transformer in Naibabad.

Option 4

This option is indicated in figure 4.4 and models a single 500 kV circuit from Serder substation to a new substation in Afghanistan near the border. At this substation a power transformer steps down the 500 kV to 220 kV. A single circuit is taken from this substation to Naibabad. A bundled conductor matching the 500 kV circuit conductors is used for the single circuit between the new substation and Naibabad. The line will be isolated in 500 kV but operated in 220 kV.

In summary this option has 400 km of single circuit 500 kV line,100 km of single circuit 220 kV line (designed for 500 kV) and one 500 MVA 500/220 kV transformers at the border, north of Naibabad.

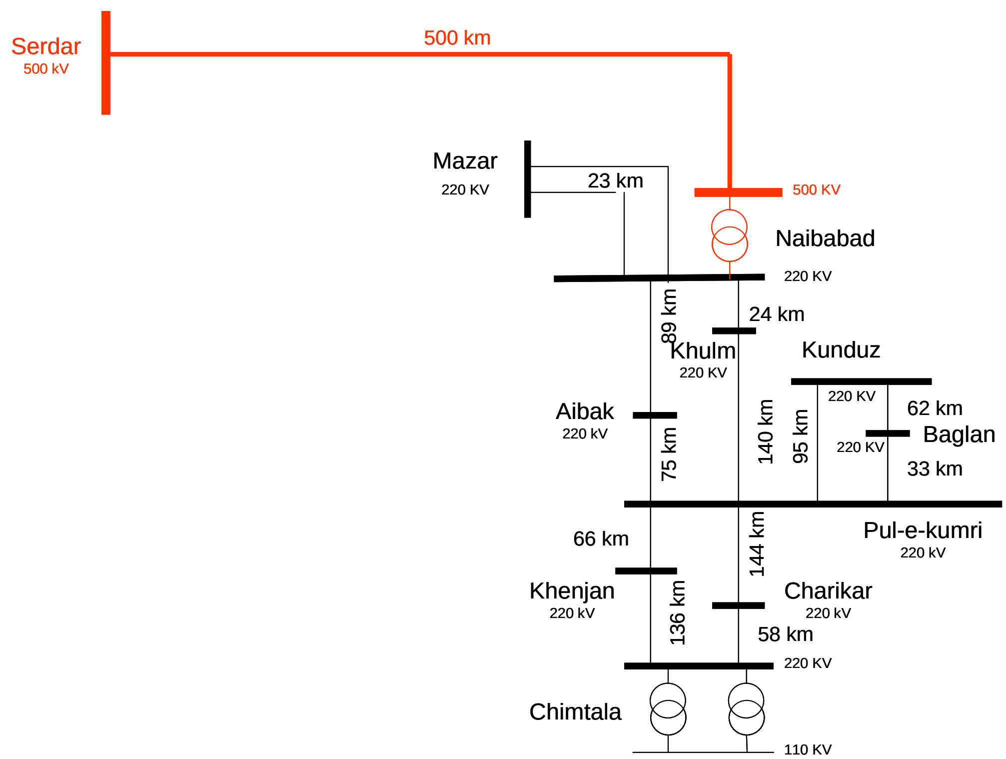


Figure 4.3 Turkmenistan Source Option 3

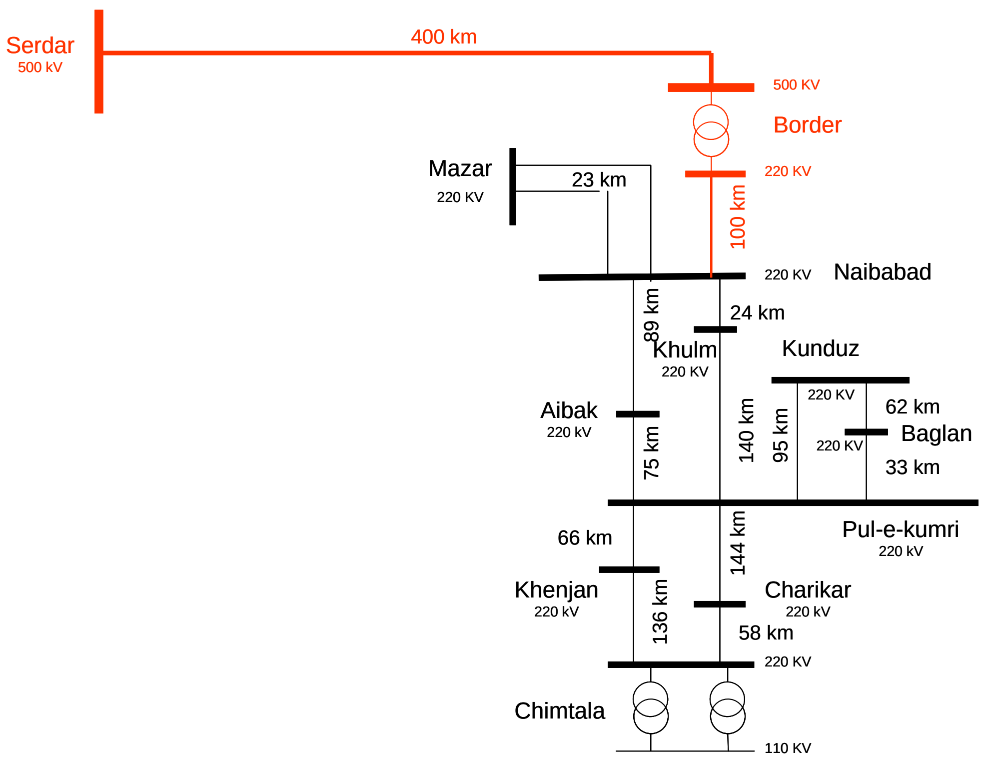


Figure 4.4 Turkmenistan Source Option 4

4.2 PV and V-Q Analysis

4.2.1 V-Q Analysis

The V-Q relationship shows the sensitivity of the voltage of a given bus with respect to changes in the reactive power injection at that bus. The reactive power margin at the selected bus can be easily determined and serves as a preliminary indication of the "distance" to the voltage collapse in the system. The figure shows a typical V-Q curve and indicates how the reactive power margin is determined.

V-Q curves were obtained for the bus Chimtala 220 kV as a first step to evaluate the transfer limits. Furthermore, these curves were obtained not only for the base case condition but also considering contingencies. The result is the plot of a family of V-Q curves which are used to determine the reactive power margin of the base case and the impact of each contingency in this margin.

Although the reactive power margin determined by the Q-V analysis cannot be used as an absolute measure of "distance" to voltage collapse, the changes in reactive power margin for a given bus following contingencies provide a good picture of the relative impact of each contingency on this margin and, therefore, can be used to determine which contingencies have the greatest impact on voltage stability.

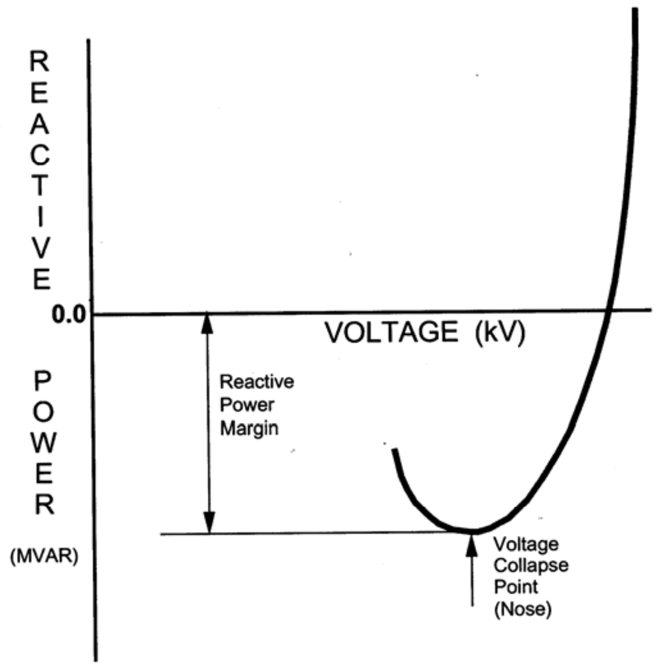


Figure 4.5 V-Q Curve and Reactive Power Margin

The minimum point of the curve (where dQ/dV = 0) is the critical point, i.e., all points of the curve to the left of the minima are unstable since further lowering the voltage at the bus requires more reactive power injected at the bus. The points to the right of the minima are stable, and the intersection of the V-Q curve with the horizontal axis is the voltage at the bus without additional reactive power compensation (base case condition).

If the minimum point of the V-Q curve is above the horizontal axis, the system is deficient in reactive power and usually a conventional power flow solution cannot be obtained. This indicates a voltage collapse condition and the system cannot be operated without reactive power compensation being added. This is not a situation often obtained in real systems under normal operation conditions, but could arise from contingencies and/or unusually stressed operation conditions.

To avoid voltage collapse conditions, adequate reactive power margins should be maintained under all conditions. The available reactive power margin can be associated with the distance between the point of minimum of the curve and the horizontal axis, as shown the figure, where a positive reactive power margin corresponds to the case where the point of minimum corresponds to a negative value for the reactive power.

The reactive power margin is a useful measure of the robustness of the system to meet uncertainties in assumptions such as load level and other variables. It is debatable if the reactive power margin, as provided by the QV analysis alone, can be considered a precise and reliable measurement of how far or close the system is from a voltage collapse condition. Basically, the load is usually represented as a constant MVA in power flow studies and the reactive power injection applied in the calculation of V-Q curves is also a constant power injection, which are approximations to the actual behavior of the loads and reactive power compensation.

On the other hand, even though the results of the QV analysis cannot be considered the final answer regarding the distance to the voltage collapse, the comparison of the results obtained under different scenarios is very useful in highlighting those conditions with the greatest impact on the reactive power margin and thus, determining the most critical conditions that would result in system operation closer to the voltage collapse point.

QV analysis was performed for all the 4 options. Results are presented in figures 4.6 to 4.9. The following conclusions can be obtained from the figures:

- The critical point in all the options is around 0.95 pu.
- The reactive compensation margin for the base case is around zero which indicates that not further compensation will prevent the system for a voltage collapse.

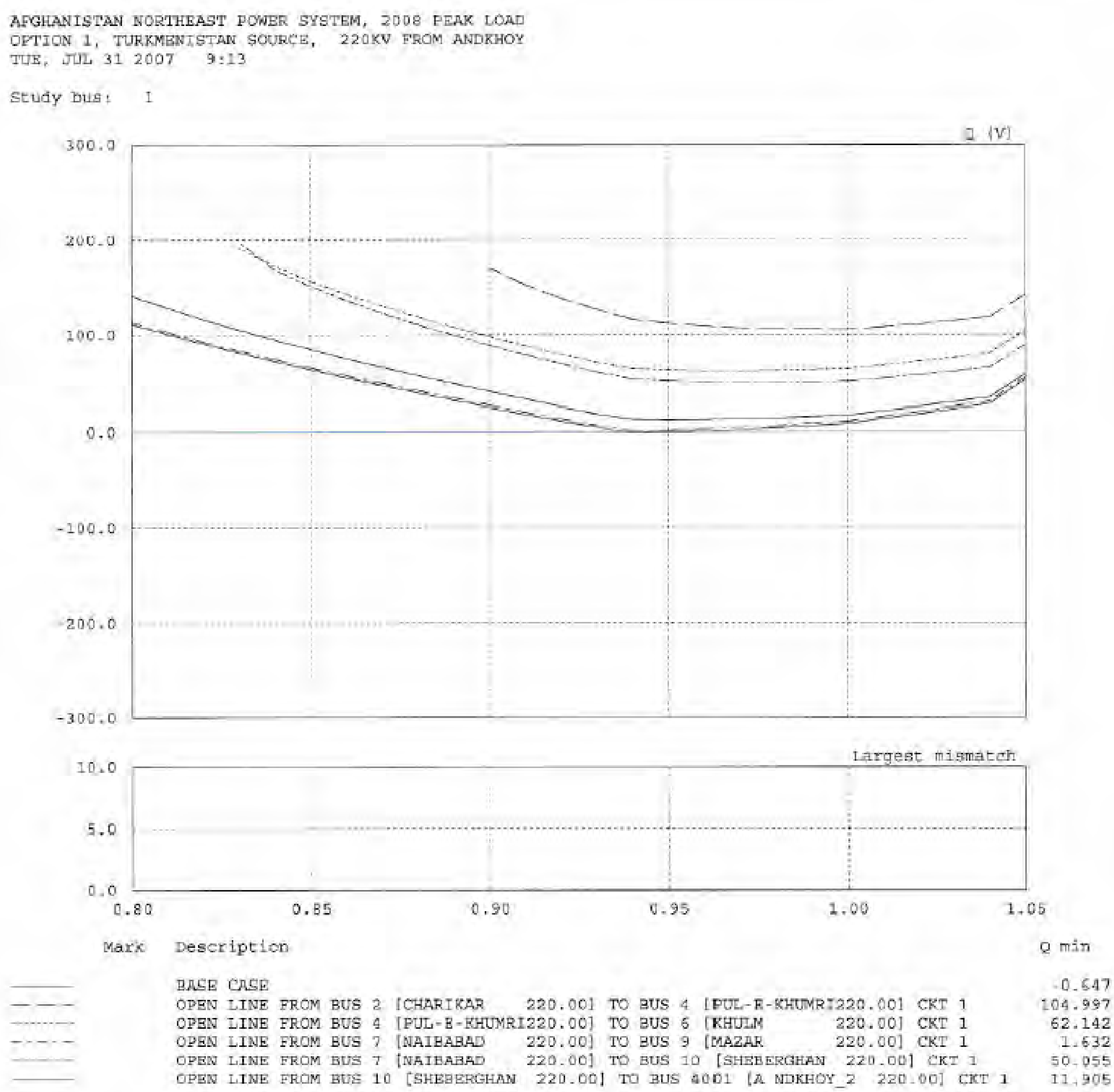


Figure 4.6 QV Results Turkmenistan Option 1

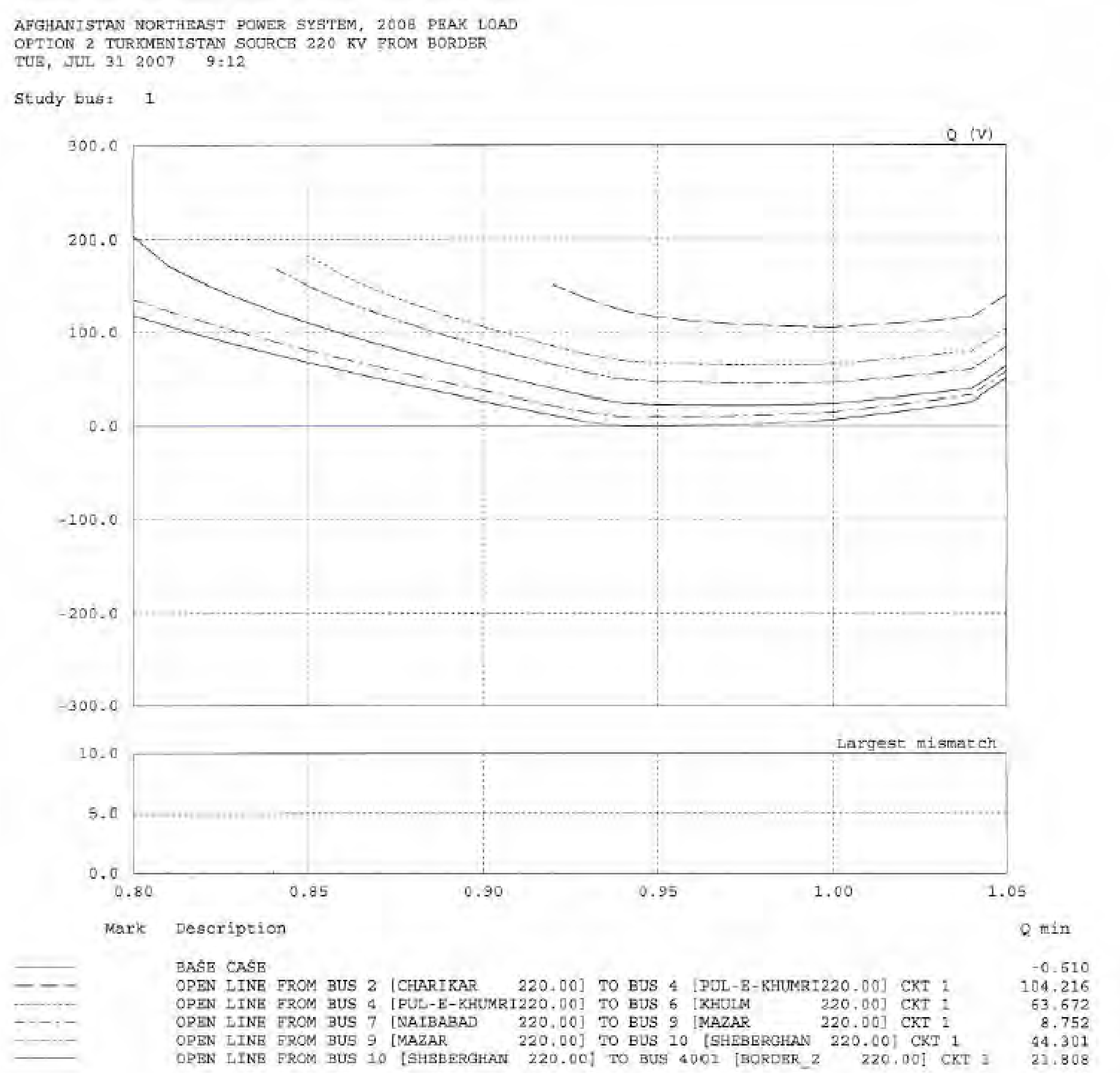


Figure 4.7 QV Results Turkmenistan Option 2

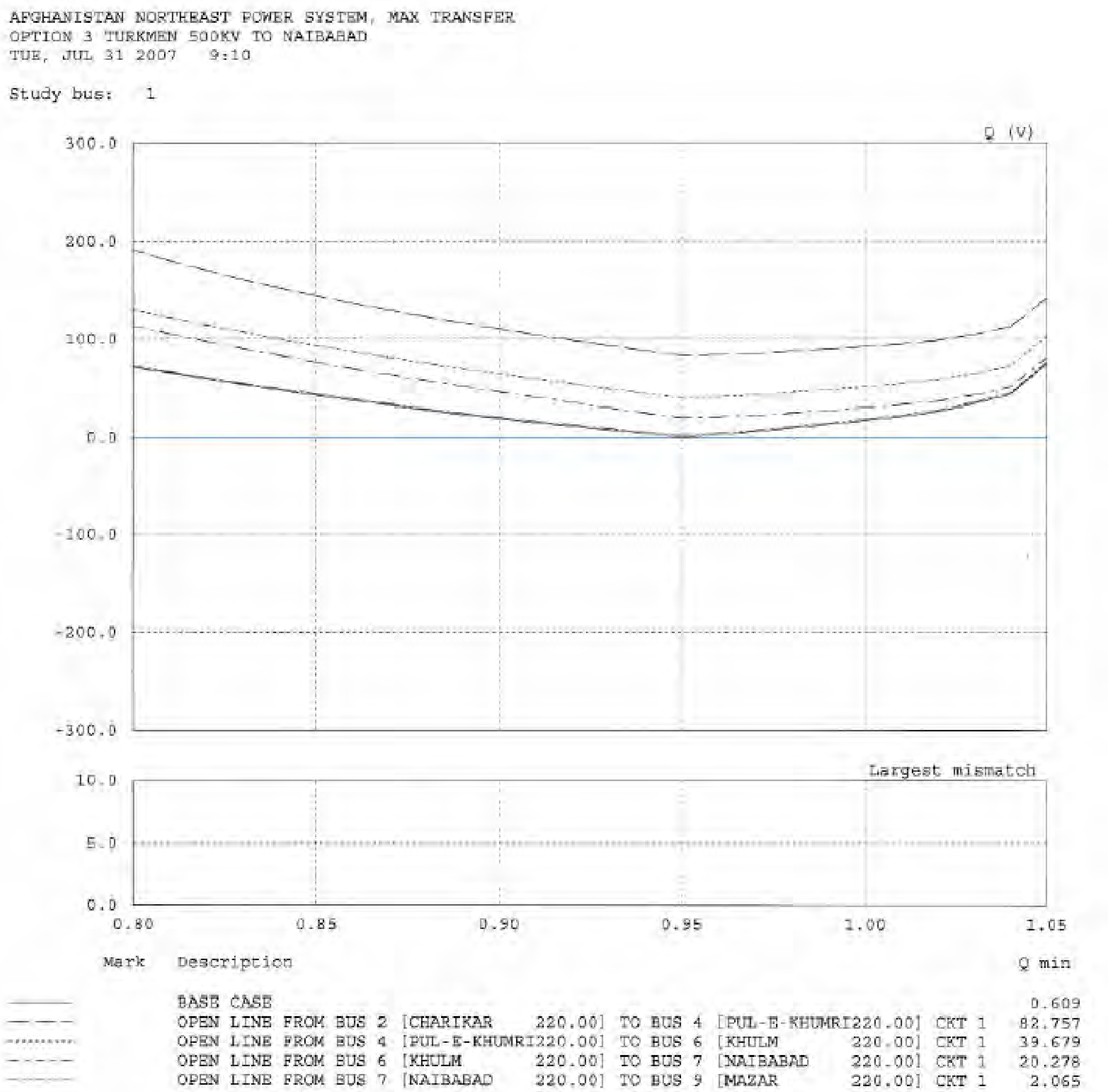


Figure 4.8 QV Results Turkmenistan Option 3

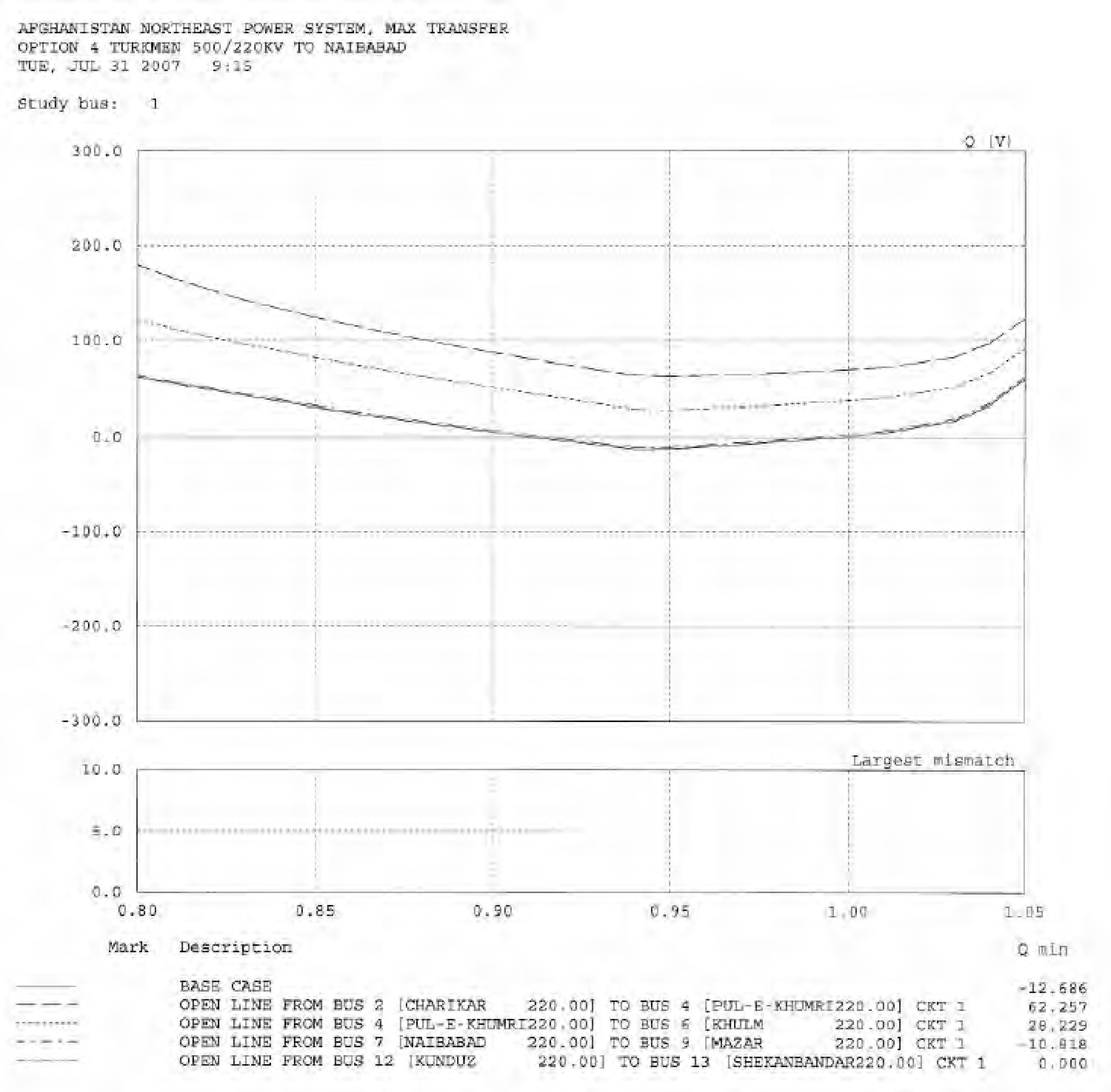


Figure 4.9 QV Results Turkmenistan Option 4

4.2.2 PV Analysis

Voltage security margins are also evaluated using PV analysis. The PV analysis was performed using the PV evaluation activities inside PSS/E. PV analysis is a steady-state tool that develops a curve relating the voltage at a given bus (or buses) to the increase in power flow across an interface.

The benefit of this methodology is that it provides an indication of proximity to voltage collapse throughout a range of load levels or flows. As transfer increases, the voltage at specific buses in the region can vary significantly, while some specific bus voltages could appear to remain within acceptable values.

Figures 4.10 to 4.13 show the PV curves for each of the different options. The curves indicate the voltage performance in Chimtala 110 kV with different increments in the transfer level over a specified initial load in the Kabul area. Curves for normal conditions and contingencies are included.

The results of PV analysis can be considered as an initial estimation of the transfer limit. However they need to be verified with conventional load flow. The following results were obtained for each option:

4.2.2.1 Option 1

Figure 4.10 shows the PV curve for Turkmenistan option 1. The curve shows the bus voltage performance in per unit for the different cases against the increment in the transfer limit over an initial value. For this option the initial value was set in 200 MW.

In normal conditions it can be seen that after 20 MW incremental transfer the voltage level in Chimtala, starts to decrease with an increasing slope, collapsing between 40 to 45 MW. This means than the transfer limit in normal conditions could be around 245 MW. Results that need to be verified further with a detailed load flow analysis.

The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can only be increased in less than 5 MW.

4.2.2.2 Option 2

Figure 4.11 shows the PV curve for Turkmenistan option 2. The PV results for this option are similar to Option 1 results .The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can only be increased in less than 5 MW.

4.2.2.3 Option 3

Figure 4.12 shows the PV curve for Turkmenistan option 3. For this option the initial value is 180 MW.

Under normal conditions the transfer limit can be incremented in over 45 MW. The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can be increased in around 5 MW.

4.2.2.4 Option 4

Figure 4.13 shows the PV curve for Turkmenistan option 4. For this option the initial value is 155 MW.

Under normal conditions the transfer limit can be incremented in around 55 MW. The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can be increased in 19 MW.

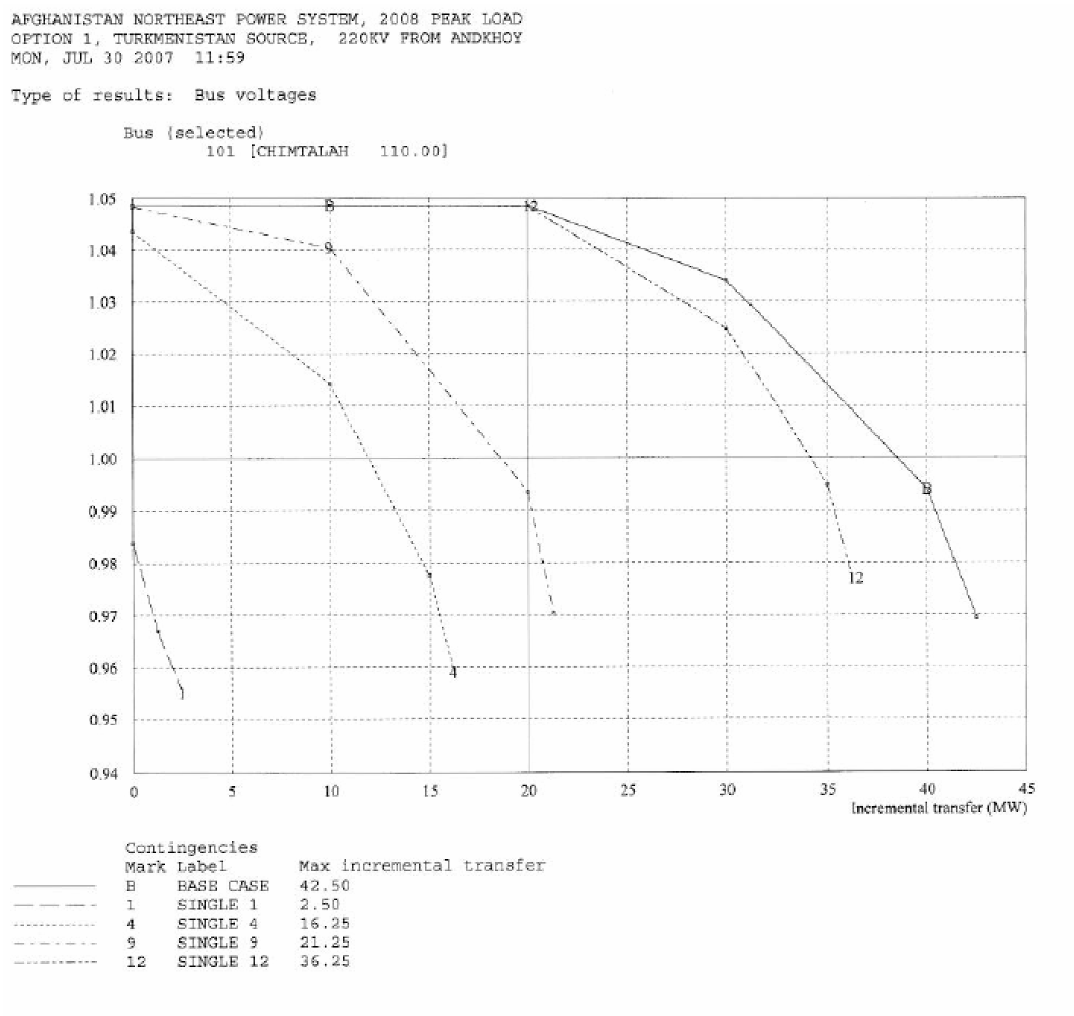


Figure 4.10 PV Results Turkmenistan Option 1

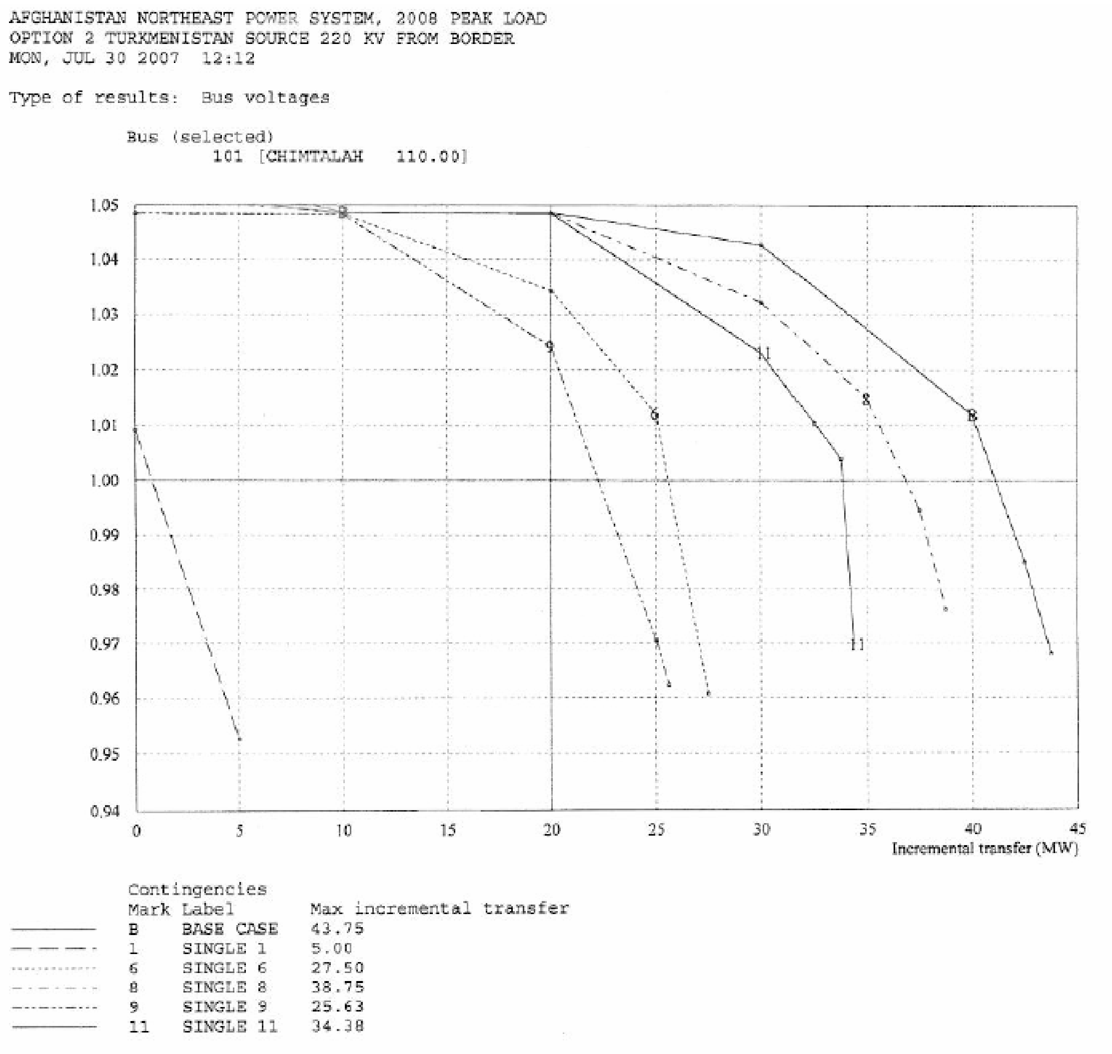


Figure 4.11 PV Results Turkmenistan Option 2

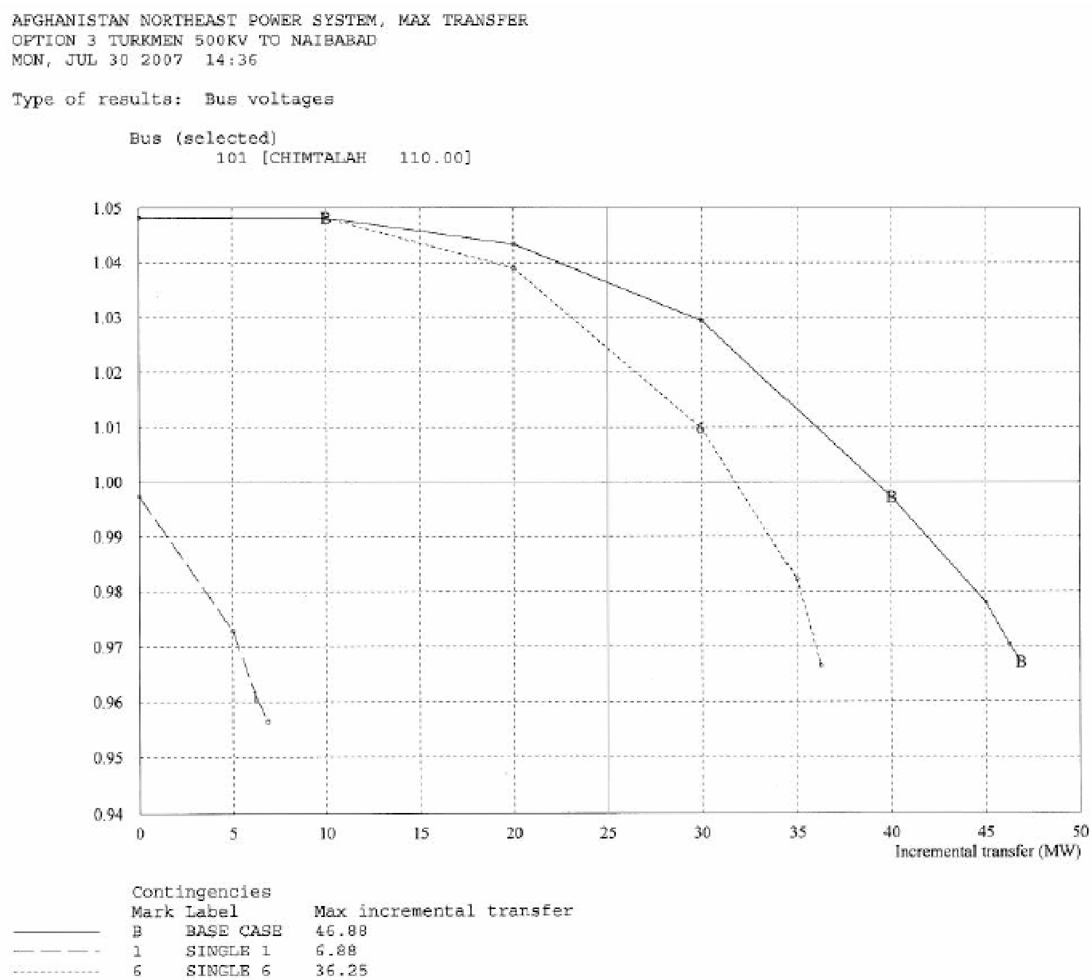


Figure 4.12 PV Results Turkmenistan Option 3

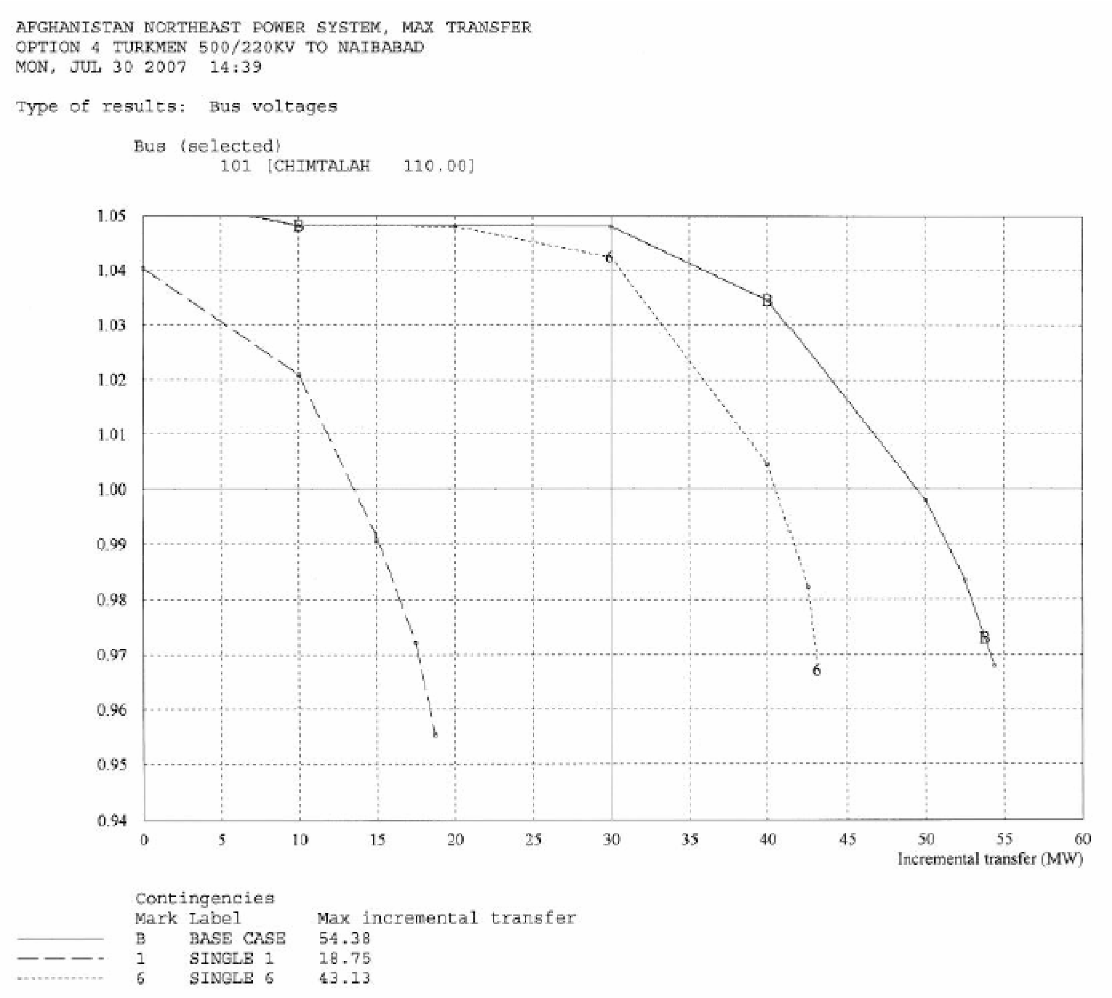


Figure 4.13 PV Results Turkmenistan Option 4

4.3 Steady State Analysis

The results obtained in the QV and PV studies were validated with detailed load flow analysis.

In a first step, reactive compensation was adjusted in order to improve the transfer limit as much as possible.

The second step was to run the load flow cases in order to define the maximum transfer limit to Kabul area, under normal conditions and under contingencies.

Finally, light load conditions were simulated in order to define additional reactive compensation requirements.

4.3.1 Reactive Compensation

Table 4.1 shows the required reactance for all the options in order to maximize the power transfer to Kabul area.

Reactive Compensation (MVAR)	Chimtala 220 kV		Chimtala 110 kV		Kabul North 110 kV		Pul-E-Khumri 220 kV		Naibabad 500 kV		Andkhoy 500 kV		Border 500 kV		Border 220 kV		Serder 500 kV	
Case	C	R	C	R	C	R	C	R	C	R	C	R	C	R	C	R	C	R
Option 1 Maximum Transfer	80		20		20		25					260						110
Option 2 Maximum Transfer	80		20		20		30							260				85
Option 3 Maximum Transfer	80		20		20		30			280								220
Option 4 Maximum Transfer	80		20		20		30									200		240

C	Capacitors
R	Reactors

Table 4.1 Turkmenistan Maximum Transfer Reactive Compensation

In summary 100 MVAR in shunt capacitors are required in Chimtala substation: 80 MVAR in 220 kV and 20 MVAR in 110 kV. 20 MVAR are required in Kabul North 110 kV.

Additionally between 25 and 30 MVAR in shunt capacitors are required in Pul-e-kumri 220 kV substation.

In addition reactors are also required in Andkhoy, Border and Serder substations in order to control the bus voltage. Required reactors are in the range between 85 MVAR to 280 MVAR as shown in table 4.1.

4.3.2 Maximum Transfer

Table 4.2 summarizes the steady state analysis results for all the Turkmenistan options under maximum transfer conditions. System losses under normal conditions are also reported for each option.

The following normal conditions cases were analyzed:

- Normal: in this case no intermediate loads are included in 220 kV substations between the source and Chimtala. The transmission link is basically dedicated to transfer power from Serder Substation to Kabul.
- Normal with load in 220 kV: in this case intermediate 220 kV loads are included in the analysis

- Normal with load in 220 kV and 100 MW in Sheberghan: similar to the previous case but with a new 100 MW generation plant connected to Sheberghan substation in 110 kV.

- Normal without load in 220 kV and 100 MW in Sheberghan: similar to the previous case but with a new 100 MW generation plant connected to Sheberghan substation in 110 kV.

- Normal with single conductor between Andkhoy Naibabad: similar to the original normal case but using a single conductor for the 220 kV lines between Andkhoy and Naibabad instead of bundled conductors. This case applies only to option 1.

TURKMENISTAN SOURCE Power Transfer Limit to Chimtala 110 kV Bus				
Transfer Limit to Kabul 110 kV (MW) **Case**	**Option 1: Andkhoy 500/220 kV 2 x 220 kV Bundled Lines to Sheberghan-Naibabad**	**Option 2: Border 500/220 kV 2 x 220 kV Bundled Lines to Sheberghan-Mazar-Naibabad**	**Option 3: Line 500 kV Serder -Naibabad**	**Option 4: Line 500 kV Serder -Border Line 500 kV Border Naibabad operated in 220 kV**
Normal	248.0	245.8	226.8	208.8
Normal with Single Conductor Andk Naibabad	230.8	NA	NA	NA
Normal with Loads in 220 kV (*)	201.2	199.4	193.2	172.4
Normal with Loads 220 kV and 100 MW in Sheberghan	202.6	203.6	NA	NA
Normal without Loads 220 kV and 100 MW in Sheberghan	239.2	248.4	NA	NA
Contingency Pul E Khumri - Charikar	206.6	205.6	186.2	179.8
Contingency Naibabad-Pul E Khumri	219.4	217.0	203.2	194.2
Contingency Mazar E Sharif - Naibabad	NA	241.2	NA	NA
Contingency Sheberghan - Mazar E Shariff	NA	226.6	NA	NA
Contingency Sheberghan - Naibabad	226.0	NA	NA	NA
Contingency Border - Sheberghan	NA	234.8	NA	NA
Contingency Andkhoy Sheberghan	241.6	NA	NA	NA
Contingency Loss a Transformer in Chimtala	139.6	129.5	133.9	141.3

*Condition where all the substations along the 220 kV line are loaded.

Table 4.2 Turkmenistan Maximum Transfer Results

The following conclusions can be obtained from the results:

- Option 1 and 2 provide the maximum power import capability with option 1 having a slight advantage in both the import capability and system losses.

- With loads in the intermediate substations at Mazar, Sheberghan, Khulm, Aybak, Pul e Kumri, Kenjan and Charikar supplied the transfer limit decreases by 30 to 50 MW. Similar results are obtained with Sheberghan Power Plant power output connected to NEPS.

- Without loads in the intermediate substations and with the Sheberghan Power Plant connected to NEPS the transfer limit is in the range of the original normal conditions case.

- The worst contingency is noted to be the loss of one transformer in Chimtala when the maximum load that can be transferred is limited in a range between 130 and 140 MW.

- The second worst contingency is the loss of the Pul-e-kumri - Charikar line when the transfer is limited to a range between 180 to 210 MW.

It should be noted that to facilitate the reduced power transmission capability under contingency conditions load shedding should be implemented by suitable relay devices.

Load flow results for each case are presented in Appendix B to E.

4.3.3 Light Load Cases

Light Load Cases were simulated for each of the supply options. For these cases the load in Kabul area was adjusted up to the level in which the net transfer to the Chimtala substation reaches 50 MW.

The objective of the light load cases analysis is to verify that the voltage levels in the system busbars are between the normal conditions margin. In the case that over voltages were present the first step was to disconnect the shunt compensation. If even with the shunt compensation disconnected the voltage limit is exceeded then shunt reactors were added to the system.

Two light load cases were analyzed for each option. In the first case both the 220 kV Naibabab Chimtala lines were in service. In the second case one of the lines was disconnected as a corrective measure to reduce over voltages. In our opinion, the second option is not feasible from the operational point of view, since the disconnection of the line every day during the light load hours will reduce circuit breakers life and will increase its maintenance costs.

Results are shown in table 4.3

Reactive Compensation (MVAR)	Chimtala 220 kV		Chimtala 110 kV		Kabul North 110 kV		Pul-E-Khumri 220 kV		Naibabad 500 kV		Naibabad 220 kV		Andkhoy 500 kV		Border 500 kV		Border 220 kV		Serder 500 kV	
Case	C	R	C	R	C	R	C	R	C	R	C	R	C	R	C	R	C	R	C	R
Option 1																				
Maximum Transfer	~~80~~		~~20~~		~~20~~		~~25~~							260						110
Light Load												60		260						150
Light Load 1 Line 220 kV Off														260						130
Option 2																				
Maximum Transfer	~~80~~		~~20~~		~~20~~		~~30~~									260				85
Light Load												60				260				120
Light Load 1 Line 220 kV Off												20				260				90
Option 3																				
Maximum Transfer	~~80~~		~~20~~		~~20~~		~~30~~			280										220
Light Load										280										320
Light Load 1 Line 220 kV Off										280										240
Option 4																				
Maximum Transfer	~~80~~		~~20~~		~~20~~		~~30~~											200		240
Light Load																		200		270
Light Load 1 Line 220 kV Off																		200		230

C Capacitors
R Reactors
(arrow) Disconnected Under Light Load

Table 4.3 Turkmenistan Light Load Cases Reactive Compensation

The following conclusions can be obtained from the results:

- Under light load conditions all the shunt capacitors banks need to be disconnected.
- For Options 1 and 2, an additional 60 MVAR reactor is required in Naibabad 220 kV switchyard. This reactor can be reduced to 20 MVAR if one of the Chimtala Naibabad lines is disconnected.

- In Serder 500 kV substation the reactors capacity need to be incremented in a range between 30 and 100 MVAR.

The load flows for the cases with light load conditions are included in Appendix B to E.

4.4 Short Circuit Analysis

Short circuit simulations were run using the ANSI standards for each of the options. The reports are included in Appendix F.

The summary report for each fault case includes the following:

- The bus number, name and base voltage of the faulted bus, along with the maximum operating voltage and contact parting time input values.
- Three phase fault results, including symmetrical fault MVA, symmetrical fault current in kA, asymmetrical fault current in kA, the ANSI X/R ratio, and the multiplying factor.
- Line-to-ground fault results, including symmetrical fault current in kA, asymmetrical fault current in kA, the ANSI X/R ratio, and the multiplying factor.
- Line-to-line-to-ground fault results, including symmetrical phase current in kA, and three times the zero sequence symmetrical faults current in kA.
- The positive sequence Thevenin impedance as obtained from the decoupled positive sequence admittance matrices.
- The zero sequence Thevenin impedance as obtained from the decoupled zero sequence admittance matrices.

In all the options the short circuit levels are below 10 kA in any bus and for any fault condition. Standard Circuit Breakers in 220 and 110 kV should have interruption capacity to handle these levels.

4.5 Transient Stability Analysis

The previous analysis simulated the system behavior under steady state conditions, assuming that the system will survive the transient period (first 20 seconds) after a contingency occurs.

In order to study the transient behavior of the system a worst case scenario of a three phase fault at different parts of the system was studied for Turkmenistan Option 1. It should be realized that three phase faults are rare. Generally single phase to ground faults have greater chances of occurring and these are less onerous. It is recommended that further studies be done to study these cases in detail when the Turkmenistan System details are available and a comprehensive study can be performed.

4.5.1 Generator Units Model

The models block diagrams and data are included in appendix F.

Three models were used for each unit, the generator model, the excitation system model and the governor model.

The model selection and data set up were done using the Siemens PTI models library and standard data.

4.5.2 Selected Events

Using the results of the steady state analysis the more critical contingencies were selected in order to be evaluated under transient conditions. These are:

- Event 1: Loss of the 500 kV Serdar-Border line
- Event 2: Loss of the 220 kV Sheberghan Naibabad line
- Event 3: Loss of the 220 kV Andkhoy Sheberghan line
- Event 4: Loss of the Naibabad Pul-e-kumri line
- Event 5: Loss of the Pul-e-kumri Charikar line
- Event 6 Loss of the Chimtala Charikar line
- Event 7: Loss of a transformer in Chimtala
- Event 8: bus fault in Pul-e-kumri cleared with the trip of the lines to Charikar and to Khlum.

4.5.3 Transient Stability Results

The results of the transient stability analysis are presented in a series of graphics which show in each generator bus the evolution, during the 20 seconds simulation period, of the following parameters:

- Frequency
- Angle Difference (against a reference bus)
- Power Generation in MW
- Voltage

Depending upon the results, corrective actions (load shedding) were introduced in order to preserve (if possible) system stability.

In order to illustrate the information discussed in the transient stability model output, the event number 5 is discussed in detail.

A summary of the results of all contingencies is included at the end of this section. Graphics for all the cases are included in appendix H.

4.5.3.1 Event Number 5 Results

Voltage

Figures 4.14 to 4.16 show the voltage profile in selected buses during the transient stability simulations.

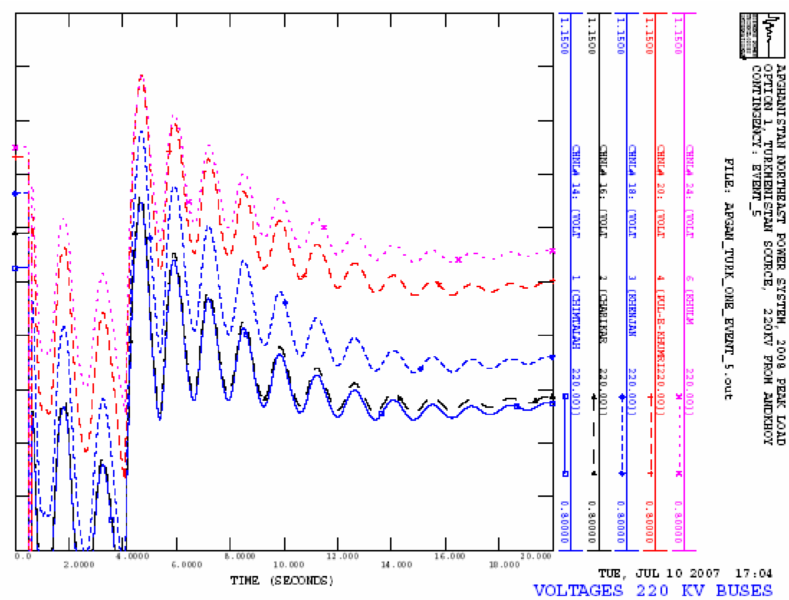


Figure 4.14 Voltages 220 kV Buses

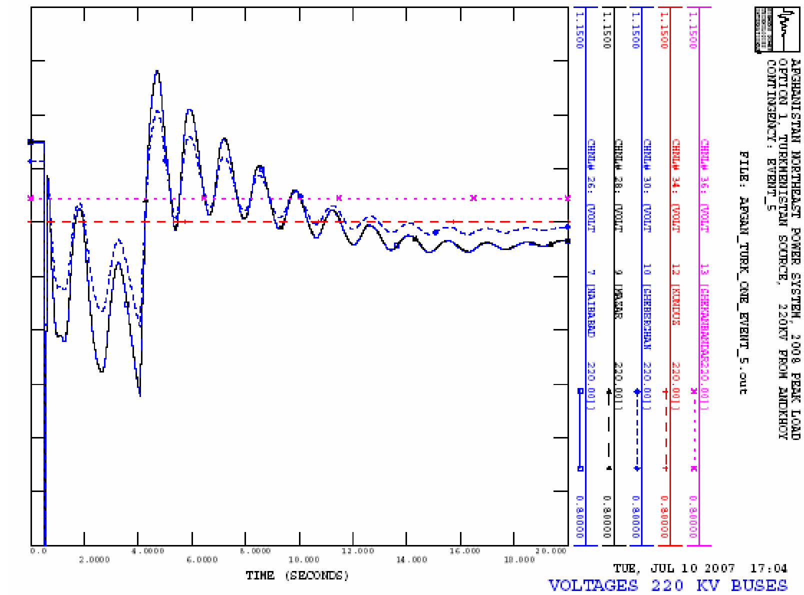


Figure 4.15 Voltages 220 kV

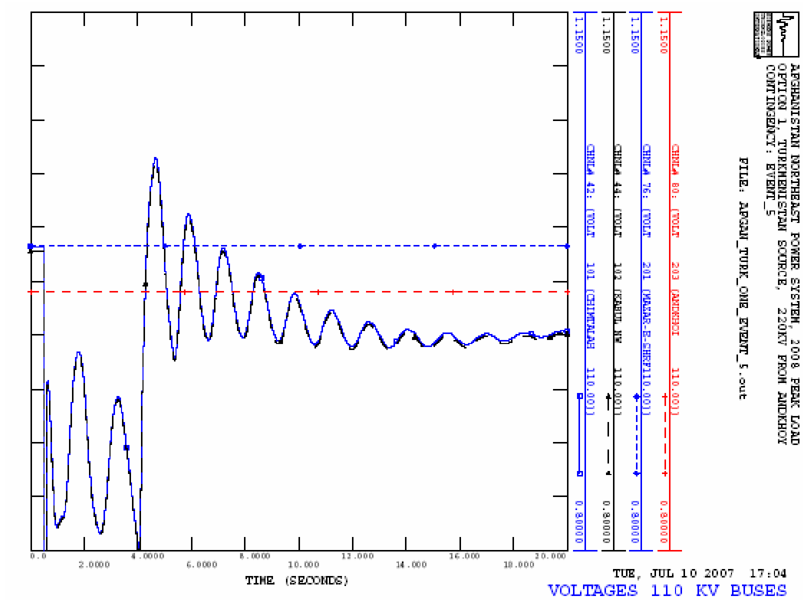


Figure 4.16 Voltages 110 kV

The voltages after the fault is cleared have the tendency to decrease rapidly. Approximately at 2 seconds, is it necessary to proceed with a load shedding of 20% of the load in busses 104 Kabul North, 102 Kabul Northwest and 101 Chimtala 110 kV. After the load shedding, the voltage recoveries immediately, reaching a stable behavior at the end of the simulation period. In order to reach this voltage recovery it was necessary to increase the shunt capacitor compensation in Pul-e-kumri substation in 5 MVAR.

Frequency

Figures 4.17 and 4.18 shows the frequency behavior in selected busses. The system frequency tends to stabilize after 10 seconds.

Rotor Angles Difference

Generators angle difference against bus 4100 Serdar are shown in figure 4.19 and 4.20. After 10 seconds all the generators angles have a stable behavior.

Generated Power

The generated power behavior is shown in figures 4.21 and 4.22. Once again all the generators tend to stabilize during the simulation interval.

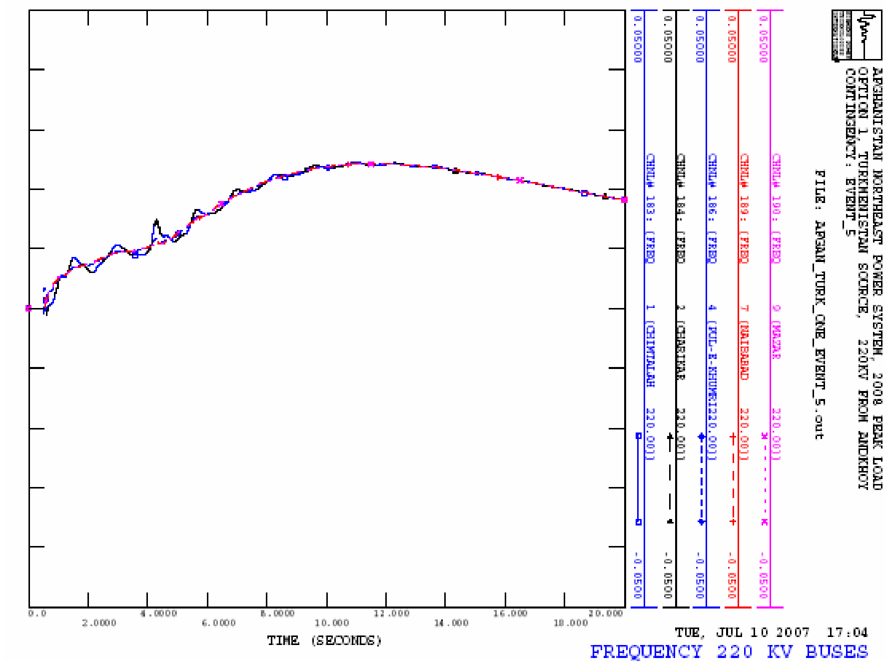


Figure 4.17 Frequency 220 kV Buses

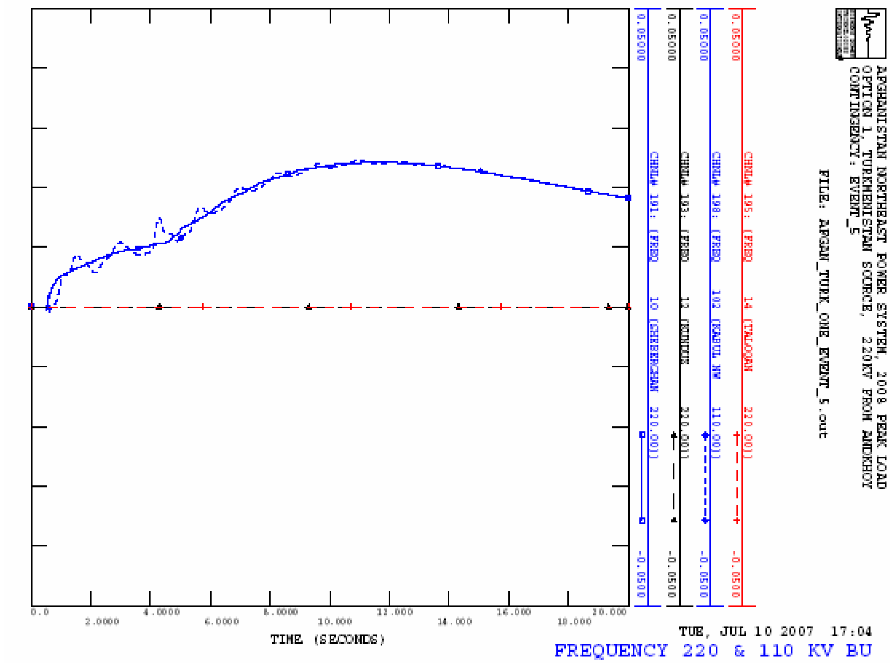


Figure 4.18 Frequency 220 & 110 kV Buses

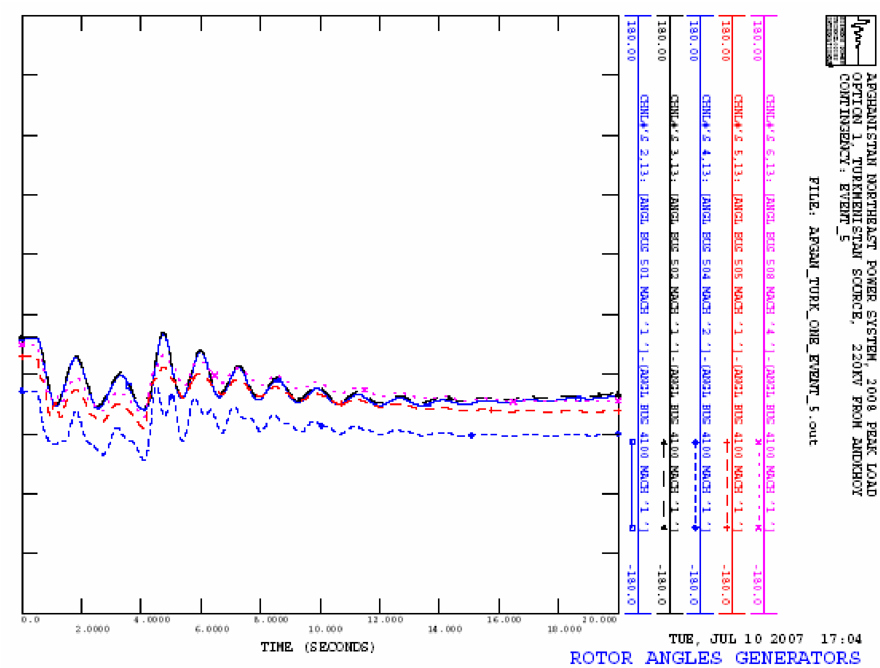


Figure 4.19 Rotor Angles

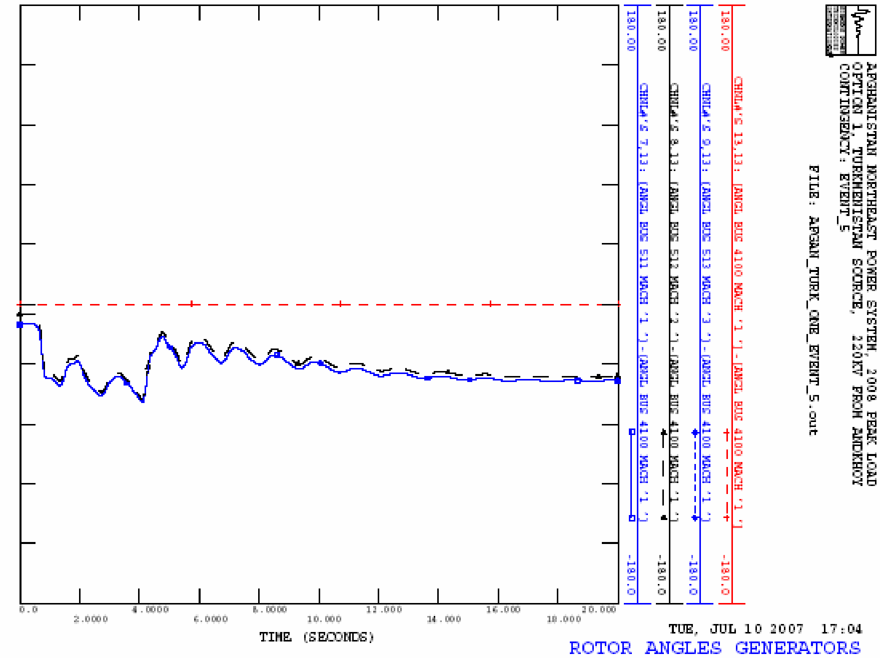


Figure 4.20 Rotor Angles

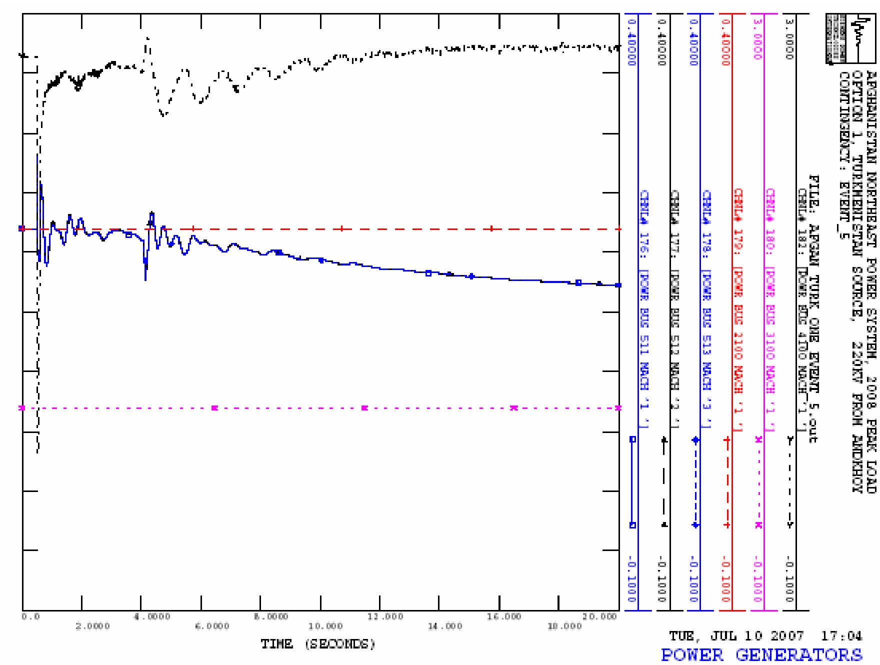


Figure 4.21 Generated Power

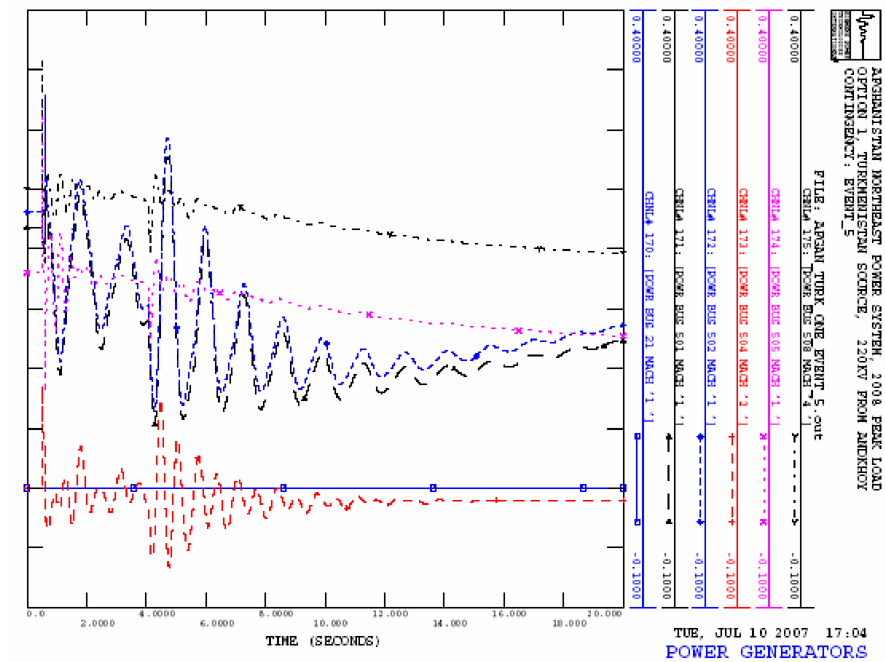


Figure 4.22 Generated Power

4.5.3.2 Summary Results

Table 4.4 summarizes the transient stability study results for all the events. Only three of them turn out to be unstable:

- Event 1, The loss of the Serder –Andkhoy line: The System becomes unstable since there is insufficient generation in Afghanistan to balance the load. The system is likely to experience a black out and has to be reestablished gradually.
- Event 5, The loss of Pul e Kumri-Charikar line: in order to survive the transient period the System requires five additional MVAR of reactive compensation and 48 MW of load shedding in Kabul. Similar load shedding is also required for Event 6.
- Event 8, The loss of the 220 kV lines from Pul e Kumri to Khulm and from Pul e Kumri to Charikar for a bus fault at Pul e Kumri. The system will become unstable and is likely to experience black out. The system has to be reestablished gradually. However it should be noted that the bus faults are rare.

TURKMENISTAN SOURCE OPTION 1 TRANSIENT STABILITY ANALYSIS RESULTS		
Event Number	Description	Comments
1	Loss of Serdar - Border 500 kV line	Unstable
2	Loss of 220 kV circuit Sheberghan - Naibabad	Stable
3	Loss of 220 kV circuit Andkhoy -Sheberghan	Stable
4	Loss of line Naibabad - Pul - E- Khumri	Stable
5	Loss of line Pul-E-Khumri - Charikar	Unstable even with tripping of load. Aditional 5 MVAr required at Pul_E-Khumri to have stable system but with load shedding of 20 % on buses 104 (24 MW) 102 (13 MW) 101 (11 MW)
6	Loss of Chimtalah - Charikar	Unstable unless load shedding of 20% at buses 104 (24 MW) 102 (13 MW) 101 (11)
7	Loss of Chimtalah Transformer	Stable
8	Fault in Pul-E-Kumri bus with Loss of line Pul-E-Kumri - Charikar and Pul-E-Khumri - Khulm	Unstable

Table 4.4 Transient Stability Results for Afghanistan Option 1

Section

5

Uzbekistan Source

This section of the report describes the main results and findings in the power system analysis of the different interconnection options for the Uzbekistan Source. Siemens PTI software PSSE 30.1 was used for load flow, contingency and active and reactive power margin studies.

Transient stability analysis for Uzbekistan source was not included in the scope of work.

5.1 Interconnection Options

Three options were studied for the import of power from the Uzbekistan source to Kabul.

Option 1

This option is indicated in figure 5.1 and models the import of power over a new 220 kV transmission line from Surkhan substation in Uzbekistan to Naibabad Switchyard and the existing 110 kV transmission line from Amu substation in Uzbekistan to Mazar e Sherif.

The new 220 kV line will have a length of 48 km for Surkhan to the border and then 55 km from the border to Naibabad Switchyard for a total length of 103 km.

Option 2

This option is indicated in figure 5.2 and models the import of power over a new 220 kV double circuit transmission line from Surkhan substation to Naibabad switchyard in Afghanistan.

The existing 110 kV line from Amu to Mazar will be disconnected for this option. Mazar load will be supplied from Naibabad through the 220 kV double circuit line under construction.

Option 3

This option is indicated in figure 5.3 and models the import of power over a new 220 kV transmission line from Amu substation in Uzbekistan to Naibabad and the existing 110 kV transmission line from Amu substation in Uzbekistan to Mazar e Sherif.

The new 220 kV line will have a length of 16 km from Amu substation to border and 71 km from border to Naibabad. .

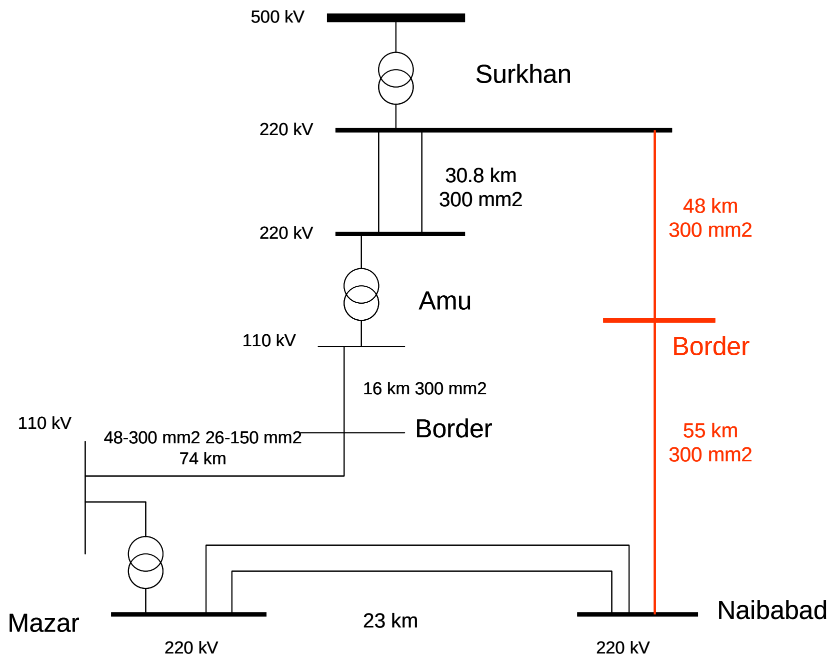


Figure 5.1 Uzbekistan Source Option 1

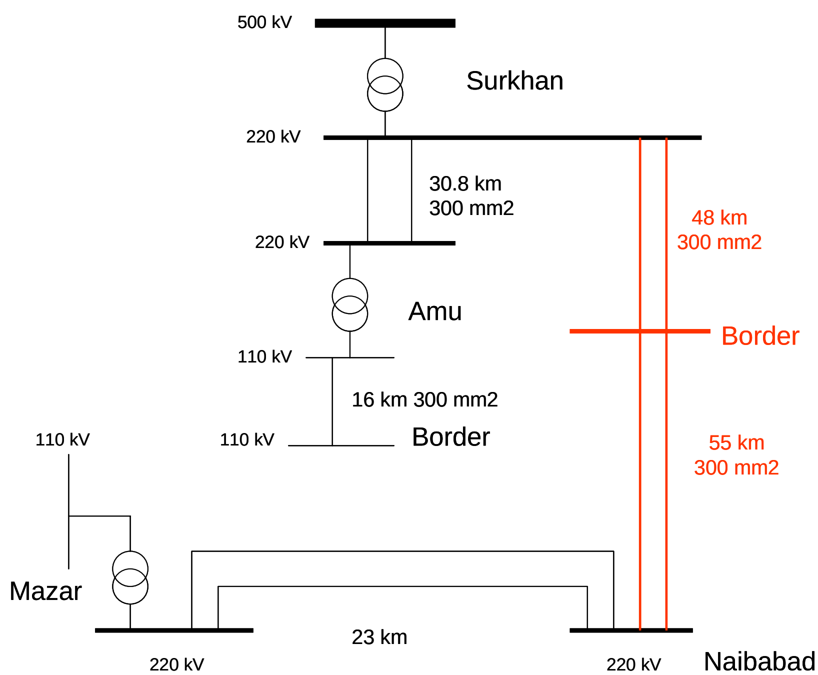


Figure 5.2 Uzbekistan Source Option 2

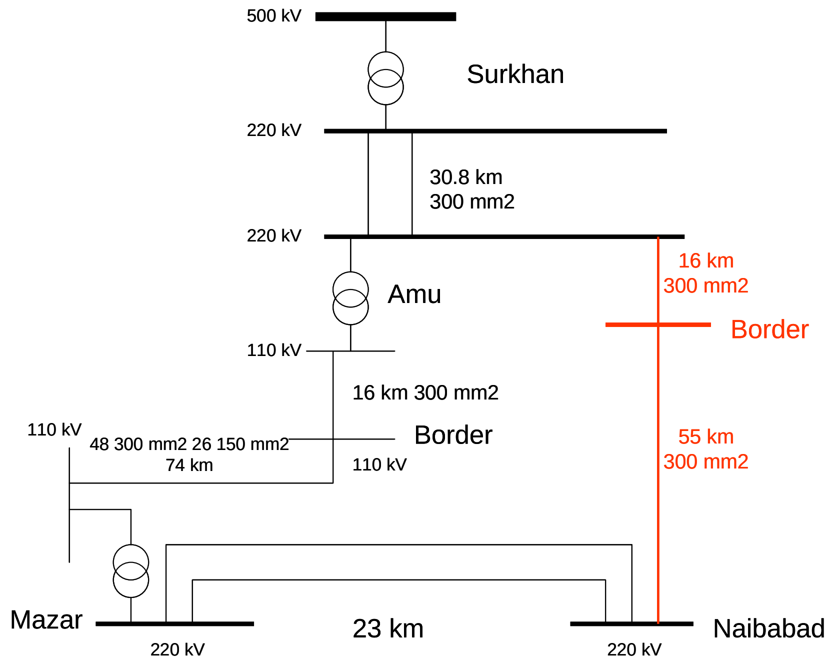


Figure 5.3 Uzbekistan Source Option 3

5.2 PV and V-Q Analysis

5.2.1 V-Q Analysis

QV analysis was performed for all the 3 options. Results are presented in figures 5.4 to 5.6.

The following conclusions can be obtained from the figures:

- The critical point in all the options is between 0.90 and 0.95 pu.
- The reactive compensation margin for the base case is around zero which indicates that not further compensation will prevent the system for a voltage collapse.

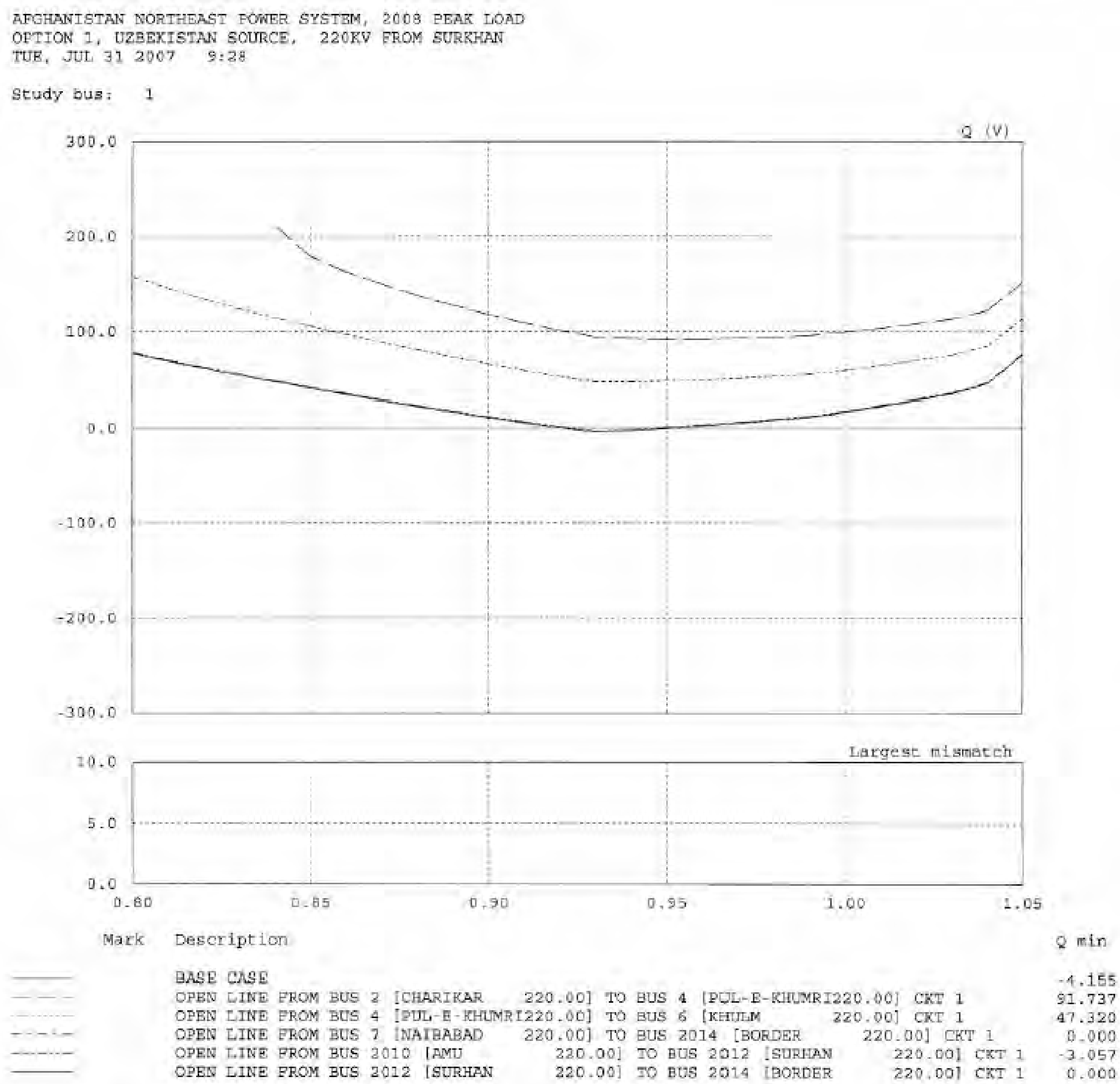


Figure 5.4 QV Results Uzbekistan Option 1

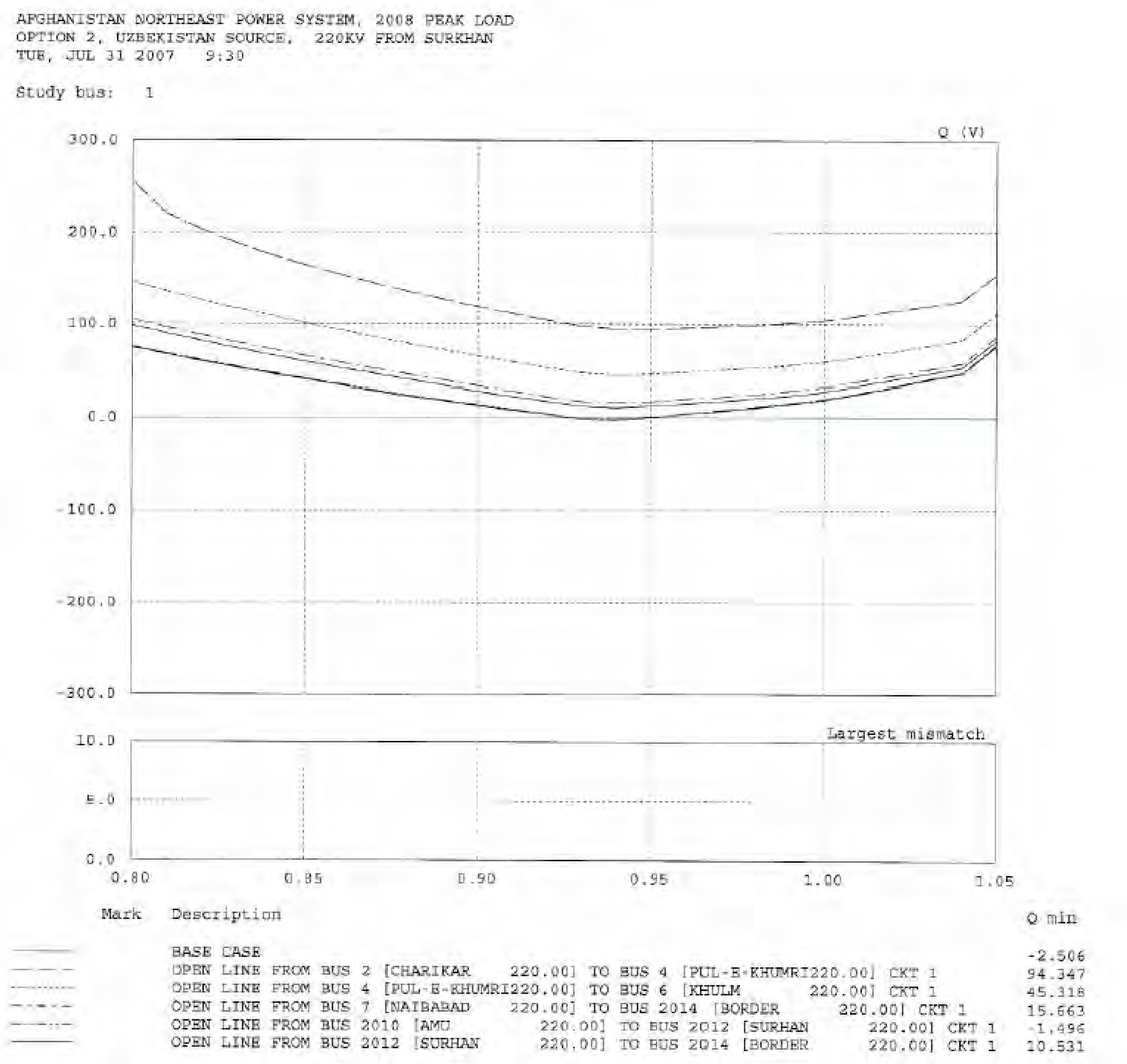


Figure 5.5 QV Results Uzbekistan Option 2

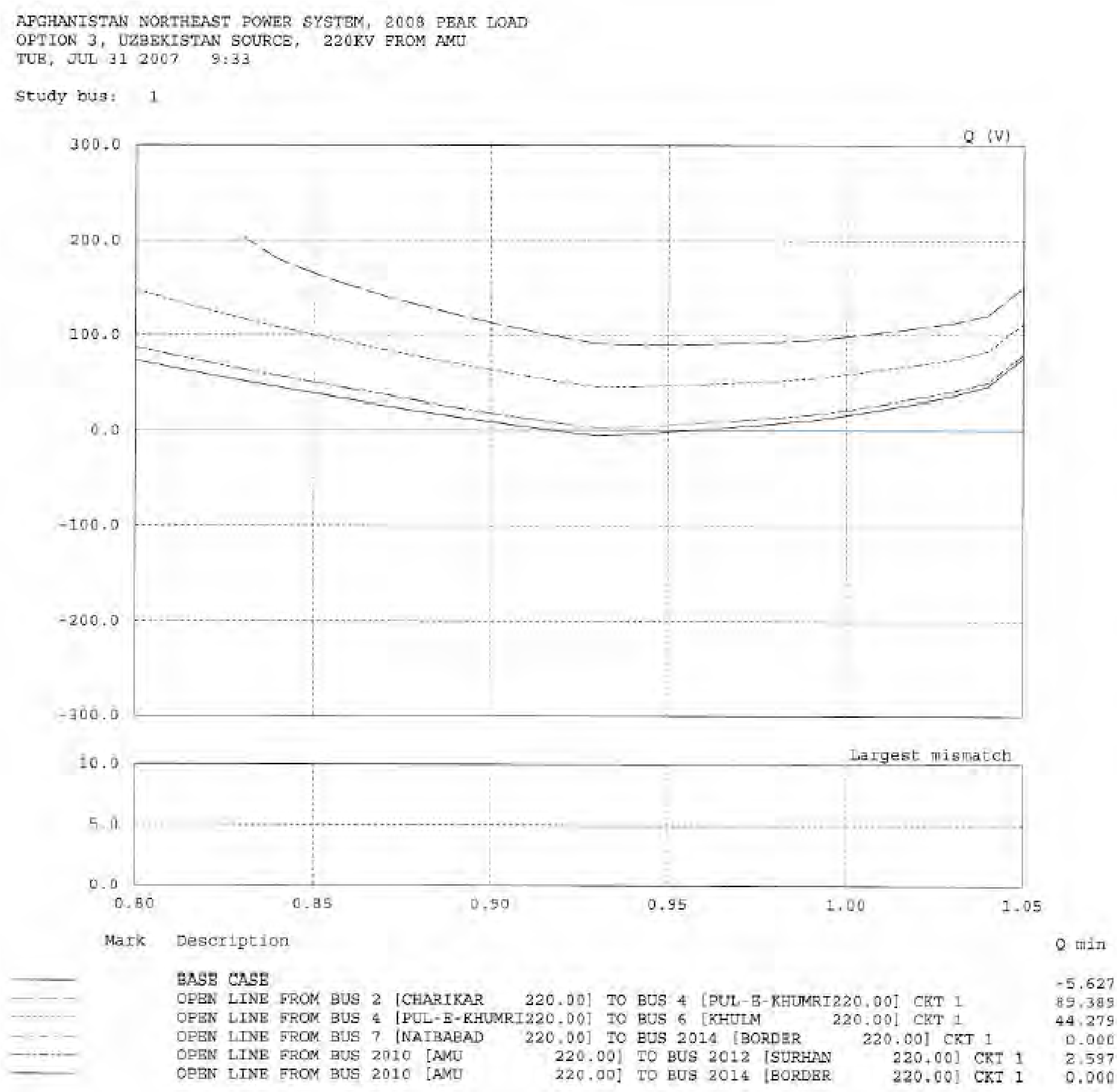


Figure 5.6 QV Results Uzbekistan Option 3

5.2.2 PV Analysis

Figures 5.7 to 5.9 show the PV curves for each option. The curves indicate the voltage performance in Chimtala 110 kV with different increments in the transfer level over a specified initial load in the Kabul area. Curves for normal conditions and contingencies are included.

The results of PV analysis can be considered as an initial estimation of the transfer limit. However they need to be verified with conventional load flow. The following results were obtained for each option:

5.2.2.1 Option 1

Figure 5.7 shows the PV curve for Uzbekistan option 1. The curve shows the bus voltage performance in per unit for the different cases against the increment in the transfer limit over an initial value. For this option the initial value was set in 180 MW.

In normal conditions it can be seen that after 20 MW incremental transfer the voltage level in Chimtala, starts to decrease with an increasing slope, collapsing between 50 to 55 MW. This means than the transfer limit in normal conditions could be around 230 MW. Results that need to be verified further with a detailed load flow analysis.

The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can only be increased in less than 15 MW.

5.2.2.2 Option 2

Figure 5.8 shows the PV curve for Uzbekistan option 2. For this option the initial value is 180 MW.

Again In normal conditions, after 20 MW incremental transfer the voltage level in Chimtala, starts to decrease with an increasing slope, collapsing in around 60 MW. This means than the transfer limit in normal conditions could be around 240 MW. Results that need to be verified further with a detailed load flow analysis.

The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can only be increased in less than 20 MW.

5.2.2.3 Option 3

Figure 5.9 shows the PV curve for Uzbekistan option 3. For this option the initial value is 190 MW.

Under normal conditions the transfer limit can be incremented in over 40 MW. The worst contingency is loss of the line Pul-e-kumri – Charikar in which the transfer limit can be increased in around 3 MW.

Figure 5.7 PV Results Uzbekistan Option 1

Figure 5.8 PV Results Uzbekistan Option 2

Figure 5.9 PV Results Uzbekistan Option 3

5.3 Steady State Analysis

The results obtained in the QV and PV studies were validated with detailed load flow analysis.

In a first step, reactive compensation was adjusted in order to improve the transfer limit as much as possible.

The second step was to run the load flow cases in order to define the maximum transfer limit to Kabul area, under normal conditions and under contingencies.

Finally, light load conditions were simulated in order to define additional reactive compensation requirements.

5.3.1 Reactive Compensation

Table 5.1 shows the required reactive compensation for all the options, in order to maximize the power transfer to Kabul area.

Reactive Compensation (MVAR)	Chimtala 220 kV		Chimtala 110 kV		Kabul North 110 kV		Pul-E-Khumri 220 kV	
Case	C	R	C	R	C	R	C	R
Option 1 Maximum Transfer	80		20		20		25	
Option 2 Maximum Transfer	80		20		20		25	
Option 3 Maximum Transfer	80		20		20		25	

C	Capacitors
R	Reactors

Table 5.1 Uzbekistan Maximum Transfer Reactive Compensation

In summary 100 MVAR in shunt capacitors are required in Chimtala substation: 80 MVAR in 220 kV and 20 MVAR in 110 kV. 20 MVAR are required in Kabul North 110 kV.

Additionally 25 MVAR shunt capacitors are required in Pul-e-kumri 220 kV substation.

These requirements are similar to the ones for the Turkmenistan supply options.

No reactors are required under maximum transfer conditions.

5.3.2 Maximum Transfer

Table 5.2 summarizes the steady state analysis results for all the Uzbekistan options under maximum transfer conditions. System losses under normal conditions are also reported for each option.

The following normal conditions cases were analyzed:

- Normal: in this case no intermediate loads are included in 220 kV substations between the source and Chimtala. The transmission link is basically dedicated to transfer power from the source to Kabul.
- Normal with loads in 220 kV and 100 MW in Sheberghan: in this case intermediate 220 kV loads are included in the analysis, and a new 100 MW generation plant is connected to Sheberghan substation in 110 kV.
- Normal without loads in 220 kV and 100 MW in Sheberghan: same at the previous case but without intermediate 220 kV loads.

UZBEKISTAN SOURCE Power Transfer Limit to Chimtala 110 kV Bus (MW)			
Case	**Option 1**	**Option 2**	**Option 3**
Normal	230.4	242.0	231.4
Normal with local loads (*) and Sheberghan-Naibabad Line	208.8	220.2	220.6
Normal without local loads (*) and Sheberghan-Naibabad Line	256.0	263.8	259.0
Contingency Pul E Kumri - Charikar	193.2	200.8	194.6
Contingency Naibabad-Pul E Kumri	209.8	219.0	208.2
Contingency Surkhan Naibabad 220 kV	63.6	227.4	NA
Contingency Amu Border 220 kV	NA	NA	79.6
Contingency Amu Surkhan 220 kV	226.0	NA	229.8
Contingency Border Mazar 110 kV	227.4	242.0	228.6
Contingency Loss a Transformer in Mazar	226.6	247.4	233.8
Contingency Loss a Transformer in Chimtala	143.5	144.7	144.6
System Wide Losses (MW)	44.0	40.4	42.2

*Condition where all the substations along the 220 kV line are loaded.

Table 5.2 Uzbekistan Maximum Transfer Results

The following conclusions can be obtained from the results:

- Option 2 provides the maximum power import capability. Under this option a maximum of 242 MW can be imported into the 110 kV bus in Chimtala under normal conditions and no additional loads in the rest of the 220 kV substations. Option 2 has also the minimum system wide losses.

- With loads in the intermediate substations at Mazar, Sheberghan, Khulm, Aybak, Pul e Kumri, Kenjan and Charikar supplied and with the new power plant in Sheberghan, the transfer limit decreases by 22 MW.

- Without loads in the intermediate substations at Mazar, Sheberghan, Khulm, Aybak, Pul e Kumri, Kenjan and Charikar supplied and with the new power plant in Sheberghan, the transfer limit can go up to 264 MW.

- The worst contingency is noted to be the loss of one transformer in Chimtala where the maximum load that can be transferred is limited in a range between 143 and 145 MW.

- The second worst contingency the loss of the Pul-e-kumri - Charikar line when the transfer limit is limited to a range between 193 to 201 MW.

It should be noted that to facilitate the reduced power transmission capability under contingency conditions load shedding should be implemented by suitable relay devices.

Load flow results for each case are presented in Appendix I to K.

5.3.3 Light Load Cases

Light Load Cases were simulated for each of the supply options. For these cases the load in Kabul area was adjusted up to the level at which the net transfer to the Chimtala substation reaches 50 MW.

The objective of the light load cases analysis is to verify that the voltage levels in the system busbars are between the normal conditions margin. In the case that over voltages were present the first step was to disconnect the shunt compensation. If even with the shunt compensation disconnected the voltage limit is exceeded then shunt reactors were added to the system.

Two light load cases were analyzed for each option. In the first case both the 220 kV Naibabab Chimtala lines were in service. In the second case one of the lines was disconnected as a corrective measure to reduce over voltages. In our opinion, the second option is not feasible from the operational point of view, since the disconnection of the line every day during the light load hours will reduce circuit breakers life and will increase its maintenance costs.

Results are shown in table 5.3. The following conclusions can be obtained from the results:

- Under light load conditions all the shunt capacitors banks need to be disconnected.

- For Options 1 and 3, an additional reactor between 20 and 35 MVAR, is required in Naibabad 220 kV switchyard. In option 1, this reactor can be reduced to 20 MVAR if one of the Chimtala Naibabad lines is disconnected.

- 500 kV reactors are required in Surkhan for Options 2 and 3 in a range between 40 to 80 MVAR. In option 2 the reactor can be reduced from 80 to 45 MVAR if one of the Chimtala Naibabad lines is disconnected. For option 3 also the reactor is no longer required under the same condition.

The load flows for the cases with light load conditions are included in Appendix I to K.

Reactive Compensation (MVAR)	Chimtala 220 kV		Chimtala 110 kV		Kabul North 110 kV		Pul-E-Khumri 220 kV		Naibabad 220 kV		Surkhan 500 kV	
Case	C	R	C	R	C	R	C	R	C	R	C	R
Option 1 Maximum Transfer Light Load Light Load 1 Line 220 kV Off	80 (disconnected under light load)		20 (disconnected under light load)		20 (disconnected under light load)		25 (disconnected under light load)			 35 20		
Option 2 Maximum Transfer Light Load Light Load 1 Line 220 kV Off	80 (disconnected under light load)		20 (disconnected under light load)		20 (disconnected under light load)		25 (disconnected under light load)					 80 45
Option 3 Maximum Transfer Light Load Light Load 1 Line 220 kV Off	80 (disconnected under light load)		20 (disconnected under light load)		20 (disconnected under light load)		25 (disconnected under light load)			 20 20		 40

C Capacitors
R Reactors
Disconnected Under Light Load

Table 5.3 Uzbekistan Light Load Cases Reactive Compensation

5.4 Short Circuit Analysis

Short circuit simulations were run using the ANSI standards, each of the options. The reports are included in Appendix L.

The summary report for each fault case includes the following:

- The bus number, name and base voltage of the faulted bus, along with the maximum operating voltage and contact parting time input values.

- Three phase fault results, including symmetrical fault MVA, symmetrical fault current in kA, asymmetrical fault current in kA, the ANSI X/R ratio, and the multiplying factor.

- Line-to-ground fault results, including symmetrical fault current in kA, asymmetrical fault current in kA, the ANSI X/R ratio, and the multiplying factor.

- Line-to-line-to-ground fault results, including symmetrical phase current in kA, and three times the zero sequence symmetrical faults current in kA.

- The positive sequence Thevenin impedance as obtained from the decoupled positive sequence admittance matrices.

- The zero sequence Thevenin impedance as obtained from the decoupled zero sequence admittance matrices.

In all the options the short circuit levels are below 7 kA in any bus and for any fault condition. Standard Circuit Breakers in 220 and 110 kV should have interruption capacity to handle these levels.

Section

6

Tajikistan Source

This section of the report describes the main results and findings in the power system analysis of the interconnection to the Tajikistan Source. Siemens PTI software PSSE 30.1 was used for load flow, contingency and active and reactive power margin studies.

Transient stability analysis for Tajikistan source was not included in the scope of work.

6.1 Interconnection Options

Tajikistan proposed interconnection scheme is shown in figure 6.1. The interconnection point in Tajikistan will be the Sangtuda 220 kV substation. Two 220 kV circuits will go from Sangtuda to the border and from there to Kunduz and to Pul-e-kumri. The distance from Sangtuda to the border is 117 km and from the border to Pul-e-kumri 156 km. The total distance from the source to the Pul-e-kumri will be 273 km.

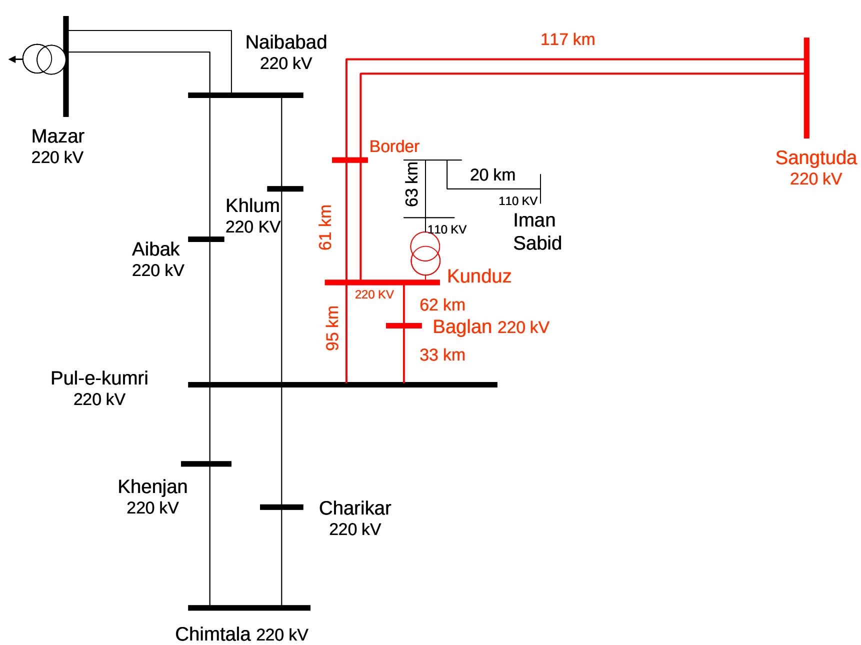


Figure 6.1 Tajikistan 220 kV Source Option

A special case was analyzed in which the existing 110-35 kV interconnection between Geran (in Tajikistan) and Kunduz is upgraded to 110 kV and is used to reinforce the 220 kV circuits as shown in figure 6.2.

At present Geran substation is interconnected by a 75 km single 220 kV line from Golovnaya. A 32 km double circuit 220 kV line connects Golovnaya with Sangtuda.

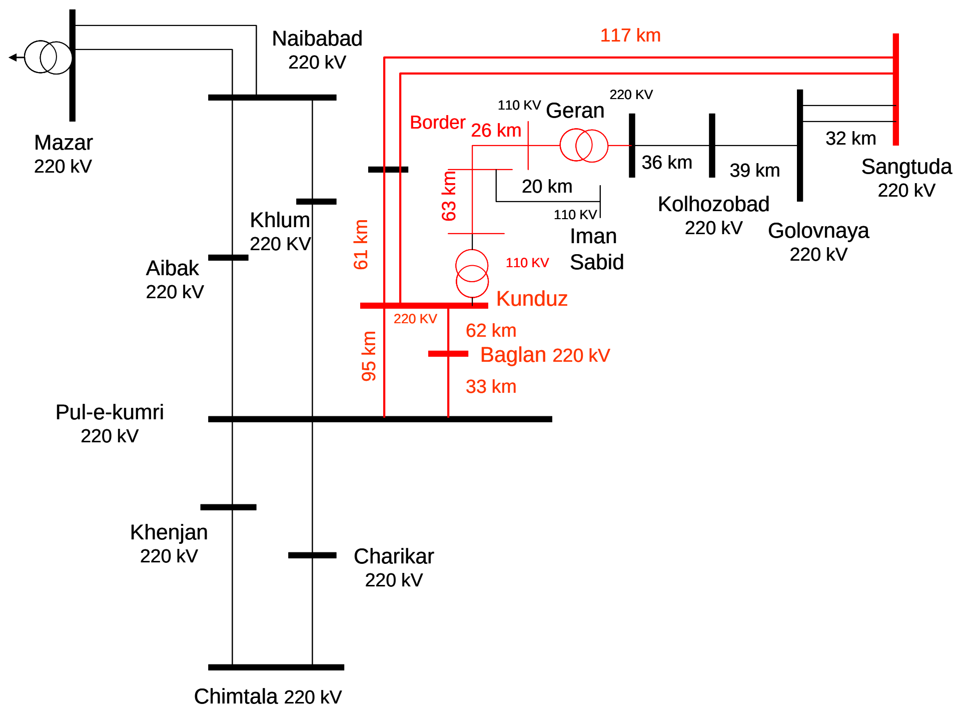


Figure 6.2 Tajikistan 220 kV and 110 kV Source Option

6.2 PV and V-Q Analysis

6.2.1 V-Q Analysis

QV analysis was performed for the proposed interconnection. Results are presented in figure 6.3

The following conclusions can be obtained from the figures:

- The critical point in all the options is between 0.90 and 0.95 pu.
- The reactive compensation margin for the base case is around zero which indicates that not further compensation will prevent the system for a voltage collapse.

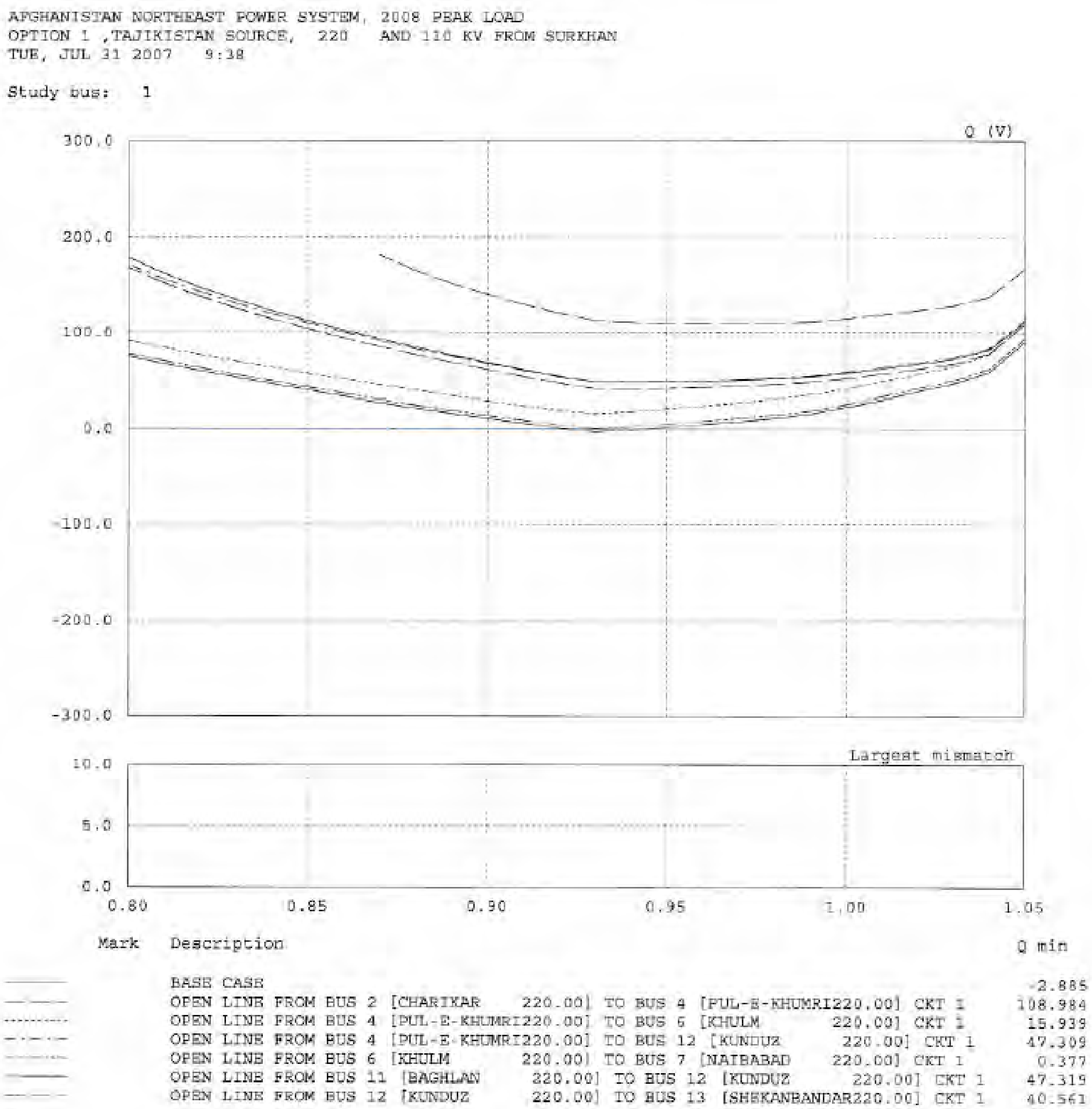


Figure 6.3 QV Results Tajikistan 220 kV Option

6.2.2 PV Analysis

Figure 6.4 shows the PV curves for Tajikistan option 1. The curve indicates the voltage performance in Chimtala 110 kV with different increments in the transfer level over a specified initial load in the Kabul area. Normal conditions and contingencies are included.

The results of PV analysis can be considered as an initial estimation of the transfer limit. However they need to be verified with conventional load flow.

The curve in the figure shows the bus voltage performance in per unit for the different cases against the increment in the transfer limit over an initial value. For this option the initial value was set in 180 MW.

In normal conditions the voltage level in Chimtala, starts to decrease with an increasing slope, collapsing between 40 to 45 MW. This means than the transfer limit in normal conditions could be around 220 MW. Results that need to be verified further with a detailed load flow analysis.

The worst contingency is loss of the line Pul-e-kumri –Charikar in which the transfer limit can only be increased in less than 5 MW.

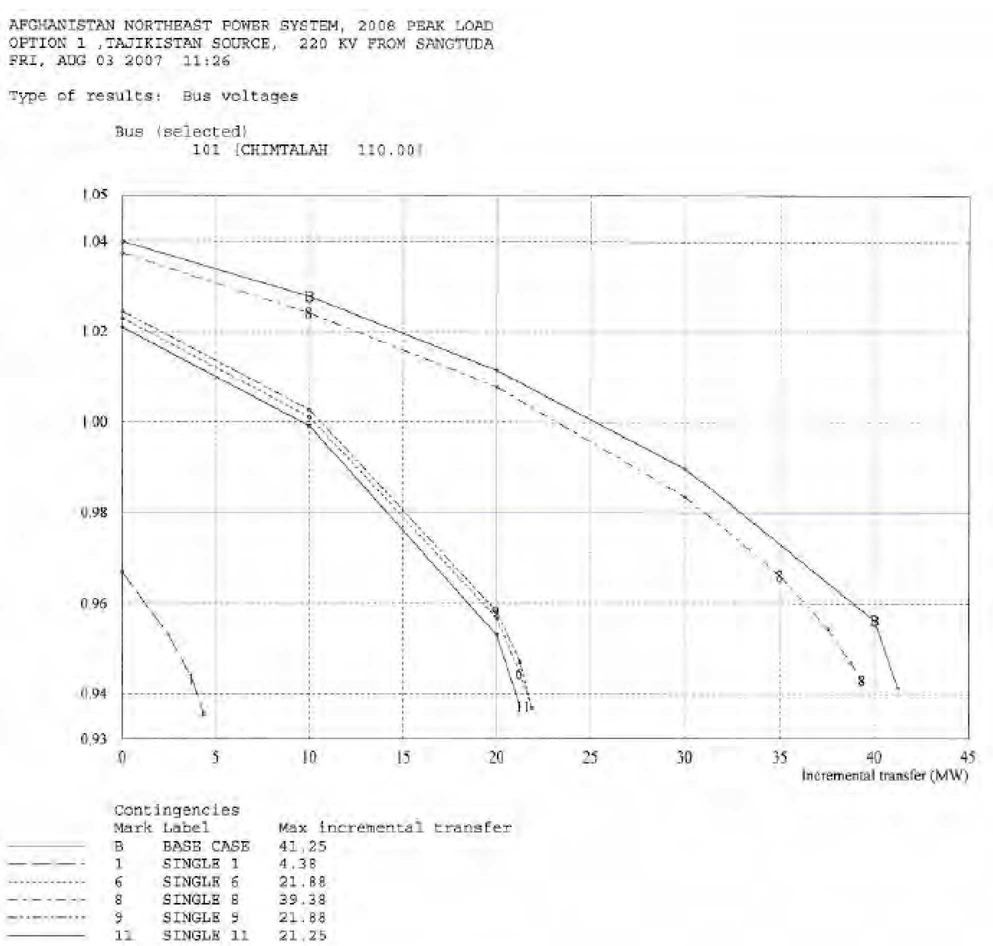


Figure 6.4 QV Results Tajikistan 220 kV Option

6.3 Steady State Analysis

The results obtained in the QV and PV studies were validated with detailed load flow analysis.

In a first step, reactive compensation was adjusted in order to improve the transfer limit as much as possible.

The second step was to run the load flow cases in order to define the maximum transfer limit to Kabul area, under normal conditions and under contingencies.

Finally, light load conditions were simulated in order to define additional reactive compensation requirements.

6.3.1 Reactive Compensation

Table 6.1 shows the required reactance in order to maximize the power transfer to Kabul area.

Reactive Compensation (MVAR)	Chimtala 220 kV		Chimtala 110 kV		Kabul North 110 kV		Pul-E-Khumri 220 kV		Kunduz 220 kV	
Case	C	R	C	R	C	R	C	R	C	R
Option 220 kV Source Maximum Transfer	100		20		20		50		40	

C	Capacitors
R	Reactors

Table 6.1 Tajikistan Maximum Transfer Reactive Compensation

In summary 120 MVAR in shunt capacitors are required in Chimtala substation: 100 MVAR in 220 kV and 20 MVAR in 110 kV. 20 MVAR are required in Kabul North.

Additionally between 50 MVAR in shunt capacitors are required in Pul-e-kumri 220 kV substation and 40 MVAR in Kunduz 220 kV.

No reactors are required under maximum transfer conditions.

6.3.2 Maximum Transfer

Table 6.2 summarizes the steady state analysis results under maximum transfer conditions. System losses under normal conditions are also reported.

The following normal conditions cases were analyzed:

- Normal: in this case intermediate loads were not included in the 220 kV substations. Mazar and Sheberghan areas were disconnected from the NEPS system and connected to Uzbekistan and Turkmenistan sources

- Normal with Taluqan load out: similar to the previous case but with all the loads associated with the Taluqan substation disconnected from the system. This case the transmission link is basically dedicated to transfer from Sangtuda to Kabul.

- Normal with Mazar and Sheberghan loads: in this case Mazar and Sheberghan are connected to Naibabad 220 kV switchyard. The new 100 MW generation in Sheberghan is on line. This case was also analyzed with the intermediate 220 kV loads disconnected.

- Normal with Mazar, Sheberghan and Geran Kunduz 110 kV: same as the previous case but including the 110 kV interconnection from Geran.

TAJIKISTAN SOURCE Power Transfer Limit to Chimtala 110 kV Bus (MW)	
Case	**Option 220 kV Source**
Normal Conditions	229.6
Normal with Taluqan Load Out	241.2
Contingency Pul E Khumri - Charikar	188.2
Contingency Naibabad-Pul E Khumri	226.8
Contingency Kunduz-Pul E Khumri	208.0
Contingency Kunduz- Baghlan	209.2
Contingency Shekanbandar-Kunduz	211.0
Contingency Sangtuda Shekanbandar	194.8
Contingency Loss a Transformer in Chimtala	149.2
Normal with Mazar, Line Sheberghan-Naibabad	216.0
Normal with Mazar, Line Sheberghan-Naibabad no 220 kV Loads (*)	270.0
Contingency Santugda Sherkanbandar with Mazar, Line Sheberghan-Naibabad	181.0
Normal with Mazar, Line Sheberghan-Naibabad and Geran Kunduz 110 kV	235.6
kV	204.2

System Wide Losses (MW)	64.2

*Condition where all the substations along the 220 kV line are loaded.

Table 6.2 Tajikistan Maximum Transfer Results

The following conclusions can be obtained from the results:

- Under normal conditions 229.6 MW is the transfer limit to Kabul area. This limit can be increased to 241.2 MW if Taluqan is disconnected from the system. If Mazar and Sheberghan loads are supplied from Tajikistan then the transfer limit to Kabul decreases to 216 MW. This is increased to 235.6 MW if the 110 kV Geran Kunduz line is working in parallel with the 220 kV Sangtuda Kunduz line.

- With the new Sheberghan power plant connected to the system and no intermediate loads in 220 kV, the transfer limit can go up to 270 MW. However an additional 50 MVAR reactor is required in Naibabad 220 kV to avoid over voltages, since the lines Pul-E-Kumri – Naibabad – Sheberghan are light loaded when the intermediate loads are disconnected.

- The worst contingency is noted to be the loss of one transformer in Chimtala when the maximum load that can be transferred is limited to 149.2 MW.

- The second worst contingency is the loss of Sangtuda-Sherkhanbandar line –and Mazar, Sheberghan load supplied by Tajikistan. In this case the transfer is limited to 181 MW

It should be noted that to facilitate the reduced power transmission capability under contingency conditions load shedding should be implemented by suitable relay devices.

Load flow results for each case are presented in Appendix M.

6.3.3 Light Load Cases

Light Load Cases were simulated by adjusting the load in Kabul area to the level in which the net transfer to the Chimtala substation reaches 50 MW.

The objective of the light load cases analysis is to verify that the voltage levels in the system busbars are between the normal conditions margin. In the case that over voltages were present the first step was to disconnect the shunt compensation. If even with the shunt compensation disconnected the voltage limit is exceeded then shunt reactors were added to the system.

Two light load cases were analyzed. In the first case both 220 kV Naibabad Chimtala lines were in service. In the second case one of the lines was disconnected as a corrective measure to reduce over voltages. In our opinion, the second option is not feasible from the operational point of view, since the disconnection of the line every day during the light load hours will reduce circuit breakers life and will increase its maintenance costs.

Results are shown in table 6.3. The following conclusions can be obtained from the results:

- Under light load conditions the shunt capacitors banks Chimtala and Pul-e-kumri need to be disconnected.

- A 10 MVAR reactor is required in Naibabad 220 kV switchyard and a 75 MVAR reactor is required in Sangtuda 220 kV switchyard when both Naibabad-Chimtala lines are in operation.

- If one of the Chimtala – Naibabad lines is disconnected then no reactor is required in Chimtala 220 kV and the Sangtuda reactor can be reduced to 65 MVAR from 75 MVAR.

The load flows for the cases with light load conditions are included in Appendix M.

Reactive Compensation (MVAR)	Chimtala 220 kV		Chimtala 110 kV		Kabul North 110 kV		Pul-E-Khumri 220 kV		Naibabad 220 kV		Kunduz 220 kV		Sangtuda 220 kV	
Case	C	R	C	R	C	R	C	R	C	R	C	R	C	R
Option 220 kV Source														
Maximum Transfer	~~100~~		~~20~~		~~20~~		~~50~~				40			
Light Load										10				75
Light Load 1 Line 220 kV Off														65

C Capacitors
R Reactors
↘ Disconnected Under Light Load

Table 6.3 Tajikistan Light Load Cases Reactive Compensation

6.4 Short Circuit Analysis

Short circuit simulations were run using the ANSI standards. The reports are included in Appendix N.

The summary report for each fault case includes the following:

- The bus number, name and base voltage of the faulted bus, along with the maximum operating voltage and contact parting time input values.
- Three phase fault results, including symmetrical fault MVA, symmetrical fault current in kA, asymmetrical fault current in kA, the ANSI X/R ratio, and the multiplying factor.
- Line-to-ground fault results, including symmetrical fault current in kA, asymmetrical fault current in kA, the ANSI X/R ratio, and the multiplying factor.
- Line-to-line-to-ground fault results, including symmetrical phase current in kA, and three times the zero sequence symmetrical faults current in kA.
- The positive sequence Thevenin impedance as obtained from the decoupled positive sequence admittance matrices.

- The zero sequence Thevenin impedance as obtained from the decoupled zero sequence admittance matrices.

The short circuit levels are below 8 kA in any bus and for any fault condition.

Appendix

A

System Data

Appendix

B

Turkmenistan Option 1 Load Flows

Appendix

C

Turkmenistan Option 2 Load Flows

Appendix

D

Turkmenistan Option 3 Load Flows

Appendix

E

Turkmenistan Option 4 Load Flows

Appendix

F

Turkmenistan Short Circuit Results

Appendix

G

Transient Stability Models and Data

Appendix

H

Transient Stability Results

Appendix

I

Uzbekistan Option 1 Load Flows

Appendix

J

Uzbekistan Option 2 Load Flows

Appendix

K

Uzbekistan Option 3 Load Flows

Appendix

L

Uzbekistan Short Circuit Results

Appendix

M

Tajikistan Option 1 Load Flows

Appendix

N

Tajikistan Short Circuit Results