AZERBAIJAN-GEORGIA-TURKEY
AGT POWER BRIDGE PROJECT

Working Group Phase II

Final Report

Study of the Technical Potential for Trade of Electricity Between the Countries of Azerbaijan, Georgia and Turkey

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This Report was prepared by the United States Energy Association and Turkish Electricity Transmission Company as the volunteer Technical Coordinator of the AGT Power Bridge Project

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Contents

EXECUTIVE SUMMARY

The Azerbaijan-Georgia-Turkey (AGT) Power Bridge Project was established in 2009 by Azerenerji, the Georgian State Electrosystem and the Turkish Electricity Transmission Company. It is supported by the United States Agency for International Development and the United States Energy Association. This report marks the completion of Phase II of its analysis. It includes the study of the technical potential for trade of electricity between the countries of Azerbaijan, Georgia and Turkey utilizing load flow studies, short circuit analysis, contingency analysis and dynamic analysis. The Turkish Electricity Transmission Company (TEIAS) of Turkey was responsible for drafting the full report.

AGT Project Goals and Objectives

The AGT Power Bridge Project was developed to study and analyze the high voltage electricity networks in Turkey, Georgia and Azerbaijan from a sub-regional perspective to determine their capacity to support increased trade and exchange of electricity. The project is supported by the participating transmission system opertors, USAID and USEA. TEIAS of Turkey serves as the technical coordinator and sub-regional model integrator.

The project recognizes that Azerbaijan and Georgia have excess generating capacity and Turkey has a rapidly growing demand for electricity. Turkey is in the final phase of testing for synchronous operation with ENTSO-E, providing an export route to Europe for Azerbaijan, Georgia and Turkey in the near future.

The AGT Power Bridge Project Phase II studies complement the analysis performed in AGT Project Phase I, which conducted preliminary load flow analyses.

The goals of the AGT Project Phase II studies are:

- Complement the AGT Project Phase I study results with dynamic analysis, including voltage and frequency stability and power quality, with a focus by the countries on the analysis which is most important from the perspective of their individual transmission grids. For example, given its large size and connection to the ENTSO-E network, voltage stability and power quality at the transmission grid close to the Georgian border are more important to TEIAS than overall frequency stability. For the Georgian State Electrosystem (GSE), frequency stability in addition to voltage stability and power quality was most important. Azerenerji did not focus on power quality as a concern given its synchronous connection with GSE. Instead, it focused on frequency and voltage stability. By combining these analyses, this report identifies the most critical technical issues for regional trade within each transmission system operator (TSO).

- Analyze the high voltage networks in each of the countries from a sub-regional perspective to identify investments that will improve the network's capacity to support trade and exchange while optimizing overall system security and reliability.

- Provide engineers and policy makers with information on transmission reinforcements within the networks necessary to support increased trade and improve system security.

- Promote the results of the analysis to a wide audience of policy and regulatory authorities, and international donors and financial institutions, and

- Emphasize the conclusions of the project and give recommendations for follow up studies.

The scope of the Phase II studies includes the following:

- Define realistic load flow scenarios.

- Conduct computer simulation analyses based on the load flow scenarios agreed to by each party, including:

    - Static load flow analysis,
    - Contingency analysis,
    - Dynamic simulations and stability analysis,
    - Power quality analysis for the border substations in Turkey and Georgia due to asynchronous connection through the high voltage direct current back-to-back (HVDC B2B) substations being constructed to connect the GSE and TEIAS systems.

- Organize interim meetings to ensure that the load flow scenarios are consistent and interim results of each party are discussed and agreed mutually, before proceding further.

Project History

The Azerbaijan-Georgia-Turkey (AGT) Power Bridge Project was established in 2009 with the signing of the Project Memoandum of Understanding by Azerenerji, the Georgian State Electrosystem (GSE), the Turkish Electricity Transmission Company (TEIAS) and the United States Energy Association. Upon execution of the MOU, the Power System Simulator for Engineers (PSS/E) was selected as the common software planning platform for the project and the United States Energy Association procured a license for the PSS/E software for Azerenreji. The Georgian State Electrosystem and TEIAS provided training in load flow and transient behavior analysis during the life of the project for Azerenerji and the Azerbaijan Research and Design Institute of Power Engineering.

The following Working Group and Steering Committee meetings were conducted at strategic intervals to discuss and review work products:

- **April 2009** – Project Memorandum of Understanding Executed

  July 2009 – GSE and TEIAS conduct training for Azereneri and the Azerbaijan Research and Design Institute of Power Engineering on the Use and Application of PSS/E for load flow analysis. Azerenerji load flow model created

- **November 2009** – Working Group meeting to select four analytical scenarios for the 2015 planing horizon.

- **January 2010** – Working Group meeting to review preliminary load flow analysis

  April 2010 – GSE conducts training for Azerenerji and the Azerbaijan Research and Design Institute of Power Engineering on the use and application of PSS/E for transient analysis.

- **September 2010** – Working Group meeting to finalize Phase I Load Flow study
- **March 2011** – Working Group meeting to commence Phase II Transient Analysis study, add interim planning year models for 2013, 2015 and 2017 and select additional scenarios for analysis
- **November 2011** – Working Group meeting to review of draft findings of Phase II Transient Analysis study
- **February 2012** – Steering Committee meeting to accept Final Phase II report

Main Conclusions

- Capacity values of the HVDC B2B substations are utilized in the analysis as the physical transfer limits to determine the secure transfer limits. After establishing the asychronous connections in the future, the actual transfer amounts will be determined based on the realization of transmission investments, network security level and electricity market conditions of all countries.
- Particularly during Spring scenarios, when most of the hydroelectric power plants in the Turkish region close to border are operating with a high capacity factor, the import capacity from Georgia should be determined by the dispatching department considering the most recent system topology and giving the priority to system security.
    - Depending on the electricity market conditions in Turkey, redispatching might be necessary in this region as a short term measure to resolve the transmission bottleneck (e.g., 2013 expected minimum load conditions) in either the day ahead market mechanism or the balancing and settlement market mechanism.
- The secure amount of electricity export/import between countries depends on the following:
    - For the converter station in Akhaltsikhe, it is observed that power transfer via the converter station is possible in the sense of power quality/converter operational stability. This level can be reached under the typical transmission system conditions from the power quality point of view (i.e., high SCMVA) by including synchronous condensers. Each converter block should be equipped with its own switchable filter blocks to cope with various SCMVA levels.
    - Important transmission reinforcements and/or installing emergency measures and phase measurement units (PMU) are necessary in the countries for the secure and reliable power exhange between the countries and to increase the amount of power exhange gradually.

1. INTRODUCTION

The studies performed within the scope of AGT Power Bridge Project Phase II complent studies conducted during Phase I of the the project. Details of the AGT Project Phase I studies are given in the AGT Project Phase I Final Report.

The main purpose of Phase I was to identify bottlenecks to exchanging power between Turkey and Georgia and also between Georgia and Azerbaijan based on short circuit MVA (SCMVA) and load flow analysis for selected scenarios. Although very important results are drawn in Phase I, complementary AGT Project Phase II studies were necessary given the following considerations:

- Energy exports to Turkey from Georgia were modeled as a constant load at the 500 kV Akhaltsikhe Substation (SS). Although the results give important indications from a static analysis point of view, these results required further investigation and verification using dynamic and power quality analyses, since the connection between Turkey and Georgia will be asynchronous through the HVDC B2B substation. One of the main concerns of the power transfer through HVDC B2B stations is the behavior of reactive power and voltage stability. Therefore, the static analysis conducted in Phase I, which did not take into account reactive power, has been complemented with dynamic analysis (voltage and frequency stability and power quality analysis).

- Secure and reliable power transfer between the countries depends on the different loading conditions in each country. In the Phase I study, power flow and contingency analysis were performed for only four seasonal scenarios; summer minimum loads, summer maximum loads, winter minimum loads and winter maximum loads. However, spring minimum loading conditions are perhaps more important than summer/winter peak and minimum loading conditions, especially given the prevalence of hydroelectric generation in the Turkish and Georigian power systems located in close proximity to the border. Also, given that hydro conditions in the border regions of Turkey and Georgia are quite similar, in addition to loading scenarios the anlaysis must conisder generation scenarios from existing and potential hydroelectric generators (to be constructed).

These were the the main drivers of the AGT Power Bridge Project Phase II studies, which were performed based on the following methodology agreed to in advance by each of the participating TSOs:

- Analysis of country's system was performed by the following companies:
    - Turkey: TEIAS (by the support of TUBITAK UZAY Institute Power Systems Department)
    - Georgia: GSE
    - Azerbaijan: Azerenerji (by the support of the Azerbaijan Research and Design Institute of Power Engineering)

- Each party considered the secure limits of power transfer from their own transmission network's point of view based on static, dynamic and power quality analyses and investigated necessary transmission enforcements for their system security and reliability.

- Analysis was based on mutually agreed to load flow scenarios, with each party focused on weak points of their transmission system for security and reliability.

- PSS/E software was the common analytical platform. Matlab Simulink were also utilized in power quality analysis performed by TUBITAK UZAY for TEIAS.

The report is organized as follows. Section four gives a brief summary of the analysis performed for the Turkish Power System by TEIAS and the TUBITAK UZAY Power Systems Department. The analysis performed for the Georgian Power System by GSE and the Azerbaijan Power System by Azerenerji are summarized in Section five and six. The conclusions are given in Section seven, which is indeed the overall conclusion of the AGT Project (including both Phase I and II). The conclusions also include important recommendations for follow up projects.

The full analytical reports from each party are given in the Appendices. The full report corresponding to the Turkish Power System in the region close to border with Georgia is given in Annex two. The report corresponding to the analysis performed for the Georgian Power System and the Azerbaijan Power System are given in Annexes three and four, respectively.

2. ANALYSIS PERFORMED BY TEIAS & TUBITAK UZAY FOR THE TURKISH POWER SYSTEM

The original version of the study prepared by TEIAS and TUBITAK UZAY Power Systems Department is attached to this report as Annex two. The full report includes three main sections: 1) Power quality analysis (switching analysis) in which the HVDC B2B substations' capacities are evaluated for SCMVA of the busbars at the coupling points; 2) Security analysis in which load flow and contingency analysis are performed to determine safe transfer limits; 3) Dynamic analysis in which voltage stability is analysed. The focus of the report is to analyze the effects of different levels of power import from Georgia to Turkey to identify possible transmission bottlenecks in the Turkish network and to identify measures needed to increase safe transfer amounts.

A brief history is also given about the full Turkish study. Important milestones are described as follows. According to the Minutes of Meeting (MoM) in Ankara between the Turkish and Georgian parties on 08-09.12.2010, feasibility analysis for power transfer to Turkey through the HVDC substations was performed by both countries' experts, individually. Each party considered the secure limits of power transfer from their own transmission network point of view. A second meetng was organized between the Turkish and Georgian parties in Tbilisi on 18.02.2011 to discuss the initial results and ensure that the ongoing studies were aligned. Finally, a workshop was performed in Ankara with participation of TEIAS, GSE and Azerenerji on 19-20 April 2011 to share the draft results. The scenarios were also fixed in this workshop before finalizing the study. Several draft reports were prepared in the interim.

The full Turkish report provided in Annex 1 includes the feasibility analysis methodology and final results. The feasibility of power transfer from Georgia to Turkey was analyzed with computer simulations (MATLAB ™ under the license of TUBITAK UZAY and PSS/E ™ under the license of TEIAS) based on the scenarios and network models (as described in detail later in this report).

The report provides an introduction to the HVDC B2B substations which will enable asynchronous power transfer between Turkey and Georgia. It can be summarized as follows:

- As agreed by the Turkish and Georgian parties, asynchronous interconnection between Georgia and Turkey will be established via HVDC B2B Substations (SS) located in the Akhaltsikhe and Batumi regions of Georgia. The details of the substations are:
    - 3x350 MW HVDC B2B converters will be installed at the Akhaltsikhe SS by the Georgian party by 2017.
        - This interconnection between the Akhaltsikhe region of Georgia and the Borcka region of Turkey is planned to be established at the Akhaltsikhe SS (in Georgia) and Borcka SS (in Turkey) (see Figure 1).
        - A second line from that region is planned to connect the Akhaltsikhe SS and Tortum SS, which is included in the investment plan of Turkey (see Figure 1).

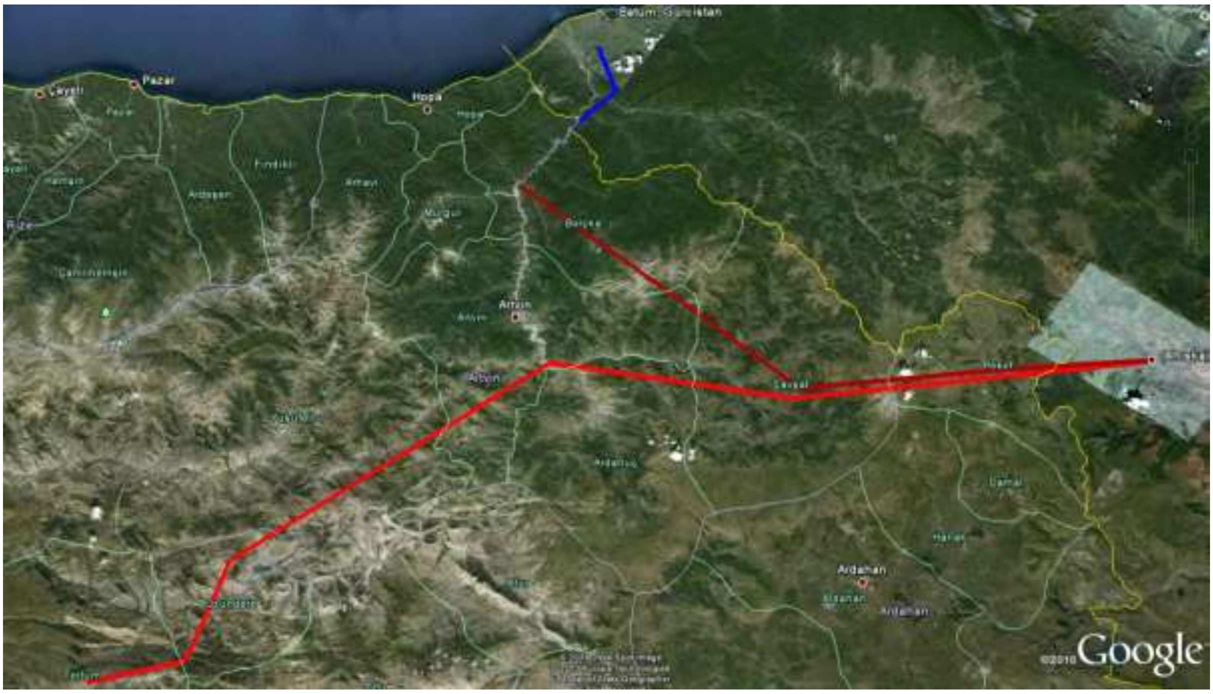

Figure 1.The basic transmission routes (blue line: Muratli – Batumi line representation; dark red line: Borcka – Akhaltsikhe line representation, light red line: Y. Tortum-Akhaltsikhe line representation).

- o 2x175 MW HVDC B2B converters are planned to be installed at the Batumi region by the Georgian party by 2015.
  - The interconnection in the Batumi region of Georgia will be between the Batumi substation and the Muratli substation in Turkey (see Figure 1).

2.1. Studies performed by TEIAS and TUBITAK UZAY

- Load Flow and Contingency Analysis
- Dynamic Analysis
- Switching and Power Quality Analysis

2.2. Main Results

- Capacity values of HVDC B2B substations are utilized in the analysis as the **physical transfer limits** to determine the **secure transfer limits**. After the establishment of the asychronous connections in the future, the **actual transfer amounts** will be determined based on both network security and electricity market conditions of both countries. The relationships between these concepts are illustrated below:

Physical Transfer Limits	**≥**	**Secure Transfer Limits (per settlement period)**	**≥**	**Actual Transfer Amounts (per settlement period)**
↕		↕		↕
HVDC B2B SS capacity		**Security Analysis**		**Market Conditions**

- According to the Turkish Grid Code, the Turkish Electricity Transmission System is designed based on the (n-1) criterion, which means that no element of the power system should be overloaded in the event of a single contingency. Within this scope, (n-1) security analyses were performed for the above summarized scenarios.

- The contingency simulation results regarding the Georgia HVDC Interconnection are provided in the following tables. The most important contingencies regarding the interconnection with Georgia are classified with respect to their effect on the security of the Turkish electricity transmission system and possible protective (and/or preventive) measures required to maintain stability in the Turkish network.

Legends for the following tables
CS: Contingency Single
350 MW Import: Only one block of 2x350 MW Akhaltsikhe converter is in operation
700 MW Import: Two blocks of 2x350 MW Akhaltsikhe converter are in operation
1050 MW Import: Two blocks of 2x350 MW Akhaltsikhe converter and 350 MW Batumi converter are in operation

(green)	No problems related to Georgia Interconnection
(yellow)	Minor redispatch problems related to Georgia Interconnection (< 100 MW)
(orange)	Major redispatch problems related to Georgia Interconnection (> 100 MW)
(red)	Unsecure

Table 1. Summary Results for 2013 Scenarios

	2013 Expected Peak Load Conditions			2013 Expected Spring Load Conditions		
	350 MW Import	700 MW Import	1050 MW Import	350 MW Import	700 MW Import	1050 MW Import
N Case (Base Case, i.e., no outage)	Appendix A-I BASE CASE	Appendix A-II BASE CASE	Appendix A-III BASE CASE	Appendix A-IV BASE CASE	No Base Case (Unsecure)	No Base Case (Unsecure)
The Outage of Borcka-Deriner 380 kV Line	Appendix A-I CS 514	Appendix A-II CS 514	Appendix A-III CS 514	Appendix A-IV CS 527		
The Outage of Deriner-Artvin 380 kV Line	Appendix A-I CS 577	Appendix A-II CS 577	Appendix A-III CS 577	Appendix A-IV CS 597		
The Outage of Y. Tortum-Erzurum 380 kV Line	Appendix A-I CS 330	Appendix A-II CS 330	Appendix A-III CS 330	Appendix A-IV CS 341		
The Outage of Erzurum-Ozluce 380 kV Line	Appendix A-I CS 8	Appendix A-II CS 8	Appendix A-III CS 8	Appendix A-IV CS 8		
The Outage of Ozluce-Keban 380 kV Line	Appendix A-I CS 7	Appendix A-II CS 7	Appendix A-II CS 7	Appendix A-IV CS 7		
The Outage of Borcka-Kalkandere 380 kV Line	Appendix A-I CS 516	Appendix A-II CS 516	Appendix A-III CS 516	Appendix A-IV CS 529		
The Outage of Kalkandere-Tirebolu 380 kV Line	Appendix A-I CS 161	Appendix A-II CS 161	Appendix A-III CS 161	Appendix A-IV CS 161		
The Outage of Tirebolu-Borasco 380 kV Line	Appendix A-I CS 162	Appendix A-II CS 162	Appendix A-III CS 162	Appendix A-IV CS 162		
The Outage of Borasco-Kayabasi 380 kV Line	Appendix A-I CS 116	Appendix A-II CS 116	Appendix A-III CS 116	Appendix A-IV CS 115		
The Outage of Borasco-Carsamba 380 kV Line	Appendix A-I CS 192	Appendix A-II CS 192	Appendix A-III CS 192	Appendix A-IV CS 193		
The Outage of Carsamba-Kayabasi 380 kV Line	Appendix A-I CS 115	Appendix A-II CS 115	Appendix A-III CS 115	Appendix A-IV CS 114		
The Outage of Boyabat-Kursunlu 380 kV Line	Appendix A-I CS 93	Appendix A-II CS 93	Appendix A-III CS 93	Appendix A-IV CS 92		
The Outage of Borcka-Artvin Double Circuit 154 kV Line	Appendix A-I CS 519 & 520	Appendix A-II CS 519 & 520	Appendix A-III CS 519 & 520	Appendix A-IV CS 532 & 533		
The Outage of Muratli-Borcka Double Circuit 154 kV Line	Appendix A-I CS 509 & 510	Appendix A-II CS 509 & 510	Appendix A-III CS 509 & 510	Appendix A-IV CS 521 & 522		

Table 2. Summary Results for 2015 Scenarios

	2015 Expected Summer Peak Load Conditions			2015 Expected Spring Load Conditions		
	350 MW Import	700 MW Import	1050 MW Import	350 MW Import	700 MW Import	1050 MW Import
N Case (Base Case, i.e., no outage)	Appendix B-I BASE CASE	Appendix B-II BASE CASE	Appendix B-III BASE CASE	Appendix B-IV BASE CASE	Appendix B-V BASE CASE	No Base Case (Unsecure)
The Outage of Borcka-Deriner 380 kV Line	Appendix B-I CS 530	Appendix B-II CS 530	Appendix B-III CS 530	Appendix B-IV CS 552	Appendix B-V CS 552	
The Outage of Deriner-Artvin 380 kV Line	Appendix B-I CS 595	Appendix B-II CS 595	Appendix B-III CS 595	Appendix B-IV CS 627	Appendix B-V CS 627	
The Outage of Borçka-Ispir 380 kV Line	Appendix B-I CS 531	Appendix B-II CS 531	Appendix B-III CS 531	Appendix B-IV CS 554	Appendix B-V CS 554	
The Outage of Y. Tortum-Erzurum 380 kV Line	Appendix B-I CS 340	Appendix B-II CS 340	Appendix B-III CS 340	Appendix B-IV CS 360	Appendix B-V CS 360	
The Outage of Erzurum-Ozluce 380 kV Line	Appendix B-I CS 10	Appendix B-II CS 10	Appendix B-III CS 10	Appendix B-IV CS 10	Appendix B-V CS 10	
The Outage of Erzurum-Agri 380 kV Line	Appendix B-I CS 343	Appendix B-II CS 343	Appendix B-III CS 343	Appendix B-IV CS 363	Appendix B-V CS 363	
The Outage of Erzurum-Ispir 380 kV Line	Appendix B-I CS 341	Appendix B-II CS 341	Appendix B-III CS 341	Appendix B-IV CS 361	Appendix B-V CS 361	
The Outage of Ozluce-Keban 380 kV Line	Appendix B-I CS 9	Appendix B-II CS 9	Appendix B-III CS 9	Appendix B-IV CS 9	Appendix B-V CS 9	
The Outage of Borcka-Kalkandere 380 kV Line	Appendix B-I CS 532	Appendix B-II CS 532	Appendix B-III CS 532	Appendix B-IV CS 555	Appendix B-V CS 555	
The Outage of Kalkandere-Tirebolu 380 kV Line	Appendix B-I CS 166	Appendix B-II CS 166	Appendix B-III CS 166	Appendix B-IV CS 168	Appendix B-V CS 168	
The Outage of Tirebolu-Ordu 380 kV Line	Appendix B-I CS 167	Appendix B-II CS 167	Appendix B-III CS 167	Appendix B-IV CS 169	Appendix B-V CS 169	
The Outage of Ordu-Borasco 380 kV Line	Appendix B-I CS 297	Appendix B-II CS 297	Appendix B-III CS 297	Appendix B-IV CS 305	Appendix B-V CS 305	
The Outage of Borasco-Kayabasi 380 kV Line	Appendix B-I CS 118	Appendix B-II CS 118	Appendix B-III CS 118	Appendix B-IV CS 117	Appendix B-V CS 117	
The Outage of Borasco-Carsamba 380 kV Line	Appendix B-I CS 197	Appendix B-II CS 197	Appendix B-III CS 197	Appendix B-IV CS 200	Appendix B-V CS 200	
The Outage of Carsamba-Kayabasi 380 kV Line	Appendix B-I CS 191	Appendix B-II CS 191	Appendix B-III CS 191	Appendix B-IV CS 194	Appendix B-V CS 194	
The Outage of Ordu-Resadiye 380 kV Line	Appendix B-I CS 135	Appendix B-II CS 135	Appendix B-III CS 135	Appendix B-IV CS 134	Appendix B-V CS 134	
The Outage of Boyabat-Kursunlu 380 kV Line	Appendix B-I CS 95	Appendix B-II CS 95	Appendix B-III CS 95	Appendix B-IV CS 94	Appendix B-V CS 94	
The Outage of Ispir-Bagistas 380 kV Line	Appendix B-I CS 5	Appendix B-II CS 5	Appendix B-III CS 5	Appendix B-IV CS 5	Appendix B-V CS 5	
The Outage of Bagistas-Keban 380 kV Line	Appendix B-I CS 4	Appendix B-II CS 4	Appendix B-III CS 4	Appendix B-IV CS 4	Appendix B-V CS 4	
The Outage of Borcka-Artvin Double Circuit 154 kV Line	Appendix B-I CS 535 & 536	Appendix B-II CS 535 & 536	Appendix B-III CS 535 & 536	Appendix B-IV CS 559 &560	Appendix B-V CS 559 &560	
The Outage of Muratli-Borcka Double Circuit 154 kV Line	Appendix B-I CS 525 & 526	Appendix B-II C S 525 & 526	Appendix B-III C S 525 & 526	Appendix B-IV CS 546 & 547	Appendix B-V CS 546 & 547	

Table 3. Summary Results for 2017

	2017 Expected Peak Load Conditions				2017 Expected Spring Load Conditions			
	350 MW Import	700 MW Import	1050 MW Import	1400 MW Import	350 MW Import	700 MW Import	1050 MW Import	1400 MW Import
N Case (Base Case, i.e., no outage)	Appendix C-I BASE CASE	Appendix C-II BASE CASE	Appendix C-III BASE CASE	Appendix C-IV BASE CASE	Appendix C-V BASE CASE	Appendix C-VI BASE CASE	No Base Case (Unsecure)	No Base Case (Unsecure)
The Outage of Borcka-Deriner 380 kV Line	Appendix C-I CS 535	Appendix C-II CS 535	Appendix C-III CS 535	Appendix C-IV CS 535	Appendix C-V CS 564	Appendix C-VI CS 563		
The Outage of Deriner-Artvin 380 kV Line	Appendix C-I CS 600	Appendix C-II CS 600	Appendix C-III CS 600	Appendix C-IV CS 600	Appendix C-V CS 637	Appendix C-VI CS 636		
The Outage of Y. Tortum-Erzurum 380 kV Line	Appendix C-I CS 344	Appendix C-II CS 344	Appendix C-III CS 344	Appendix C-IV CS 344	Appendix C-V CS 370	Appendix C-VI CS 370		
The Outage of Erzurum-Ozluce 380 kV Line	Appendix C-I CS 11	Appendix C-II CS 11	Appendix C-III CS 11	Appendix C-I CS 11	Appendix C-V CS 11	Appendix C-VI CS 11		
The Outage of Erzurum-Agri 380 kV Line	Appendix C-I CS 341	Appendix C-II CS 341	Appendix C-III CS 341	Appendix C-IV CS 341	Appendix C-V CS 373	Appendix C-VI CS 367		
The Outage of Erzurum-Ispir380 kV Line	Appendix C-I CS 345	Appendix C-II CS 345	Appendix C-III CS 345	Appendix C-IV CS 345	Appendix C-V CS 371	Appendix C-VI CS 367		
The Outage of Ozluce-Keban 380 kV Line	Appendix C-I CS 10	Appendix C-II CS 10	Appendix C-III CS 10	Appendix C-IV CS 10	Appendix C-V CS 10	Appendix C-VI CS 10		
The Outage of Borcka-Kalkandere 380 kV Line	Appendix C-I CS 537	Appendix C-II CS 537	Appendix C-III CS 537	Appendix C-IV CS 537	Appendix C-V CS 566	Appendix C-VI CS 565		
The Outage of Kalkandere-Tirebolu 380 kV Line	Appendix C-I CS 167	Appendix C-II CS 167	Appendix C-III CS 167	Appendix C-IV CS 167	Appendix C-V CS 169	Appendix C-VI CS 169		
The Outage of Tirebolu-Ordu 380 kV Line	Appendix C-I CS 168	Appendix C-II CS 168	Appendix C-III CS 168	Appendix C-IV CS 168	Appendix C-V CS 170	Appendix C-VI CS 170		
The Outage of Ordu-Borasco 380 kV Line	Appendix C-I CS 298	Appendix C-II CS 298	Appendix C-III CS 298	Appendix C-I CS 298	Appendix C-V CS 307	Appendix C-VI CS 307		
The Outage of Borasco-Kayabasi 380 kV Line	Appendix C-I CS 119	Appendix C-II CS 119	Appendix C-III CS 119	Appendix C-IV CS 119	Appendix C-V CS 118	Appendix C-VI CS 118		
The Outage of Borasco-Carsamba 380 kV Line	Appendix C-I CS 198	Appendix C-II CS 198	Appendix C-III CS 198	Appendix C-IV CS 198	Appendix C-V CS 201	Appendix C-VI CS 201		
The Outage of Carsamba-Kayabasi 380 kV Line	Appendix C-I CS 192	Appendix C-II CS 192	Appendix C-III CS 192	Appendix C-IV CS 192	Appendix C-V CS 195	Appendix C-VI CS 195		

The Outage of Ordu-Resadiye 380 kV Line	Appendix C-I CS 136	Appendix C-II CS 136	Appendix C-III CS 136	Appendix C-IV CS 136	Appendix C-V CS 135	Appendix C-VI CS 135		
The Outage of Boyabat-Kursunlu 380 kV Line	Appendix C-I CS 96	Appendix C-II CS 96	Appendix C-III CS 96	Appendix C-IV CS 96	Appendix C-V CS 95	Appendix C-VI CS 95		
The Outage of Ispir-Bagistas 380 kV Line	Appendix C-I CS 6	Appendix C-II CS 6	Appendix C-III CS 6	Appendix C-IV CS 6	Appendix C-V CS 6	Appendix C-VI CS 6		
The Outage of Ispir-Borçka 380 kV Line	Appendix C-I CS 5	Appendix C-II CS 5	Appendix C-III CS 5	Appendix C-IV CS 5	Appendix C-V CS 5	Appendix C-Iı CS 5		
The Outage of Borcka-Artvin Double Circuit 154 kV Line	Appendix C-I CS 540 & 541	Appendix C-II CS 540 & 541	Appendix C-III CS 540 & 541	Appendix C-IV CS 540 & 541	Appendix C-V CS 569&570	Appendix C-VI CS 569&570		
The Outage of Muratli-Borcka Double Circuit 154 kV Line	Appendix C-I CS 530 & 531	Appendix C-II CS 530 & 531	Appendix C-III CS 530 & 531	Appendix C-IV CS 530 & 531	Appendix C-V CS 557&558	Appendix C-VI CS 557&558		

2.3. Main Conclusions

The main conclusions drawn from the report are given below:

- **<u>For the 2013 scenario</u>** it is considered that the 400kV Borcka – Akhaltsikhe interconnection line is in service. The conclusions for the 2013 scenario regarding the secure operation of the transmission system and system stability can be summarized as follows:

  - For the converter station in Akhaltsikhe (2x350 MW), 700 MW power transfer via the converter station is technically possible in the sense of power quality and converter operational stability concerns, provided that 3x60 MVar synchronous condensers are constructed at 400 kV side (i.e., Turkish side) of Akhaltsikhe substation.

  - According to the simulation results, the expected feasible operation band could be between ~470-700 MW depending on the operational constraints of the Turkish system (ESCR, etc.). Therefore, each converter block should be equipped with its own switchable filter blocks. This fact should be taken into account in the Back to Back substations' design. If systems' regimes allow, the Back to Back station can be used at its maximum capacity.

  - For the B2B Converter Station in Batumi, it has been observed that the capacity of 350 MW is within the limits of safe power transfer, satisfying dynamic overvoltage and frequent commutation failure constraints.

  - Considering the transmission bottleneck in the Turkish region for the analyzed 2013 scenarios, the initial power import capacity from Georgia to Turkey is recommended not to exceed 700 MW in the normal transmission system conditions, with the presence of a special protection scheme that coordinates the outages of Deriner-Erzurum 400 kV and/or Borcka-Tirebolu 400 kV lines with fast reduction of power import from Georgia and/or tripping some hydropower units in Turkey and even tripping the Akhaltsikhe 400 kV transmission line (if necessary). A special protection scheme for coordinating outages is planned to be completed with collaboration between GSE and TEIAS by the beginning of 2013.

  - Especially during the spring flood period (aproximately 3-3,5months) depending on the water regime, when most of the hydroelectric power plants in the Turkish region are in operation with high capacity factor, the total import capacity from Georgia could be less than 350 MW. The total import capacity should be determined by the Dispatching Department of both parties by considering the most recent system topology, available generation capacity and giving the priority to system security.

  - Accordingly, the net transfer capacity (NTC) of the interconnection lines should be determined for each settlement period.

- **<u>For the 2015 scenario</u>** results regarding the secure operation of the transmission system and system stability can be summarized as follows:

  - The effect of adding new 400 kV transmission lines which will start from Borcka and end at the 400kV Keban substation and other reinforcements included in the TEIAS investment program increases trading capacity up to 1050 MW depending on the network constraints. This means that Batumi-Muratli and Borcka-Akhaltsikhe B2B substations can be utilized at their full capacity provided that the corresponding reinforcements stated in the Final Report will be realized.

  - When the total installed generating capacity in the Turkish region increases (especially for HPPs); the total import capacity is restricted during flood (spring) period (aproximately 3-3,5months) by up to 700 MW. The total import capacity should be determined by the Dispatching Department of both parties by considering the most recent system topology, available generation capacity and giving the priority to system security.

- **For the 2017 scenario**, the second interconnection line from Akhaltsikhe to Yeni Tortum in the Georgian and Turkish power systems enable power imports from Georgia up to 1400 MW (3x350 MW B2B at Akhaltsikhe substation and 350 MW B2B at Batumi Substation) depending on the network constraints of both power systems.

3. ANALYSIS PERFORMED BY GSE FOR GEORGIAN POWER SYSTEM

The original version of the study report prepared by GSE is attached as Annex three. The full Georgian report focuses on the power export capabilities from Georgia to Turkey and power transfer capabilities from Azerbaijan to Turkey through Georgia for the years 2013, 2015 and 2017. The report was prepared by the Georgian State Electrosystem (GSE).

3.1. Studies performed by GSE

The report gives details of the following analyses:

- Load Flow and Contingency
- Dynamic
- Switching and Power Quality
- Short Circuit

PSS/E software was used to conduct steady state, N-1 dynamic and static analysis, and analysis of emergency automation systems. Simplorer software was used to conduct switching analysis, including N-1. Details regarding the scenarios, modeling, assumptions, and results are provided in Annex three.

3.2. Main Results

A summary of the principle findings in the full report are as follows:

- In each scenario, given the loss of the Akhaltske –Borcka line or the Batumi-Muratli line, generation at the the Enguri hydro plant must be re-dispatched by automated protection systems. For example, in the 2015 Spring Minimum scenario, the loss of the Akhaltske-Borcka line would require Enguri to reduce generation by 620 MW, while the loss of the Batumi-Murtatli line would require Enguri to reduce generation by 300 MW. In the 2015 Summer and Winter maximum load scenarios, the loss of Akhaltske-Borcka would require Enguri to reduce its generation by 720 MW.

- Similar calculations are made for the loss of the Mukrhani overhead line (OHL) connecting Gardabani with the Samukh substation in Azerbaijan. In the event of the loss of this line, 225 MW and 300 MW of Georgian load must be shed to restore system balance in both the Winter Max 2015 and Winter Max 2017 Scenarios 1, respectively.

- In all cases, the adjustments are presumed to be made by automated protection systems, which are already installed on the GSE system.

- The following tables summarize the study results. Light green signifies that following an N-1 outage all system parameters remain in normal ranges; orange color signifies that following an N-1 outage, some system parameters deviate from permitted ranges. These may be improved by dispatch actions. Red signifies that the system parameters have inadmissible values or the system will not converge following an N-1 incident.

Figure 2. N-1 Steady State Analysis Results for 2013.

Out of servise	Winter		Spring		Summer		Autumn	
	max	min	max	min	max	min	max	min
Enguri-Zestafoni						1-6		
Enguri-Jvari								
Zestafoni-Qsani								
Zestafoni-Akhalcikhe								
Qsani-Gardabani								
Gardabani-Marneuli								
Qsani-Marneuli								
Marneuli-Akhalcikhe								
Gardabani-Samukh			9-3					9-8
Samukh-AzTPP								
AzTPP-Apsheron								
AT-Enguri	12-1		12-3					
AT-Zestafoni								
AT-Qsani								
AT-Jvari								
AT-Gardabani								

Figure 3. N-1 Steady State Analysis Results for 2015.

Out of servise	Winter	Spring	Summer	Autumn
	max	min	max	min
Enguri-Tskhaltubo				
Enguri-Jvari				
Jvari-Tskhaltubo				
Tskhaltubo-Zestafoni				
Tskhaltubo-Akhaltsikhe				
Zestafoni-Qsani				
Zestafoni-Akhalcikhe				
Qsani-Gardabani				
Gardabani-Marneuli				
Qsani-Marneuli				
Marneuli-Akhalcikhe				
Gardabani-Samukh	12-1			
Samukh-AzTPP				
AzTPP-Apsheron				
AT-Enguri	15-1			
AT-Zestafoni				
AT-Tskhaltubo				
AT-Qsani				
AT-Jvari				
AT-Gardabani				
AT-Akhaltsikhe				

Figure 4. N-1 Analysis for 2017-1 (1400 MW Export to TR) Year

Out of servise	Winter	Spring	Summer	Autumn
	max	min	max	min
Enguri-Tskhaltubo				
Enguri-Jvari				
Jvari-Tskhaltubo				
Tskhaltubo-Akhaltsikhe				
Tskhaltubo-Zestafoni				
Khudoni-Jvari				
Zestafoni-Qsani				
Zestafoni-Akhalcikhe				
Qsani-Gardabani				
Gardabani-Marneuli				
Qsani-Marneuli				
Marneuli-Akhalcikhe				
Gardabani-Samukh	12-1			12-4
Samukh-AzTPP				
AzTPP-Apsheron				
AT-Enguri				
AT-Zestafoni				
AT-Qsani				
AT-Jvari				
AT-Gardabani				
AT-Alhaltsikhe				
AT-Marneuli				
AT-Tskhaltubo				
AT-Knudoni				

- Power Quality Analysis Results:
  - For the 2013 Scenarios: according to the simulation results, at some busburs without ac filters, the harmonic contents exceed the desirable value. After filters are installed, even in the worst case when a 500 kV line is out of service, total harmonic distortion (THD) is reduced to a permissible value. The maximum value of THD is in Akhaltsikhe and it is 1.75%. Thus, approximate harmonic analysis shows that results are within permissible levels.

  - For the 2015 Scenarios: at the Akhaltsikhe 500 kV busbars in normal and N-1 conditions without filters, THD = 3.98 % and 4.35 % respectively. When filters are installed the normal condition for THD = 2.24% and in N-1 the THD = 2.57. As long as for Georgia three percent or less is treated as permitted, the THD values at the Akhaltsikhe 500 kV busbars with filters are within permissible levels for normal and N-1 operating conditions.

  - For the 2017 Scenarios: during 700 MW export to Turkey via the Akhaltsikhe B2B, at the Akhaltsikhe 500 kV busbars in normal and N-1 conditions without filters, THD = 3.44% and 3.85% respectively. When filters are installed THD = 2.12% in normal oprerating conditions and in N-1 condition THD = 2.23. As long as Georgia permits three percent, the THD values at the Akhaltsikhe 500 kV busbars in normal and N-1 conditions are within permissible levels when filters are installed.

    During 1050 MW exports to Turkey via the Akhaltsikhe B2B, at the Akhaltsikhe 500 kV busbars in normal and N-1 conditions without filters, THD = 3.7% and 3.95% respectively. When filters are installed in normal condition operating conditions, THD = 2.35% and in N-1 condition THD = 2.3%. As long as Georgia permits three percent, the THD values at the Akhaltsikhe 500 kV busbars in normal and N-1 conditions are within permissible levels when filters are installed.

3.3. Main Conclusions

- The following high voltage transmission reinforcements are necessary to satisfy the reliability criterion in Georgian Power System.
    - **For 2013**, an asynchronous interconnection between Georgia and Turkey is planned to be established via a line commutated HVDC back to back (B2B) Substation located in the Akhaltsikhe region of Georgia. The second end of mentioned line will be tied with substation located in Borcka region of Turkey.
        - To provide reliable power exports from Georgia and Azerbaijan to Turkey, in addition to the Akhaltsikhe substation it is necessary to build new 500 kV substations at Jvari and Marneuli. It is also necessary to construct internal 500 kV lines connecting the Akhaltsikhe B2B with 500 kV substations at Zestafoni and Marneuli and 500 kV lines between substations at Ksani -- Marneuli, Gardabani -- Marneuli and Enguri – Jvari. Moreover, the reinforcement of the 220 kV power gird in the western part of Georgia should be considered (see Figure 5).

Figure 5. Map of Georgian System for 2013.

- For 2015, a second asynchronous interconnection between Georgia and Turkey will be in service. The connection will be provided by a B2B substation, which will be located in the Adjara region of Georgia, near Batumi. The second end of the tie line will be connected with a substation located in the Muratli region of Turkey.

  - In order to provide power export from Georgia and Azerbaijan to Turkey in a reliable manner, after the 2013 reinforcements of the Georgian system, there are plans to construct a 500 kV component of the Tskaltubo substation, with 500 kV lines connecting to the 500 kV substations at Akhaltsikhe and Jvari. Moreover, the existing 500 kV line Imereti between the 500 kV substations at Enguri and Zestafoni will be split. It will enter and exit from the 500 KV Substation at Tskaltubo. New power plants will also start operation (see Figure 6).

Figure 6. Map of Georgian System for 2015.

- **For 2017**, power plants including the Khudoni Hydro Power Plant (HPP), the Namakhvani HPP Cascade and others, with corresponding substations and OHLs connecting to system will be put into operation (see Figure 7).

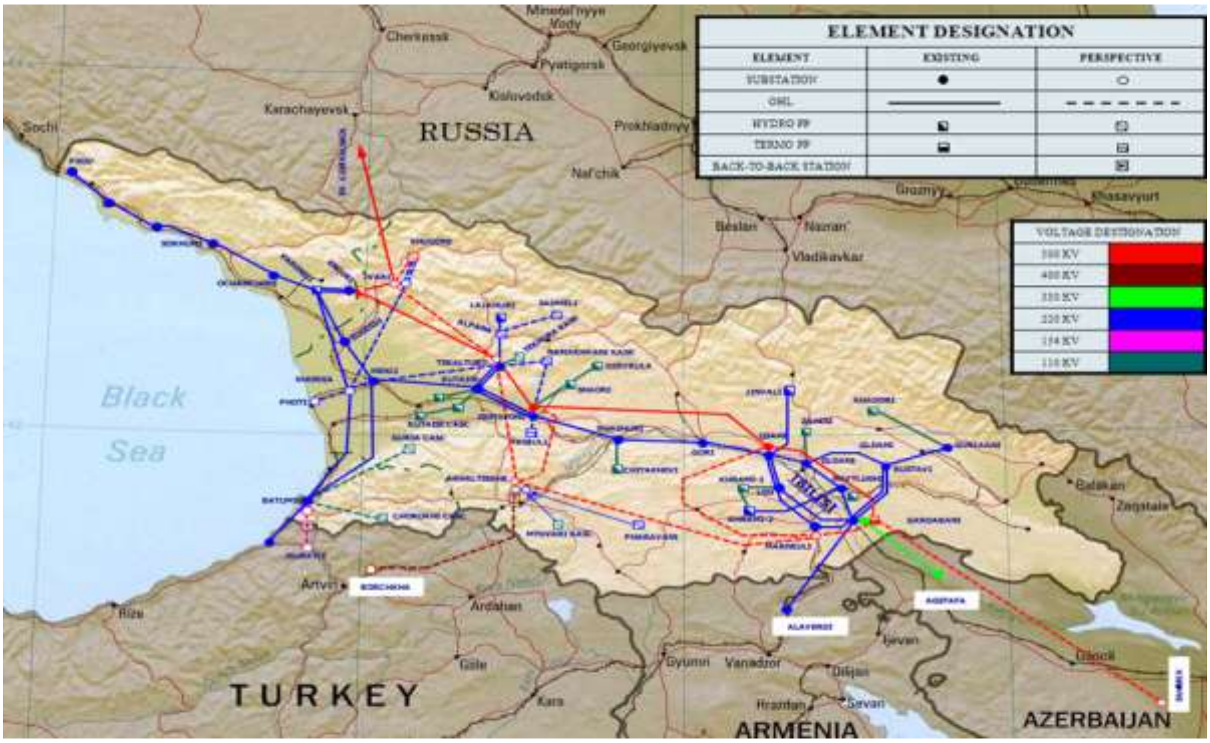

Figure 7. Map of Georgian System for 2017.

- In the event of a loss of an important transmission line (i.e., N-1 contingency cases):
  - The Enguri Hydro Plant must be re-dispatched by automated protection systems. The amount of redispatch depends on the contingency and energy import/export from/to Azerbaijan/Turkey.
  - Georgian load must be shed to restore system balance in the Winter Max 2015 and Winter Max 2017 Scenario 1, respectively.
  - The adjustments should be made by automated protection systems, which are already installed on the GSE system.

4. ANALYSIS PROVIDED BY AZERENEJI FOR AZERBAIJAN UNIFIED POWER SYSTEM AND PERFORMED BY THE AZERBAIJAN RESEARCH AND DESIGN INSTITUTE OF POWER ENGINEERING.

The study report prepared by Azernerji is attached as Annex four. Priorities for the Azerbaijan power sector include increasing efficiency, operational security, energy trading, as well as integration of renewable energy and interconnection with neighboring systems.

Currently, there are 21 power plants with a total generating capacity of 6.5 GW (with a per capita of more than 700 kW). The total length of all transmission lines at all voltage classes (500-35 kV) is 12,000 km. Approximately 98 % of the generation sources on the grid are managed by JSC "Azerenerji". The map of Azerbaijan Power System is shown below.

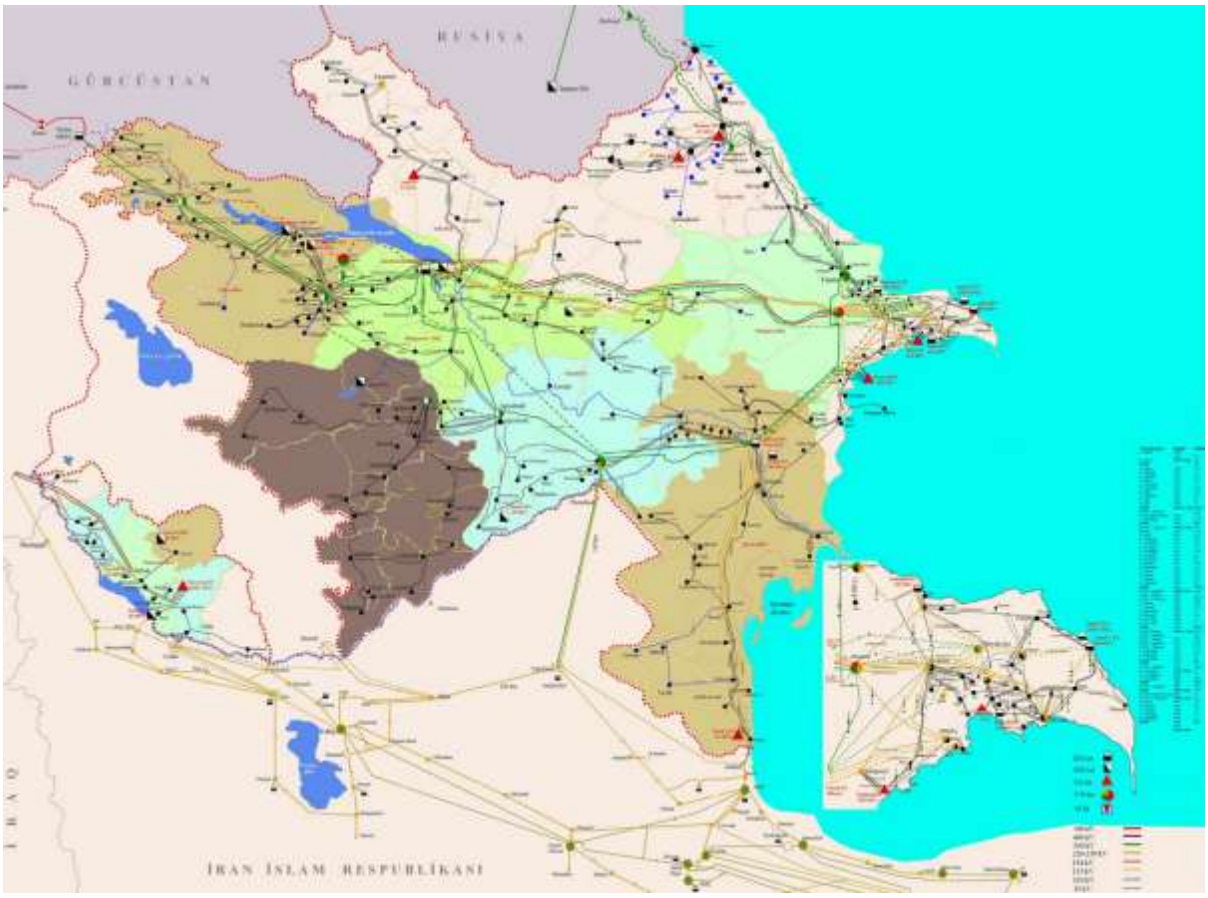

Figure 8. Map of Azerbaijan Power System.

The strategic directions of the development of the electric power industry of Azerbaijan are as follow:

1. Replacing technology and equipment for the generation, transport and distribution of electricity by the most advanced and efficient technologies and equipment;
2. Balancing development of power generating facilities and backbone networks to provide the necessary level of reliability and efficiency for electricity consumers;
3. Optimization of development and operation of power generating facilities, i.e. a system capable of reducing production costs and electricity tariffs while ensuring supply;

4. Integrating the Azerbaijan power generation system with the systems of neighboring countries;
5. Developing renewable energy source and reducing the negative impact of traditional generation on the environment through the use of innovative technologies.

One of the priority directions of development of the National Power System is expansion and integration with power systems of of others countries. Currently, there are interconnections at 330 kV with the Russian Federation and three interconnection lines of 330, 220 and 110 kV level with Iran.

In the South Caucasus region, Azerbaijan's power system is rapidly developing. Over the past 10 years, the installed capacity has increased by more than 30% (2000 MW). In 2015 and 2017, there is a plan to connect the Azerbaijan power system to the Georgian and Turkish power systems through the "Power Bridge". This parallel work will strengthen the strategic importance of Azerbaijan in the South Caucasus, as well as in the Eurasian Union.

4.1. Studies performed by Azerenerji

- Load Flow and Contingency Analysis
- Dynamic Analysis

Though development of the high voltage interstate connections and the creation of bulk power systems have the potential for significant benefits, the potential for instability increases due to complications in monitoring, operating and controling a large-scale, interconnected system. Therefore, it is necessary to check system stability in normal and forced modes of operation.

The PSS-E software was used to develop the analysis in Annex four of this report. The first section of Annex four provides stability analysis carried out both for the current system and for potential connections from Azerbaijan to Georgia and Turkey, and the North Caucasus (the Russian Federation) through the "Power Bridge" for the years 2012-2013. In the the second part, the schemes and operation modes of the Azerbaijan power system during power transmission to Georgia are modeled for the 2015 and 2017 planning horizon. The following types of disturbance were invesitaged: switching off the most overloaded 500 kV and 330 kV OHLs and third phase short circuit in plant buses. Results for power flow, frequency, voltage, and the processes of the relative angle change are presented in the annex.

4.2. Main Results

- Load flow analysis results for normal and N-1 contingency conditions are summarized in the following tables for 2012-2013, 2015 and 2017, respectively.

Table 4. 2012-2013 Load Flow Analysis Results (Normal conditions and N-1)

P, MW		1 st Apsheron 330 kV OHL	2nd Apsheron 500 kV OHL	1 st AzTPP-Goranboy 330 kV OHL	2st AzTPP-Goranboy 330 kV OHL	AzTPP - Samukh 500 kV OHL	AzTPP - Samukh 330 kV OHL	3 Mingechavir 330 kV OHL	Apsheron - Yashma 330 kV OHL	Agjabedi - Goranboy 330 kV OHL	Imishli – Goranboy 330 kV OHL	Akstafa - Gardabani 330kV OHL	Samukh - Gardabani 500 kV OHL
4402	3200	205	356	316	282	421	198	65	108	350	237	198	396
		X	437	360	321	408	217	98	88	401	280	197	391
		323	X	365	325	501	174	153	139	438	311	180	399
		219	367	X	472	454	258	72	108	332	222	191	400
		217	365	493	X	448	248	71	108	335	224	192	395
		196	407	404	361	X	417	57	106	331	221	259	329
		211	351	375	335	501	X	69	109	347	234	187	406
		220	384	326	204	417	291	X	112	361	246	199	394
		192	368	315	281	418	199	69	X	348	235	198	391
		268	431	251	224	388	185	94	104	X	432	199	383
		244	402	275	246	402	190	83	105	490	X	199	390
		207	345	295	263	506	160	66	111	354	240	X	594
		202	378	357	319	294	275	62	108	341	229	585	X

Table 5. 2015 Load Flow Analysis Results (Normal conditions and N-1)

P, MW		1st Apsheron 330 kV OHL	2nd Apsheron 500 kV OHL	1st AzTPP-Goranboy 330 kV OHL	2 nd AzHPP-Goranboy 330 kV OHL	AzHPP-Samukh 330 kV OHL	AzTPP-Samukh 500 kV OHL	3 Mingechavir 330 kV OHL	Apsheron-Yashma 330 kV OHL	Agjabedi-Goranboy 330 kV OHL	Imishli-Goranboy 330 kV OHL
5344	5175	244	381	375	336	240	446	87	163	413	282
		x	478	430	385	264	435	130	137	474	334
		374	x	434	388	222	528	189	193	507	362
		262	395	x	565	313	481	96	163	391	264
		259	393	589	x	301	475	95	163	395	267
		252	376	450	403	x	539	92	164	409	279
		237	436	470	421	478	x	79	159	393	265
		265	419	389	348	247	440	x	168	428	295
		225	400	374	334	241	442	95	x	409	279
		325	473	304	272	228	415	128	158	x	519
		291	436	329	294	232	426	111	160	581	x

Dynamic Stability Studies for 2012 and 2013 Scenarios:

When each of the the following two interconnection lines are lost, 500 kV Samukh-Gardabani and 330 kV Akhstafa-Gardabani, a power deficit on Georgia side is observed and frequency reduces to 48.29Hz. The investigations in the Georgia power system shows that in the event of a loss of 891 MW, frequency drops to 47.5 Hz. The frequency changes at the Azerbaijan Thermal Power Plant are negligible.

Simulating a loss of the Azerbaijan Thermal Power Plant and the Shimal Combined Cycle plant by switching them off leads to a reduction of power flow. Switching off the Enguri hydropower plant leads to an increase in the power flow from the Azerbaijan system. Frequency changes are minimal during the transient processes. Based on the relative angles of the fluctuation of power generators located in Azerbaijan and Georgia, the system is stable.

When simulating a loss of the 500 kV and 330 kV interconnection lines equipped with automatic reclosers, changes of voltage and power and the relative angles show that the system remains stable. The cycle of the first amplitude depends on the load rejection scale. The calculation of the three phase short circuit shows that the system is stable. Oscillation of power plant's relative angles is more noticable under a three phase chort circuit on the 500 kV busbar at the Azerbaijan Thermal Power Plant buses.

Dynamic Stability Studies for 2015 Scenario:

The system remains stable in all types of disturbances. Changes in real time angles occur during the loss of units in the Baku TPP and the Shimal Combined Cycle Power Plant. The level of the decrease in frequency depends on the strength of the static characteristics of the Azerbaijan power System. For example, during a power reduction of 1360 MW, i.e., at the 330 kV buses at the Azerbaijan Thermal Power Plant generator when 5 units are lost (26,3%), frequency drops to 48.874 Hz. The coefficient K = 11.679.

When simulating a loss by switching off the Gardabani overhead lines of 330 kV and 500 kV and the 600 MW load buses are switched off, the frequency in the Azerbaijan power system increases in value up to 50.248 Hz. Generators in the Shimal combined cycle power plant are connected to the 330 kV Samukh substation. When switching off interconnection lines with automatic recloser units with a two second time delay units on the 500 kV and 330 kV busbars are swiched. The process changes of the relative angles shows that the system is stable.

4.3. Main Conclusions

The main conclusions drawn in the report are as follow:

In case of losing important transmission lines, the frequency of the Azerbaijan Themal Power Plant does have significant changes in all of the scenarios

The scheme and modes in Georgian and Turkishpower systems ("Power Bridge"), as well as the North Caucasus (RF) match the conditions of the power systems functioning with interconnection lines. The modes, the elements of the design parameters and the scheme of the years 2012-2013 were , taken into account, as given by the Georgian power system). The required load for 2015 and 2017 for Azerbaijan-Georgia-Turkey through the “Power Bridge” was demonstrated.

The results obtained can be used to solve emergency control issues in power unions (pools) in the future when the Azerbaijan power system is both an importer and exporter.

Effective “Anti - Emergency Management” is important. The optimal location of hardware smart grid technology, in particular, PMU, is essential. The location may be obtained on the basis of a theory of measurement (criteria of observability and controllability) and sensitivity. The results of the pre-project studies on “AGT Power Bridge” shows the capability of controlling the transient processes by using simultaneous measurement of the complex voltage and current (PMU) at the end of the ties.

5. AGT WORKING GROUP RECOMMENDATIONS

- Capacity values of HVDC B2B substations are utilized in the analysis as the physical transfer limits in determining the secure transfer limits. After the establishment of the asychronous connections in the future, the actual transfer amounts will be determined based on both network security and electricity market conditions of all countries.

- Particularly during Spring scenarios, when most of the hydroelectric power plants in the Turkey close to border are operating with a high capacity factor, the import capacity from Georgia should be determined by the dispatching department considering the most recent system topology and giving the priority to system security.

    - Depending on the electricity market conditions in Turkey, redispatching might be necessary in this region as a short term measure to resolve the transmission bottleneck (e.g., 2013 expected minimum load conditions) in either the day ahead market mechanism or the balancing and settlement market mechanism.

- Secure amount level of electricity export/import between countries depends on the followings:

    - For the converter station in Akhaltsikhe, it is observed that power transfer via the converter station is possible in the sense of power quality/converter operational stability. This level can be reached under the typical transmission system conditions from the power quality point of view (i.e., high SCMVA) by including synchronous condensers.

    - Each converter block should be equipped with its own switchable filter blocks to cope with various SCMVA levels.

    - Following transmission reinforcements and emergency measures are necessary for the secure and reliable power exhange between the countries:

      Turkish Grid:

        - New 400 kV transmission routes that connect the region with the strong substations at south and west part of Turkey increases the transmission capacity. However, the total installed hydroelectric generating capacity in the region is also expected to increase. This restricts the import capacity during the Spring season due to the water regime. Therefore, although total import capacity should be determined by the Dispatching Department of both parties by considering the most recent system topology, available generation capacity and giving the priority to system security, to be on the safe side, a special protection scheme must be considered in case of emergency system conditions.

        - 2013 Scenarios: Especially during flood (Spring) period (aproximately 3-3,5months) in Turkish side, considering the transmission bottleneck and water regime in the region, when most of the hydroelectric power plants in the Turkish region are in operation with high capacity factor, the total import capacity from Georgia could be less than 350 MW. The initial power import capacity from Georgia to Turkey is recommended not to exceed 700 MW along the year, even in the normal transmission system conditions. The total import capacity should be determined by the Dispatching Department of both parties by considering the most recent system topology, available generation capacity and giving the priority to system security.

- These power exports even require presence of a special protection scheme that coordinates the outages of Deriner-Erzurum or Borcka Tirebolu lines with fast power reduction of power import from Georgia and/or the possibility of tripping of Akhaltsikhe 400 kV transmission line (and/or some units of Borcka-Deriner HPPs), if necessary.

- 2015 Scenarios: When the total installed generating capacity among the Turkish region increases (especially for HPPs); the total import capacity is restricted during flood(spring) period (aproximately 3-3,5months) up to 700 MW. The total import capacity should be determined by the Dispatching Department of both parties by considering the most recent system topology, available generation capacity and giving the priority to system security.

- 2017 Scenarios: the second interconnection line from Akhaltsikhe to Yeni Tortum in Turkish and Georgian power systems enable power import from Georgia up to 1400 MW (3x350 MW B2B at Akhaltsikhe substation and 350 MW B2B at Batumi Substation) depending on the network constraints of both power systems.

Georgian Grid:

- To provide reliable power exports from Georgia and Azerbaijan to Turkey in addition to the Akhaltsikhe substation, it is necessary to build in Georgia new 500 kV substations at Jvari and Marneuli. It is also necessary to construct internal 500 kV lines connecting the Akhaltsikhe B2B with 500 kV substations Zestafoni and Marneuli and 500 kV lines between substations Ksani -Marneuli, Gardabani - Marneuli and Enguri – Jvari. Moreover, the reinforcement of the 220 kV power gird in the western part of Georgia should be considered.

- In order to provide power export from Georgia and Azerbaijan to Turkey in reliably manner, after 2013 years reinforcements of Georgian system, it is planned to build 500 kV part in Tskaltubo substation, with 500 kV lines connecting with 500 kV substations Akhaltsikhe and Jvari. Moreover, existing 500 kV line Imereti between 500 kV substations Enguri and Zestafoni will be split, it will enter and exit from substation Tskaltubo 500 kV substation.

- Enguri Hydro Plant must be re-dispatched by automated protection systems. The amount of redispatch depends on the contingency and energy import/export from/to Azerbaijan/Turkey.

- Georgian load must be shed to restore system balance in some maximum loading. The adjustments should be made by automated protection systems.

Azerbaijan Grid:

- 500 kV Samukh-Gardabani OHL between Azerbaijan and Georgia is the key reinforcement to support energy exchange between the countries.

- In case of loosing important transmission lines, the frequency of the Azerbaijan TPP changes unimportantly in all scenarios.

- Effective “Anti - Emergency Management” is important for the solution of the problem optimal location of hardware intellectual technology, in particular, phaser measurement units (PMU). The answer may be obtained on the basis of a theory of measurement (criteria of observability and controllability) and sensitivity.

- Example of the results of the pre-project studies on “AGT Power Bridge” shows the capability of controlling and transient processes in this regard by using simultaneous measurement of the complex voltage and current (PMU) at the end of the ties.

6. AGT STEERING COMMITTEE MEETING RECOMMENDATIONS

The Azerbaijan-Georgia-Turkey (AGT) Power Bridge Working Group and Steering Committee conducted meetings in Istanbul, Turkey on February 2 and 3, 2012. Participating in the meetings were representatives from the Turkish Ministry of Energy and Natural Resources, Georgian Ministry of Energy and Natural Resources, Azerenerji, Georgian State Electrosystem, Turkish Electricity Transmission Company, Tubitak Uzay, United States Agency for International Development and the United States Energy Association. The International Finance Corporation participated as an observer to the Steering Committee meeting.

The objective of the meetings was to review the final draft of the AGT Power Bridge Phase II report, which analyzes the sub-regional network to identify investments necessary to increase trade and exchange of electricity and to strengthen network reliability. The draft was presented to the Steering Committee on February 3. The Steering Committee evaluated the findings and made a consensus recommendation on potential follow-up actions to be taken based on the findings of this phase of the project. During the meetings each TSO presented the findings of its own analysis. Taken together, the individual analyses form the combined findings and recommendations of the Phase II report.

The underlying analysis contained in the report proves export of electricity from Azerbaijan and Georgia through the back-to-back interconnection being constructed to connect Akhalske (GE) to Borcka (TR) is feasible in terms of capacity, power quality and system stability. Although proven feasible, significant congestion in Turkey's transmission network limits the capacity Turkey's network to securely accept imports from Georgia. Coupled with development of Georgia's export oriented generating capacity, this factor presents challenges to allocating cross-border transmission capacity between Georgia and Azerbaijan at the back-to-back station.

The addition of the new 500 kV line connecting Azerbaijan's power system with Georgia's strengthens their synchronous connection and confers obvious benefits to both parties. It provides an export path for Azeri electricity to Georgia and through Georgia to Turkey. It gives Georgia seasonal access to Azerbaijan's thermal capacity when Georgia's hydroelectric plants operate at low capacity factors. And, it provides Azerbaijan with additional fast reacting reserves for frequency and voltage control through access to Georgian hydropower plants.

It also increases the risk that instability in one system will spread to the other. As a result, the Working Group and Steering Committee recommended that the TSOs focus on a coordinated approach to developing and deploying elements of an automated emergency protection system. Such a system would monitor the networks with the use of smart grid technology (phasor measurement units (PMU)) and in the event of a forced outage, take pre-emptive actions to avoid cascading blackouts.

Discussions at the Working Group and Steering Committee emphasized the importance of developing mechanisms for sharing primary and secondary reserves and settling payments when one system uses another system's reserves. While it is premature to contemplate an ancillary services market in this sub-region, all parties would benefit from further discussion on this subject. Turkey, which is now synchronously connected with ENTSO-E and has a maturing energy market, volunteered to serve as an educator and facilitator in such discussions.

The following summarizes the most important points of discussion at the Working Group and Steering Committee meetings.

<u>TEIAS</u>

TEIAS reported that although it is technically feasible to import power through the back-to-back station in terms of power quality, bottlenecks in its transmission system limit imports to a considerable extent. This is because there are no load centers in northeast Turkey, which is the region where the back-to-back station is located. As such, imports from Georgia must pass through a single 400kV line that is already heavily loaded. The situation is exacerbated by development of some 6,000 MW of new hydroelectric generation capacity on the Turkish side of the border with Georgia. When Turkish hydropower plants are operating with high capacity factors and the load is low in the spring flood season, they will compete for access to the transmission line with the Georgian plants located just across the border. This will create additional congestion if not managed properly by dispatchers from each TSO. Though TEIAS plans to add a second parallel 400 kV line in 2015, it may not contribute significantly to alleviating congestion as additional generation capacity will be developed in the same border region.

TEIAS reports that for the 2013 planning scenario, it is technically possible to transfer up to 700 MW from Georgia to Turkey via the back-to-back station depending on the seasonal generation/loading conditions of the Turkish network. During the spring season when Turkish hydropower plants are operating with high capacity factors, the upper limit for secure import capacity will be 350 MW due to Turkish network congestion. Even under normal operating conditions, the secure limit for imports will be no greater than 700 MW.
The effect of adding a second 400 kV line from Borcka to Keban will increase the physical import capacity up to 1050 MW for the 2015 planning scenario depending on seasonal generation/loading conditions. However, during the spring season the secure import capacity will most likely be limited to 700 MW, again due to expected congestion in the Turkish network.

For the 2017 planning scenario, it is assumed that a second back-to-back station will be constructed to connect Batumi (GE) to Muratli (TR) with the capacity of 350 MW. This will raise the potential capacity to import from Georgia to 1,400 MW (1,050 MW from Akhaltske-Borcka and 350 MW from Batumi-Muratli). However, the secure import limits will be dictated by the generation patterns and loading conditions of the Turkish network, which for 2017 is difficult to accurately forecast.

<u>Azerenerji</u>

Azerenerji reported that with the completion of the 500 kV line connecting it to Georgia it plans to export up to 650 MW to Turkey through Georgia via the back-to-back substation being constructed to connect Akhaltske (GE) to Borcka (TR). The analysis performed by Azerenerji proves that it will be technically feasible to do so once the 500 kV interconnection to Georgia is energized. Even with the loss of a major transmission line in Azerbaijan or its interconnection with Georgia, the Azerenerji transmission system will remain stable and frequency will not fluctuate.

However, in the event of the loss of the back-to-back substation due to an unplanned outage, the 650 MW exported to Georgia and Turkey will flow inadvertently to Russia causing instability in the North Caucasus grid. To avoid this and other stability problems that may arise as Azerbaijan and Georgia strengthen their synchronous interconnection, Azerenerji recommended a coordinated, automated emergency management protection system be deployed by the three TSOs participating in the Project. Such a system could include the phasor measurement units (PMU) to provide wide area awareness of frequency and voltage in real time. In addition to the pre-emptive actions an automated protection scheme takes to avoid cascading blackouts, it would play an important role in coordinating the use of primary and secondary reserves, which are called upon to restore the system in the event of unplanned transmission and generation outages.

As discussed above, planning for, coordinating the use of, and settling payment when one system's reserves are used by another is a commercial/market issue that arises as connections among the three countries are strengthened. A second commercial/market issue arising from the findings of the study is the allocation of cross-border transmission capacity between Georgia and Turkey at the back-to-back station.

Currently, Azerbaijan shares a limited interconnection with Russia through a 330 kV line. Though Azerbaijan could consider building a stronger interconnection to the Northern Caucasus, Russia's network in this region is not well developed. Therefore, there will be considerable limitations to Azerbaijan's exports to Russia for the foreseeable future. The Steering Committee in its meeting report recommended including Russia in the AGT Power Bridge Project and conducting analyses of the Northern Caucasus network.

GSE

The analysis conducted by the Georgian State Electrosystem focused on the stability of its network when exporting through the back-to-back station to Turkey. GSE reported that assuming the addition of a second back-to-back station connecting Batumi (GE) and Muratli (TR) and other planned network reinforcements, it is technically feasible to export to Turkey 700 MW in 2013; 1000 MW in 2015; and up to 1,400 MW in 2017. While doing so, power quality remains acceptable and the system remains stable in the event of an unplanned outage by redispatching the Enguri hydropower plant and, in limited cases load shedding, triggered by automated protection systems already installed on the GSE network.

Based on the findings and recommendations contained in the Phase II report, the Steering Committee recommended the following subjects for the third phase of the project:

- Update the sub-regional model to reflect actual developments in each system in the out year planning scenarios
- Update the analyses to take into account developments of each of the power systems – load flow, static and dynamic behavior
- Include Russia to take the Northern Caucasus power system into account
- Study the establishment of automated emergency management systems, including the deployment of PMUs to support wide are awareness among the three TSOs
- Verify the dynamic models by comparing them to results of actual unplanned outages
- Calculate net transfer capacities (NTC) and available (ATC) using ENTSO-E methodologies
- Propose grid code modifications in each country needed to improve reliability
- Recommend methodologies for allocating transfer capacity using ENTSO-E rules
- Discuss potential settlement processes used to develop compensation for reserves used by each country and other rules for electricity markets and ancillary services

ANNEX 1.

Azerbaijan-Georgia-Turkey Power Bridge Project Memorandum of Understanding

ANNEX 2.

Technical Feasibility Analysis for Georgia–Turkey HVDC Interconnection, Final Report, TEIAS & TUBITAK UZAY Power System Analysis and Planning Group, 12.05.2011.

ANNEX 3.

Technical Feasibility Analysis of Power Export From Georgia and Azerbaijan to Turkey Final Report, GSE.

ANNEX 4.

Analysis of Energy Export capabilities from Azerbaijan and Georgiya to Turkey "AGT Power Brige" Project, Report, Azerenerji, Baku-2011