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

Thursday, March 08, 2012

This publication was produced for review by the United States Agency for International Development. It was prepared by the United States Energy Association and the Turkish Electricity Transmission Company as the volunteer Technical Coordinator of the AGT Power Bridge Project

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Final Report Prepared for:

Office of Energy and Infrastructure
Bureau for Europe and Eurasia
United States Agency for International Development

Cooperative Agreement EEE-A-00-02-00054-00

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

İnönü Bulvarı No: 27 Bahçelievler
Ankara, Turkey

United States Energy Association
1300 Pennsylvania Avenue, NW
Suite 550, Mailbox 142
Washington, DC 20004
+1 202 312-1230 (USA)

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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 ^{TM} under the license of TUBITAK UZAY and PSS/E ^{TM} 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).

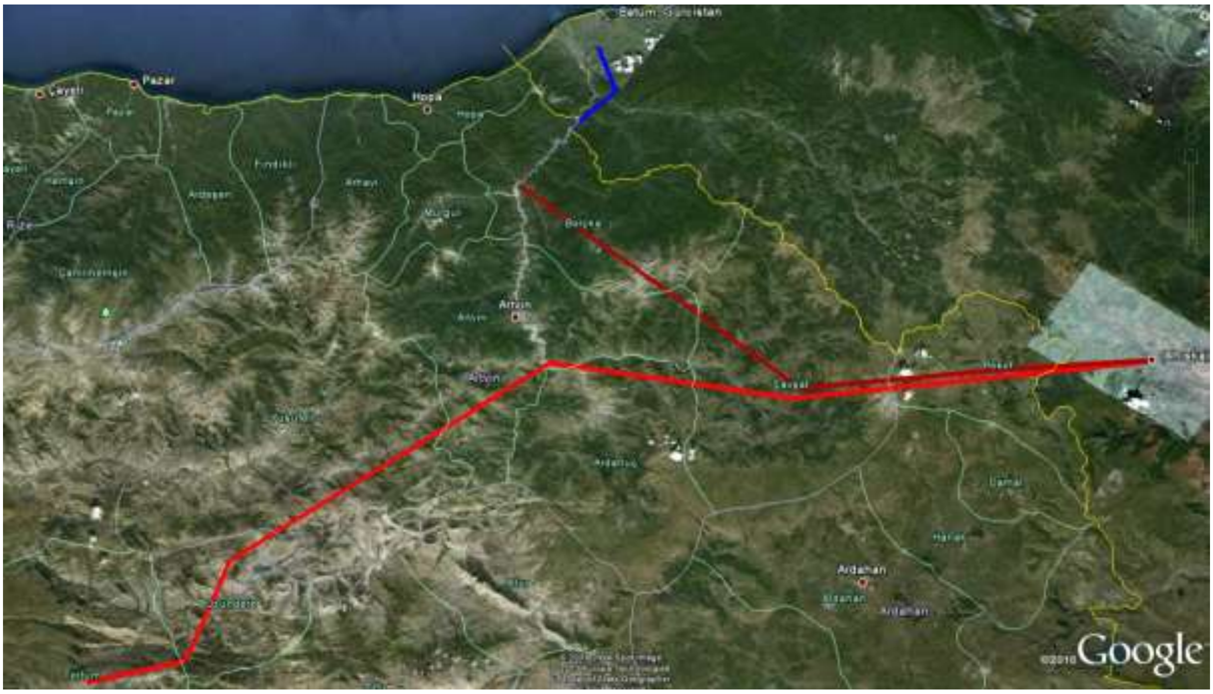


Figure 1.The basic transmission routes (blue line: Muratli – Batumi line representation; dark red line: Borcka – Akhaltsikhe line representation, light red line: Y. Tortum-Akhaltsikhe line representation).

- 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

🟩	No problems related to Georgia Interconnection
🟨	Minor redispatch problems related to Georgia Interconnection (< 100 MW)
🟧	Major redispatch problems related to Georgia Interconnection (> 100 MW)
🟥	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:

- **For the 2013 scenario** 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.

- **For the 2015 scenario** 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:
  - <u>For the 2013 Scenarios</u>: 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.

  - <u>For the 2015 Scenarios</u>: 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.

  - <u>For the 2017 Scenarios</u>: 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).

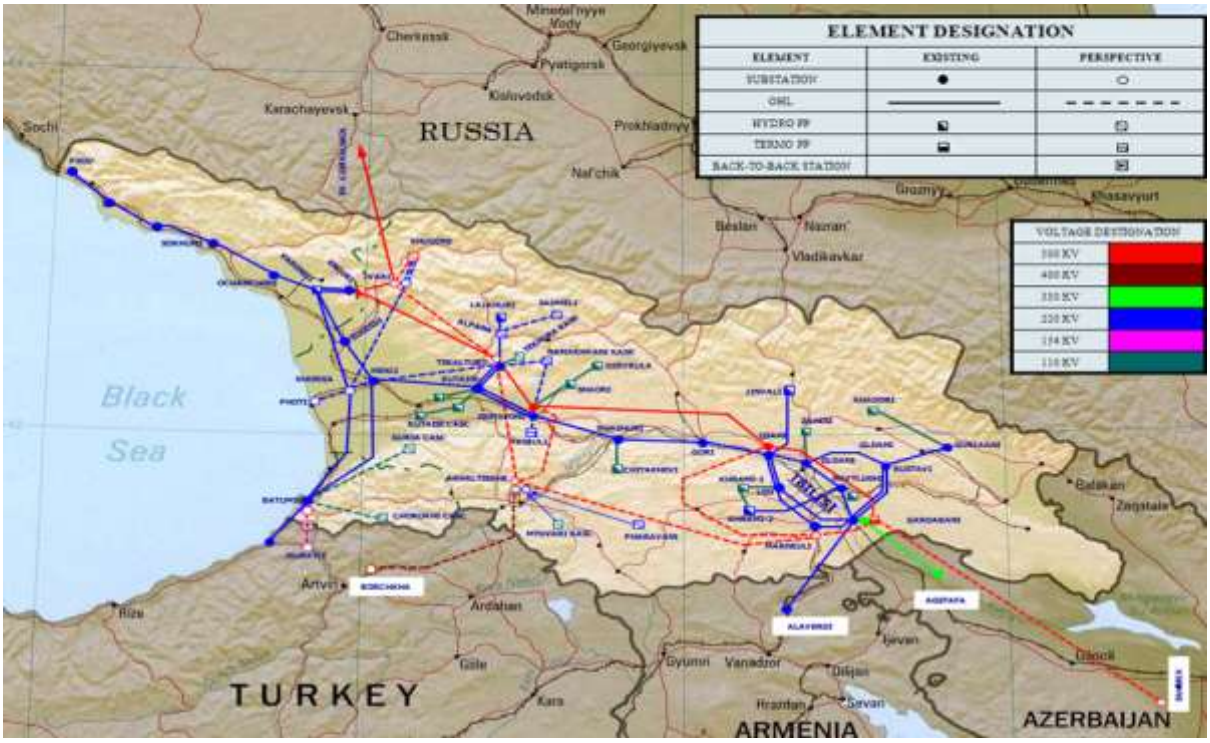


Figure 7. Map of Georgian System for 2017.

- 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.

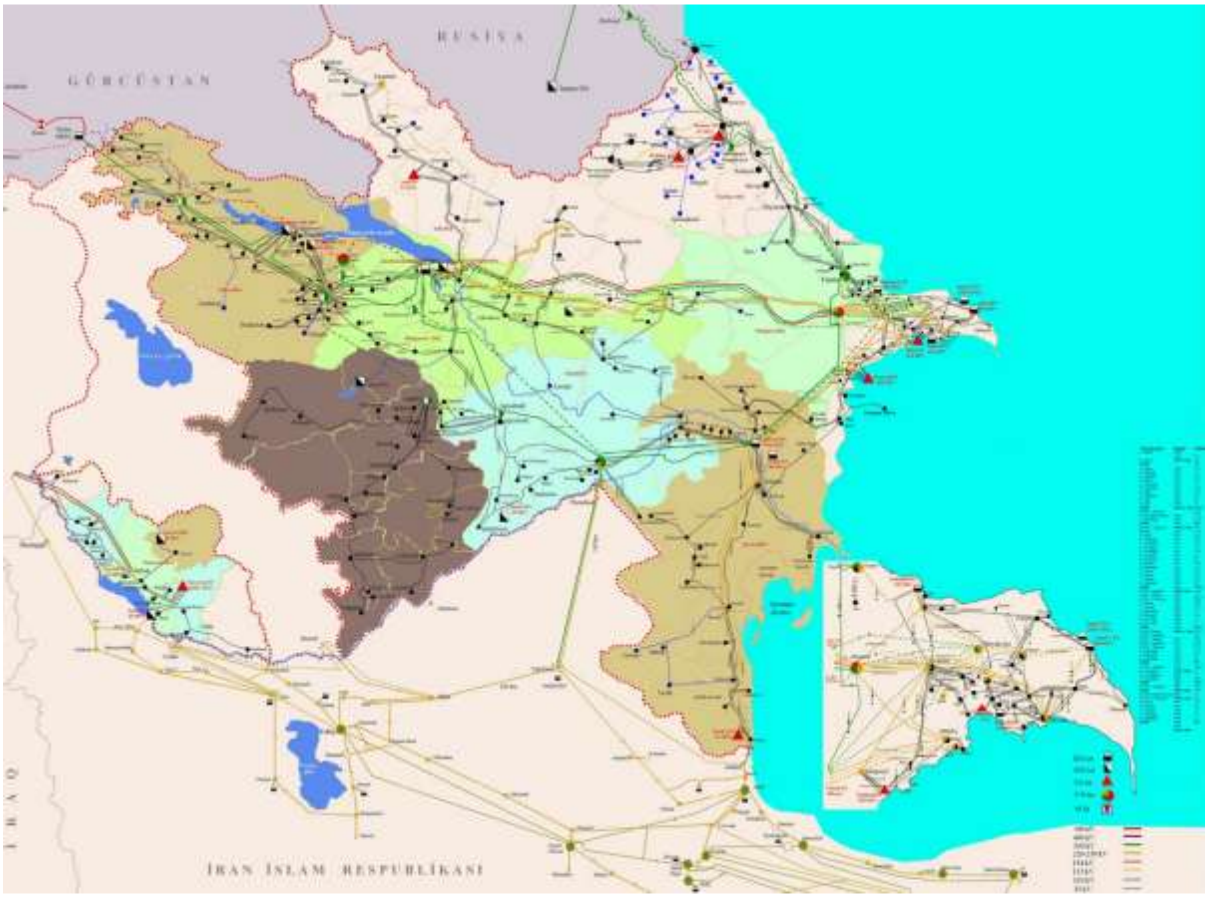


Figure 8. Map of Azerbaijan Power System.

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

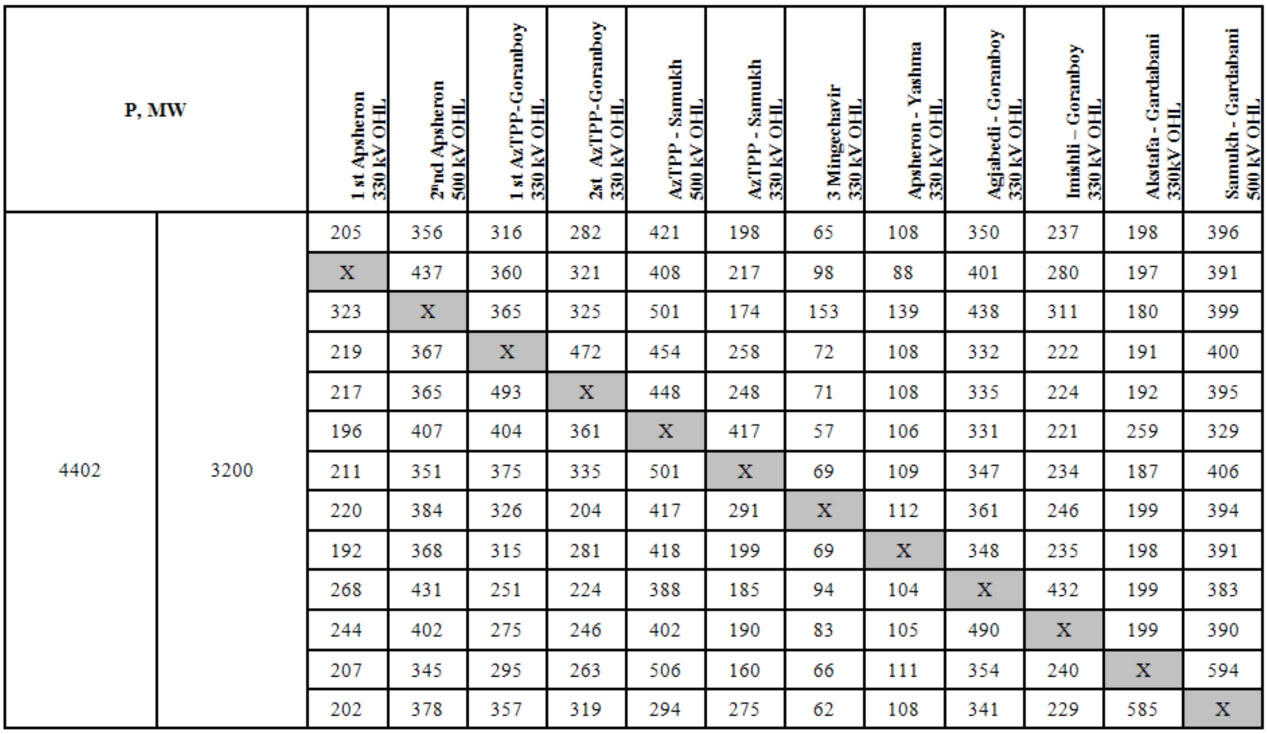
Though development of the high voltage interstate connections and the creation of bulk power systems have the potential for significant benefits, the potential for instability increases due to complications in monitoring, operating and controling a large-scale, interconnected system. Therefore, it is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

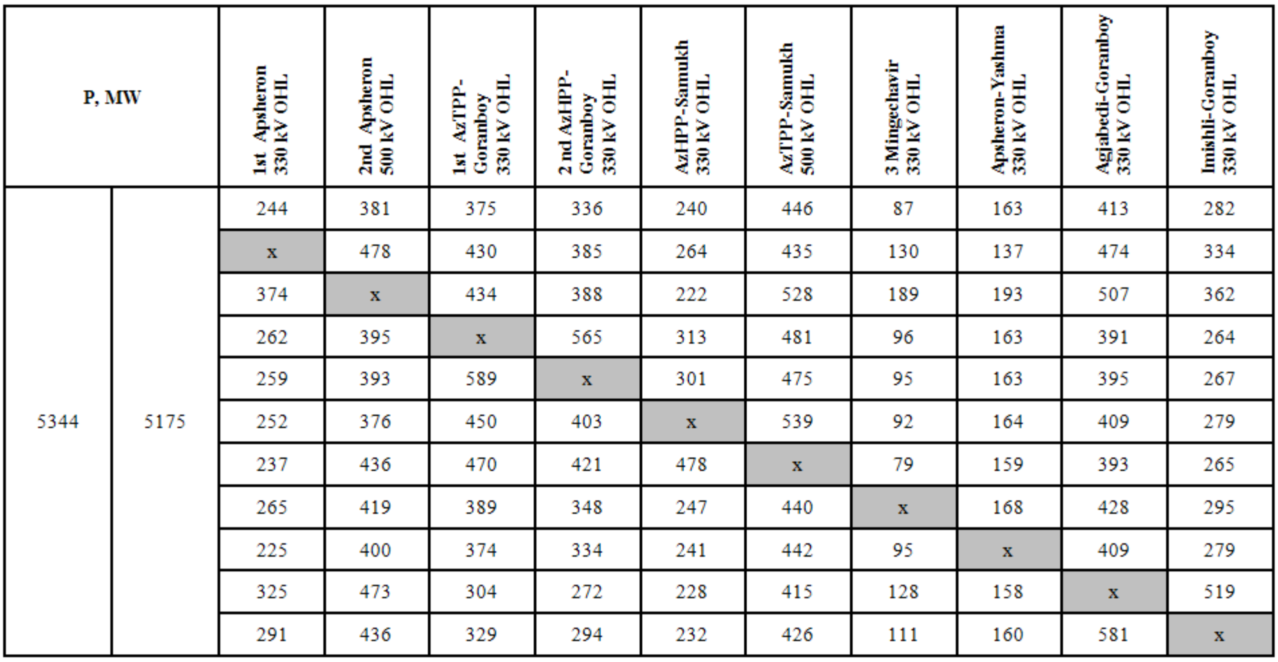
- Load flow analysis results for normal and N-1 contingency conditions are summarized in the following tables for 2012-2013, 2015 and 2017, respectively.

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.

TEIAS

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.

Azerenerji

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

ANNEX 1

Azerbaijan-Georgia-Turkey Power Bridge Project Memorandum of Understanding

MEMORANDUM OF UNDERSTANDING

SUB-REGIONAL TRANSMISSION SYSTEM PLANNING & ANALYSIS PROJECT

AZERENERGY JSC
GEORGIAN STATE ELECTROSYSTEM
TURKISH ELECTRICITY TRANSMISSION CORPORATION
UNITED STATES ENERGY ASSOCIATION

Introduction

This memorandum establishes an informal, voluntary partnership between Azerenergy JSC (Azerbaijan Republic), the Georgian State Electrosystem (GSE - Georgia) and the Turkish Electricity Transmission Corporation (TEIAS – Republic of Turkey). The partnership, with support from USAID and USEA, will study and analyze the high voltage electricity networks in each country from a sub-regional perspective to evaluate their capacity to support increased trade and exchange of electricity. This project will not address commercial issues such as specific terms of trade or volume of trade and investment. The partnership's analysis will provide engineers and policy makers with a tool to optimize the security and reliability of the sub-regional network and prioritize reinforcements within the network that are necessary to support increased trade and improve system security. A secondary objective of this effort is to support human resource development and build institutional capacity within the countries and this region.[1]

Project Goals and Objectives

- Create a joint planning/analysis group that will develop a sub-regional model of the high voltage networks using the PSS/E software as a common analytical platform;

- 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; and

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

Project Tasks

- Form a joint transmission planning analysis working group that will select a forecast year and trade scenarios to be analyzed, with appropriate input and guidance of the respective ministries in each country;

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[1] This project recognizes the growing interest in increased electricity trade in the region. It supports a technical analysis of the ability of sub-regional transmission network to facilitate greater cross border electricity trade between Azerbaijan, Georgia and Turkey.

- Collaborate, provide training and support to Azerenergy on the use and application of PSS/E;
- Construct a national model of the Azerbaijan high voltage network;
- Merge the Azerbaijan model with the completed models of Georgia and Turkey to establish a sub-regional model;
- Perform system analysis to identify/prioritize investments in the sub-regional network that will enhance trade and exchange and optimize system security and reliability. In the course of the research, it is necessary to study all aspects (technical, economic, and organizational) of a synchronous and asynchronous interconnection of the power systems of Azerbaijan, Georgia and Turkey. The results of the analysis will be used to inform but will in no way preempt the decisions of government authorities regarding sector investment priorities/decisions.
- Participate in capacity building training seminars, workshops, & study tours on an as-needed basis to support the goals and objectives of the project; and
- Prepare a report of the analysis containing recommendations for policy and regulatory authorities and international financial institutions.

Project Organization

The signatories will form a working group consisting of up to two 2 transmission engineers from each organization. USEA and USAID will also participate in the working group. The working group will develop a workplan and schedule for the project, on an annual basis. TEIAS will serve as the sub-regional model integrator.

Project Cost Sharing

USAID, through USEA, will fund the following expenses:

- Consistent with USAID regulations, purchase of PSS/E software and maintenance and support services for Acerenergy and GSE;
- Consistent with USAID regulations, hotel accommodation & daily living allowances for meetings of the working group and any training workshops; seminars and study tours.
- Support for consultants and outside institutes, as necessary.

The participating TSOs agree to fund the following expenses:

- Travel expenses to working group meetings and capacity building programs;

- Salaries of participating personnel;
- Development of national data and national model preparation; and
- Costs associated with volunteering to host meeting and training events. The hosting of meetings is voluntary and would usually involve providing a meeting room located within the host utility, providing audio-visual requirements necessary to conduct the meetings (computer, LCD projector), and coffee breaks.

Project Duration

The project is envisioned as a three year effort, subject to availability of USAID funds for years two and three.

Agreement

The following Parties agree to participate in this Black Sea Regional Project within the framework of this Memorandum:

Marlen Askerov, Vice President, Azerenergy JSC

DATE

Sulkan Zumburidze, General Director
Georgian State Electrosystem (GSE)

DATE

Mehmet Hanefi Töremiş, Deputy General Manager
Turkish Electricity Transmission Corporation (TEIAS)

DATE

Barry K. Worthington, Executive Director
United States Energy Association (USEA)

April 8, 2009
DATE

ADDENDUM 1

This MOU is executed by Azerbaijan, Georgia and Turkey. Other countries may be included in the Project only with the written consent of all existing parties.

ADDENDUM 2

An indicative workplan is appended to this Memorandum as Attachment A. It will be finalized at the initial working group meeting and maybe updated from time to time by the TSOs with input from the appropriate government ministries. The workplan for subsequent years will be circulated for review and guidance no later than 30 days prior to the end of the current year's workplan.

ANNEX 2

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

Technical Feasibility Analysis for Georgia–Turkey HVDC Interconnection

Final Report

By;

Power Systems Department
Power System Analysis and Planning Group

Turkish Electricity Transmission Company
Planning Department

12.05.2011

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Contact People

Cihangir Gençoğlu	cihangir.gencoglu@uzay.tubitak.gov.tr
Özgür Tanıdır	ozgur.tanidir@uzay.tubitak.gov.tr
Osman Bülent Tör	osman.tor@uzay.tubitak.gov.tr

TUBITAK UZAY Power Systems Department / TÜBİTAK UZAY Güç Sistemleri Bölümü

METU Campus, 06531, Ankara, Turkey / ODTÜ Yerleşkesi, 06531, Ankara, Türkiye
T: +90 312 2101054
F: +90 312 2101315

1. Introduction

As agreed by by both Turkish and Georgian parties, asynchronous interconnection between Georgia and Turkey is planned to be established via line commutated back to back (B2B) HVDC Substations (SS) located in Akhaltsikhe and Batumi regions of Georgia. Details of the substations are:

- 3x350 MW HVDC B2B converters are planned to be installed at Akhaltsikhe SS by the Georgian party until 2017.
  - This interconnection between Akhaltsikhe region of Georgia and Borcka region of Turkey is planned to be established between Akhaltsikhe SS (in Georgia) and Borcka SS (in Turkey) (see Figure 1).
  - The second line from that region is planned to be between Akhaltsikhe SS and Tortum SS which is under investment planning program of Turkey (see Figure 1).
- 2x175 MW HVDC B2B converters are planned to be installed at the Batumi region by the Georgian party until 2015.
  - The interconnection between Batumi region of Georgia will be between Batumi SS and Muratli SS in Turkey (see Figure 1).

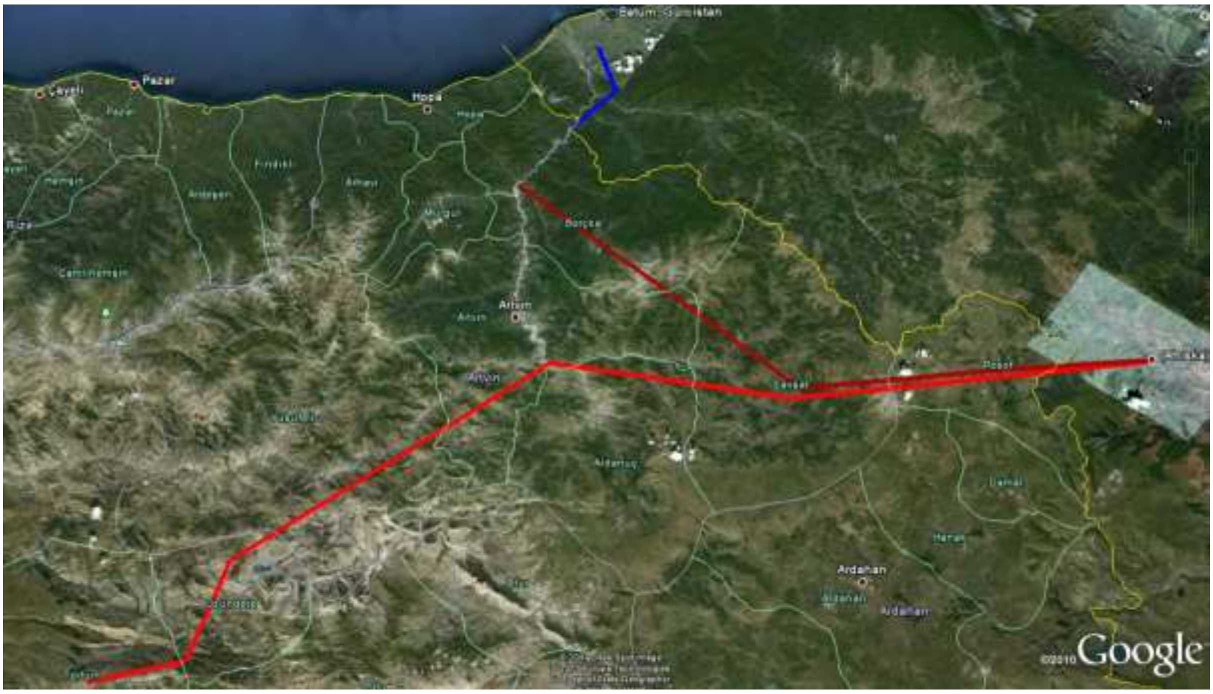


Figure 1: The basic transmission routes (blue line: Muratli – Batumi line representation; dark red line: Borcka – Akhaltsikhe line representation, light red line: Y. Tortum-Akhaltsikhe line representation).

According to the Minutes of Meeting (MoM) in Ankara between Turkish and Georgian parties on 08-09.12.2010 [1], feasibility analysis for power transfer to Turkey through these HVDC substations has to be performed by both countries' experts individually. Each party should consider secure limits of power transfer from their transmission network point of view. Another meeting was organized between Turkish and Georgian parties in Tbilisi on 18.02.2011 [2] in order to discuss the initial results and ensure that the ongoing studies are aligned. Finally, a workshop was performed in Ankara on 19-20 April 2011 to share the draft results [3]. The scenarios are also fixed in this workshop before finalizing the study. Several draft reports have been prepared until finalization of the study [4], [5].

This report includes the feasibility analysis methodology and **final** results of TUBITAK UZAY Power System Analysis Group, in the context of general consultancy agreement that signed between TUBITAK UZAY and TEIAS on 24.08.2010, in the scope of planning studies for Turkish power system. The feasibility of power transfer from Georgia to Turkey is analyzed with computer simulations (MATLAB ^{TM} under the license of TUBITAK UZAY and PSS/E ^{TM} under the license of TEIAS) based on the scenarios and network models (as described in detail later in this report) that agreed during the meetings mentioned above.

The report includes 3 main parts: 1) Power quality analysis (switching analysis) in which HVDC B2B substations' capacities are evaluated in the sense of short circuit MVA (SCMVA) of the busbars at the coupling points, 2) Security analysis in which load flow and contingency analysis are performed in order to determine safe transfer limits, 3) Dynamic analysis in which voltage stability is analysed. Main focus of this report is to analyze the effects of different levels of power import from Georgia to Turkey on the possible transmission bottlenecks in Turkish network and measures in order to increase **safe** transfer amounts.

The report is organized as follows. Section 4 presents all the scenarios to be analysed and modeling of the network including all assumptions. Power quality, security and dynamic analysis and results are given in Section 5, 6 and 7, respectively. Section 8 emphasizes the requirement for a special protection scheme in order to ensure that Turkish network will not operate in a state which can result in a regional black out. The report ends with conclusion and remarks. All supportive documents including analysis results are included as attachments.

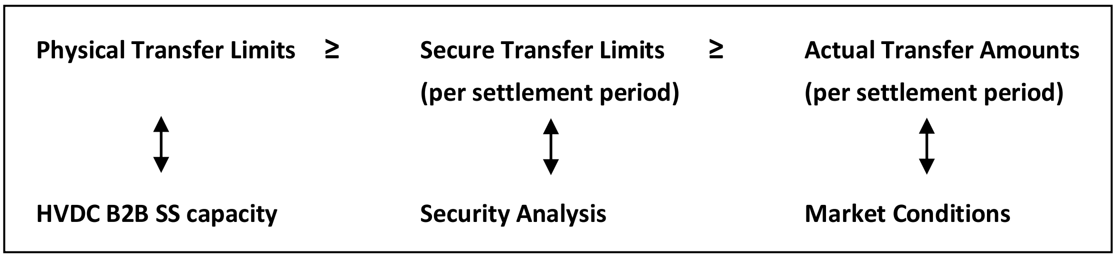
2. Analysis Scenarios and Modeling

The following scenarios have been fixed by both parties to be analysed during the meetings [1]-[3]:

B2B substations' **capacity**:

- 2013: 2x350 MW Akhaltsike; 2x175 MW Batumi
- 2015: 2x350 MW Akhaltsike; 2x175 MW Batumi
- 2017: 3x350 MW Akhaltsike; 2x175 MW Batumi

It is important to note that, those 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 both countries. The relationship between these concepts are illustrated below:



In Turkey, grid planning scenarios are generally based on summer peak, winter peak and spring minimum loading conditions. Given the hydraulic conditions at the region during the spring and occurance of recent Turkish annual peak loading in summer, the most important scenarios for Turkey in the sense of secure energy import form Georgia are envisaged to be determined by **summer peak** and **spring minimum** loading conditions. Depending on the network conditions as well as trnasmission line and substation investments, the analysis results of those two scenarios will provide **upper and lower limits** of **secure power transfer** from Georgia to Turkey.

2.1. Turkish Regional Grid Model

2.1.1. Generation and Loading Profile of the Region in Turkey

2.1.1.1. Key power plants in the region (existing, under construction and planned)

The following table (Table 1) summarizes the loading scenarios of the **key** generators of the region that affect the power flow in the 400 kV backbone of Turkey. The seasonal loading conditions of the similar generators existing in the network are taken as reference in developing the corresponding generation scenarios. Different loadings of the generators with respect to summer/spring loading conditions are colored in the table to emphasize the increase of generation from hydraulic power plants in the region during spring loading conditions. Representation of the existing and planned small power plants is presented in the following section.

Table 1: Generation scheme of the key power plants in the region (existing and under construction (UC))

2013		2015		2017	
Summer	**Spring**	**Summer**	**Spring**	**Summer**	**Spring**
Borçka HPP: Single Unit (1/2), 130 MW	Borçka HPP: Two Units (2/2), 300 MW	Borçka HPP: Single Unit (1/2), 130 MW	Borçka HPP: Two Units (2/2), 300 MW	Borçka HPP: Single Unit (1/2), 130 MW	Borçka HPP: Two Units (2/2), 300 MW
Deriner HPP (UC*): Two Units (2/4), 335 MW	Deriner HPP: Four Units (4/4), 670 MW	Deriner HPP: Two Units (2/4), 335 MW	Deriner HPP: Four Units (4/4), 670 MW	Deriner HPP: Two Units (2/4), 335 MW	Deriner HPP: Four Units (4/4), 670 MW
Arkun HPP (UC*): Single Unit (1/1), 118 MW	Arkun HPP: Single Unit (1/1), 118 MW	Arkun HPP: Single Unit (1/1), 118 MW	Arkun HPP: Two Units (2/2), 237 MW	Arkun HPP: Single Unit (1/2), 118 MW	Arkun HPP: Two Units (2/2), 237 MW
Boyabat HPP (UC*): Three Units (3/3), 570 MW	Boyabat HPP: Three Units (3/3), 570 MW	Boyabat HPP: Three Units (3/3), 570 MW	Boyabat HPP: Three Units (3/3), 570 MW	Boyabat HPP: Three Units (3/3), 570 MW	Boyabat HPP: Three Units (3/3), 570 MW
H. Ugurlu HPP: Four Units (4/4), 456 MW	H. Ugurlu HPP: Four Units (4/4), 456 MW	H. Ugurlu HPP: Four Units (4/4), 456 MW	H. Ugurlu HPP: Four Units (4/4), 456 MW	H. Ugurlu HPP: Four Units (4/4), 456 MW	H. Ugurlu HPP: Four Units (4/4), 456 MW
Altınkaya HPP: Four Units (4/4), 600 MW	Altınkaya HPP: Three Units (3/4), 288 MW	Altınkaya HPP: Four Units (4/4), 600 MW	Altınkaya HPP: Three Units (3/4), 288 MW	Altınkaya HPP: Four Units (4/4), 600 MW	Altınkaya HPP: Three Units (3/4), 288 MW
Borasco NGCCPP (UC*): Single Unit (1/1), 867 MW	Borasco NGCCPP: Single Unit (1/1), 867 MW	Borasco NGCCPP: Single Unit (1/1), 867 MW	Borasco NGCCPP: Single Unit (1/1), 867 MW	Borasco NGCCPP: Single Unit (1/1), 867 MW	Borasco NGCCPP: Single Unit (1/1), 867 MW
-	-	-	-	Yusufeli HPP: Single Unit (1/3), 190 MW	Yusufeli HPP: Single Unit (1/3), 190

2.1.1.2. Small hydraulic power generation potential in the region

In Figure 2, the generating facilities (red circles) either in operation or construction or planned, together with the **main** load centers (yellow circles) and the expected main transmission routes in 2013 (black lines) related to the Georgia Interconnection, are illustrated. Given considerable amount of generation with respect to consumption of the region itself, it is essential that there is (and will be) a unidirectional power flow from the Black Sea Region to the load centers located in the South East Anatolia region, Ankara region and the Marmara region (Istanbul, Adapazari).

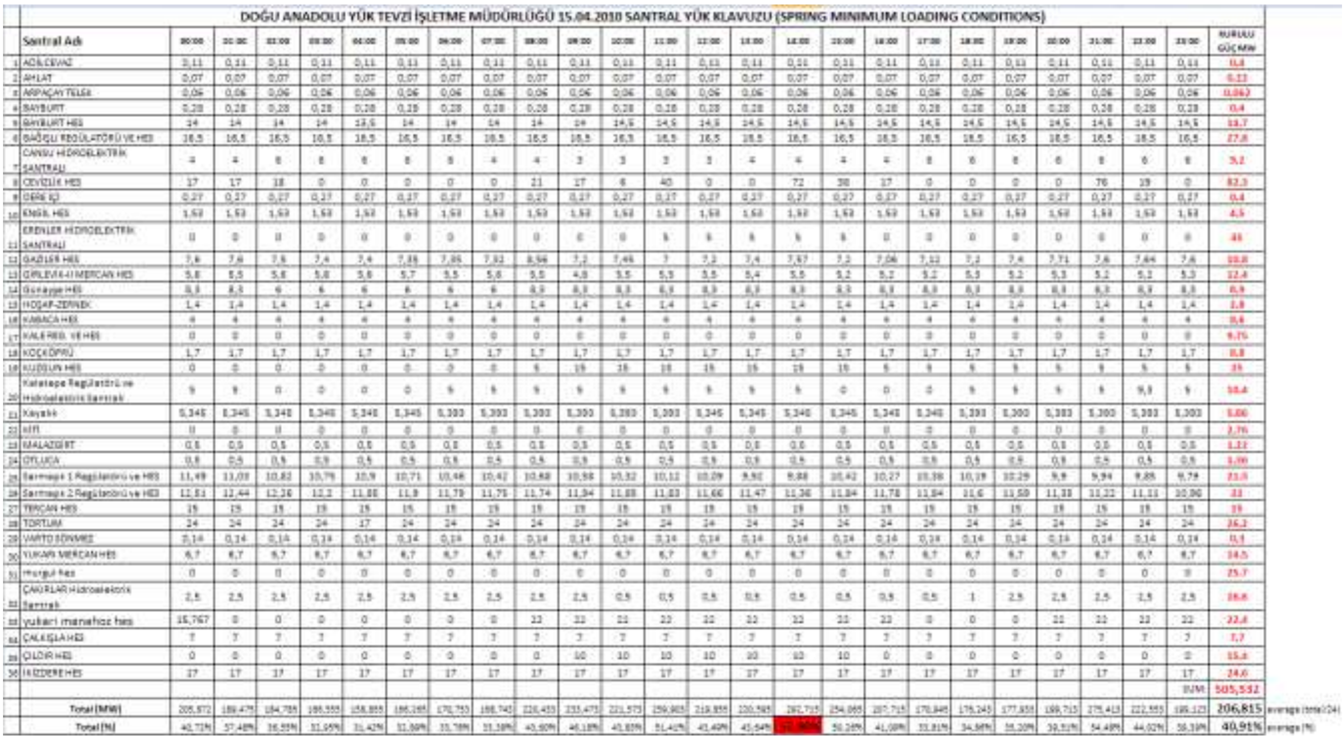
Note that, although dispatch of the generating units in Turkey is subjected to system security and electricity market conditions in Turkey, almost all those generators around the region are hydraulic type (many run-of-river), and therefore, it is reasonable to assume that a considerable amount of generation is to be dispatched particularly during spring and initial summer periods, given the hydrological conditions and competitiveness of those generating units. In order to reflect this to the analysis, the following study is performed:

Figure 2: The basic transmission routes related to Georgia Interconnection (blue line: Muratli – Batumi line representation; red line: Borcka – Akhaltsikhe line representation, black lines: expected transmission highways in 2013, red circles: major generating facilities, yellow circles: major load centers).

- First, the existing hydraulic generation is investigated for typical days to represent:
  - 2010 Summer maximum loading conditions, and
  - 2010 Spring minimum loading conditions
- Then, maximum loading of the run of the river type generation with respect to total capacity is determined both for each hour and the day. The results are summarized in the following tables.
- A loading factor for the run of the river type generation is determined to be utilized in the analysis as marked with red in the corresponding tables.
- The hydroelectric power plants with **reservoir storage capacity** are assumed to operate at 50% of their capacity during summer and full capacity during spring conditions (see also Table 1 above).
- Finally, license applications to Energy Market Regulatory Authority (EMRA) of Turkey or project applications to TEIAS are investigated in order to determine total capacity potential at the region.

The following tables (Tables 1-5) summarize the methodology to assign loading factors of run-of-river type hydraulic power plants (both existing and planned) utilized in the analysis.

Table 2: Typical day representing spring minimum loading conditions in 2010



DOĞU ANADOLU YÜK TEVZİ İŞLETME MÜDÜRLÜĞÜ 15.04.2010 SANTRAL YÜK KLAVUZU (SPRING MINIMUM LOADING CONDITIONS)

Table 3: Typical day representing summer maximum loading conditions in 2010

DOĞU ANADOLU YÜK TEVZİ İŞLETME MÜDÜRLÜĞÜ 15.08.2010 SANTRAL YÜK KLAVUZU (SUMMER MAXIMUM LOADING CONDITIONS)

Table 4: Summary of the loading factors for typical maximum and minimum loading conditions of run-of-river type htdraulic power plants in 2010.

Loading condition	Maximum loading factor of the analysed day	Average loading factor of the analyzed day	Loading factor utilized in the analysis
Spring minimum	58%	41%	60%
Summer maximum	33%	20%	20%

Table 5: Total foreseen small hydraulic electricity generation installed capacity in the region.

Year	Expected total small scale hydraulic electricity generation (installed) capacity
2013	~4125 MW
2015	~5100 MW
2017	~5514 MW

2.1.2. Key transmission line and substation investments at the region (EHV)

The following table summarizes the **key** transmission line and substation projects which are assumed to be completed by the corresponding years in sequence. This table is developed by the collaboration between TEIAS and TUBITAK UZAY experts and approved by TEIAS.

Table 6: The key planned transmission system investments

2013	2015	2017
Agri-Van 400 kV Tr. Line		
Van-Siirt and Siirt-Batman 400 kV Tr. lines		
Kalkandere 400 kV substation		
Resadiye 400 kV substation		
Kayabasi-Resadiye 400 kV Tr. line		
Arkun-Y. Tortum 400 kV Tr. lines		
Borcka-Artvin and Artvin-Y. Tortum 154 kV double circuit Tr. Lines		
300 MVA autotransformer at Borcka SS		
Agri-Van 400 kV Tr. Line		
Van-Siirt and Siirt Batman 400 kV Tr. Lines		
	Borcka-Ispir 400 kV Tr. Line	
	Ispir-Bagistas 400 kV Tr. Line	
	Ispir-Erzurum 400 kV Tr. Line	
	Bagistas-Keban 400 kV Tr. Line	
	Ispir 400 kV substation	
	Ordu 400 kV substation	
	Ordu-Resadiye 400 kV Tr. Line	
	Arkun-Ispir 400 kV Tr. Line	
		Akhaltsikhe-Y.Tortum 400 kV Tr. Line

2.1.3. Equivalent Representation of the Remaining Turkish network

In the analysis, the Turkish network is represented with infinite buses at the Kayabasi, Kursunlu and Keban substations (i.e., the entire Black Sea Region and East Anatolia Region transmission systems are modeled in detail). The transmission ring between Van and Keban buses is modeled with an equivalent line.

The Parameters of the Equivalent Line:

- ✓ For peak load conditions: 0.0075+0.1353j
- ✓ For minimum load conditions: 0.00571+0.1247j

2.2. Georgian Grid Model

Akhaltsikhe 500 kV SS and Batumi 220 kV SS are modeled as **infinite buses** to model Georgian Grid in the analysis (i.e., the security analysis are only performed for the Turkish transmission system). That is, both substations in Georgia are assumed to have a **sufficient SCMVA** to provide a secure power transfer from Georgian network to Turkey, which is indeed verified by the analysis of Georgian party [1]-[3].

2.3. Transmission Line between Borcka SS (Turkey) to Akhaltsike SS (Georgia)

Technical Specifications taken from TEIAS, as (see Figure 1 above):

- ✓ U_{base} = 400 kV
- ✓ Type and cross-section of conductor : 3B Cardinal 954 MCM
- ✓ Length = ~160 km effective length
- ✓ Rated current (thermal limit) = 3144 A
- ✓ Rated power (thermal limit) = 2178 MVA
- ✓ Series resistance = 0.0208 Ω/km. per phase
- ✓ Series reactance = 0.266 Ω/km. per phase (the line is assumed to be perfectly transposed)
- ✓ Charging susceptance = 4.31 µS/km per phase

2.4. Transmission Line between Yeni Tortum SS (Turkey) to Akhaltsike SS (Georgia)

Technical Specifications taken from TEIAS, as (see Figure 1 above):

- ✓ U_{base} = 400 kV
- ✓ Type and cross-section of conductor : 3B Cardinal 954 MCM
- ✓ Length = ~160 km effective length
- ✓ Rated current (thermal limit) = 3144 A
- ✓ Rated power (thermal limit) = 2178 MVA
- ✓ Series resistance = 0.0208 Ω/km. per phase
- ✓ Series reactance = 0.266 Ω/km. per phase (the line is assumed to be perfectly transposed)
- ✓ Charging susceptance = 4.31 µS/km per phase

2.5. Transmission Line between Muratli SS (Turkey) to Batumi SS (Georgia)

Technical Specifications taken from TEIAS, as (see Figure 1 above):

- ✓ U_{base} = 154 kV
- ✓ Type and cross-section of conductor : 2 x 1272 MCM (i.e., double circuit)
- ✓ Length = ~15 km
- ✓ Rated current (thermal limit) = 2 x 1260 A
- ✓ Rated power (thermal limit) = 2 x 336 MVA
- ✓ Series resistance = 0.0472 Ω/km. per phase
- ✓ Series reactance = 0.372 Ω/km. per phase (the line is assumed to be perfectly transposed)
- ✓ Charging susceptance = 3.154 µS/km per phase

2.6. HVDC Converter Stations at 400 kV Akhaltsikhe SS

The technical details of the AC and DC interface between the two power systems at Akhaltsikhe substation are as listed below:

DC B2B Station (Structure of a Single Block: 350 MW transfer capacity):

Following data are based on either those data that provided by TEIAS or the assumptions (typical applications/parameters) proposed by TUBITAK UZAY experts, and notated by "***Assumptions***".

- Converter Transformer:
    - ***Assumptions***: (Georgian side 500 kV, Turkish side 400 kV (Yg)) / 45 kV (Y Δ), 420 MVA (%U_k= 0.12 pu at each winding) at Akhaltsike (Georgia) SS with On-Load Tap Changing Capability (at least 5 steps).
- Converter Blocks:
    - ✓ Twelve pulse configuration

    - ✓ Vdc_{rated} = 107 kV
    - ✓ I_{rated} =3271 A (=350 MW/107 kV)
    - ✓ Simulation ***Assumptions***:
        - ○ $\gamma_{rated} \sim 18^o$ (inverter side)
        - ○ $\alpha_{rated} \sim 18^o$ (rectifier side)
        - ○ $\gamma_{min} = 15^o$, $\gamma_{max} = 28^o$, (inverter side)
        - ○ $\alpha_{min} = 5^o$, $\alpha_{max} = 20^o$, (rectifier side)
    - ✓ DC line smoothing reactance: 2x50 mH
- Thyristor Valves ***Assumptions***: the thyristor valves to be utilized in the converter blocks are modeled with their system level equivalents, which includes the following assumptions:
    - ✓ No voltage drop on the thyristor valves (i.e., forward voltage = 0V, both at the rectifier side and at the inverter side)
    - ✓ No switching losses in the converter

The basic configuration of the two six pulse bridges that comprise the twelve pulse converter is illustrated is illustrated in Figure 3.

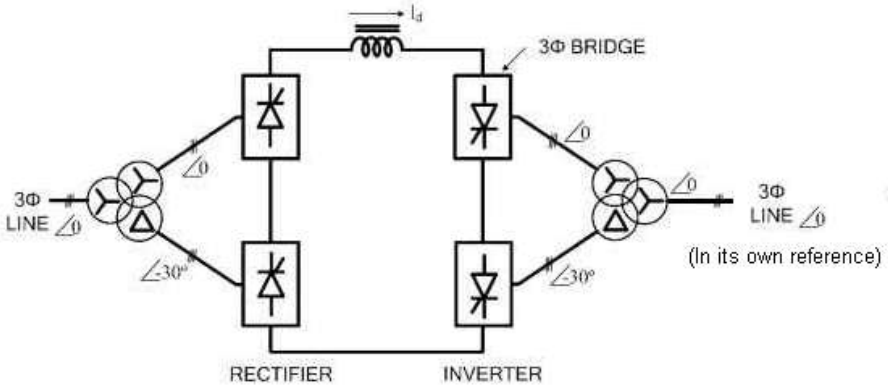


Figure 3: The topology of a 12 pulse B2B Substation

Harmonic filters: No data provided regarding the harmonic filters. Therefore, the following topology is ***assumed*** in computer simulations:

- Filter Blocks ***Assumptions***: 2 separate harmonic filter blocks (i.e., one for each 350 MW converter) are utilized in this study. The reason of this selection will be explained in the short circuit analysis section of this report. Note that no additional power factor correction shunt capacitors are utilized. The technical details of the harmonic filters are given below:
    - ✓ 11th Harmonic Filter: Single tuned series RLC filter (band pass) (the reason of this selection will be explained in detail at the harmonic analysis section (i.e., Section 4.2.1.3.a)):
        - ○ V_{rated} = 400 kV
        - ○ f_{rated} = 50 Hz
        - ○ Q_{rated} = 52.5 MVAr (for each 350 MW block)
        - ○ f_0 = 550 Hz
        - ○ Q (quality factor) = 300
    - ✓ 13th Harmonic Filter: Single tuned series RLC filter (band pass) (the reason of this selection will be explained in detail at the harmonic analysis section):
        - ○ V_{rated} = 400 kV
        - ○ f_{rated} = 50 Hz

        - Q_{rated} = 52.5 MVAr (for each 350 MW block)
        - f_0 = 650 Hz
        - Q (quality factor) = 100
    - ✓ 24th Harmonic Filter: High pass RLC filter (the reason of this selection will be explained in detail at the harmonic analysis section):
        - V_{rated} = 400 kV
        - f_{rated} = 50 Hz
        - Q_{rated} = 52.5 MVAr (for each 350 MW block)
        - f_0 = 1200 Hz
        - Q (quality factor) = 3
- It has also been assumed that 3x60 MVA **synchronous condensers** are installed in the 400 kV Akhaltsikhe swithchyard. This information is approved by Georgian party although the corresponding project was not provided.
- **Important**: The independent operation of two single converter blocks necessitates independent harmonic filters in both sides of the converter substation as well (i.e. 400 kV Akhaltsikhe side and 500 kV Akhaltsikhe side). Explicitly, there should be seperate 11th, 13th and 24th harmonic filters, each rated at 52.5 MVAr for each 350 MW converter block, which means extra feeder, circuit breaker, disconnecting switch, related auxiliary equipments (for measurement, protection and telecommunication) and space requirement at both AC switchyards. This should be kept in mind.

2.7. HVDC Converter Stations at 220 kV Batumi SS

It is also planned to construct a 2x175 MW capacity converter substation at Batumi region of Georgia. It is ***assumed*** that the B2B converter will be of the same technology with the single one to be installed at Akhaltsikhe substation described above, except the following differences:

DC B2B Station (Structure of a Single Block):

- Following data are based on either those data that provided by TEIAS or the assumptions (typical applications/parameters) proposed by TUBITAK UZAY experts, and notated by "***Assumptions***".Converter Transformer:
    - ***Assumptions***: (Georgian side 220 kV, Turkish side 154 kV (Yg)) / 45 kV (Y Δ), 420 MVA ($\%U_k$= 0.12 pu at each winding) at Akhaltsikhe (Georgia) SS with On-Load Tap Changing Capability.
- Converter Blocks:
    - ✓ Twelve pulse configuration
    - ✓ Vdc_{rated} = 107 kV
    - ✓ I_{rated} =3271 A (=350 MW/107 kV)
    - ✓ Simulation ***Assumptions***:
        - $\gamma_{rated} \sim 18^o$ (inverter side)
        - $\alpha_{rated} \sim 18^o$ (rectifier side)
        - $\gamma_{min} = 15^o$, $\gamma_{max} = 28^o$, (inverter side)
        - $\alpha_{min} = 5^o$, $\alpha_{max} = 20^o$, (rectifier side)
    - ✓ DC line smoothing reactance: 2x50 mH
- Thyristor Valves ***Assumptions***: the thyristor valves to be utilized in the converter blocks are modeled with their system level equivalents, which includes the following assumptions:
    - ✓ No voltage drop on the thyristor valves (i.e., forward voltage = 0V, both at the rectifier side and at the inverter side)

- ✓ No switching losses in the converter

The basic configuration of the converter station is illustrated in Figure 3.

Harmonic filters: The following topology is ***assumed*** in computer simulations:

- Filter Blocks ***Assumptions***: The technical details of the harmonic filters are given below:
  - ✓ 11th Harmonic Filter: Single tuned series RLC filter (band pass):
    - ○ V_{rated} = 154 kV
    - ○ f_{rated} = 50 Hz
    - ○ Q_{rated} = 52.5 MVAr
    - ○ f_0 = 550 Hz
    - ○ Q (quality factor) = 100
  - ✓ 13th Harmonic Filter: Single tuned series RLC filter (band pass):
    - ○ V_{rated} = 154 kV
    - ○ f_{rated} = 50 Hz
    - ○ Q_{rated} = 52.5 MVAr
    - ○ f_0 = 650 Hz
    - ○ Q (quality factor) = 100
  - ✓ 24th Harmonic Filter: High pass RLC filter:
    - ○ V_{rated} = 154 kV
    - ○ f_{rated} = 50 Hz
    - ○ Q_{rated} = 52.5 MVAr
    - ○ f_0 = 1200 Hz
    - ○ Q (quality factor) = 3
  - ✓ Power Factor Correction Capacitor
    - ○ V_{rated} = 154 kV
    - ○ f_{rated} = 50 Hz
    - ○ Q_{rated} = 52.5 MVAr (for each 350 MW block)

2.8. HVDC B2B Converter Model

The CDC7T model in PSS-E [6] as illustrated in Figure 4 is utilized to model the HVDC B2B station in load flow studies. Although the B2B converter enables bilateral transfer of power between both sides, since it is expected that Turkish side will generally be the importing side, the inverter side of the B2B station is assumed to be Turkey, whereas the rectifier side is assumed to be Georgia throughout the analysis.

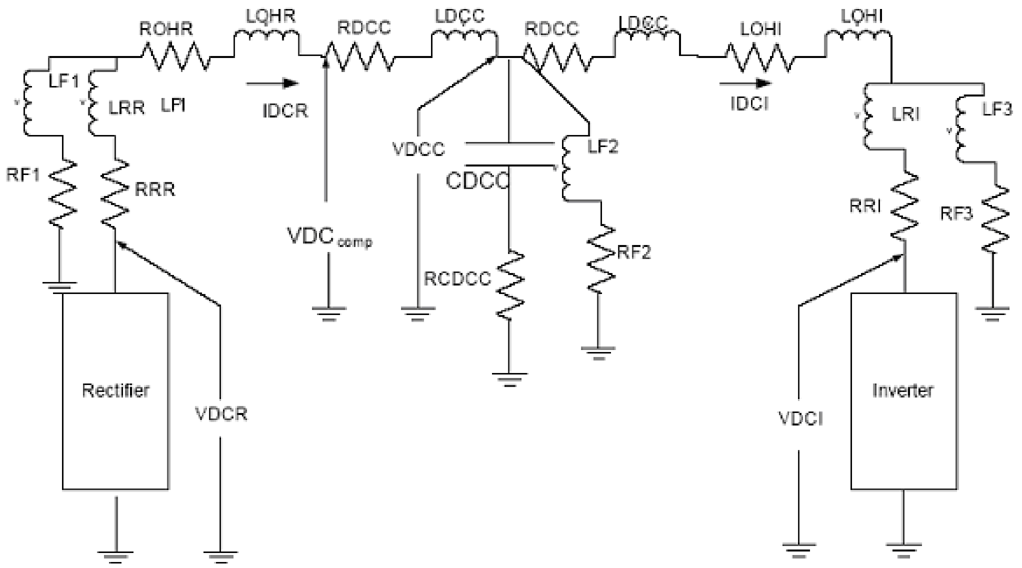


Figure 4: The CDC7T HVDC link model [1]

3. Part 1: Power Quality Analysis (Switching Analysis)

The de facto control philosophy of HVDC B2B stations is as follows [7]:

- The inverter side controls the DC bus voltage (on D-F line in Figure 6)
- The rectifier side controls the DC bus current (on B-C line in Figure 6)

The B2B station models in this study are constructed based on this methodology. Note that the normal operating point of the B2B converter is point E in Figure 6. The controller structures of the bridge converters are of the discrete nonlinear PI type (together with limiters, mode selection logic, etc.). It should be mentioned here that the inverter side control is more dependent on grid conditions than the rectifier side (due to minimum off time of the thyristors). Although the B2B converter enables bilateral transfer of power between both sides, since it is expected that Turkish side will generally be the importing side, the inverter side of the B2B station is assumed to be Turkey, whereas the rectifier side is assumed to be Georgia throughout the analysis.

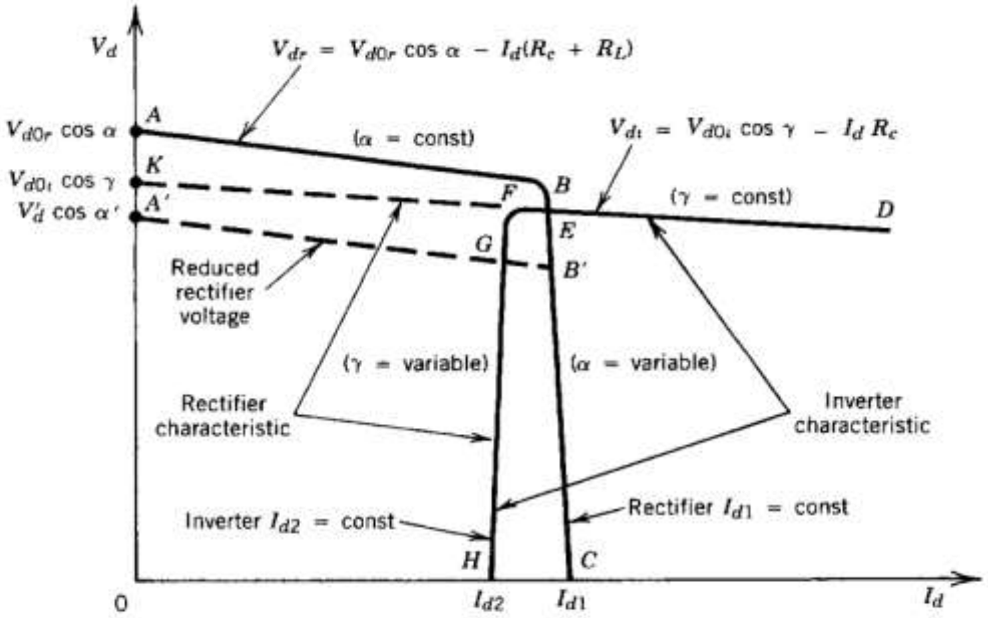


Figure 5: The operating curves of B2B converter stations [7]

3.1. Calculation of Effective Short Circuit Ratio (ESCR)

The most crutial parameter that determines the capability of the grid to handle conventional line frequency commutated B2B stations is the strength of the AC system, which is related to the equivalent Thevenin impedance of the grid. HVDC interfaces at the weak points of AC systems may result in problems such as harmonic resonance, instability and frequent commutation failures [2].

Effective Short Circuit Ratio is an index for evaluating some of the complex and variable interactions between AC and DC systems, which is calculated according to the below formula:

$$ESCR = \frac{SCMVA_{grid} - S_{filter}}{P_{dc}}$$

A figure of merit for the healthy operation of conventional line frequency commuted HVDC interfaces is **ESCR ≥ 2.5 (3 is a more conservative and safe limit)** [2]**.** Therefore, the results of the analysis in the following sections will be discussed based on this criterion.

3.2. Analysis for the Converter Station at Akhaltsikhe 500 kV SS

In the following sections, the feasibility of power transfer via DC back to back substation located at Akhaltsikhe SS will be analyzed for different grid conditions in Turkish side. Two different grid conditions will be analyzed, which are classified as optimistic and pessimistic scenarios, based on the effective short circuit ratio at the DC back to back substation connection point, as described below.

3.2.1. Optimistic Scenario (in the sense of grid conditions in Turkey)

3.2.1.1. ESCR Calculation

The **maximum** value of SCMVA at Borcka SS is expected to be 3000 MVA (in case of all expected generating units are in operation, without the synchronous condensers at Akhaltsikhe SS). Therefore, considering also the transmission line between Borcka and Akhaltsikhe, the maximum value of SCMVA at Akhaltsikhe end of the line is reduced to 1668 MVA due to 160 km single circuit overhead line between Borcka and Akhaltsikhe substations. However, the synchronous condensers increase the SCMVA by ~570 MVA.

In addition, the harmonic filters generally produce a total reactive power at an amount of 60% of the rated DC power, which means:

11th harmonic filters = 2x52.5 MVAr

13th harmonic filters = 2x52.5 MVAr

24th harmonic filters = 2x52.5 MVAr

Note that no power factor compensation is required for the optimistic scenario (will be explained in the reactive power requirement calculation)

Therefore, the amount of safe power transfer which will avoid dynamical overvoltages (DOV) and frequent commutation failures is calculated as:

$$P_{dc\,safe} = \frac{SCMVA_{grid} - S_{filter}}{ESCR_{safe}} \approx 720\ \mathrm{MW}$$

3.2.1.2. Reactive Power Requirement Calculation

As a result of the power quality simulation studies, it has been found out that transfer of 700 MW from Georgia to Borcka seems *possible* only for the optimistic scenario in the sense of power quality standards of the Turkish Grid Code, provided the compensation of at least two of the proposed 3x75 MVA synchronous condensers. However, static and dynamic analysis results should be taken into account before giving any final decision.

3.2.1.3. Simulation Results

a) Harmonics Analysis

It is essential that any nonlinear load is a harmonic current source and hence should be sufficiently compensated in order not to overload the electrical equipment with excessive reactive power that has no practical use. Since a group of customers are interconnected to the power system at a specific node (Point of Common Coupling, PCC), the transmission system operator is responsible from maintaining an acceptable sinusoidal voltage wave shape for the quality of supply.

Any B2B converter is, similarly, a source of harmonic currents and hence should be compensated adequately so as to maintain the power quality standards defined in the Turkish Grid Code [9].

Similar to the case in the 5.2.1.2. section of this report, as the optimistic scenario, 700 MW power transfer from Georgia is analyzed in this section (i.e., Turkey is the inverter side). The time domain simulation results of the B2B converter is illustrated in Figure 6.

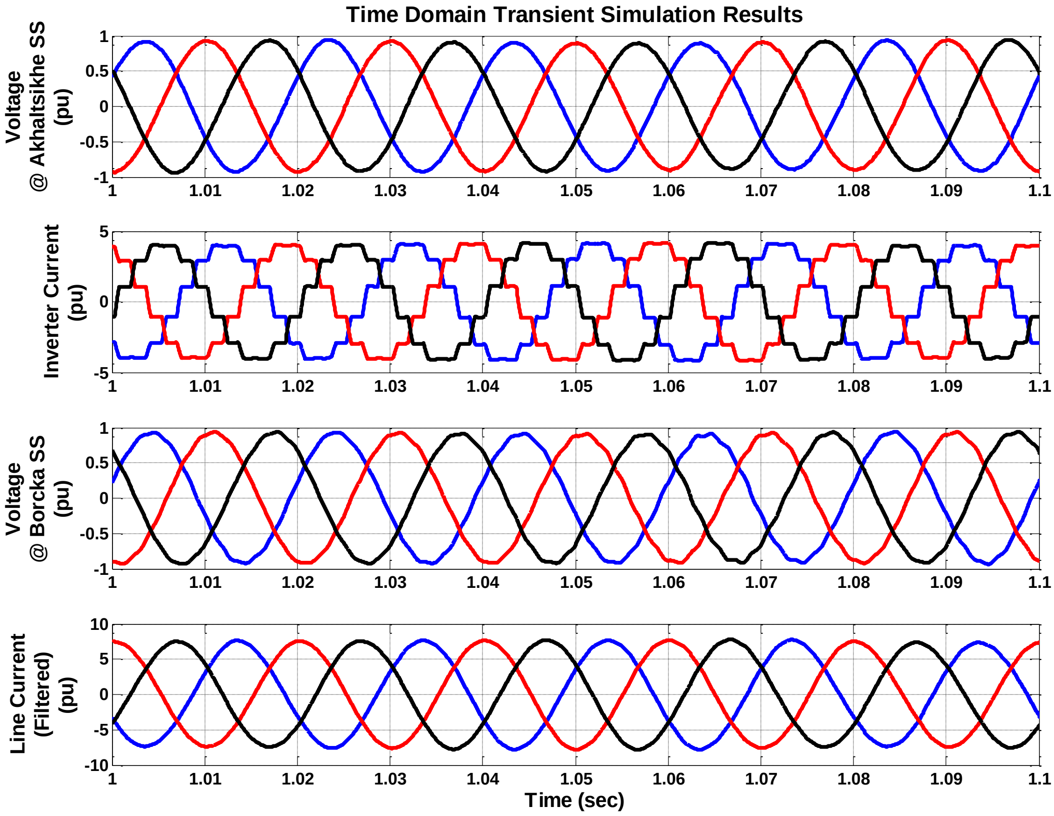


Figure 6: Time domain transient switching results of the B2B converter

One can immediately see the distortion on the voltage wave shape at Borcka substation, due to the nonlinear nature of the inverter. The harmonic spectrum of the inverter current is illustrated in Figure 7.

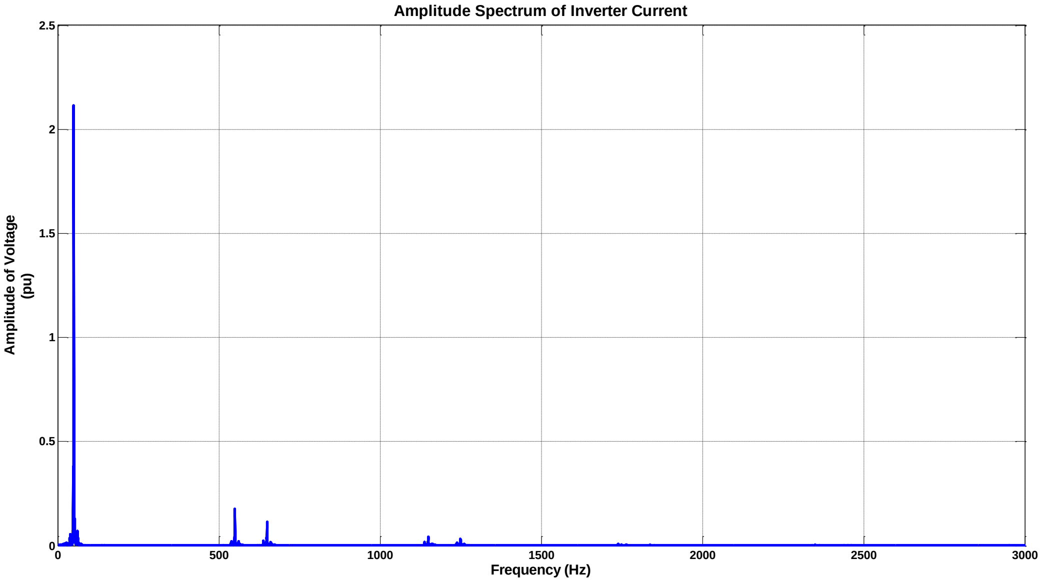


Figure 7: The harmonic spectrum of inverter current

As can be readily seen in Figure 7, the most dominant harmonic of the inverter current is the 11th harmonic. This verifies the necessity of the harmonic filters that should be tuned as mentioned in the 3.4. section of this report. It should be noted that in most applications, the 11th and 13th harmonic filters are tuned with a quality factor of 100.

The harmonic spectrum of line current at the receiving end of the transmission line (i.e., Borcka substation) is illustrated in Figure 8. It can be observed that the problematic harmonic components are eliminated by analyzing Figure 6 and Figure 8 together.

The harmonic spectrum of voltage at Borcka substation is illustrated in Figure 9. The comparison of the harmonic components of the voltage waveform illustrated in Figure 6 and Figure 9 are listed in Table 7. It can be seen that all requirements of the grid code are satisfied with the topology expressed in the third part of this study. Another very important point for the assessment of the results of Table 7 is that, according to the power quality measurements taken by TEIAS power quality monitoring system it can be seen that no serious harmonic distortion at Borcka busbar (PCC for Turkish transmission system) is present and hence most of the permitted room for harmonic voltage distortion will be occupied by the B2B converter (especially by the 11th harmonic, which is written in red in Table 7).

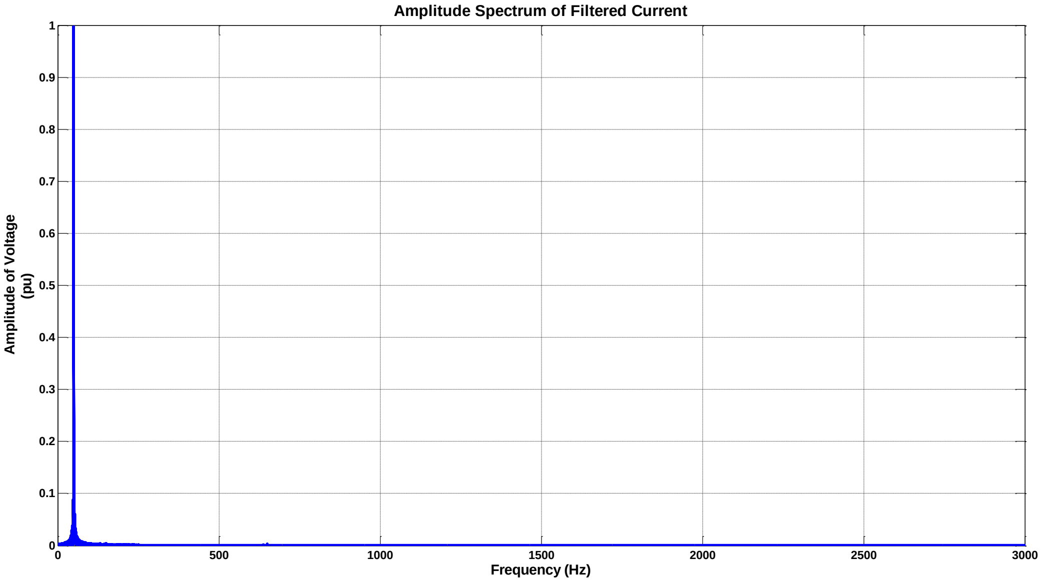


Figure 8: The harmonic spectrum of the current at the receiving end (Borcka substation) of the transmission line

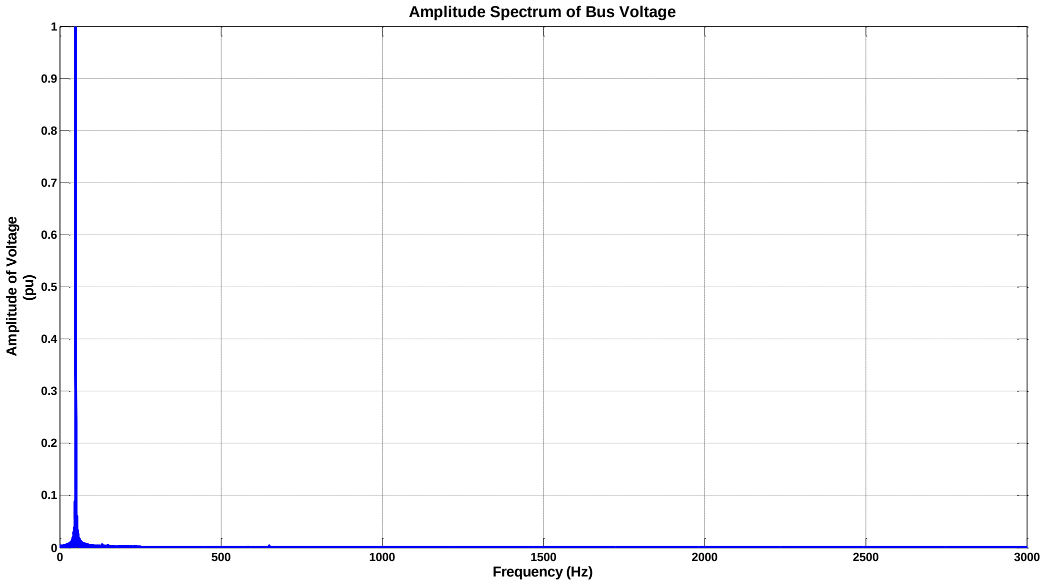


Figure 9: The harmonic spectrum of the voltage at Borcka substation

Table 7: The comparison of the voltage harmonics related to the B2B converter and Turkish grid code requirements

Odd Harmonics (Non multiples of 3)			Odd Harmonics (Multiples of 3)			Even Harmonics		
Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)
5	1.25	0.1468	3	1.0	0.5145	2	0.75	0.4000
7	1.0	0.0391	9	0.4	0.0654	4	0.6	0.1543
11	0.7	0.6106	15	0.2	0.0594	6	0.4	0.0045
13	0.7	0.0348	21	0.2	0.0230	8	0.4	0.0724
17	0.4	0.0873	>21	0.2	OK	10	0.4	0.0579
19	0.4	0.0109				12	0.2	0.1136
23	0.4	0.0399				>12	0.2	OK
25	0.4	0.0386						
>25	0.2+0.2 (25/h)	OK						
THD < % 2 OK, but very close to the limit								

b) Voltage Dips and Swells Analysis, and Voltage Regulation for Converter Start up

Since the converter station is connected at a relatively weak transmission node, it has been observed that with the operation of the converter station:

i) If the converter is not in service, by the compensation of the synchronous condensers, the voltage at the 400 kV Akhaltsikshe substation terminal of the line can be maintained within the permissible limits (which will most probably not cause a breakdown) despite the capacitive effect of the harmonic filter blocks at nominal frequency and the long transmission line, in case the **unregulated** voltage at Borcka substation tends to be around 400 kV (i.e., Borcka HPP is not in operation).

ii) However, in order to minimize the risk of failures, while the converter is being put into service (note that any switching operation should not cause a voltage dip larger than 2% according to Turkish Grid Code),
  - Coordination should be provided via the Turkish regional load dispatch center to maintain rated voltage at Borcka substation.
  - The inverter should be brought to its desired operating point (Note that as the converter will increase its power, it will draw reactive power from the system, hence it should be brought to its desired operating point progressively in coordination with the RLDC).

In conclusion, voltage regulation by Borcka and/or Deriner HPPs might be necessary in order to start up the converter.

c) Voltage Imbalance

Within the operation of the converter station, all three phases are expected to be loaded in a balanced manner, in case no failures occur.

d) Flicker

Since the converter station is connected at a relatively weak transmission node, depending on its controller parameters and operating point, it *might* cause flicker problems at Borcka SS. Since the aforementioned phenomenon is a stochastic process, the exact value of the flicker amplitude should be determined by measurements in the future.

e) Interharmonics and Subharmonics

Since the converter station (a considerable size nonlinear load) is connected to the transmission system, depending on its operating point (note that although the nominal frequency of the both systems is 50 Hz, in practice, the frequencies of two systems at any instant will most probably be different) and nature of future transmission customers connected at the PCC (i.e., Borcka SS), it *might* cause problems related to interharmonics and/or subharmonics. Therefore, in the future, special attention should be paid by the TSO, particularly if any industrial loads are to be connected at Borcka SS.

3.2.2. Pessimistic Scenario (in the sense of grid conditions in Turkey)

Important: This scenario is analyzed to assess the behavior of the Akhaltsikhe 2x350 MW B2B converter in the case of weakest grid conditions (i.e., for the lowest SCMVA possible in Borcka SS) in Turkey. Hence the results should be evaluated as the maximum power that the converter can survive its operation in the worst grid conditions (i.e., when all units of Borcka and Deriner HPPs are out of service (due to hydrological or market conditions) and Borcka-Kalkandere line is lost, (i.e., n-1)) of Turkey from the power quality point of view. **Note that this case is different from the spring**

conditions analyzed in the security analysis section!!! This scenario is denoted as pessimistic from the power quality point of view.

3.2.2.1. ESCR Calculation

The **minimum** value of SCMVA at Borcka SS is expected to be 1700 MVA when both hydraulic units of Borcka and Deriner HPPs are **not** in operation (without the synchronous condenser at Akhaltsikhe SS. This corresponds to SCMVA of 1177 MVA at the Akhaltsikhe end of the line (160 km single circuit overhead line). However, the synchronous condensers increase the SCMVA by ~530 MVA.

In addition, the harmonic filters generally produce a total reactive power at an amount of 60% of the rated DC power, which means:

11th harmonic filters = 2x52.5 MVAr

13th harmonic filters = 2x52.5 MVAr

24th harmonic filters = 2x52.5 MVAr

Therefore, the amount of safe power transfer which will avoid dynamical overvoltages (DOV) and frequent commutation failures is found as:

$$P_{dc\,safe} = \frac{SCMVA_{grid} - S_{filter}}{ESCR_{safe}} \approx 469 \text{ MW}$$

3.2.2.2. Reactive Power Requirement Calculation

As a result of the power quality simulation studies, it has been found out that transfer of 470 MW from Georgia to Borcka seems *possible* for the pessimistic scenario in the sense of power quality standards of the Turkish Grid Code, provided the compensation of at least two of the proposed 3x75 MVA synchronous condensers. However, static and dynamic analysis results should be taken into account before giving any final decision.

3.2.2.3. Simulation Results

a) Harmonics Analysis

The transmission system operator is responsible from maintaining an acceptable sinusoidal wave shape for the quality of supply. Any B2B converter is, similarly, a source of harmonic currents and hence should be compensated adequately so as to maintain the power quality standards defined in the Turkish Grid Code [3].

Similar to the case in the 4.2.2.2. section of this report, as the pessimistic scenario, 470 MW power transfer from Georgia is analyzed in this section (i.e., Turkey is the inverter side). The time domain simulation results of the B2B converter is illustrated in Figure 10. No clear distortion on the wave shape at Borcka substation can be seen in this case.

The harmonic spectrum of the inverter current is illustrated in Figure 11. As can be readily seen in Figure 11, the most dominant harmonic of the inverter current is the 11th harmonic. Therefore, the harmonic filters should be tuned as mentioned in the 3.4. section of this report.

The harmonic spectrum of line current at the receiving end of the transmission line (i.e., Borcka substation) is illustrated in Figure 12. It can be observed that the problematic harmonic components are eliminated by analyzing Figure 10 and Figure 12 together.

The harmonic spectrum of voltage at Borcka substation is illustrated in Figure 13. The comparison of the harmonic components of the voltage waveform illustrated in Figure 10 and Figure 13 are listed in Table 8. It can be seen that all requirements of the grid code are satisfied with the topology expressed in the third part of this study.

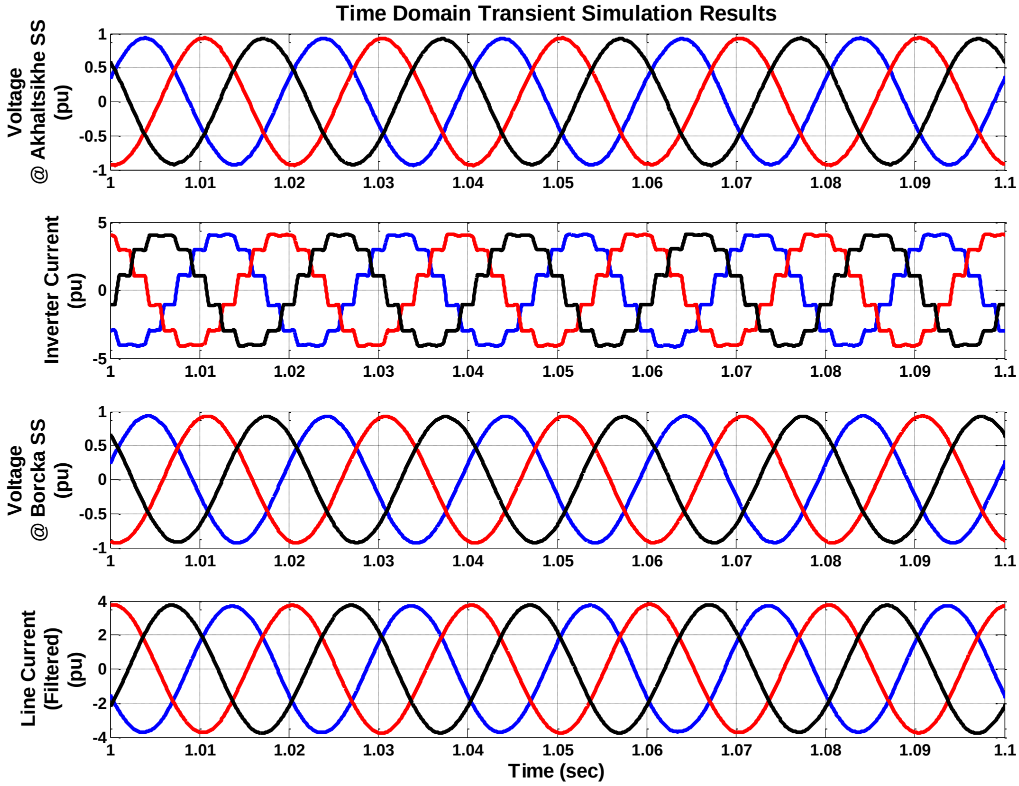


Figure 10: Time domain transient switching results of the B2B converter

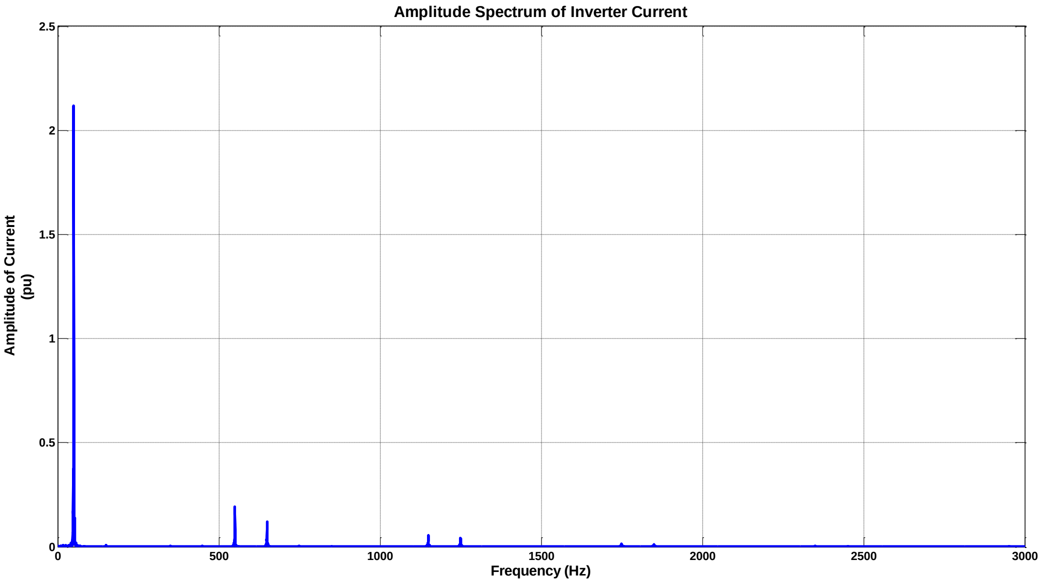


Figure 11: The harmonic spectrum of inverter current

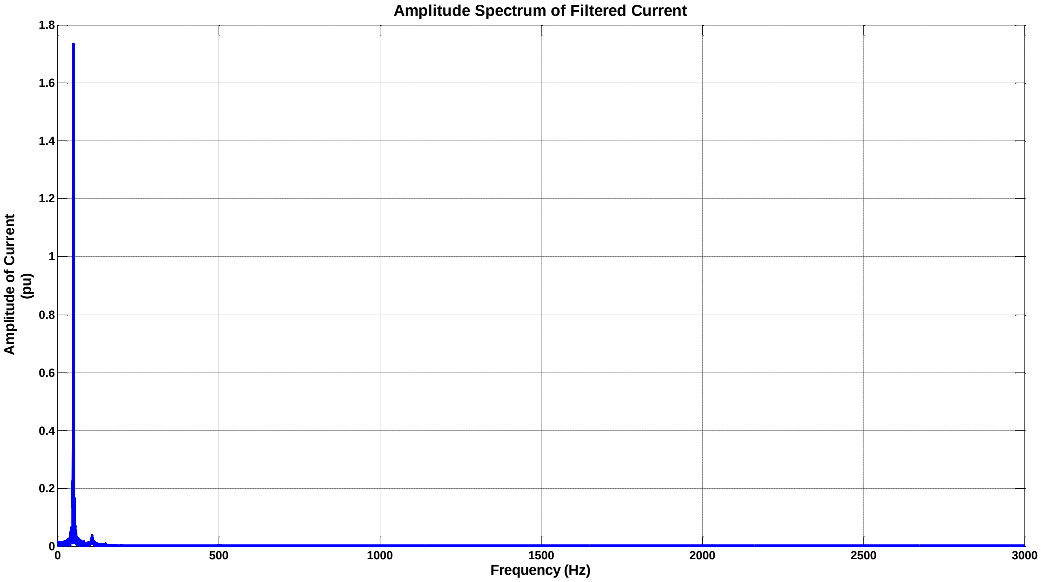


Figure 12: The harmonic spectrum of the current at the receiving end (Borcka substation) of the transmission line

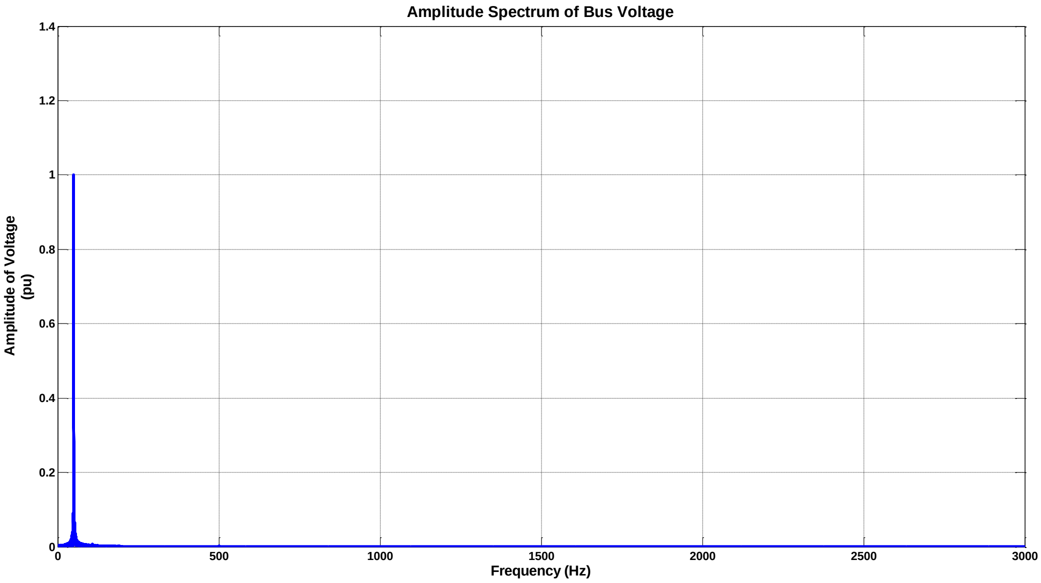


Figure 13: The harmonic spectrum of the voltage at Borcka substation

Table 8: The comparison of the voltage harmonics related to the B2B converter and the grid code requirements

Odd Harmonics (Non multiples of 3)			Odd Harmonics (Multiples of 3)			Even Harmonics		
Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)
5	1.25	0.1328	3	1.0	0.1950	2	0.75	0.7400
7	1.0	0.0263	9	0.4	0.0609	4	0.6	0.1750
11	0.7	0.0898	15	0.2	0.0345	6	0.4	0.0001
13	0.7	0.0341	21	0.2	0.0240	8	0.4	0.0462
17	0.4	0.0385	>21	0.2	OK	10	0.4	0.2227
19	0.4	0.0286				12	0.2	0.0576
23	0.4	0.0300				>12	0.2	OK
25	0.4	0.0297						
>25	0.2+0.2 (25/h)	OK						
THD < % 2 OK								

b) Voltage Dips and Swells Analysis, and Voltage Regulation for Converter Start up

Since the converter station is connected at a relatively weak transmission node, it has been observed that with the operation of the converter station:

i) If the converter is not in service, by the compensation of the synchronous condensers, the voltage at the 400 kV Akhaltsikshe substation terminal of the line can be maintained within the permissible limits (which will most probably not cause a breakdown) despite the capacitive effect of the harmonic filter blocks at nominal frequency and the long transmission line, in case the **unregulated** voltage at Borcka substation tends to be around 400 kV (i.e., Borcka HPP is not in operation).

ii) However, in order to minimize the risk of failures, while the converter is being put into service (note that any switching operation should not cause a voltage dip larger than 2% according to Turkish Grid Code),
   - Coordination should be provided via the Turkish regional load dispatch center to maintain rated voltage at Borcka substation.
   - The inverter should be brought to its desired operating point (Note that as the converter will increase its power, it will draw reactive power from the system, hence it should be brought to its desired operating point progressively in coordination with the RLDC).

In conclusion, voltage regulation by Borcka and/or Deriner HPPs might be necessary in order to start up the converter.

c) Voltage Imbalance

Within the operation of the converter station, all three phases are expected to be loaded in a balanced manner, in case no failures occur.

d) Flicker

Since the converter station is connected at a weak transmission node, depending on its controller parameters and operating point, it *might* also cause additional flicker problems at Borcka SS. Since the aforementioned phenomenon is a stochastic process, the exact value of the flicker amplitude should be determined by measurements.

e) Interharmonics and Subharmonics

Since the converter station (a considerable size nonlinear load) is connected to the transmission system, depending on its operating point (note that although the nominal frequency of the both systems is 50 Hz, in practice, the frequencies of two systems at any instant will most probably be different) and nature of future transmission customers connected at the PCC (i.e., Borcka SS), it *might* cause problems related to interharmonics and/or subharmonics. Therefore, in the future, special attention should be paid by the TSO, in case any industrial loads are to be connected at Borcka SS.

3.3. Analysis for the Converter Station at Batumi 220 kV SS

3.3.1. Optimistic Scenario (in the sense of grid conditions in Turkey)

3.3.1.1. ESCR Calculation

The **maximum** value of SCMVA at Muratli SS is expected to be 1734 MVA when both hydraulic units are in operation. This corresponds to SCMVA of 1172 MVA at the Batumi end of the line (35 km double circuit overhead line).

The harmonic filters generally produce a total reactive power at an amount of 60% of the rated DC power, which means:

11th harmonic filters = 52.5 MVAr

13th harmonic filters = 52.5 MVAr

24th harmonic filters = 52.5 MVAr

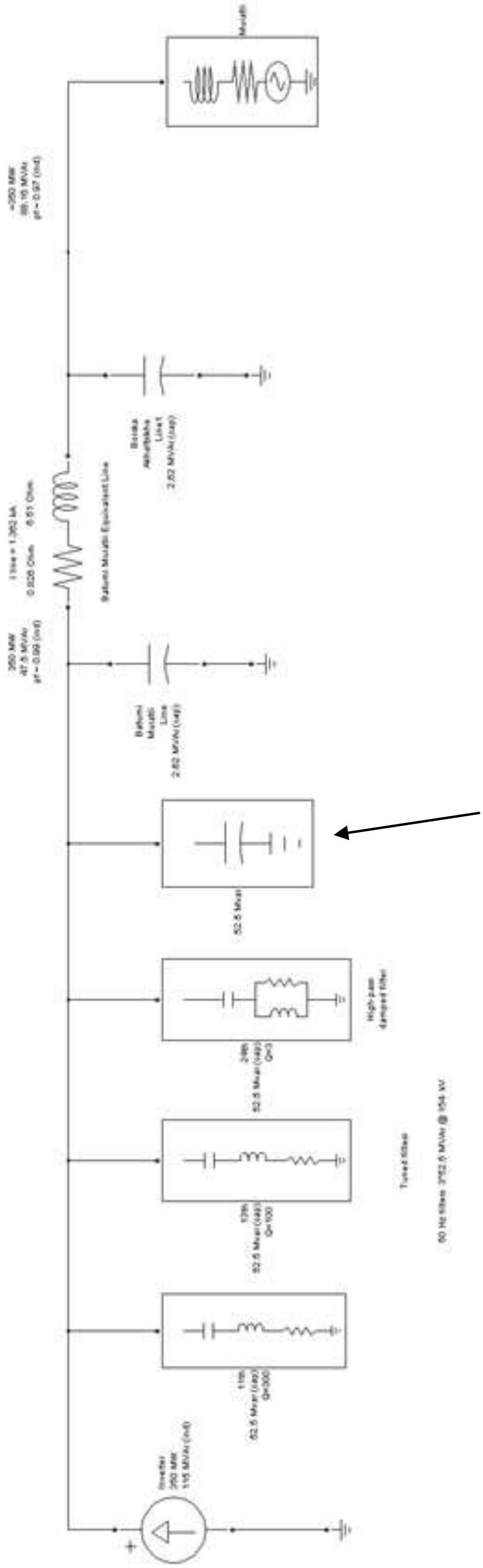
Shunt capacitor = 52.5 MVAr (power factor correction)

Therefore, the amount of safe power transfer which will avoid dynamical overvoltages (DOV) and frequent commutation failures is found as:

$$P_{dc\ safe} = \frac{SCMVA_{grid} - S_{filter}}{ESCR_{safe}} = 385 \text{ MW}$$

3.3.1.2. Reactive Power Requirement Calculation

As a result of the simulation studies for the optimistic scenario, it has been found out that transfer of 350 MW from Georgia to Muratli is possible, provided that the following compensation scheme as illustrated in Figure 14, is equipped.



The shunt capacitor here is necessary for reactive power requirement for the transfer. Note that transmissionl ine too short and therefore it needs additional compensation.

Figure 14: The basic power flow scheme for the optimistic scenario

3.3.1.3. Simulation Results

a) Harmonics Analysis

The transmission system operator is responsible from maintaining an acceptable sinusoidal wave shape for the quality of supply. Any B2B converter is, similarly, a source of harmonic currents and hence should be compensated adequately so as to maintain the power quality standards defined in the Turkish Grid Code [3].

As the optimistic scenario, 350 MW power transfer from Georgia is analyzed in this section (i.e., Turkey is the inverter side). The time domain simulation results of the B2B converter is illustrated in Figure 15. No clear distortion on the wave shape at Muratli substation can be seen in this case.

The harmonic spectrum of the inverter current is illustrated in Figure 16. As can be readily seen in Figure 16, the most dominant harmonic of the inverter current is the 11th harmonic. Therefore, the harmonic filters should be tuned as mentioned in the 4.5. section of this report.

The harmonic spectrum of line current at the receiving end of the transmission line (i.e., Muratli substation) is illustrated in Figure 17. It can be observed that the problematic harmonic components are eliminated by analyzing Figure 15 and Figure 17 together.

The harmonic spectrum of voltage at Muratli substation is illustrated in Figure 18. The comparison of the harmonic components of the voltage waveform illustrated in Figure 15 and Figure 18 are listed in Table 9. It can be seen that all requirements of the grid code are satisfied with the topology expressed in the third part of this study.

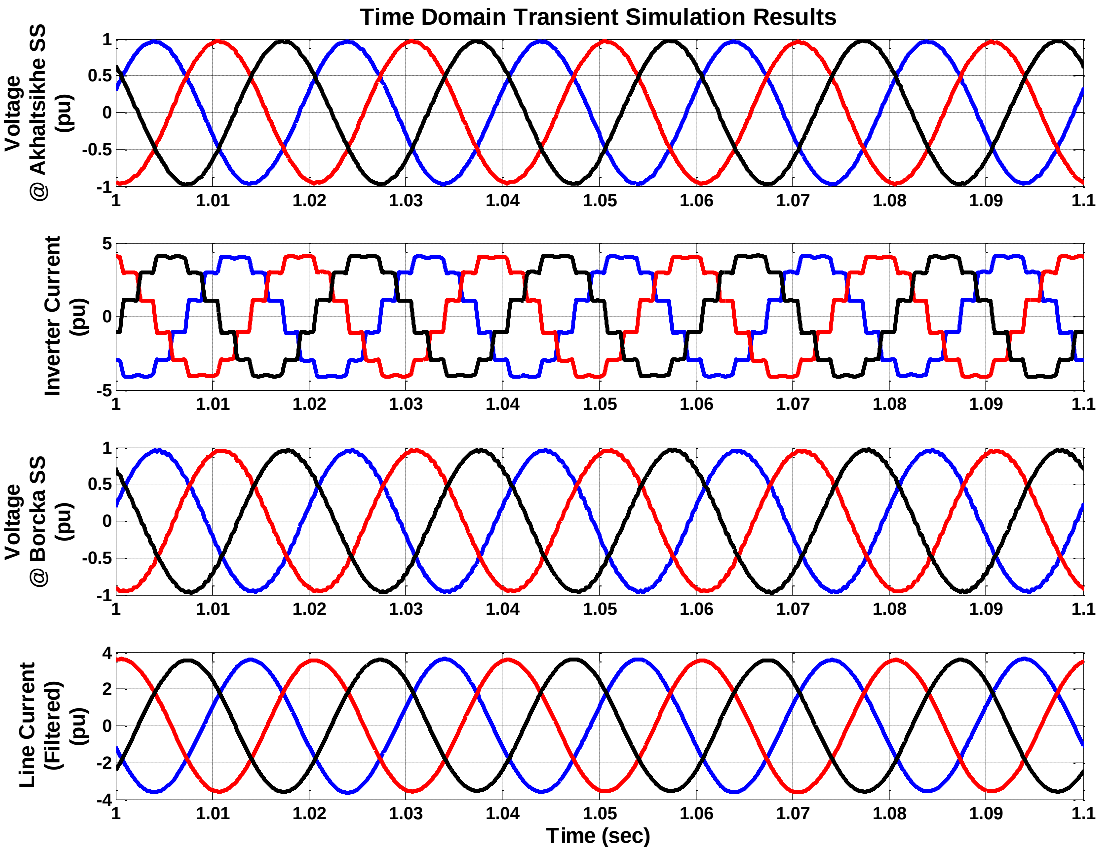


Figure 15: Time domain transient switching results of the B2B converter

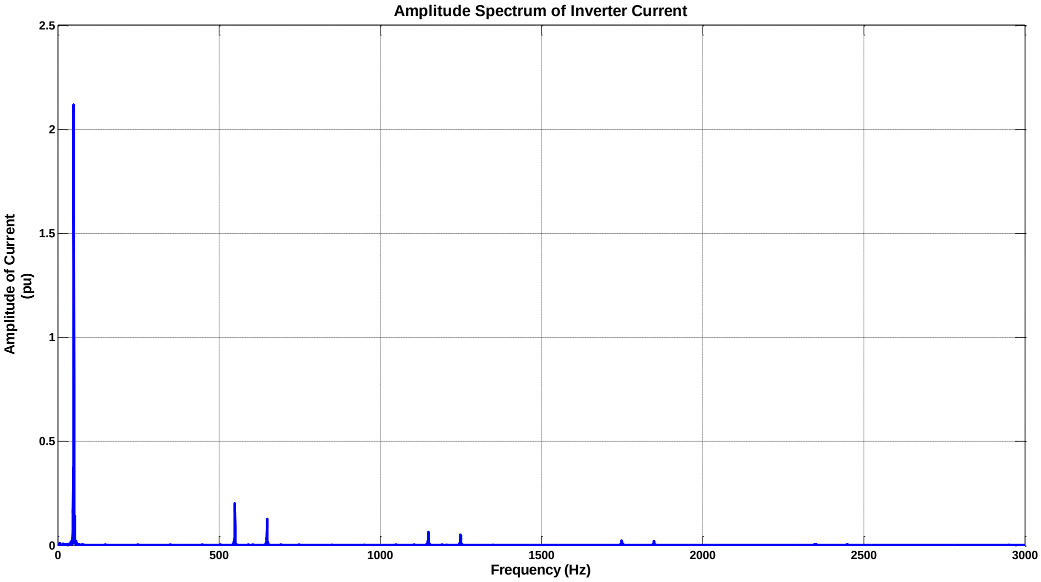


Figure 16: The harmonic spectrum of inverter current

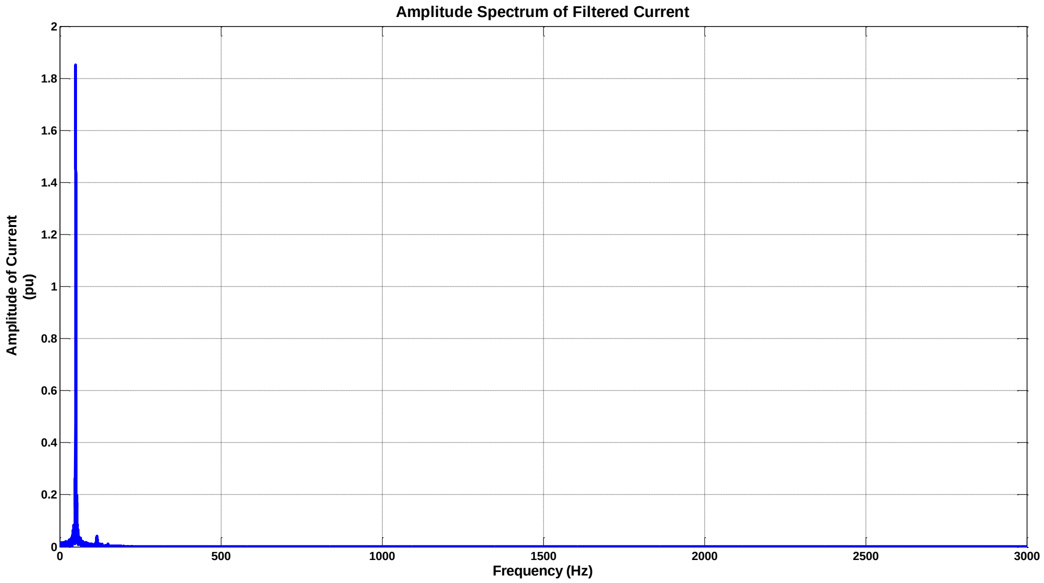


Figure 17: The harmonic spectrum of the current at the receiving end (Muratli substation) of the transmission line

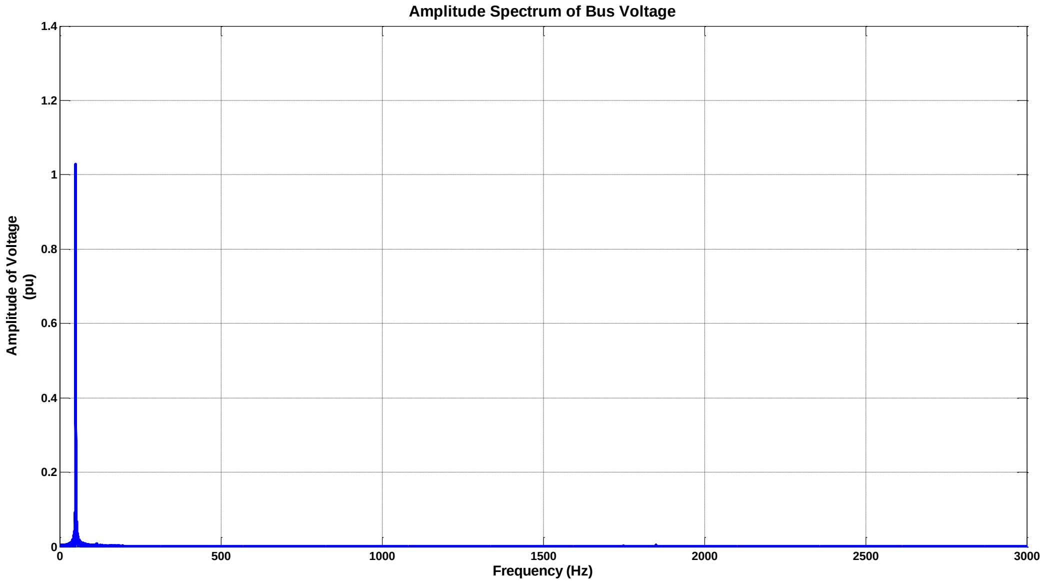


Figure 18: The harmonic spectrum of the voltage at Muratli substation

Table 9: The comparison of the voltage harmonics related to the B2B converter and grid code requirements

Odd Harmonics (Non multiples of 3)			Odd Harmonics (Multiples of 3)			Even Harmonics		
Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)
5	1.5	0.0177	3	1.5	0.3440	2	1.0	0.4500
7	1.5	0.0903	9	0.75	0.0652	4	0.8	0.1520
11	1.0	0.0611	15	0.3	0.0640	6	0.5	0.1067
13	1.0	0.0542	21	0.2	0.0292	8	0.4	0.0761
17	0.75	0.0458	>21	0.2	OK	10	0.4	0.0587
19	0.75	0.0392				12	0.2	0.0515
23	0.5	0.1457				>12	0.2	OK
25	0.5	0.1247						
>25	0.2+0.3 (25/h)	OK						
THD < % 2 OK								

b) Voltage Dips and Swells Analysis, and Voltage Regulation for Converter Start up

Since the converter station is connected at a relatively weak transmission node, it has been observed that with the operation of the converter station:

i) If the converter is not in service, the voltage at the 154 kV terminals of Batumi substation can increase up to 188 kV (which will most probably cause breakdown) due to the capacitive effect of the harmonic filter blocks at nominal frequency. Note that, in this case the **unregulated** voltage at Muratli substation tends to be around 177 kV.

ii) Hence, while the converter is being put into service (note that any switching operation should not cause a voltage dip larger than 2% according to Turkish Grid Code),
  - Coordination should be provided via the Turkish regional load dispatch center to maintain rated voltage at Batumi substation via controlling the voltage at Muratli substation.
  - The inverter should be brought to its desired operating point (Note that as the converter will increase its power, it will draw reactive power from the system, hence it should be brought to its desired operating point progressively in coordination with the RLDC)

c) Voltage Imbalance

Within the operation of the converter station, all three phases are expected to be loaded in a balanced manner, in case no failures occur.

d) Flicker

Since the converter station is connected at a weak transmission node, depending on its controller parameters and operating point, it *might* also cause additional flicker problems at Muratli SS. Since the aforementioned phenomenon is a stochastic process, the exact value of the flicker amplitude should be determined by measurements.

e) Interharmonics and Subharmonics

Since the converter station (a considerable size nonlinear load) is connected to the transmission system, depending on its operating point (note that although the nominal frequency of the both systems is 50 Hz, in practice, the frequencies of two systems at any instant will most probably be different) and nature of future transmission customers connected at the PCC (i.e., Muratli SS), it *might* cause problems related to interharmonics and/or subharmonics. Therefore, in the future, special attention should be paid by the TSO, in case any industrial loads are to be connected at Muratli SS.

3.3.2. Pessimistic Scenario (in the sense of grid conditions in Turkey)

3.3.2.1. ESCR Calculation

The **minimum** value of SCMVA at Muratli SS is expected to be 1147 MVA when both hydraulic units are **not** in operation. This corresponds to SCMVA of 870 MVA at the Batumi end of the line (35 km single circuit overhead line).

The harmonic filters generally produce a total reactive power at an amount of 60% of the rated DC power, which means:

11th harmonic filters = 52.5 MVAr

13th harmonic filters = 52.5 MVAr

24th harmonic filters = 52.5 MVAr

Shunt capacitor = 52.5 MVAr (power factor correction)

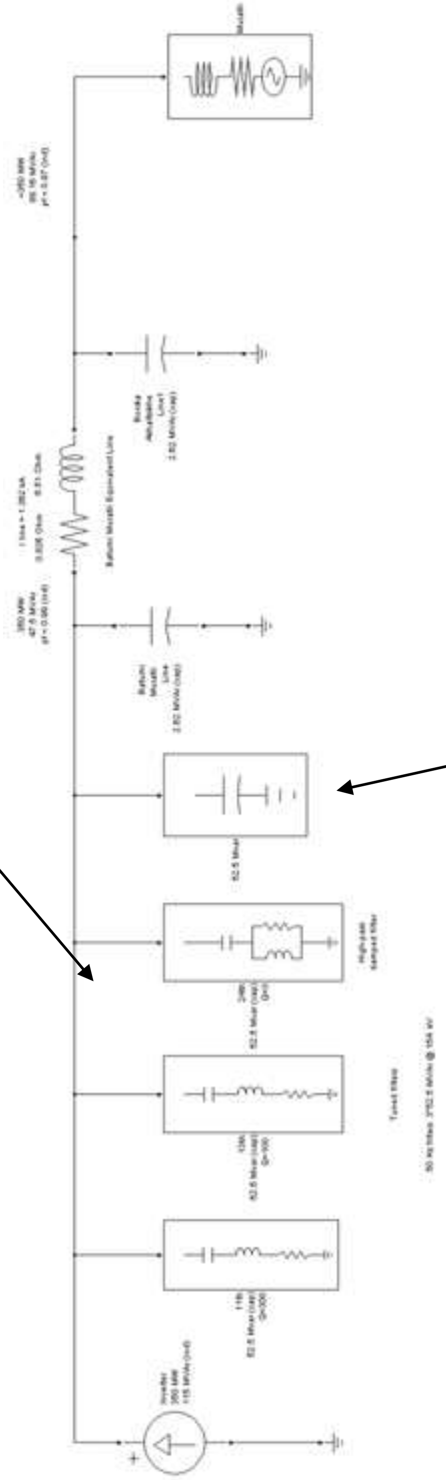
Therefore, the amount of safe power transfer which will avoid dynamical overvoltages (DOV) and frequent commutation failures is found as:

$$P_{dc\,safe} = \frac{SCMVA_{grid} - S_{filter}}{ESCR_{safe}} = 264 \text{ MW}$$

However, in the simulation studies it has been found out that transfer of 350 MW is also *possible* (Note that the safe limit is 264 MW<350 MW) with the reactive power compensation scheme explained in the following section.

3.3.2.2. Reactive Power Requirement Calculation

As a result of the simulation studies for the optimistic case, it has been found out that transfer of 350 MW from Georgia to Muratli is possible, provided that the following compensation scheme as illustrated in Figure 19, is equipped.



Filter ratings in the pessimistic scenario is same as the case in optimistic scenario.

The shunt capacitor here is necessary for reactive power requirement for the transfer. Note that transmissionl ine too short and therefore it needs additional compensation.

Figure 19: The basic power flow scheme for the optimistic scenario

3.3.2.3. Simulation Results

a) Harmonics Analysis

The transmission system operator is responsible from maintaining an acceptable sinusoidal wave shape for the quality of supply. Any B2B converter is, similarly, a source of harmonic currents and hence should be compensated adequately so as to maintain the power quality standards defined in the Turkish Grid Code [3].

As the pessimistic scenario, 350 MW power transfer from Georgia is analyzed in this section (i.e., the Turkey is the inverter side). The time domain simulation results of the B2B converter is illustrated in Figure 20. No clear distortion on the wave shape at Muratli substation can be seen in this case.

The harmonic spectrum of the inverter current is illustrated in Figure 21. As can be readily seen in Figure 21, the most dominant harmonic of the inverter current is the 11th harmonic. Therefore, the harmonic filters should be tuned as mentioned in the 3.5. section of this report.

The harmonic spectrum of line current at the receiving end of the transmission line (i.e., Muratli substation) is illustrated in Figure 22. It can be observed that the problematic harmonic components are eliminated by analyzing Figure 20 and Figure 22 together.

The harmonic spectrum of voltage at Muratli substation is illustrated in Figure 23. The comparison of the harmonic components of the voltage waveform illustrated in Figure 20 and Figure 23 are listed in Table 10. It can be seen that all requirements of the grid code are satisfied with the topology expressed in the third part of this study.

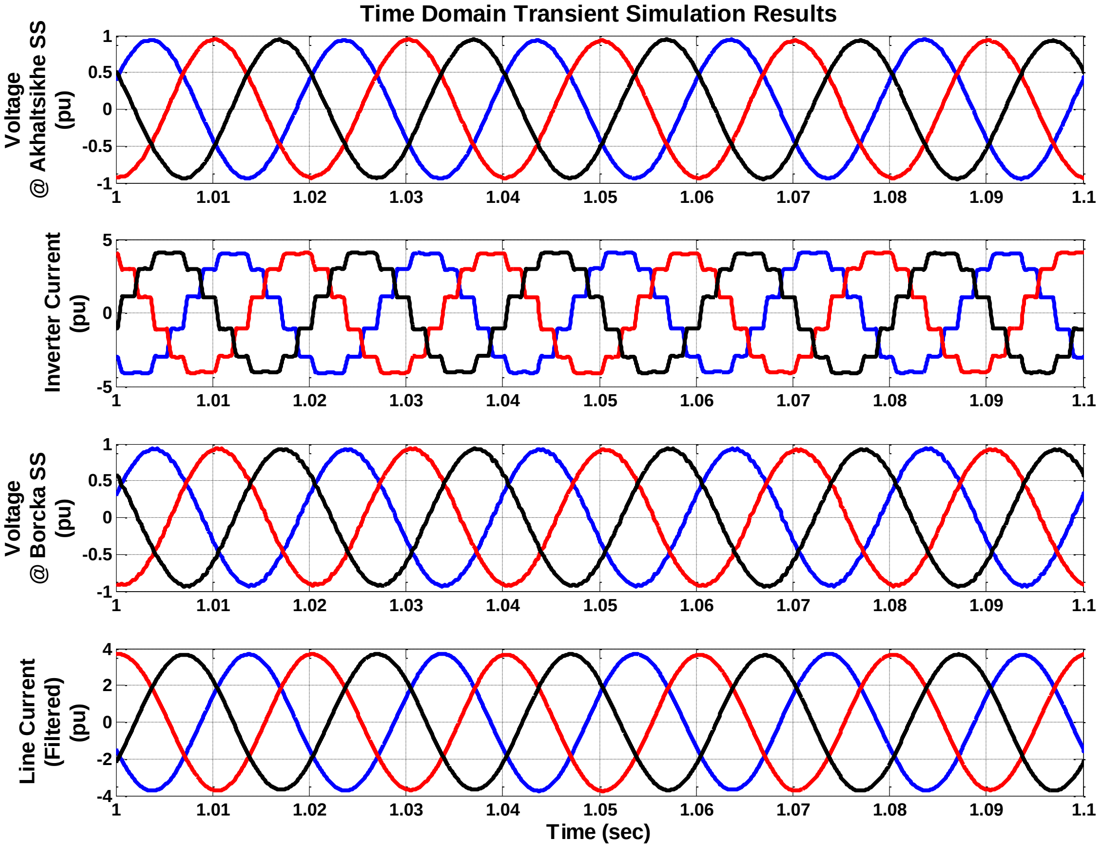


Figure 20: Time domain transient switching results of the B2B converter

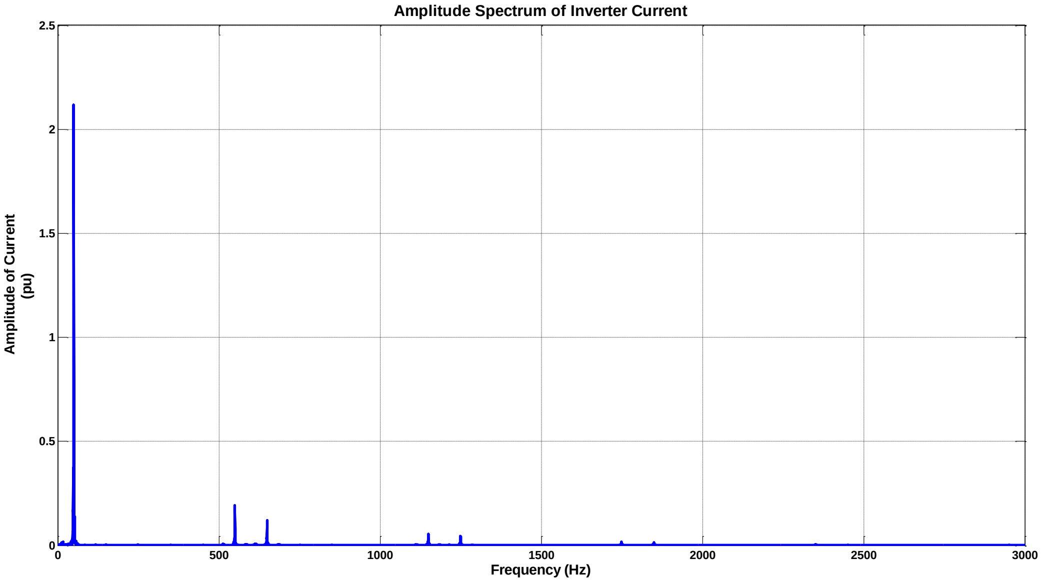


Figure 21: The harmonic spectrum of inverter current

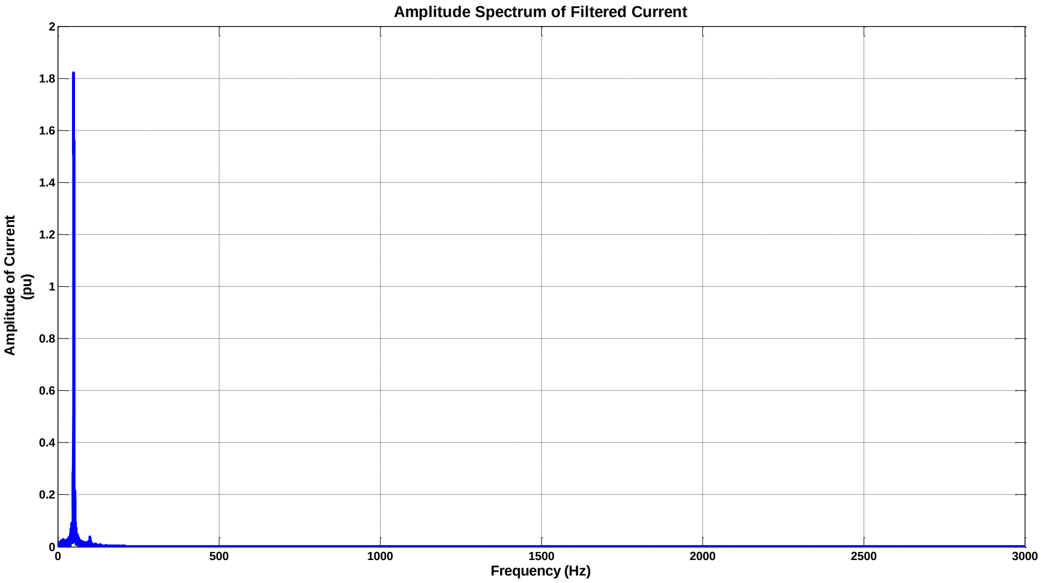


Figure 22: The harmonic spectrum of the current at the receiving end (Muratli substation) of the transmission line

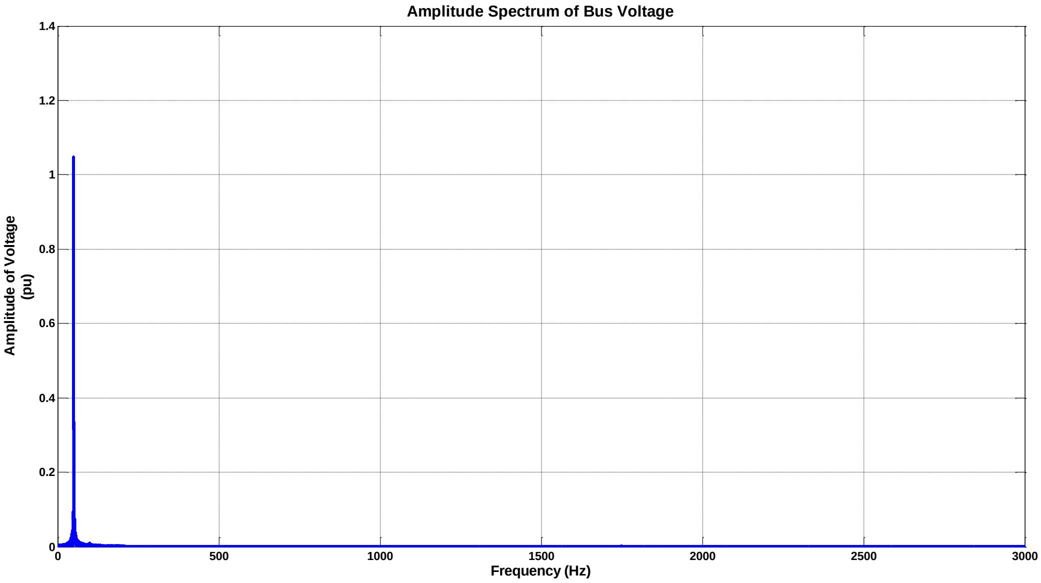


Figure 23: The harmonic spectrum of the voltage at Muratli substation

Table 10: The comparison of the voltage harmonics related to the B2B converter and grid code requirements

Odd Harmonics (Non multiples of 3)			Odd Harmonics (Multiples of 3)			Even Harmonics		
Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)	Harmonic Number	Harmonic Voltage (%)	Simulation Results (%)
5	1.5	0.1643	3	1.5	0.2741	2	1.0	0.8604
7	1.5	0.0887	9	0.75	0.0615	4	0.8	0.1741
11	1.0	0.0543	15	0.3	0.0197	6	0.5	0.1023
13	1.0	0.0532	21	0.2	0.0171	8	0.4	0.0819
17	0.75	0.0616	>21	0.2	OK	10	0.4	0.0642
19	0.75	0.0376				12	0.2	0.0528
23	0.5	0.1385				>12	0.2	OK
25	0.5	0.1552						
>25	0.2+0.3 (25/h)	OK						

b) Voltage Dips and Swells Analysis, and Voltage Regulation for Converter Start up

Since the converter station is connected at a relatively weak transmission node, it has been observed that with the operation of the converter station:

i) If the converter is not in service, the voltage at the 154 kV terminals of Batumi substation can increase up to 205 kV (which will most probably cause breakdown) due to the capacitive effect of the harmonic filter blocks at nominal frequency. Note that, in this case the **unregulated** voltage at Muratli substation tends to be around 192.5 kV.

ii) Hence, while the converter is being put into service (note that any switching operation should not cause a voltage dip larger than 2% according to Turkish Grid Code),
   - Coordination should be provided via the Turkish regional load dispatch center to maintain rated voltage at Batumi substation via controlling the voltage at Muratli substation.
   - The inverter should be brought to its desired operating point (Note that as the converter will increase its power, it will draw reactive power from the system, hence it should be brought to its desired operating point progressively in coordination with the RLDC)

c) Voltage Imbalance

Within the operation of the converter station, all three phases are expected to be loaded in a balanced manner, in case no failures occur.

d) Flicker

Since the converter station is connected at a weak transmission node, depending on its controller parameters and operating point, it *might* also cause additional flicker problems at Muratli SS.

Since the aforementioned phenomenon is a stochastic process, the exact value of the flicker amplitude should be determined by measurements.

e) Interharmonics and Subharmonics

Since the converter station (a considerable size nonlinear load) is connected to the transmission system, depending on its operating point (note that although the nominal frequency of the both systems is 50 Hz, in practice, the frequencies of two systems at any instant will most probably be different) and nature of future transmission customers connected at the PCC (i.e., Muratli SS), it *might* cause problems related to interharmonics and/or subharmonics. Therefore, in the future, special attention should be paid by the TSO, in case any industrial loads are to be connected at Muratli SS.

4. Part 2: Security Analysis (Load Flows and Contingency Analysis)

4.1. SCMVA Calculation

SCMVA calculation results regarding 2013, 2015 and 2017 scenarios are given in Appendix D.

4.2. Contingency Analysis

The detailed simulation results of the corresponding scenarios are given in the Appendices. According to Turkish Grid Code [9], the Turkish Electricity Transmission System is designed according to the (n-1) criterion, which means that no element of the power system should be overloaded in case of a single contingency. Within this scope, (n-1) security analyses are performed for the above summarized scenarios (only for the Turkish Electricity Transmission System).

The important contingencies regarding the Georgia HVDC Interconnection are tabulated in the following tables, where the most important contingencies (regarding Georgia Interconnection) are classified with respect to the extent of their effect on electricity transmission system security and possible protective (and/or preventive) measures. The annotation of the classification of the tables is as given in the legend below.

4.2.1. 2013 Scenarios

Legend

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

🟩	No problems related to Georgia Interconnection
🟨	Minor redispatch problems related to Georgia Interconnection (< 100 MW)
🟧	**Major** redispatch problems related to Georgia Interconnection (> 100 MW)
🟥	Unsecure

Table 11: Summary Results for 2013

	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	🟥	🟥

4.2.2. 2015 Scenarios

Legend

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

🟩	No problems related to Georgia Interconnection
🟨	Minor redispatch problems related to Georgia Interconnection (< 100 MW)
🟧	**Major** redispatch problems related to Georgia Interconnection (> 100 MW)
🟥	Unsecure

Table 12: Summary Results for 2015

	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	🟥

4.2.3. 2017 Scenarios

Legend

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

1400 MW Import: Three blocks of 3x350 MW Akhaltsikhe converter and 350 MW Batumi converter are in operation

🟩	No problems related to Georgia Interconnection
🟨	Minor redispatch problems related to Georgia Interconnection (< 100 MW)
🟧	**Major** redispatch problems related to Georgia Interconnection (> 100 MW)
🟥	Unsecure

Table 13: 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	🟥	🟥

5. Part 3: Short Term Voltage Stability Analysis

5.1. Analysis for the Converter Station at Akhaltsikhe 500 kV SS

5.1.1. Optimistic Scenario (in the sense of grid conditions in Turkey)

A 3 phase balanced temporary fault of 0.15 sec on the transmission line at a very close location to the converter busbar with zero fault impedance is simulated, which essentially means full load rejection of the converter. As can be observed from Figure 24, the B2B converter blocks are expected to recover after a temporary fault of 0.15 sec, in case the relevant protection schemes in the literature (e.g. Voltage Dependent Current Order Limiter, VDCOL) are utilized. The dynamic overvoltage observed (along ~0.05 sec, with respect to the ground potential) in this case, which should be considered in the insulation coordination studies are:

$DOV_{Akhaltsikhe}$ = 1.27 pu (508 kV)

DOV_{Borcka} = 1.15 pu (460 kV)

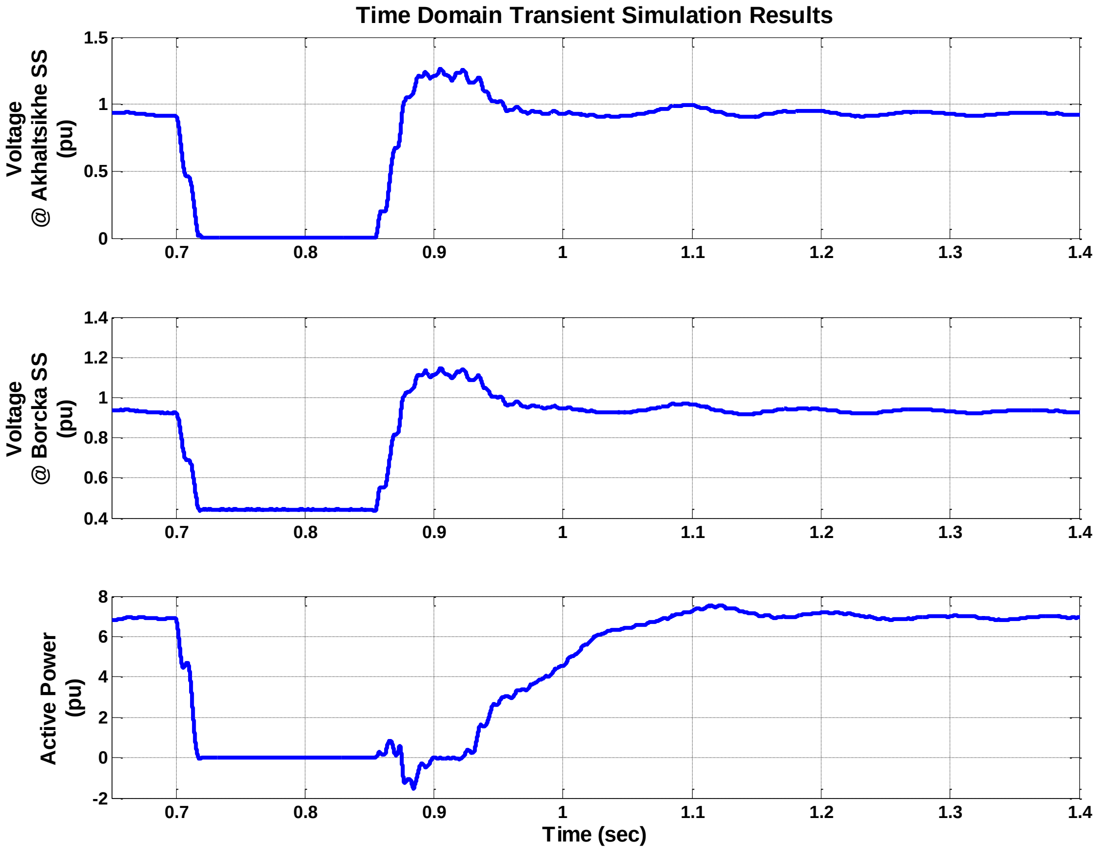


Figure 24: Short term voltage stability simulation results – Optimistic Scenario

5.1.2. Pessimistic Scenario (in the sense of grid conditions in Turkey)

A 3 phase balanced temporary fault of 0.15 sec on the transmission line at a very close location to the converter busbar with zero fault impedance is simulated, which essentially means full load rejection of the converter. As can be observed from Figure 25, the B2B converter blocks are expected to recover after a temporary fault of 0.15 sec, in case the relevant protection schemes in the literature (e.g. Voltage Dependent Current Order Limiter, VDCOL) are utilized. The dynamic overvoltage observed (along ~0.05 sec, with respect to the ground potential) in this case, which should be considered in the insulation coordination studies are:

$DOV_{Akhaltsikhe}$ = 1.37 pu (548 kV)

DOV_{Borcka} = 1.25 pu (500 kV)

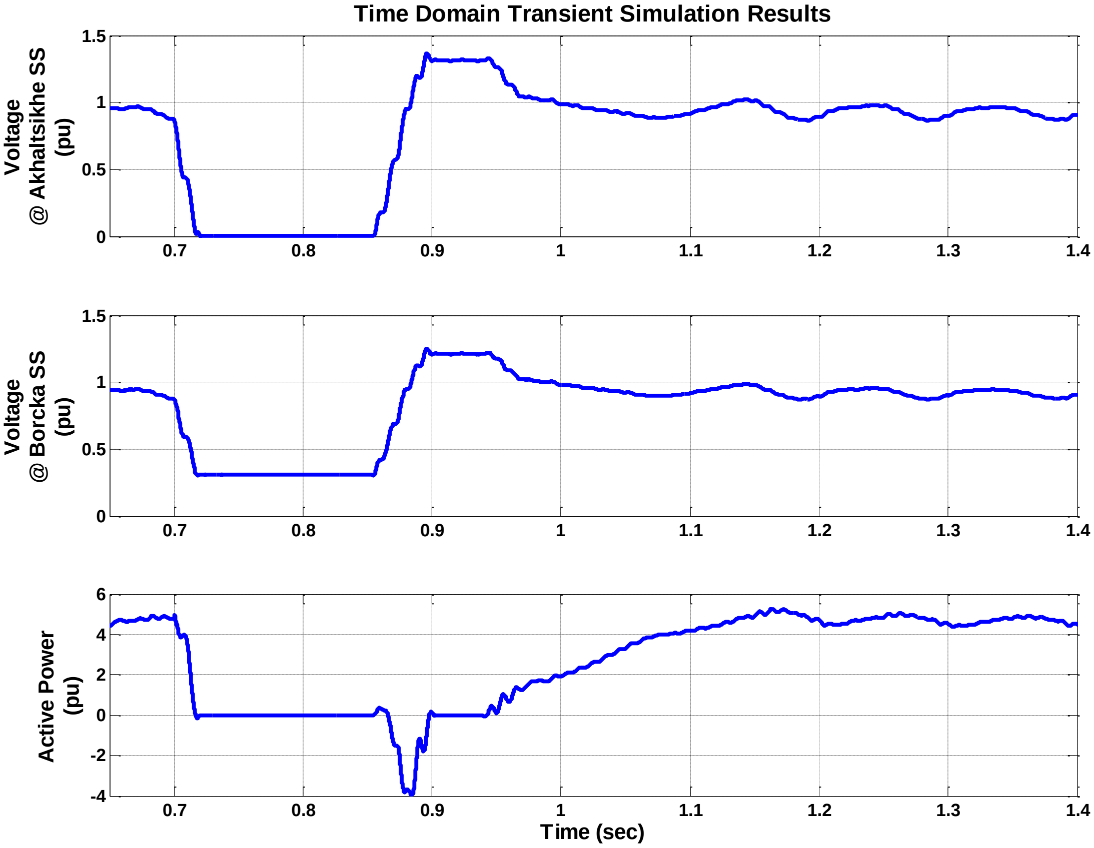


Figure 25: Short term voltage stability simulation results – Pessimistic Scenario

5.2. Analysis for the Converter Station at Batumi 220 kV SS

5.2.1. Optimistic Scenario (in the sense of grid conditions in Turkey)

A 3 phase balanced temporary fault of 0.15 sec on the transmission line at a very close location to the converter busbar with zero fault impedance is simulated, which essentially means full load rejection of the converter. As can be observed from Figure 26, the B2B converter blocks are expected to recover after a temporary fault of 0.15 sec, in case the relevant protection schemes in the literature (e.g. Voltage Dependent Current Order Limiter, VDCOL) are utilized. The dynamic overvoltage observed (along ~0.05 sec, with respect to the ground potential) in this case, which should be considered in the insulation coordination studies are:

DOV_{Batumi} = 1.28 pu (197 kV)

$DOV_{Muratli}$ = 1.18 pu (182 kV)

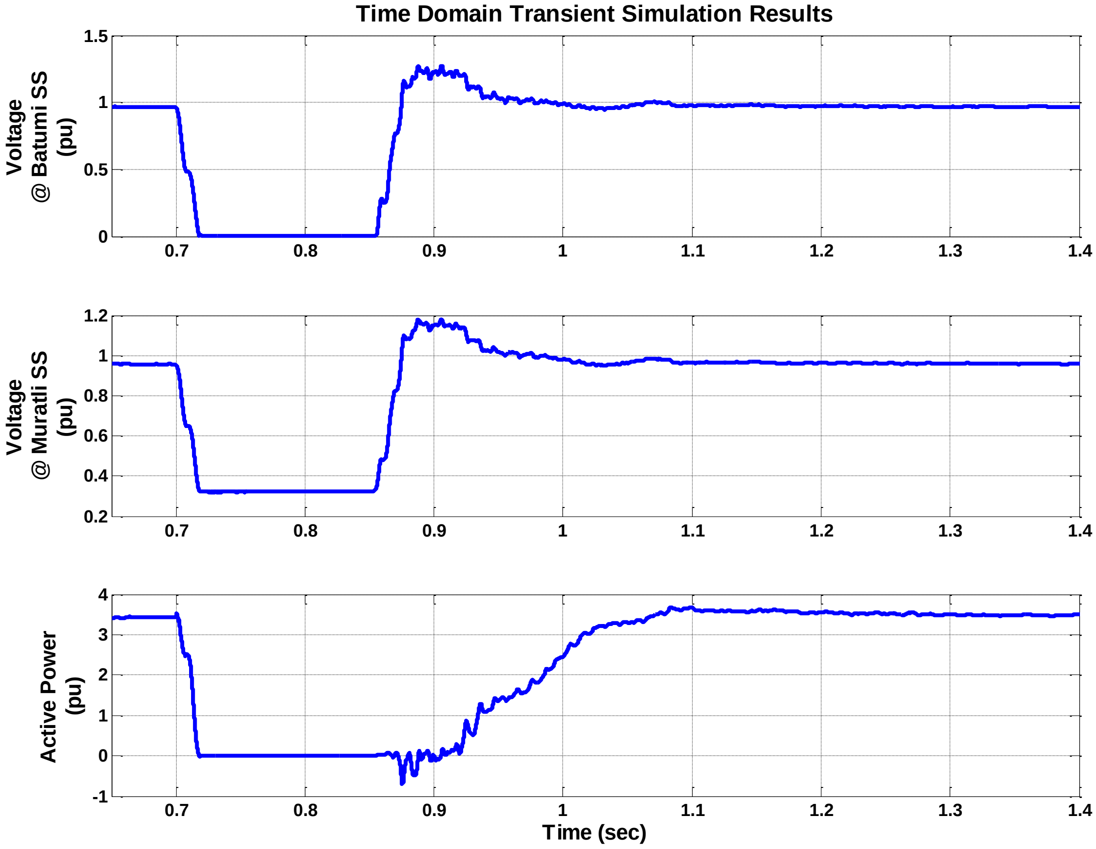


Figure 26: Short term voltage stability simulation results – Optimistic Scenario

5.2.2. Pessimistic Scenario (in the sense of grid conditions in Turkey)

A 3 phase balanced temporary fault of 0.15 sec on the transmission line at a very close location to the converter busbar with zero fault impedance is simulated, which essentially means full load rejection of the converter. As can be observed from Figure 26, the B2B converter blocks are expected to recover after a temporary fault of 0.15 sec, in case the relevant protection schemes in the literature (e.g. Voltage Dependent Current Order Limiter, VDCOL) are utilized. The dynamic overvoltage observed (along ~0.05 sec, with respect to the ground potential) in this case, which should be considered in the insulation coordination studies are:

DOV_{Batumi} = 1.35 pu (208 kV)

$DOV_{Muratli}$ = 1.25 pu (193 kV)

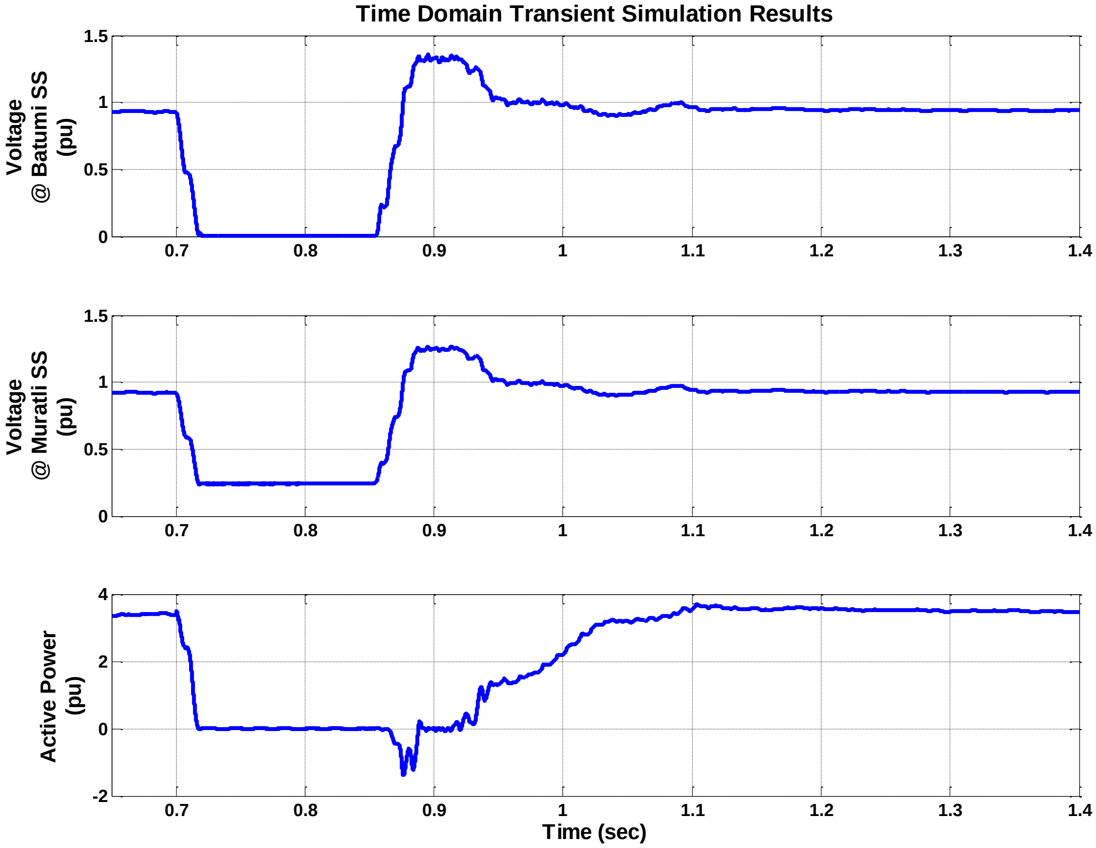


Figure 27: Short term voltage stability simulation results – Pessimistic Scenario

6. Special Protection Requirement

Regarding the analysis made for 2013, it has been observed that, any outage of particularly:

- Yeni Tortum-Erzurum (at present Deriner-Erzurum) line
- Borcka-Tirebolu line

has the possibility of causing insecure electricity transmission system conditions, by the year 2012, under the circumstances when the HPPs in the region (the key ones are Borcka and Deriner HPPs) operate close to their rated capacity together with the 700 MW import from Georgia. This can also be observed from the contingency analysis result tables (Tables 11-13).

Therefore, against the risk of regional system collapse in the case of the above mentioned line outages, equipment of a special protection scheme that coordinates the outages of the above two lines with instantaneous tripping of Akhaltsikhe 400 kV transmission line (or fast reduction of power import from Georgia and/or some units of Borcka-Deriner HPPs), when the loading on the other line will exceed a specific threshold, is recommended.

The most suitable location for such a relay is proposed to be Borcka SS due to:

- Ease of measurement and signal transmission (i.e., only some status signals from the protective relays and the corresponding circuit breakers of the substations and loading level measurement signals from the protective current transformers of the lines through Deriner-Erzurum **route** and Borcka-Tirebolu **route** have to be carried via redundant communication channels (e.g., redundant fiber optic connection, fiber optic and PLC, etc.))

Note: The "route" expression above refers to the substations and lines between the two substations.

- Speed and reliability of protective action (i.e., when a trip signal is given to a circuit breaker the communication channel in between the two stations and the electronic media in between inevitably introduce some time delay. In addition, due to increased number of equipment, the reliability level of the protective system decreases. Therefore, considering the fact that two of the candidates for tripping (i.e., Borcka HPP and Borcka-Akhaltsikhe line) are located in Borcka SS, Borcka SS is proposed to be the location for such a special protection relay.)

It should also be emphasized that, Table 11 together with the corresponding appendices, can be utilized as the trip matrix for determining the specifications for such a relay. The technical specifications of such a protection scheme should be analyzed in detail.

7. Conclusions

In this report, technical feasibility of the power import form Georgia to Turkey through HVDC B2B converter stations in both Akhaltsikhe and Batumi substations are analyzed and the effects of different levels of power import from Georgia to Turkey on the possible transmission bottlenecks in Turkish network and measures in order to increase **safe** transfer amounts are investigated.

The conclusions made about the **operation of the proposed converters** regarding the secure operation of the transmission system can be summarized as follows:

Back to Back Converter Station in Akhaltsikhe

- **2013 Scenario Results:**
  - For the converter station in Akhaltsikhe, in the simulation studies, it is observed that 700 MW power transfer via the converter station is *possible* in the sense of power quality/converter operational stability concerns. This level can be reached **under the typical transmission system conditions from the power quality point of view (i.e., high SCMVA) with the inclusion of the synchronous condensers**. The result is that, the most dominant harmonic, i.e., the 11th

harmonic, is **very close to the operational limits** specified in the Turkish Grid Code in this case [3].

Note that, the above mentioned limit is ~470 MW in the worst grid conditions (i.e., the worst (n-1) condition, meaning **lowest possible SCMVA**). Given the calculated feasible operation band, which is between ~470-700 MW, each converter block should be equipped with its own switchable filter blocks. This fact should be taken into account in design.

Back to Back Converter Station in Batumi (2x175 MW)

- **2013 Scenario Results:**
  - For the converter station in Batumi, the maximum safe power transfer limit, in order to avoid dynamic overvoltages and frequent commutation failures, is calculated as ≈385 MW (already greater than the prospective converter capacity), in the typical transmission system conditions. Note that, this limit is ~264 MW in the worst grid conditions in the sense of power quality/converter operational stability concerns.

    In the simulation studies, it has been observed that ~350 MW power transfer via the converter station is also *possible* in the worst transmission system conditions.

  - Batumi B2B project is concluded to be premature, if it is to be scheduled for 2013 and considered together with the 2x350 MW Akhaltsikhe converter, regarding the present transmission bottleneck in the region (see 1050 MW power transfer cases in Table 11).

Transmission System Security

- Even by a deductive approach, there are two basic transmission routes connecting the generation in the region of interest to the load centers in Turkey, as illustrated in Figure 2. The total thermal capacity of those two transmission paths is about ~3000 MW, whereas the generating capacity (installed capacity, planned for 2013) in the region is around ~7500 MW. Therefore, extra transmission investments are required in order to enable safe power transfer from the region.

- Considering the transmission bottleneck in the region for the analyzed 2013 scenarios, the **initial** power import capacity from Georgia to Turkey is recommended not to exceed 700 MW, even in the normal transmission system conditions, with the 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. Note that especially during spring season, according to the water regime, when most of the hydroelectric power plants in the region are operational with high capacity factor, the import capacity from Georgia should be determined by the dispatching department by considering the most recent system topology and giving the priority to system security.

- Depending on the electricity market conditions, 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 Table 11) either via the day ahead market mechanism or the balancing and settlement market mechanism.

- According to the analyzed 2015 scenario, the effect of adding new transmission route to the region (Ispir-Bağıştaş-Keban line) increases transmission capacity; nonetheless, total installed generating capacity among the region also increases (especially for HPPs) which restricts import capacity during spring season due to water regime. Therefore, to be on the safe side, special protection scheme must also be considered in case of emergency system conditions. (see Table 12).

- According to the analyzed 2017 scenario, the results are found to be similar with analysis made for 2015. Addition of second transmission line to the Akhaltsikhe back to back station (Akhaltsikhe-Y.Tortum) enables power import from Georgia up to 1400 MW, depending on the generation profile of the black sea region. However, it should be noted that due to the generation capacity and profile in the region, safe power transfer limits reduces especially in spring season.

- Although it seems import capacity will increase in 2017, realization of the transmission (by TEIAS) and generation (by the private sector) investments is going to determine the future of import capacity. As 2017 is still far beyond to evaluate generation scheme and capacity in the region, assumptions made on 2017 analysis may not be valid and import capacity can increase or decrease.

A possible way to increase the power transfer limits is to install new transmission lines from the region to the load centers (such as Gaziantep, Kahramanmaras, Diyarbakir and Sanliurfa), which will both enable wheeling possibility and increase the electricity trading capacity with the Southern neighbors (Syria and Iraq). A planned transmission line in the Borcka-Ispir-Bagistas and Keban route as illustrated in Figure 28 will serve such purposes. This option should also be evaluated in detail by technical feasibility analysis.

It should also be denoted here that the power export from Turkey to Georgia is another factor that solves the transmission bottleneck in the region.

Figure 28: Borcka-Arkun-Ispir-Bagistas-Keban Electricity Transmission Route

8. Other Remarks

In the following stage of the project (i.e., design and commissioning phase), it is recommended to consider the following issues together with the manufacturer

- Inter-area oscillation mode: the superposed oscillation of active power transferred to Turkey (e.g., +/- 10 MW) antiphase with the low frequency inter area frequency oscillations, in case the amplitude of the oscillations exceed a specific threshold (e.g., 15 or 20 mHz peak).
- Interaction with the special protection schemes of Georgia and Turkey.

9. Sonuçlar (*Conclusions in Turkish*)

Bu çalışmada, Gürcistan ve Türkiye İletim Sistemleri arasında enerji ticaretini mümkün kılmak amacıyla, Ahıska (2017 yılına kadar toplam 3x350 MW) ve Batum'da (2013 yılına kadar 2x175 MW) kurulması hedeflenen, DC Back to Back teknolojisine dayalı çözümlerin (asenkron enterkonneksiyon), Türkiye İletim Sistemi güvenliğine olan etkileri incelenmiştir. Yapılan simulasyon çalışmaları sonucunda iletim sistemi güvenliği ve sistem işletimini ilgilendiren aşağıdaki sonuçlara ulaşılmıştır:

Ahıska Back to Back İstasyonu (3x350 MW)

- **2013 Yılı Sonuçları:**
    - Dinamik aşırı gerilim ve yarı iletken anahtarlama arızaları risklerini gözeterek, en iyi şebeke şartlarında, **güvenli** azami çalışma gücü 700 MW olarak hesaplanmıştır. Bu değer en kötü iletim sistemi şartlarında (Borçka-Deriner HESlerin devre harici olduğu üretim senaryosunda (n-1) durumu) ≈470 MW'a kadar düşmektedir. Her iki durumda da Akhaltsikhe istasyonunun 400 kV barasında 3x75 MVA kapasitesinde senkron kondensör bulunduğu varsayılmıştır. Simulasyon çalışmalarında, güç kalitesi açısından, en iyi şebeke koşullarında 700 MW çalışma gücü *mümkün* görünse de, bölgesel iletim şebekesinin zayıflığından ötürü, bahsedilen çalışma koşullarında, Şebeke Yönetmeliği'nde [3] 380 kV iletim sistemi için müsade edilen **güç kalitesi limitlerine çok yaklaşılmıştır** (Özellikle 11. harmonik için, bkz. Table 7). Pratikte bu çalışma koşullarının, 400 kV Borçka barasındaki gerilim dalga şeklinde, Şebeke Yönetmeliği'nde müsade edilenden daha fazla harmonik bozulma yaratma olasılığı bulunmaktadır. Bu durumun temel sebebi, bölgedeki iletim altyapısının göreceli olarak güçsüz oluşudur.

      Dolayısıyla filtre bloklarının 470-700 MW arası çalışma rejimi gözetilerek tasarlanmaları önerilmektedir.

Batum Back to Back İstasyonu (2x175 MW)

- **2013 Yılı Sonuçları:**
    - Bu projenin, Ahıska'da 2013 yılında kurulması hedeflenen 2x350 MW konvertör ile birlikte düşünüldüğü zaman, gerçekleşmesi için gerekli iletim sistemi koşullarının 2013 yılı için olgunlaşmamış olacağı öngörülmektedir.

İletim Planlama Çalışmalarını İlgilendiren Konular

- Tümdengelim yöntemiyle dahi görülebileceği üzere, bölgede bulunan ~7000 MW kurulu gücün enterkonnekte sisteme aktarılabileceği, toplam termik kapasiteleri ~3000 MW olan iki adet ana iletim koridoru bulunmaktadır. Gürcistan bağlantısı da göz önüne alındığında, söz konusu elektrik enerjisi üretim potansiyelinin emniyetli bir şekilde enterkonnekte sisteme entegre edilebilmesi için ek iletim yatırımlarına ihtiyaç olduğu görülmektedir.

- Bölgede oluşacağı öngörülen iletim kısıtı risklerini gözeterek, en iyi şebeke şartlarında dahi, iki ülke arasındaki ticaret kapasitesinin azami 700 MW ile başlatılması önerilmektedir. Bu durumda bile Erzurum-Deriner veya Borçka Kalkandere 400 kV EİH'larının açmasının, detayları ayrıca analiz edilmesi gereken özel koruma sistemi ile Borçka-Akhaltsikhe 400 kV EİH (ve/veya Borçka-Derine HESlerin bazı üniteleri ile) ile koordine edilmesi önerilmektedir.

- Piyasa koşullarına bağlı olarak, özellikle 2013-2014 yılları için, Doğu Karadeniz ve Erzurum bölgesinde oluşabilecek iletim kısıtlarının önüne geçmek amacıyla (sistem güvenliği, kısa vadeli çözüm), MYTM tarafından bazı durumlarda bölgedeki santrallerin ya da Gürcistan elektrik enerjisi ticareti programının değiştirilmesinin (gün öncesi piyasası ya da dengeleme uzlaştırma piyasası aracılığıyla) gerekebileceği öngörülmektedir. (örnek: beklenen 2013 minimum yük koşulları, bkz. Table 11)

- 2015 yılı için yapılan analizlerde, yapılması planlanan Borçka-İspir-Bağıştaş-Keban hatttının bölgedeki iletim kapasitesini dolayısıyla Gürcistan'dan elektrik enerjisi alım kapasitesini artırdığı gözlenmiştir. Fakat, bölgede artan hidroelektrik üretim kapasitesi göz önüne alındığında, özellikle bahar ayları için, elektrik enerjisi ithalat kapasitesi, söz konusu dönem için en güncel iletim sistemi verisine dayanarak, iletim sistemi güvenliği ön planda olacak şekilde hesaplanmalıdır.

- 2017 yılı için yapılan analizler ile 2015 yılı için yapılan analizler paralellik göstermektedir. Yapılan analizerde, Ahıska-Y.Tortum arasında inşa edilmesi plananlanan ikinci iletim hattının, 1400 MW elektrik ithalatına olanak sağlayabileceği görülmüştür. Ancak, diğer analizlere benzer şekilde, özellikle bahar ayları için, elektrik enerjisi ithalat kapasitesi, söz konusu dönem için en güncel iletim sistemi verisine dayanarak, iletim sistemi güvenliği ön planda olacak şekilde hesaplanmalıdır.

- Her ne kadar analiz çalışmalarında elektrik enerjisi ithalat kapasitesi artsa da, hem özel sektör tarafından üretim alanında, hem de TEİAŞ tarafından iletim sistemi alanında gerçekleştirilecek / ertelenecek / gerçekleştirilmeyecek yatırımlara bağlı olarak, üretim profilinin değişebileceği ve bu durumun Gürcistan ile elektrik enerjisi ticaretine kapasite artışı ya da kısıtı olarak yansıyabileceği göz önüne alınmalıdır.

İki ülke arasındaki elektrik ticaret kapasitesini arttırmanın bir yolu, bölgeden (Doğu Karadeniz) yük merkezleri (Gaziantep, Kahramanmaraş, Diyarbakır, Şanlıurfa gibi) istikametlerinde iletim yatırımları gerçekleştirmektir. Bu yatırımların, aynı zamanda hem ülkeler arası elektrik enerjisi geçiş güzergahı olma ("wheeling") imkanı doğuracakları hem de güney komşuları Suriye ve Irak ile elektrik enerjisi ticareti kapasitesini arttıracakları öngörülmektedir. Borçka-Ispir-Bağıştaş ve Keban güzergahında yapılması planlanan EİH, bu kapsamda kullanılabilecek seçeneklerden bir tanesidir (bkz. Figure 28).

10. References

[1] MoM in Ankara between Turkish and Georgian parties on 8-9.12.2010
[2] MoM in Tbilisi between Turkish and Georgian parties on 18.02.2011
[3] MoM in Ankara (workshop) between Turkish and Georgian parties on 19-20.04.2011
[4] C. Gencoglu, O. B. Tor, "Technical Feasibility Analysis for Georgia-Turkey HVDC Interconnection, Part I: Power Quality and Short Term Voltage Stability Analysis," TUBITAK UZAY Power Systems Department, Ankara, Turkey, Jan. 2009.

[5] C. Gencoglu, O. Tanidir, O. B. Tor, “Technical Feasibility Analysis for Georgia-Turkey HVDC Interconnection, Part II: Transmission System Security Analysis,” TUBITAK UZAY Power Systems Department, Ankara, Turkey, Feb. 2009.

[6] Siemens PTI eNewsletter Issue 103. Available:https://www.ptius.com/pti/company/eNewsletter/2009January/Generic_PSSE_HVDC_Dynamic_Simulation_Model.html. [Accessed Feb. 10, 2010].

[7] T. Gonen, Electric Power Transmission System Engineering: Analysis and Design, CRC Press.

[8] Chan-Ki Kim, Vijay K. Sood, Gil-Soo Jang, Seong-Joo Lim, Seok-Jin Lee, HVDC Transmission: Power Conversion Applications in Power Systems, Singapore: Wiley, 2009.

[9] Turkey. Energy Market Regulatory Authority of Turkey. Elektrik Piyasası Şebeke Yönetmeliği, Ankara: Energy Market Regulatory Authority of Turkey, 2003.
Available: http://www.epdk.org.tr/documents/10157/2be5c128-9cd4-447f-a23f-8c87da44d238.
[Accessed Jan. 16, 2010].

APPENDICES

SCMVA Calculation Results for 2013-2015-2017

SCMVA Analysis Tables

Table 14: SCMVA vs Scenario Table for 2013 (Borcka- Akhaltsikhe Connection Analysis)

Bus	SCMVA	$P_{dc\ capacity\ max}$	Scenario	Remarks
Borcka 400 kV SS	7747 MVA*	926 MW	Summer	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2473 MVA*			
Borcka 400 kV SS	5897 MVA*	843 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	2266 MVA*			
Borcka 400 kV SS	6412 MVA*	868 MW		Borcka-Deriner line is out of service
Akhaltsikhe 400 kV SS (border line side)	2329 MVA*			
Borcka 400 kV SS	6793 MVA*	886 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	2374 MVA*			
Borcka 400 kV SS	9063 MVA**	962 MW	Spring	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2564 MVA**			
Borcka 400 kV SS	7211 MVA**	897 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	2401 MVA**			
Borcka 400 kV SS	6931 MVA**	885 MW		Borcka-Deriner line is out of service
Akhaltsikhe 400 kV SS (border line side)	2370 MVA**			
Borcka 400 kV SS	8035 MVA**	928 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	2479 MVA**			

Table 15: SCMVA vs Scenario Table for 2013 (Muratli-Batumi Connection Analysis)

Bus	SCMVA	$P_{dc\ capacity\ max}$	Scenario	Remarks
Muratli 154 kV SS	4005 MVA*	698 MW	Summer	All transmission lines are in operation
Batumi 154 kV SS (border line side)	1956 MVA*			
Muratli 154 kV SS	3943 MVA*	694 MW		Borcka-Kalkandere line is out of service
Batumi 154 kV SS (border line side)	1946 MVA*			
Muratli 154 kV SS	3957MVA*	694 MW		Borcka-Deriner line is out of service
Batumi 154 kV SS (border line side)	1947 MVA*			
Muratli 154 kV SS	3987 MVA*	697 MW		Borcka-Arkhun line is out of service
Batumi 154 kV SS (border line side)	1954 MVA*			
Muratli 154 kV SS	4099 MVA***	700 MW	Spring	All transmission lines are in operation
Batumi 154 kV SS (border line side)	1962 MVA***			
Muratli 154 kV SS	3982 MVA***	683 MW		Borcka-Kalkandere line is out of service
Batumi 154 kV SS (border line side)	1918 MVA***			
Muratli 154 kV SS	4023 MVA***	693 MW		Borcka-Deriner line is out of service
Batumi 154 kV SS (border line side)	1944 MVA***			
Muratli 154 kV SS	4082 MVA***	698 MW		Borcka-Arkhun line is out of service
Batumi 154 kV SS (border line side)	1957 MVA***			

Table 16: SCMVA vs Scenario Table for 2015 (Borcka- Akhaltsikhe Connection Analysis)

Bus	SCMVA	$P_{dc\ capacity\ max}$	Scenario	Remarks
Borcka 400 kV SS	8699 MVA*	950 MW	Summer	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2525 MVA*			
Borcka 400 kV SS	6759 MVA*	875 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	2342 MVA*			
Borcka 400 kV SS	7057 MVA*	900 MW		Borcka-Deriner line is out of service
Akhaltsikhe 400 kV SS (border line side)	2401 MVA*			
Borcka 400 kV SS	7318 MVA*	900 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	2401 MVA*			
Borcka 400 kV SS	10262 MVA**	1000 MW	Spring	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2651 MVA**			
Borcka 400 kV SS	8242 MVA**	940 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	2502 MVA**			
Borcka 400 kV SS	7720 MVA**	915 MW		Borcka-Deriner line is out of service
Akhaltsikhe 400 kV SS (border line side)	2454 MVA**			
Borcka 400 kV SS	8697 MVA**	955 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	2540 MVA**			

Table 17: SCMVA vs Scenario Table for 2015 (Muratli-Batumi Connection Analysis)

Bus	SCMVA	$P_{dc\ capacity\ max}$	Scenario	Remarks
Borcka 400 kV SS	4202 MVA*	714 MW	Summer	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	1997 MVA*			
Borcka 400 kV SS	4158 MVA*	712 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	1990 MVA*			
Borcka 400 kV SS	4154 MVA*	712 MW		Borcka-Deriner line is out of service
Akhaltsikhe 400 kV SS (border line side)	1990 MVA*			
Borcka 400 kV SS	4168 MVA*	712 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	1991 MVA*			
Borcka 400 kV SS	4366 MVA***	724 MW	Spring	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2020 MVA***			
Borcka 400 kV SS	4299 MVA***	714 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	1997 MVA***			
Borcka 400 kV SS	4293 MVA***	717 MW		Borcka-Deriner line is out of service
Akhaltsikhe 400 kV SS (border line side)	2004 MVA***			
Borcka 400 kV SS	4337 MVA***	721 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	2013 MVA***			

Table 18: SCMVA vs Scenario Table for 2017 (Borcka- Akhaltsikhe Connection Analysis)

Bus	SCMVA	$P_{dc\ capacity\ max}$	Scenario	Remarks
Borcka 400 kV SS	9269 MVA*	1640 MW	Summer	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	4273 MVA*			
Borcka 400 kV SS	7323 MVA*	1515 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	3948 MVA*			
Borcka 400 kV SS	8003 MVA*	1635 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	4248 MVA*			
Borcka 400 kV SS	9103 MVA*	975 MW		Akhaltsikhe-Y.Tortum line is out of service
Akhaltsikhe 400 kV SS (border line side)	2593 MVA*			
Borcka 400 kV SS	10794 MVA**	1710 MW	Spring	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	4436 MVA**			
Borcka 400 kV SS	8747 MVA**	1600 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	4158 MVA**			
Borcka 400 kV SS	9376 MVA**	1700 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	4413 MVA**			
Borcka 400 kV SS	10572 MVA**	1000 MW		Akhaltsikhe-Y.Tortum line is out of service
Akhaltsikhe 400 kV SS (border line side)	2658 MVA**			

Table 19: SCMVA vs Scenario Table for 2017 (Muratli-Batumi Connection Analysis)

Bus	SCMVA	$P_{dc\ capacity\ max}$	Scenario	Remarks
Borcka 400 kV SS	4246 MVA*	718 MW	Summer	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2005 MVA*			
Borcka 400 kV SS	4211 MVA*	717 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	1999 MVA*			
Borcka 400 kV SS	4215 MVA*	717 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	1998 MVA*			
Borcka 400 kV SS	4255 MVA*	719 MW		Akhaltsikhe-Y.Tortum line is out of service
Akhaltsikhe 400 kV SS (border line side)	2009 MVA*			
Borcka 400 kV SS	4383 MVA***	722 MW	Spring	All transmission lines are in operation
Akhaltsikhe 400 kV SS (border line side)	2017 MVA***			
Borcka 400 kV SS	4296 MVA***	710 MW		Borcka-Kalkandere line is out of service
Akhaltsikhe 400 kV SS (border line side)	1984 MVA***			
Borcka 400 kV SS	4362 MVA***	721 MW		Borcka-Arkhun line is out of service
Akhaltsikhe 400 kV SS (border line side)	2013 MVA***			
Borcka 400 kV SS	4376 MVA***	721 MW		Akhaltsikhe-Y.Tortum line is out of service
Akhaltsikhe 400 kV SS (border line side)	2014 MVA***			

* Condition in which calculations are made is 350MW import from Akhaltsikhe, 350MW import from Batumi, 225 MVar synchronous condensers exists in Akhaltsikhe 400kV busbar.

** Condition in which calculations are made is 350MW import from Akhaltsikhe, 225 MVar synchronous condensers exists in Akhaltsikhe 400kV busbar.

*** Condition in which calculations are made is 350MW import from Batumi, 225 MVar synchronous condensers exists in Akhaltsikhe 400kV busbar.

The following Appendices are not added to the report given their large size (~300 pages). They are available upon request.

APPENDIX A-I – 2013 Peak Load Scenario 350 MW Import from Georgia

Contingency Analysis Results

APPENDIX A-II – 2013 Peak Load Scenario 700 MW Import from Georgia

Contingency Analysis Results

APPENDIX A-III – 2013 Peak Load Scenario1050 MW Import from Georgia

Contingency Analysis Results

APPENDIX A-IV – 2013 Spring Load Scenario 350 MW Import from Georgia

Contingency Analysis Results

APPENDIX B-I – 2015 Peak Load Scenario 350 MW Import from Georgia

Contingency Analysis Results

APPENDIX B-II – 2015 Peak Load Scenario 700 MW Import from Georgia

Contingency Analysis Results

APPENDIX B-III – 2015 Peak Load Scenario 1050 MW Import from Georgia

Contingency Analysis Results

APPENDIX B-IV – 2015 Spring Load Scenario 350 MW Import from Georgia

Contingency Analysis Results

APPENDIX B-V – 2015 Spring Load Scenario 700 MW Import from Georgia

Contingency Analysis Results

APPENDIX C-I – 2017 Peak Load Scenario 350 MW Import from Georgia

Contingency Analysis Results

APPENDIX C-II – 2017 Peak Load Scenario 700 MW Import from Georgia

Contingency Analysis Results

APPENDIX C-III – 2017 Peak Load Scenario 1050 MW Import from Georgia

Contingency Analysis Results

APPENDIX C-IV – 2017 Peak Load Scenario 1400 MW Import from Georgia

Contingency Analysis Results

APPENDIX C-V – 2017 Spring Load Scenario 350 MW Import from Georgia

Contingency Analysis Results

APPENDIX C-VI – 2017 Spring Load Scenario 700 MW Import from Georgia

Contingency Analysis Results

ANNEX 3

Technical Feasibility Analysis of Power Export From Georgia and Azerbaijan to Turkey

Final Report, GSE.

Technical Feasibility Analysis of Power Export From Georgia and Azerbaijan to Turkey
2013, 2015, 2017-1, 2017-2

(FINAL)

Akhaltsikhe- Borcka Connection through HVDC Back to Back Subtation at Akhaltsikhe (Georgia)

Batumi-Muratli Connection through HVDC Back to Back Subtation at Batumi (Georgia)

Introduction

This report mainly is focused on research power export capabilities from Georgia to Turkey and power transfer capabilities from Azerbaijan to Turkey through Georgia for 2013, 2015 and 2017 years. The report is provided by specialists of Georgian State Electrosystem (GSE). It's prepared for meeting with specialists of TEIAS and TUBITAK UZAY, in Istanbul, to discuss power export/import feasibilities of Georgia/Turkey via Akhaltsikhe back to back substation.

For 2013 year, An asynchronous interconnection between Georgia and Turkey is planned to be established via a line commutated back to back (B2B) HVDC 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.

In order to provide power export from Georgia and Azerbaijan to Turkey in reliably manner, besides Akhaltsikhe substation, It's considered to be built in Georgia new 500 kV substations Jvari and Marneuli, also internal 500 kV lines connecting Akhaltsikhe B2B with 500 kV substations Zestafoni and Marneuli and 500 kV lines between substations Ksani -Marneuli, Gardabani - Marneuli and Enguri – Jvari. Moreover, its considered the reinforcement of 220 kV power gird's western part of Georgia (fig 1.1).

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

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. New power plants also will start operation. (see the map on fig 1.2).

For 2017 year, it's planned entrance in service of new power plants – Khudoni HPP, Namakhvani HPP Cascade and etc, with corresponding substations and OHLs connecting with system.

This report includes:

- Steady state scenarios;
- N-1 steady state analysis results;
- N-1 dynamic simulation analysis results;
- Switching analysis results, including N-1;
- System emergency automatics.
- Short Circuit Power calculation results;

For steady state, N-1 dynamic and static analysis, also for analysis of emergency automatic action had been used PSS/E software.

For switching analysis, including N-1 had been used Simplorer software.

Steady states and dynamic model includes:

- Full 220, 330 and 500 kV power gird of systems of Georgia and Azerbaijan;
- power gird with rated voltage 110 kV and lines, by witch generation units are connected with high voltage system;
- Generation units with capacity 5 MVA and more.

For 2013, All above mentioned analysis were done for 8 basic characteristic steady state scenarios:

- Winter Maximum;
- Winter Minimum;
- Spring Maximum;
- Spring Minimum;
- Summer Maximum;
- Summer Minimum;
- Autumn Maximum;
- Autumn Minimum;

Dynamic simulation and analysis were provided for emergency outage of Each 500 kV OHL of Georgia and Azerbaijan, after faults with 0.1 sec duration. B2B blocking time 0.2 sec was considered.

Based on dynamic simulation analysis, it has been obtained dynamic limits and had been obtained “new” steady scenarios had been changed, so that after each internal 500 kV line and 500/220 kV autotransformer emergency outage, Georgian-Azerbaijan system stability is preserved. So, steady state scenarios, given bellow are tested on N-1 disturbance in static and dynamic simulations.

For 2015 and 2017, Based on appendices of “Minutes of Meeting on Electrical Interconnections with the joint working group of TEIASH(Turkey) and GSE / Energo-pro (Georgia), 18 February 2011, Tbilisi/GEORGIA”, all above mentioned analysis were done for 4 basic characteristic steady state scenarios:

- Winter Maximum;
- Spring Minimum;
- Summer Maximum;
- Autumn Minimum;

Dynamic simulation and analysis were provided for emergency outage of Each 500 kV OHL of Georgia, after faults with 0.1 sec duration. B2B blocking time 0.2 sec was considered.

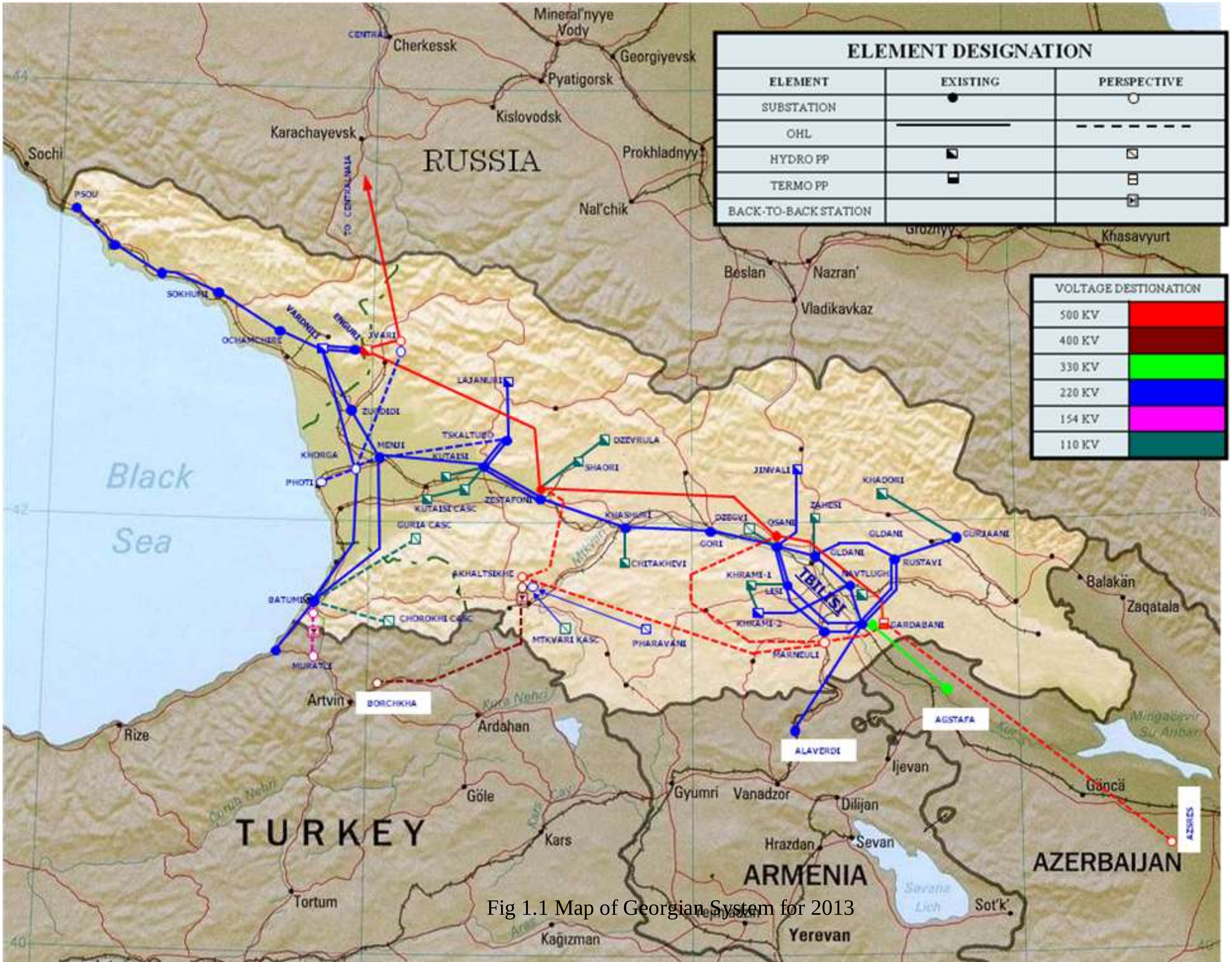


Fig 1.1 Map of Georgian System for 2013

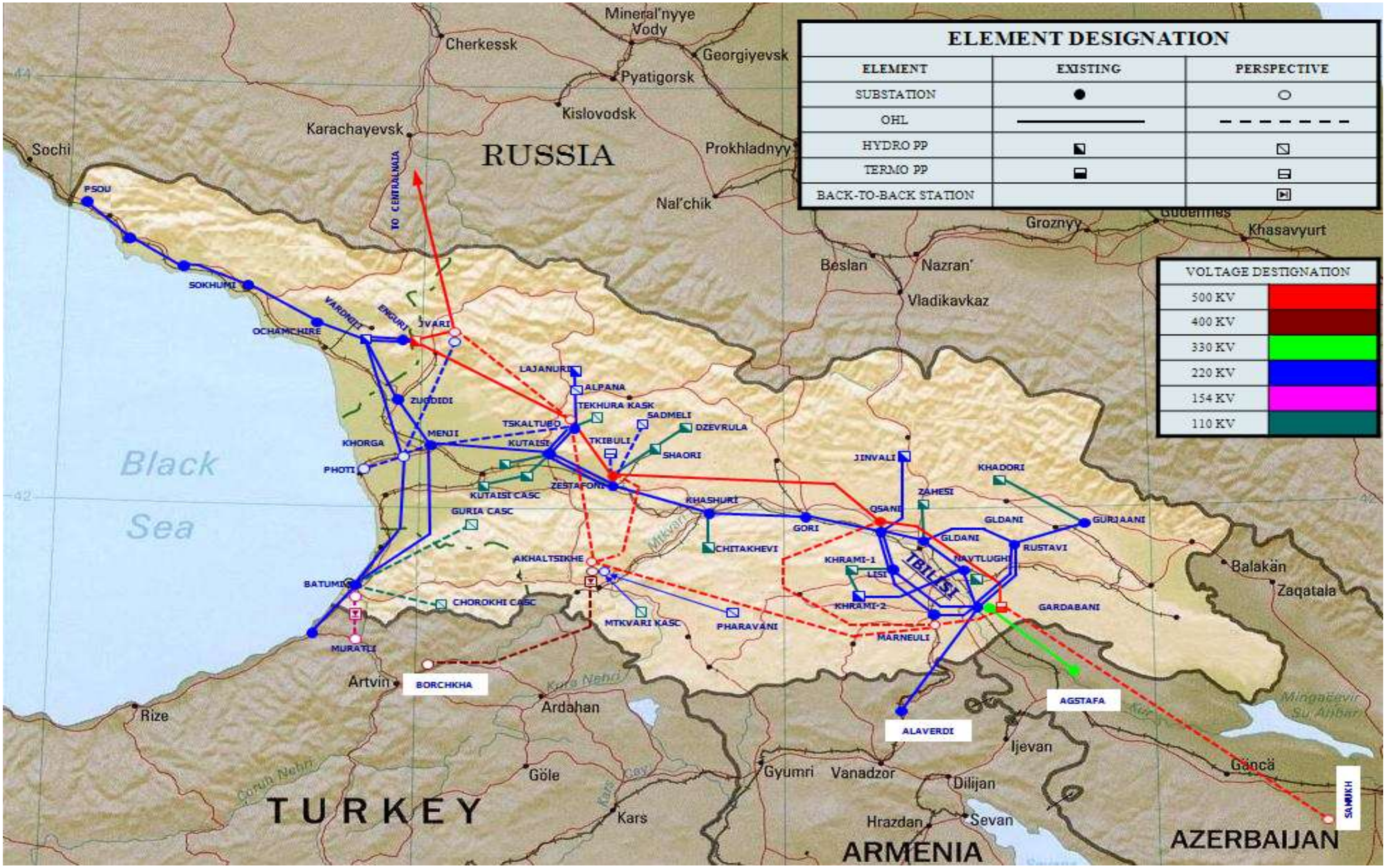


Fig 1.2 Map of Georgian System for 2015

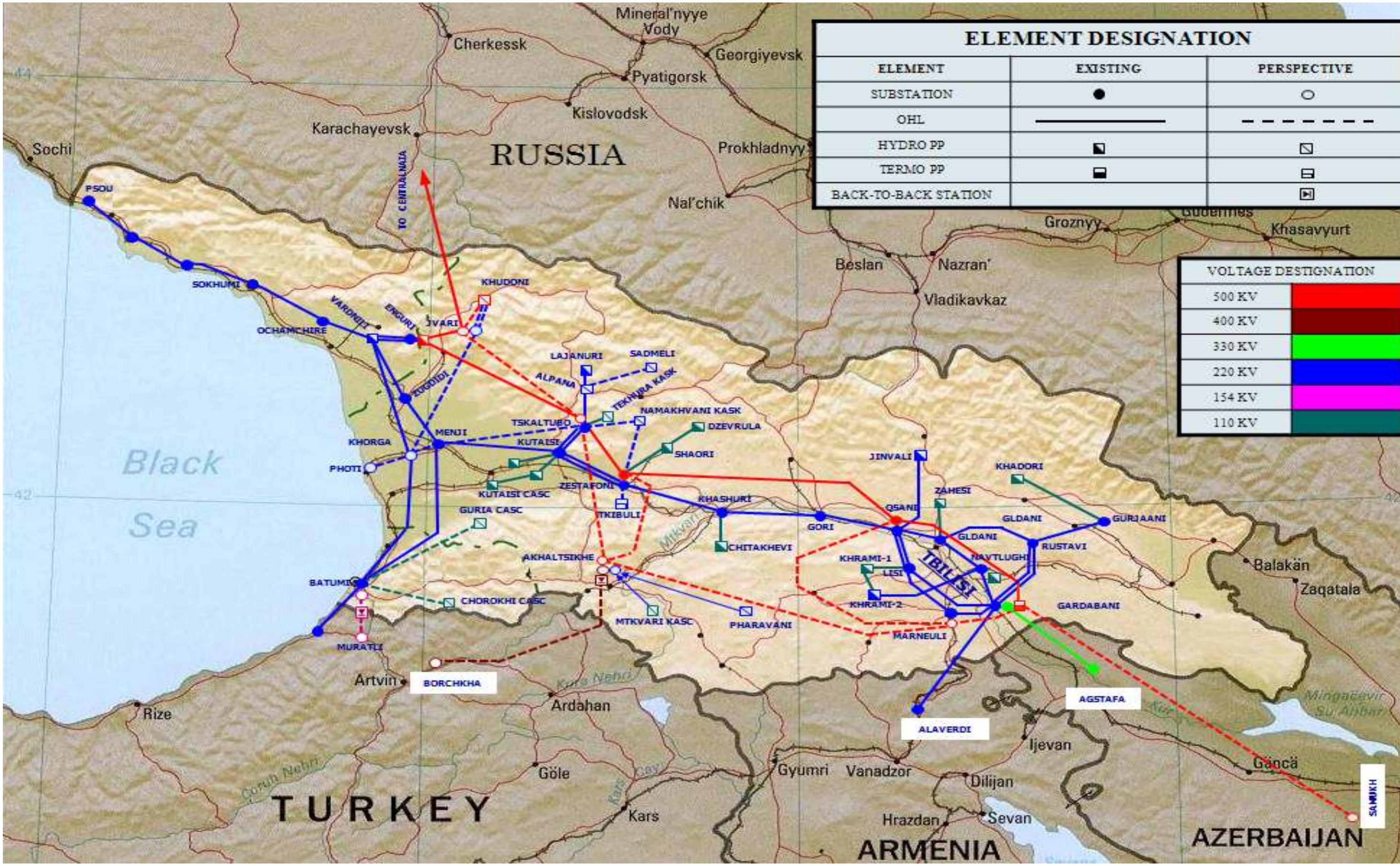
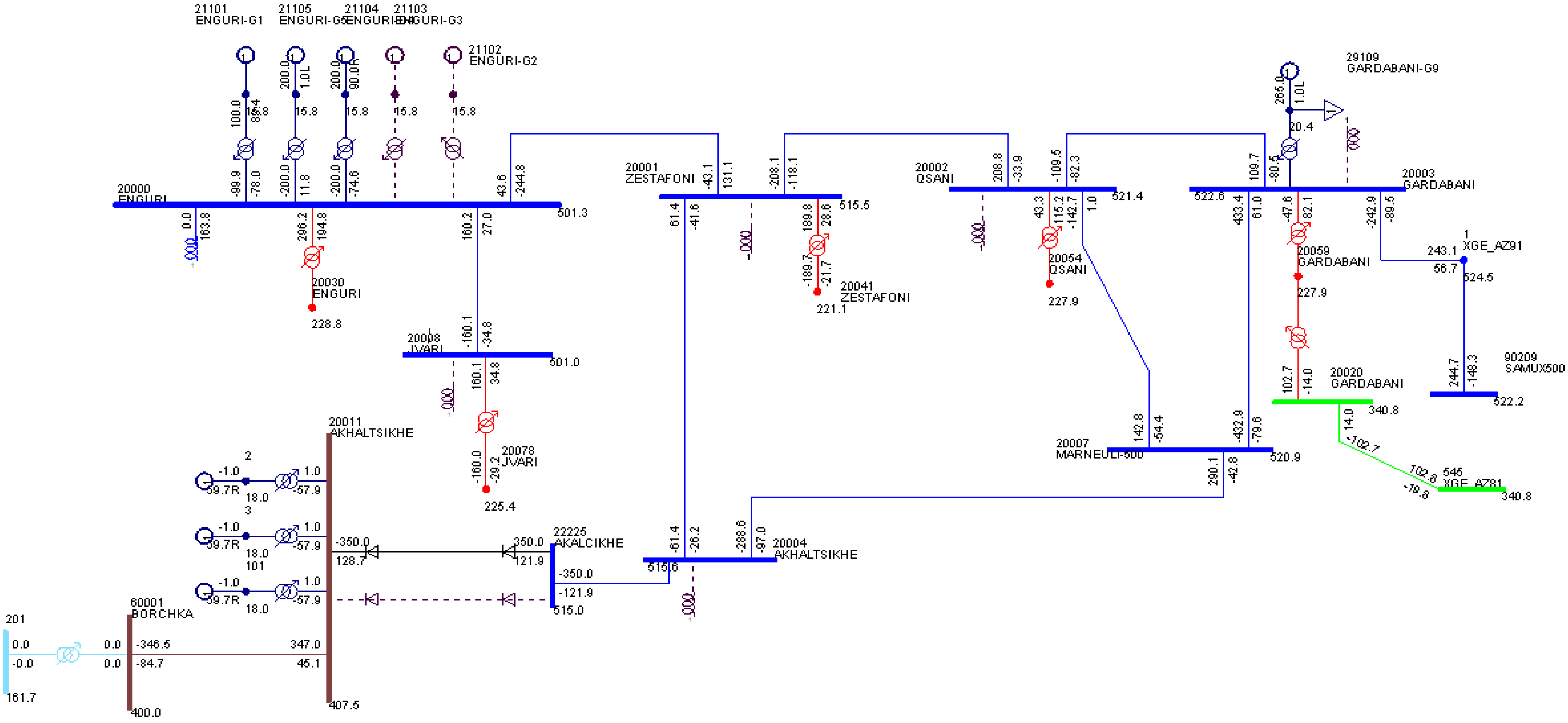


Fig 1.3 Map of Georgian System for 2017

2. Steady state scenarios

2.1 Winter Maximum 2013

GENERATION = 1652 MW, LOAD = 1617 MW, IMPORT (AZ) = 348 MW, EXPORT (TR) = 350 MW

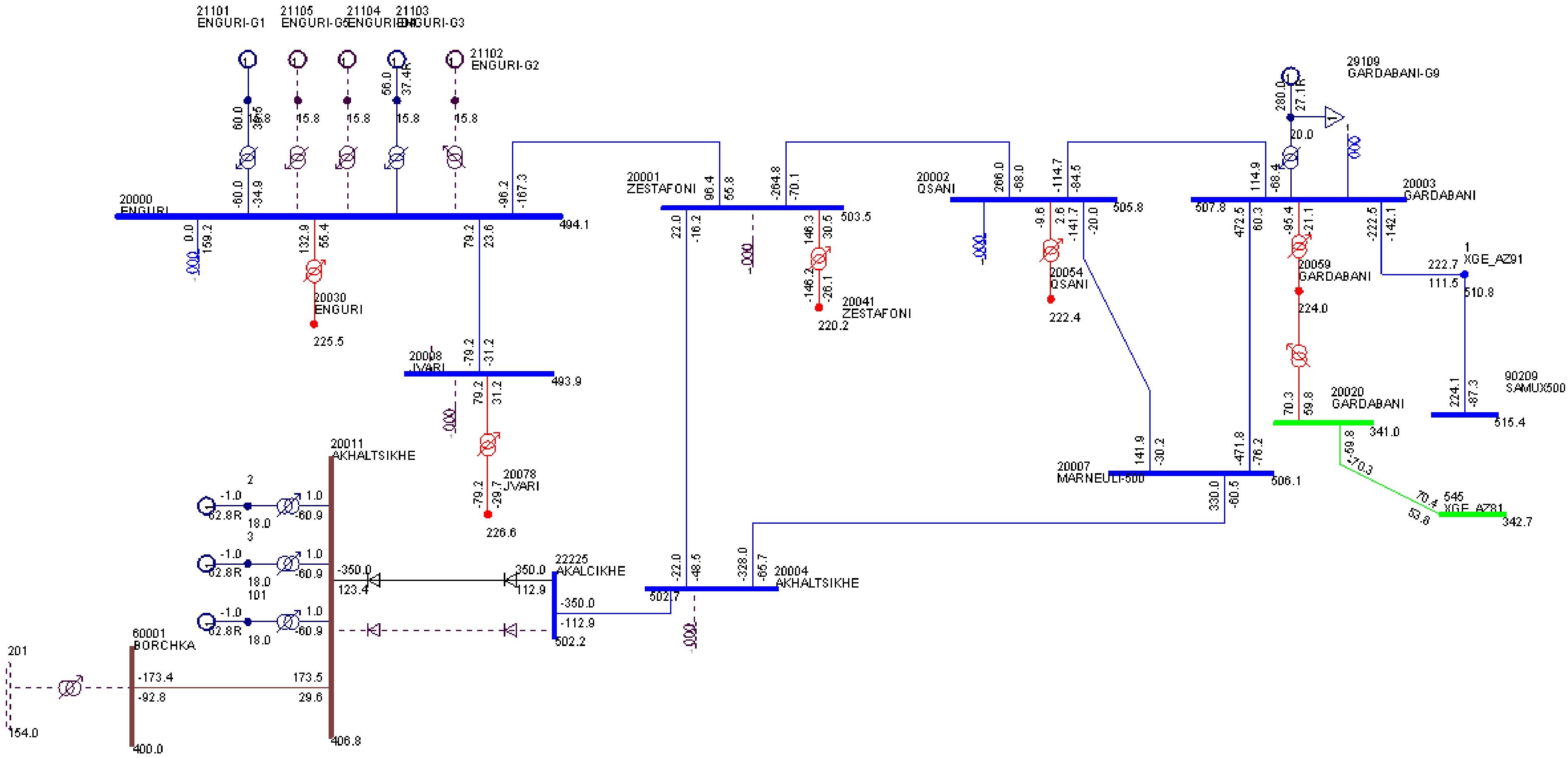


ONE B2B OF AKHALTSIKHE IS IN OPERATION

Fig 2.1

2.2 Winter Minimum 2013

GENERATION = 1021 MW, LOAD = 952 MW, IMPORT (AZ) = 298 MW, EXPORT (TR) = 350 MW

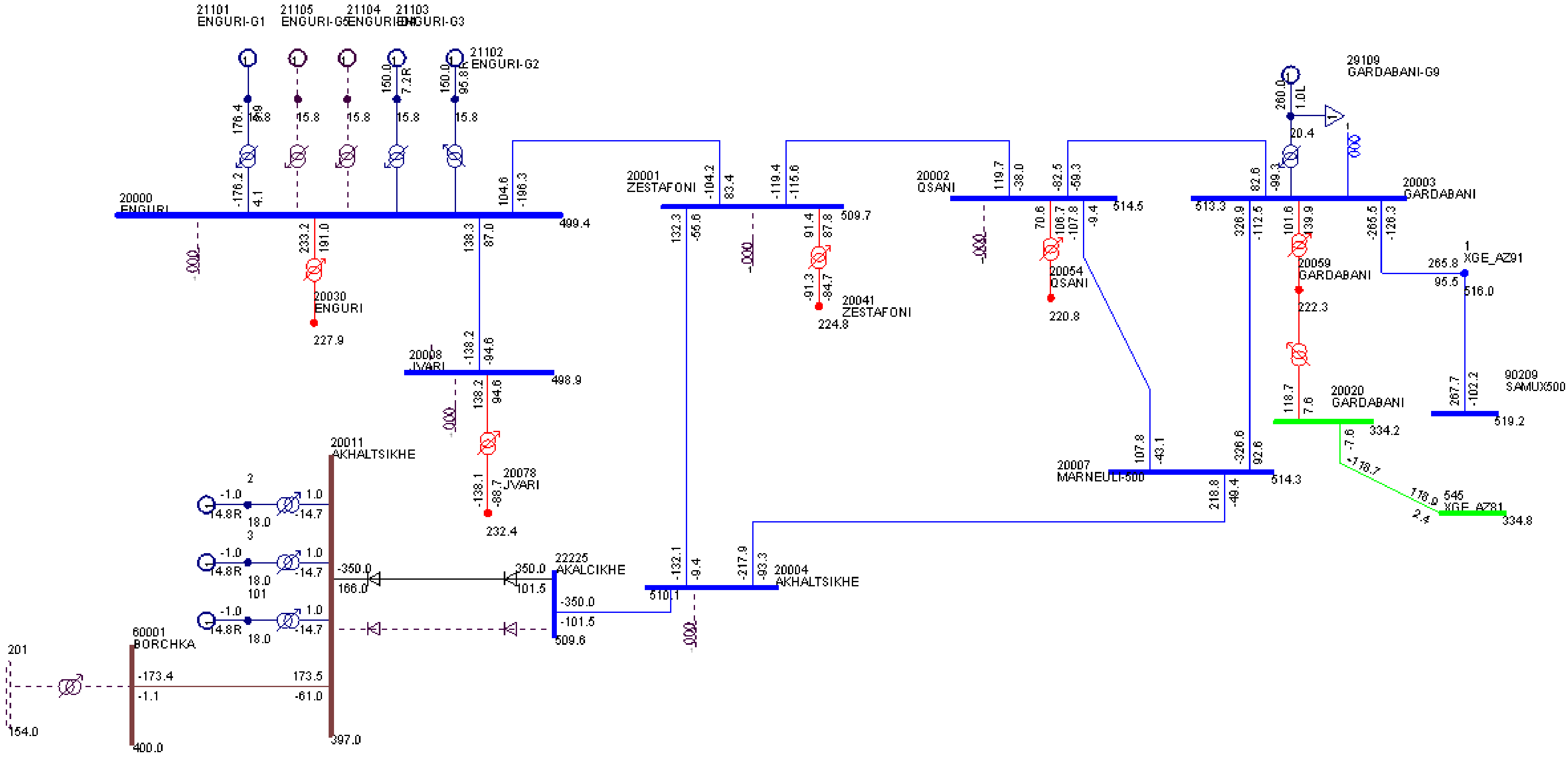


ONE B2B OF AKHALTSIKHE IS IN OPERATION

Fig 2.2

2.3 Spring Maximum 2013

GENERATION = 1543 MW, LOAD = 1549 MW, IMPORT (AZ) = 388 MW, EXPORT (TR) = 350 MW

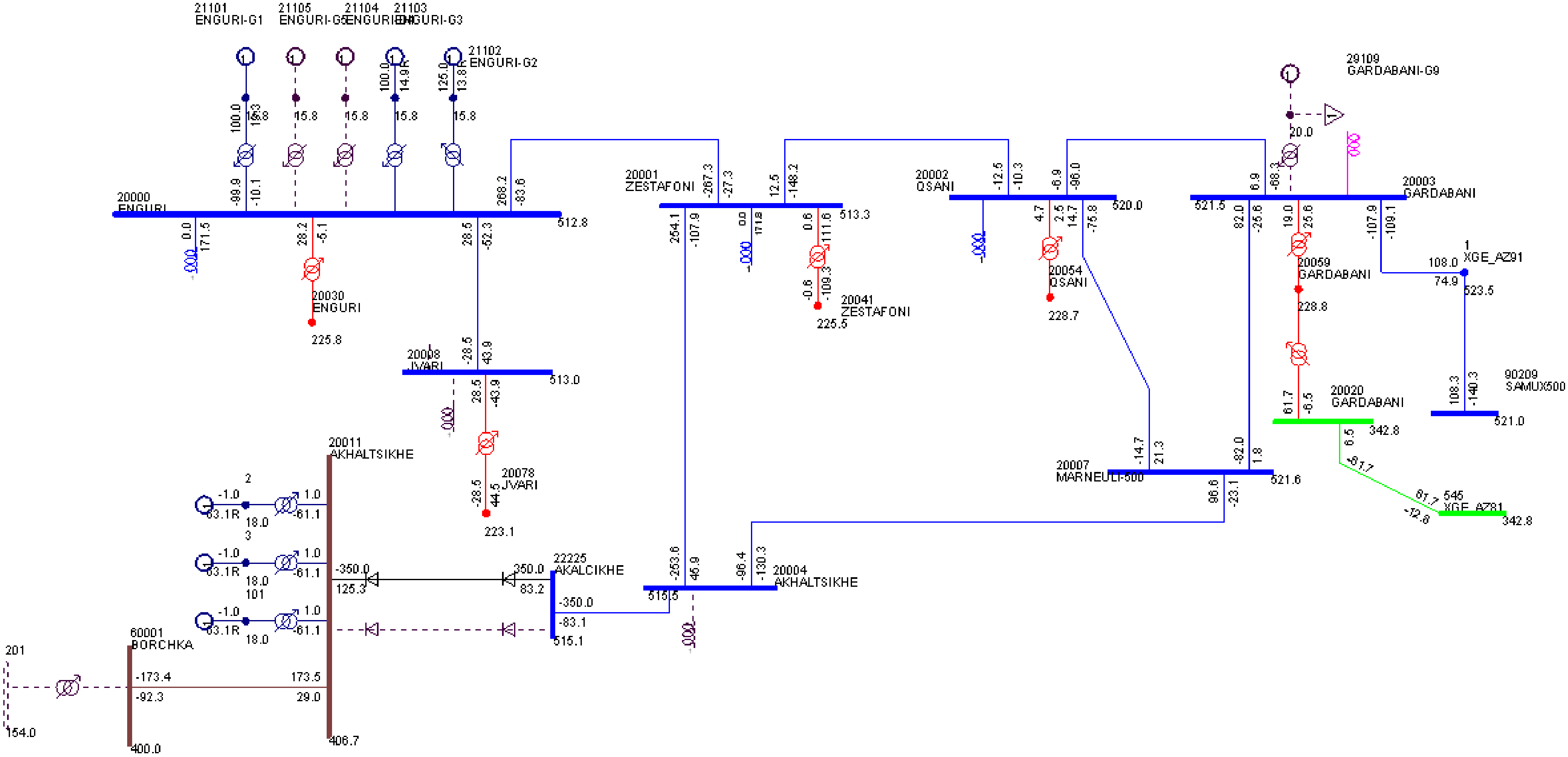


ONE B2B OF AKHALTSIKHE IS IN OPERATION

Fig 2.3

2.4 Spring Minimum 2013

`GENERATION = 970 MW, LOAD = 778 MW, IMPORT (AZ) = 170 MW, EXPORT (TR) = 350 MW`

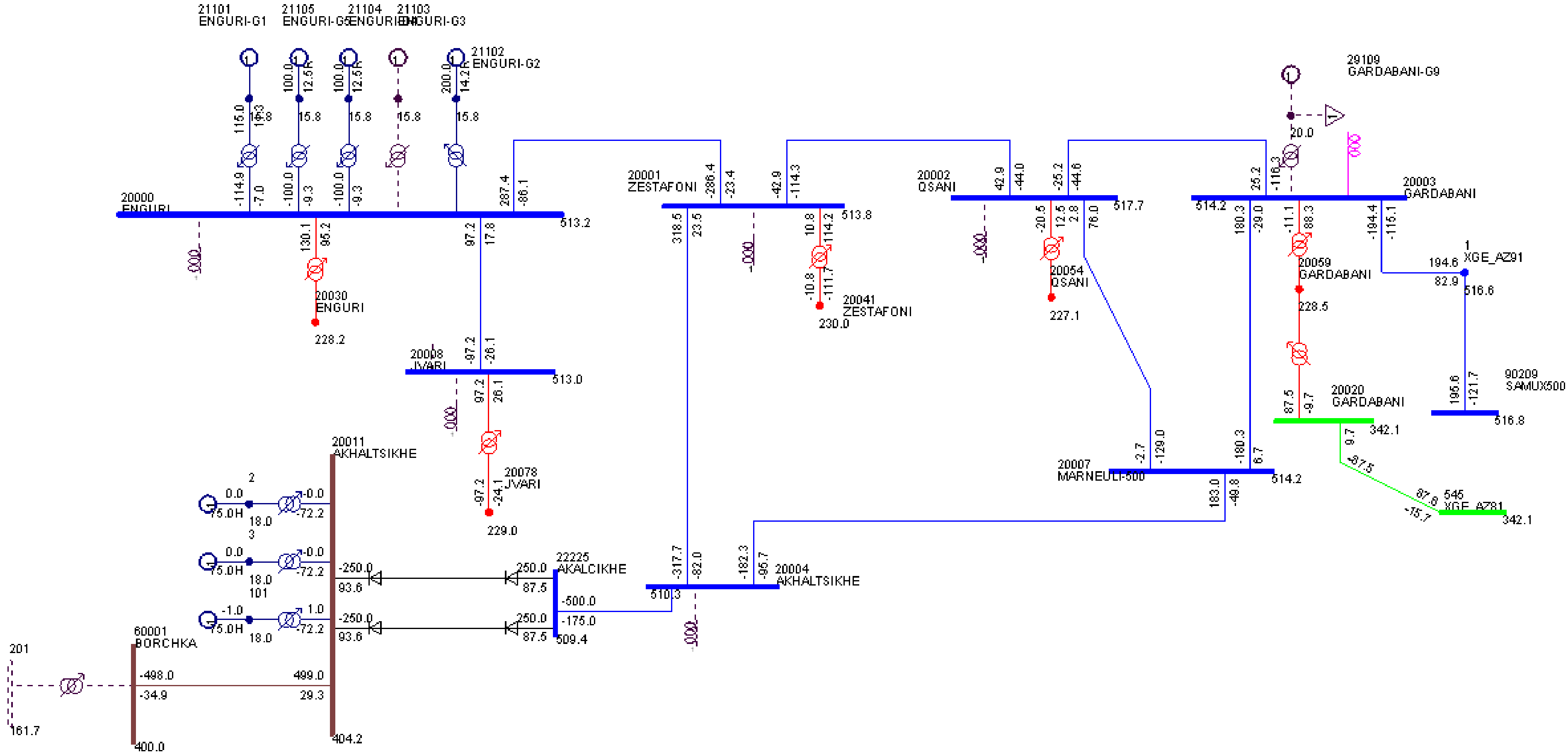


ONE B2B OF AKHALTSIKHE IS IN OPERATION

Fig 2.4

2.5 Summer Maximum 2013

GENERATION = 1340 MW, LOAD = 1100 MW, IMPORT (AZ) = 280 MW, EXPORT (TR) = 500 MW

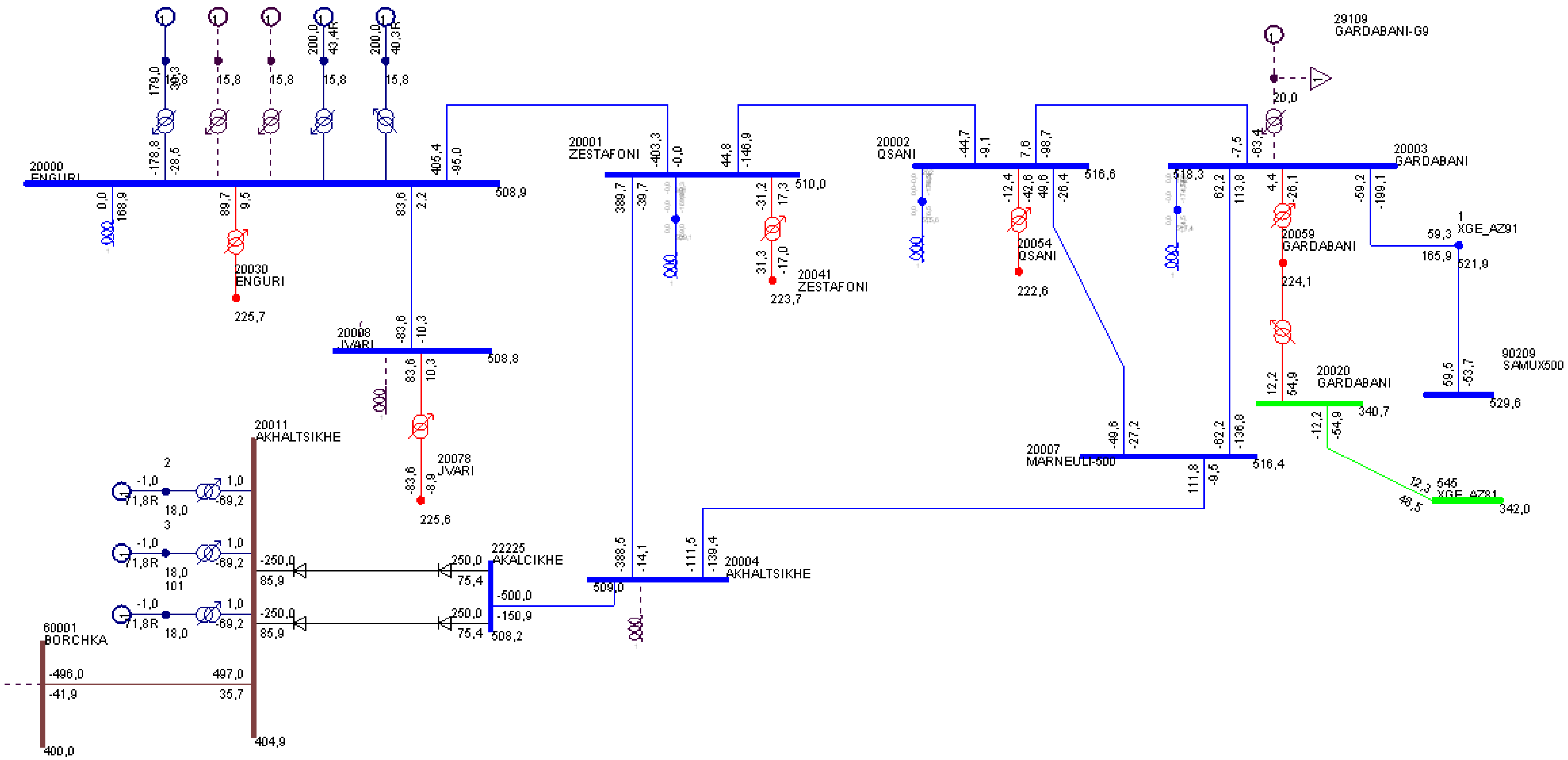


TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.5

2.6 Summer Minimum 2013

GENERATION = 1220 MW, LOAD = 780 MW, IMPORT (AZ) = 70 MW, EXPORT (TR) = 500 MW

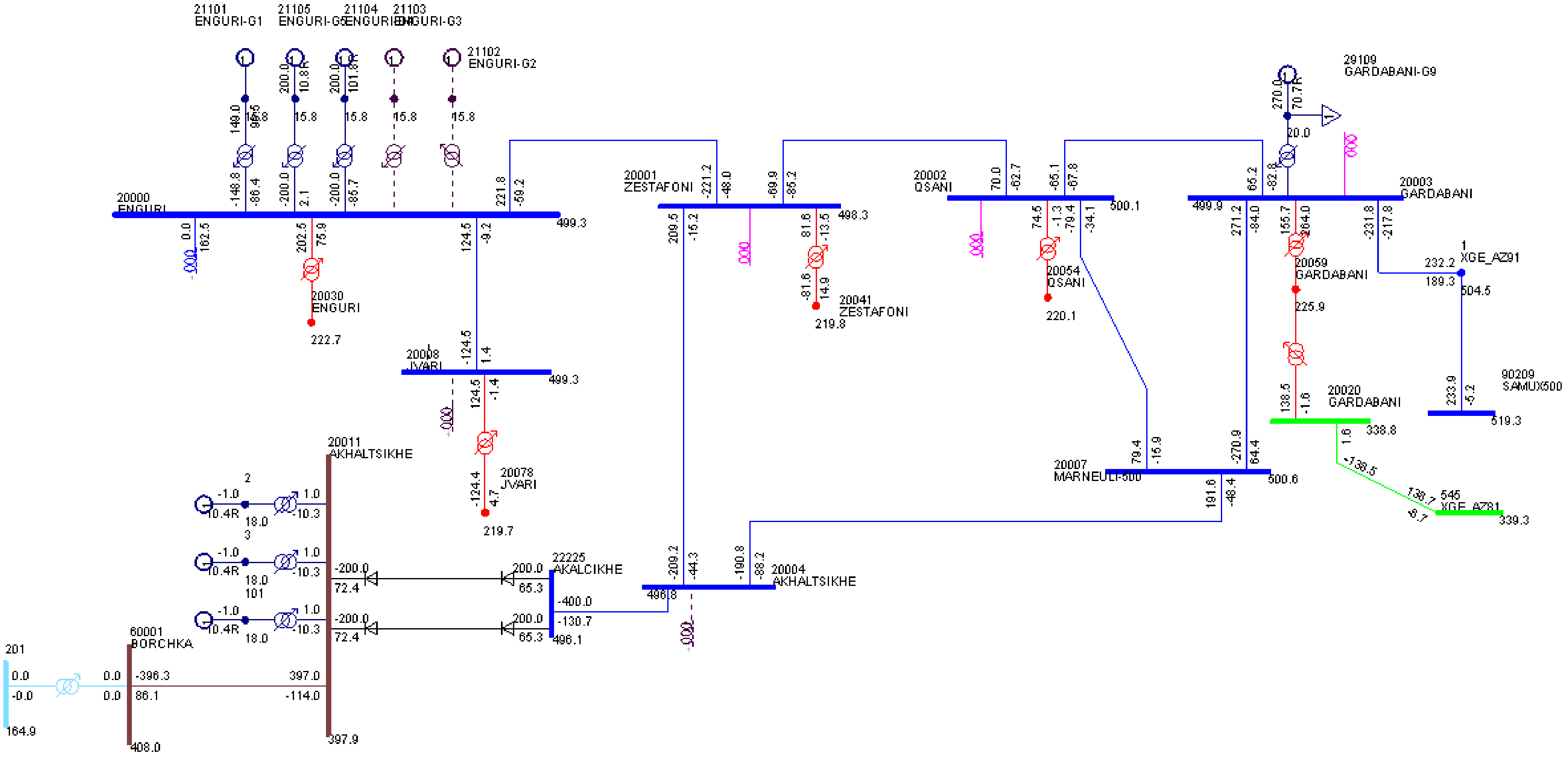


TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.6

2.7 Autumn Maximum 2013

GENERATION = 1460 MW, LOAD = 1410 MW, IMPORT (AZ) = 373 MW, EXPORT (TR) = 400 MW

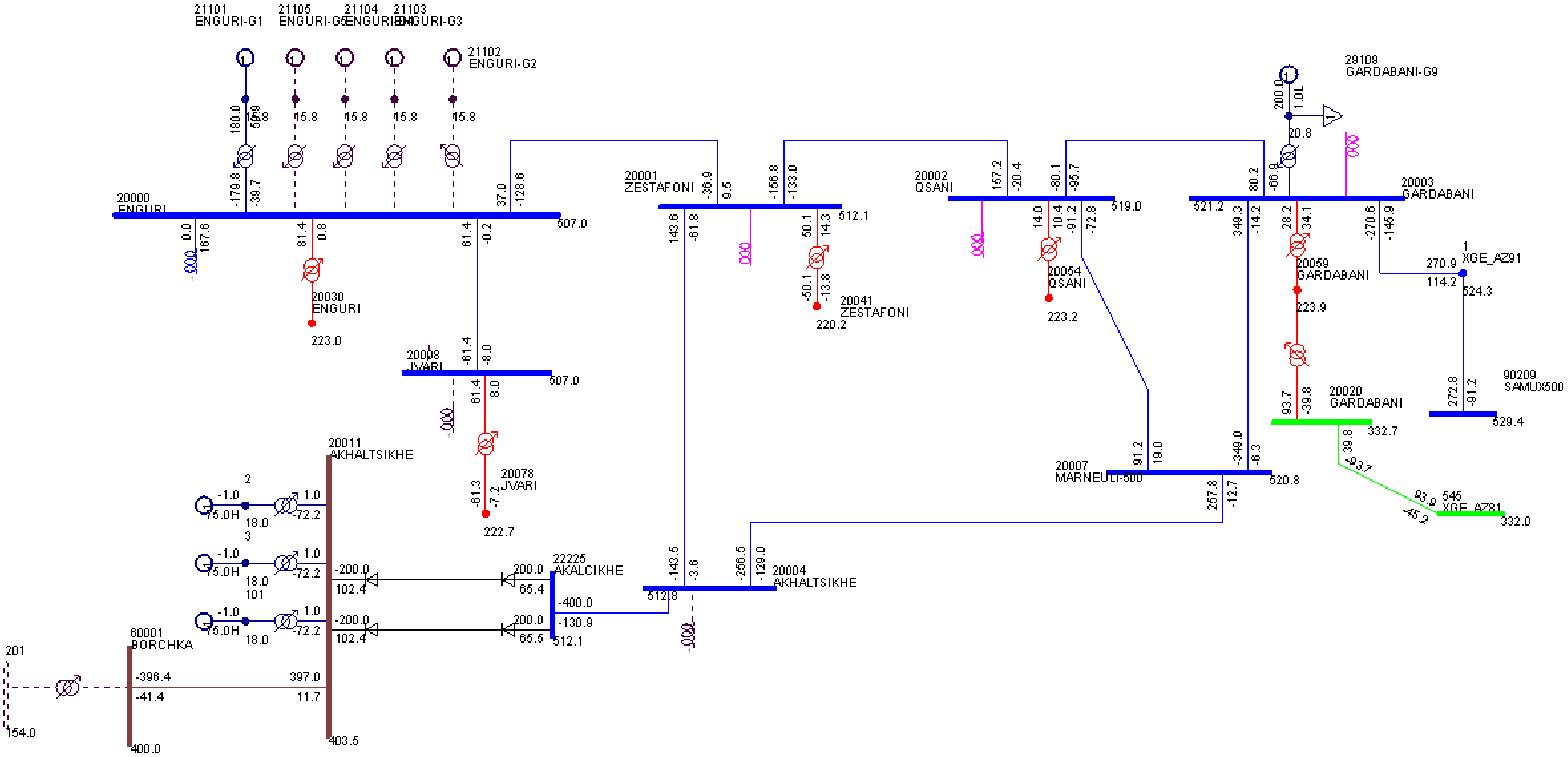


TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.7

2.8 Autumn Minimum 2013

GENERATION = 745 MW, LOAD = 742 MW, IMPORT (AZ) = 367 MW, EXPORT (TR) = 400 MW

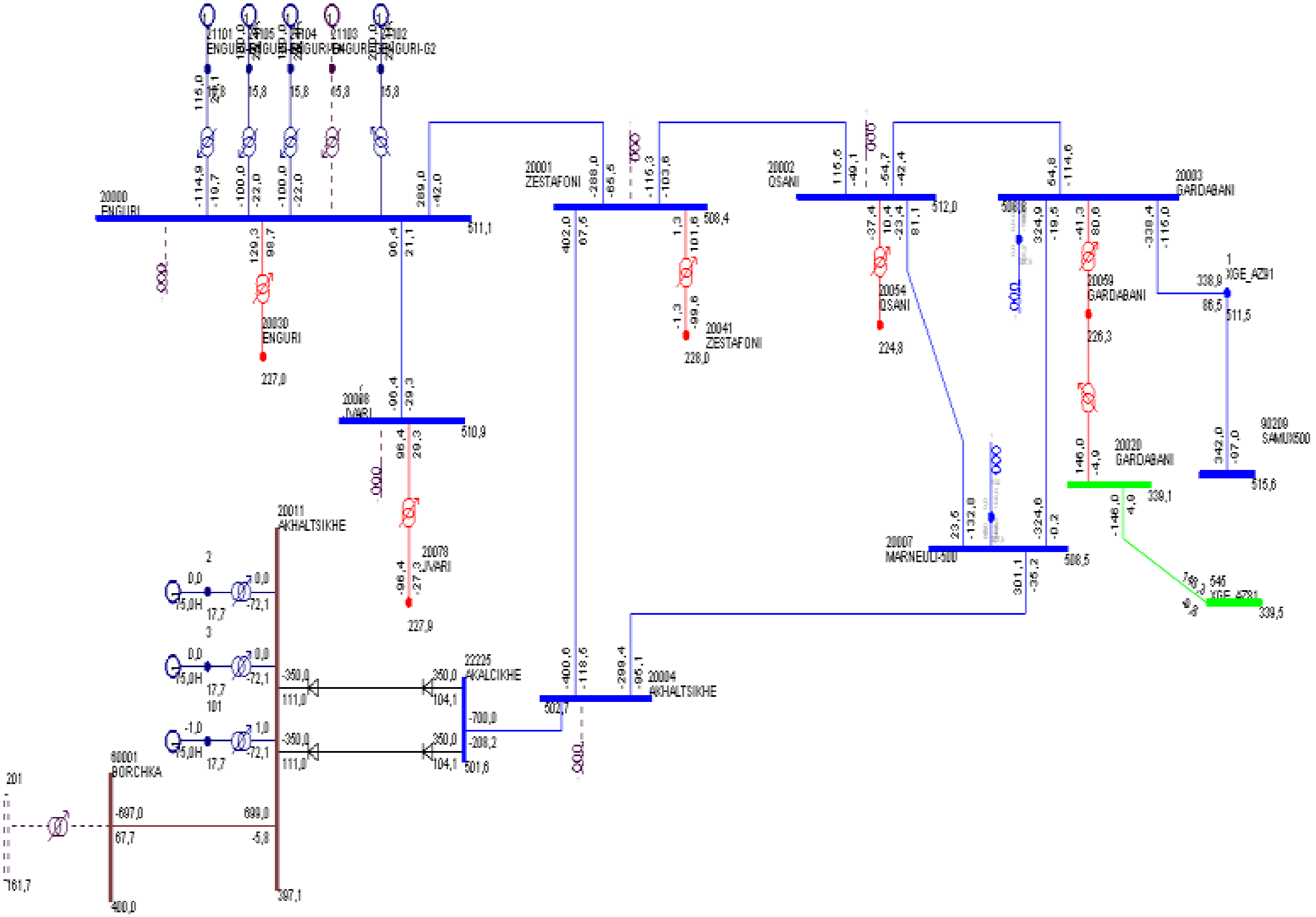


TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.8

2.9 Summer Maximum 2013– 1 (Retrieved by taking account of system automatics)

GENERATION = 1340 MW, LOAD = 1100 MW,
IMPORT (AZ) = 490 MW, EXPORT (TR) = 700 MW

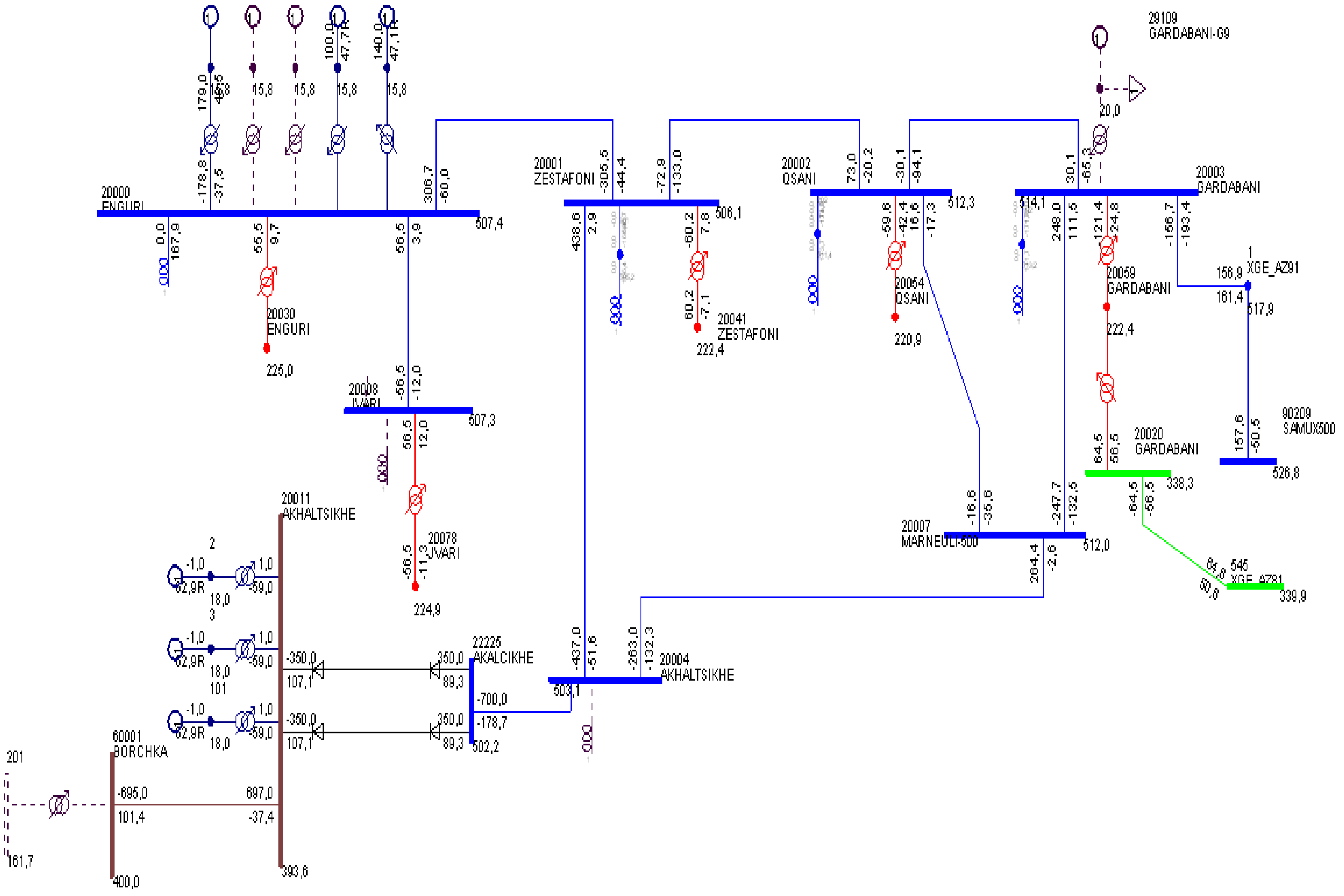


TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.9

2.10 Summer Minimum 2013– 1 (Retrieved by taking account of system automatics)

GENERATION = 1220 MW, LOAD = 780 MW,IMPORT (AZ) = 334 MW, EXPORT (TR) = 700 MW



TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.10

2.11 Autumn Maximum 2013 – 1 (Retrieved by taking account of system automatics)

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GENERATION = 1790 MW, LOAD = 1410 MW,
IMPORT (AZ) = 373 MW, EXPORT (TR) = 700 MW
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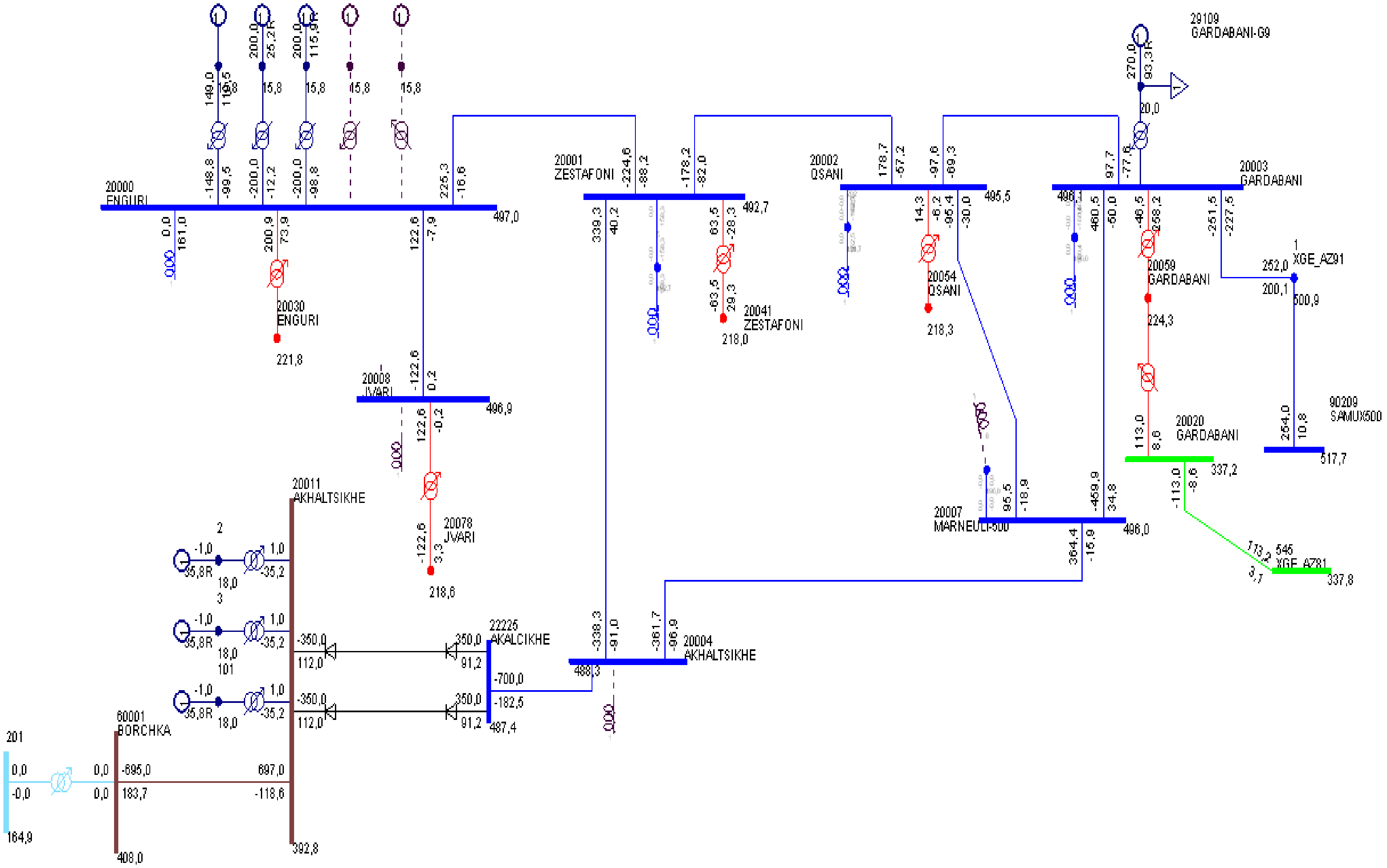
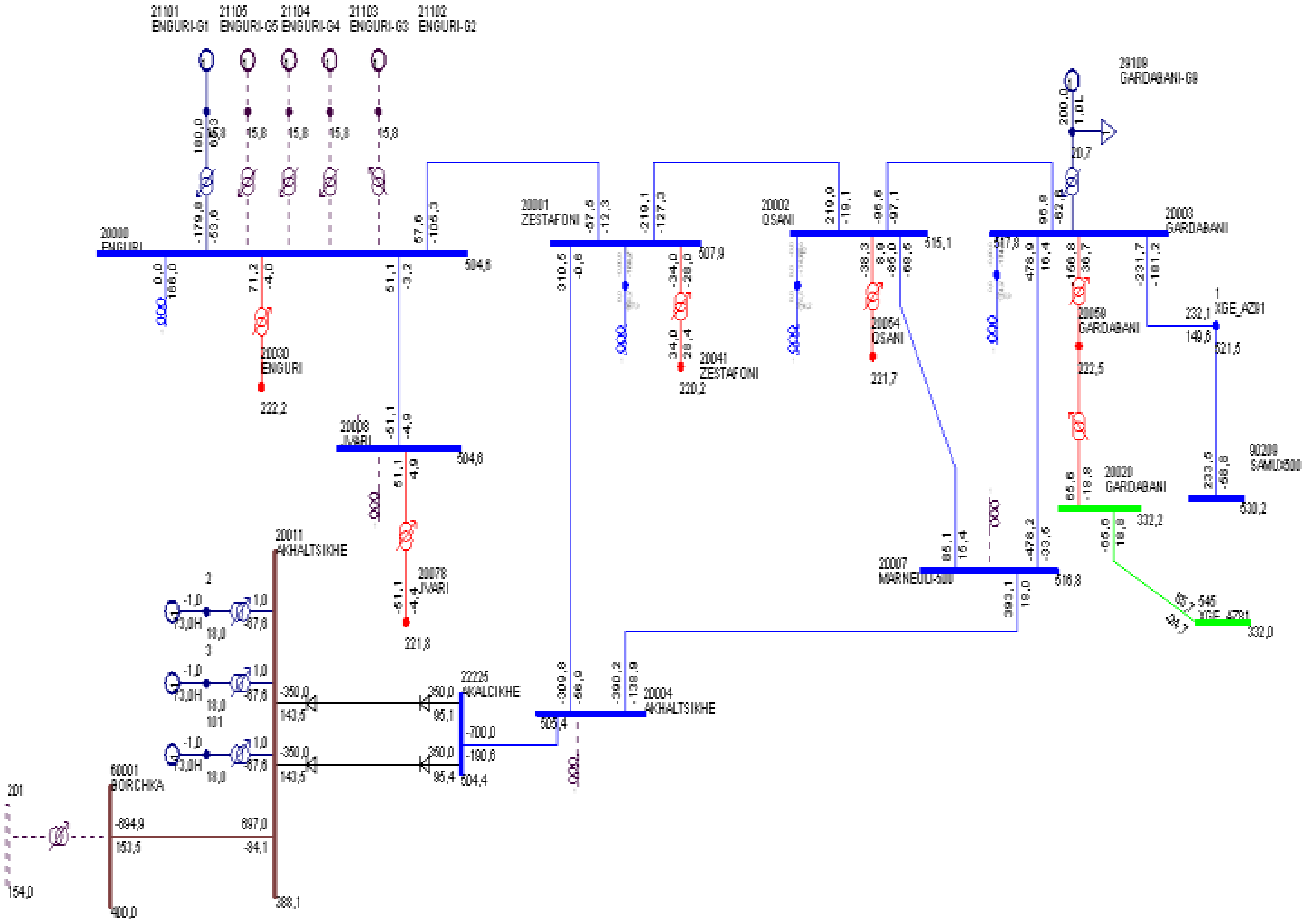


TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.11

2.12 Autumn Minimum 2013– 1 (Retrieved by taking account of system automatics)

GENERATION = 1075 MW, LOAD = 742 MW,
IMPORT (AZ) = 367 MW, EXPORT (TR) = 700 MW



TWO B2B OF AKHALTSIKHE ARE IN OPERATION

Fig 2.12

2.13 Spring Min 2015

GENERATION = 1856 MW, LOAD = 950 MW,
IMPORT(AZ) = 115 MW, EXPORT (TR) = 1000 MW
[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 300 MW]

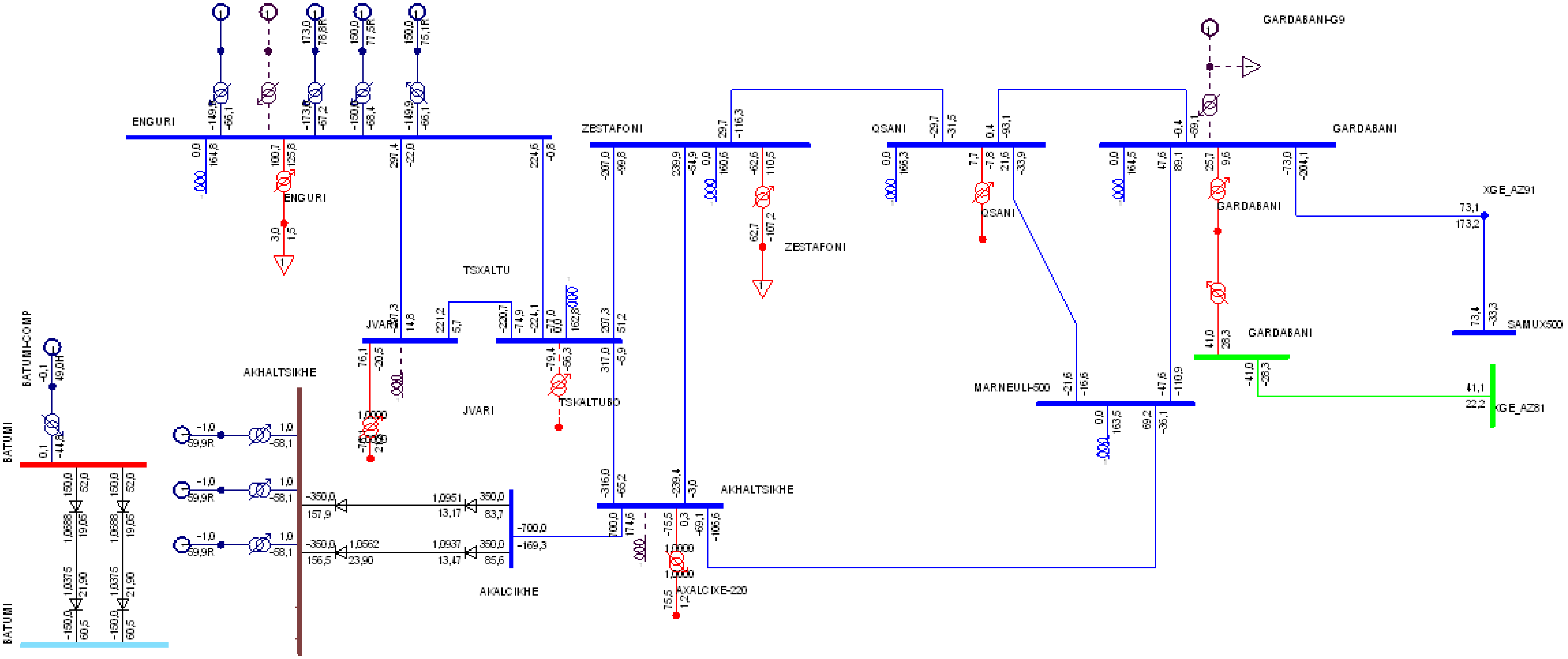


Fig 2.13

2.14 Summer max 2015

GENERATION = 2303 MW, LOAD = 1366 MW,
IMPORT(AZ) = 96 MW, EXPORT (TR) = 1000 MW
[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 300 MW]

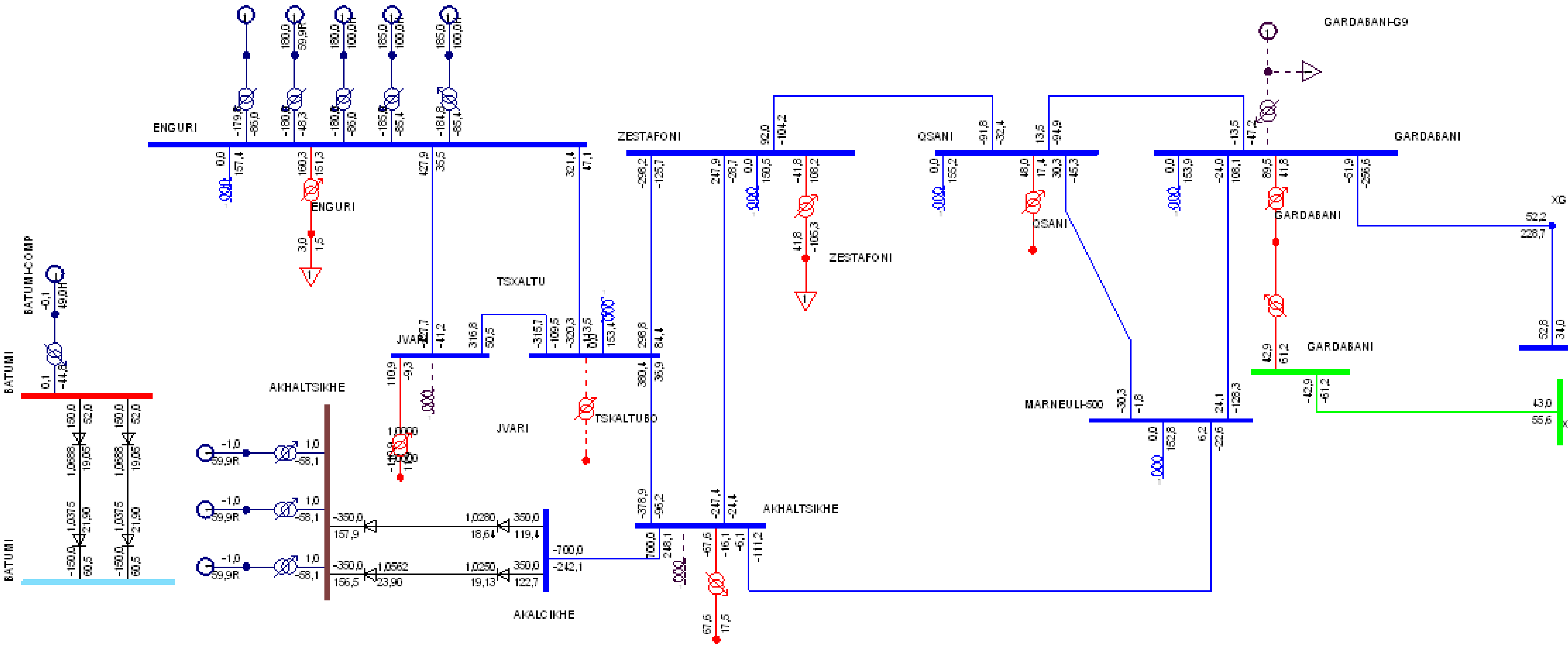


Fig 2.14

2.15 Autumn – min 2015

GENERATION = 1534 MW, LOAD = 897 MW,
IMPORT(AZ) = 333 MW, EXPORT (TR) = 950 MW
[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 250 MW]

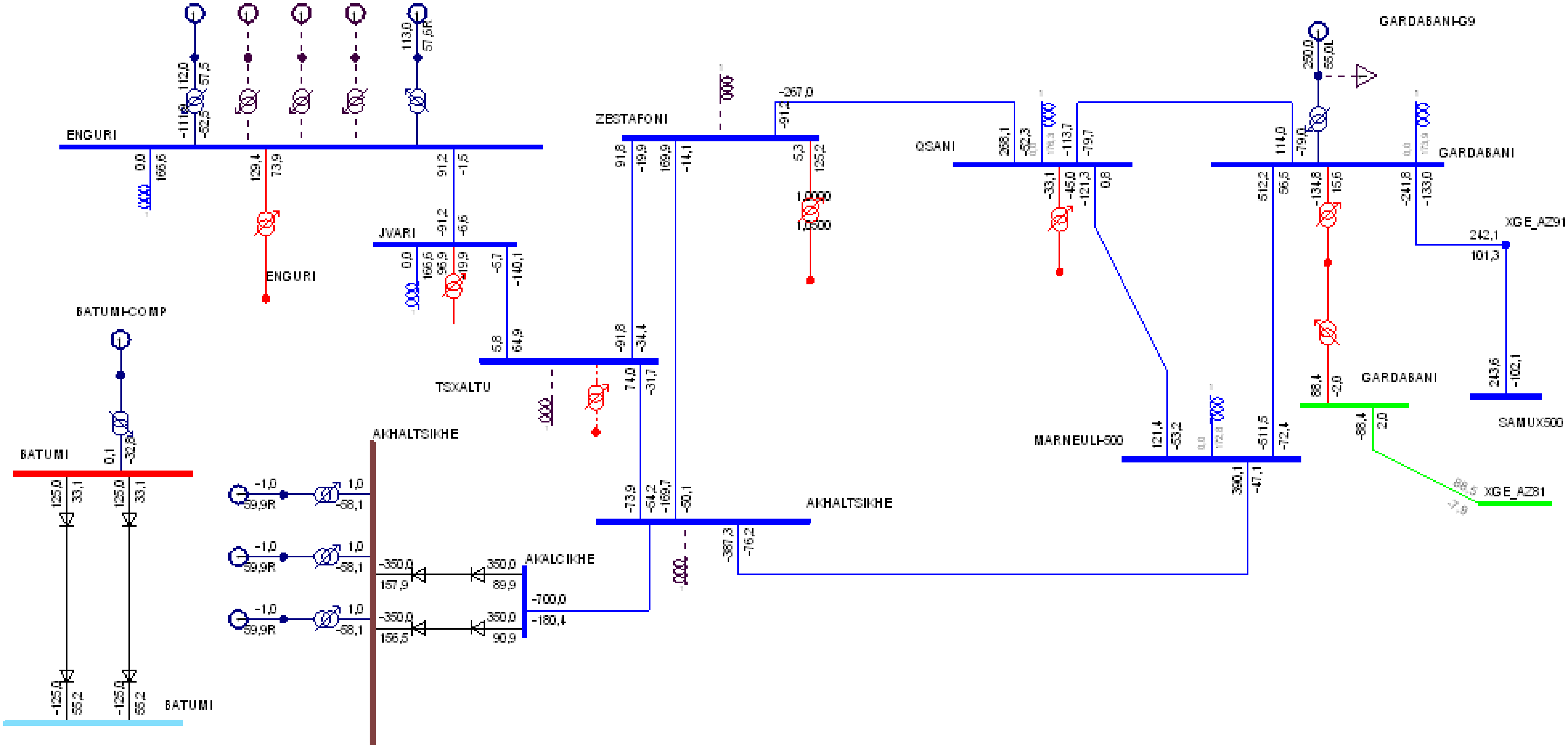


Fig 2.15

2.16 winter max 2015

GENERATION = 2242 MW, LOAD = 1731 MW,
IMPORT(AZ) = 531 MW, EXPORT (TR) = 1000 MW
[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 300 MW]

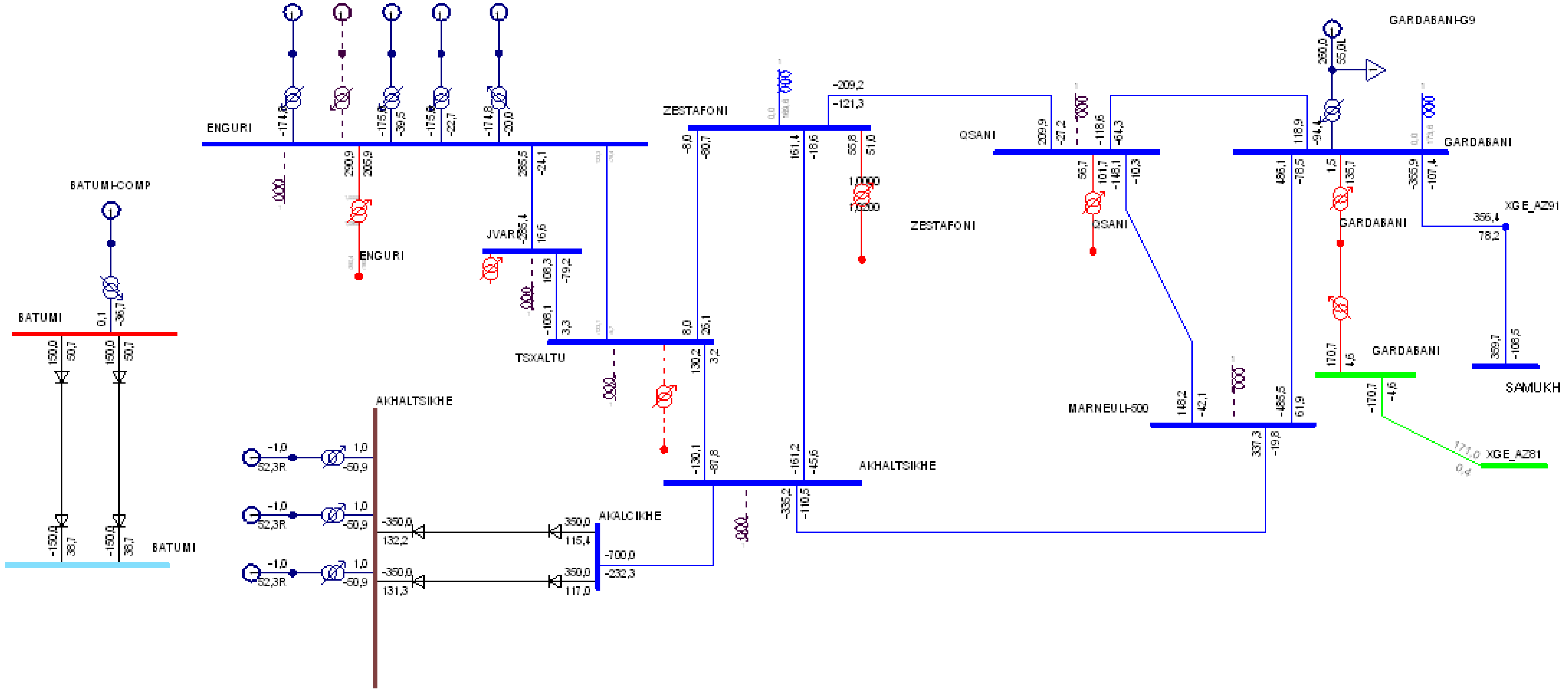


Fig 2.16

2.17 Spring Min 2017-1

GENERATION = 2280 MW, LOAD = 1012 MW,
IMPORT = 0 MW, EXPORT (TR) = 1050 MW[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW], EXPORT (AZ) = 187 MW

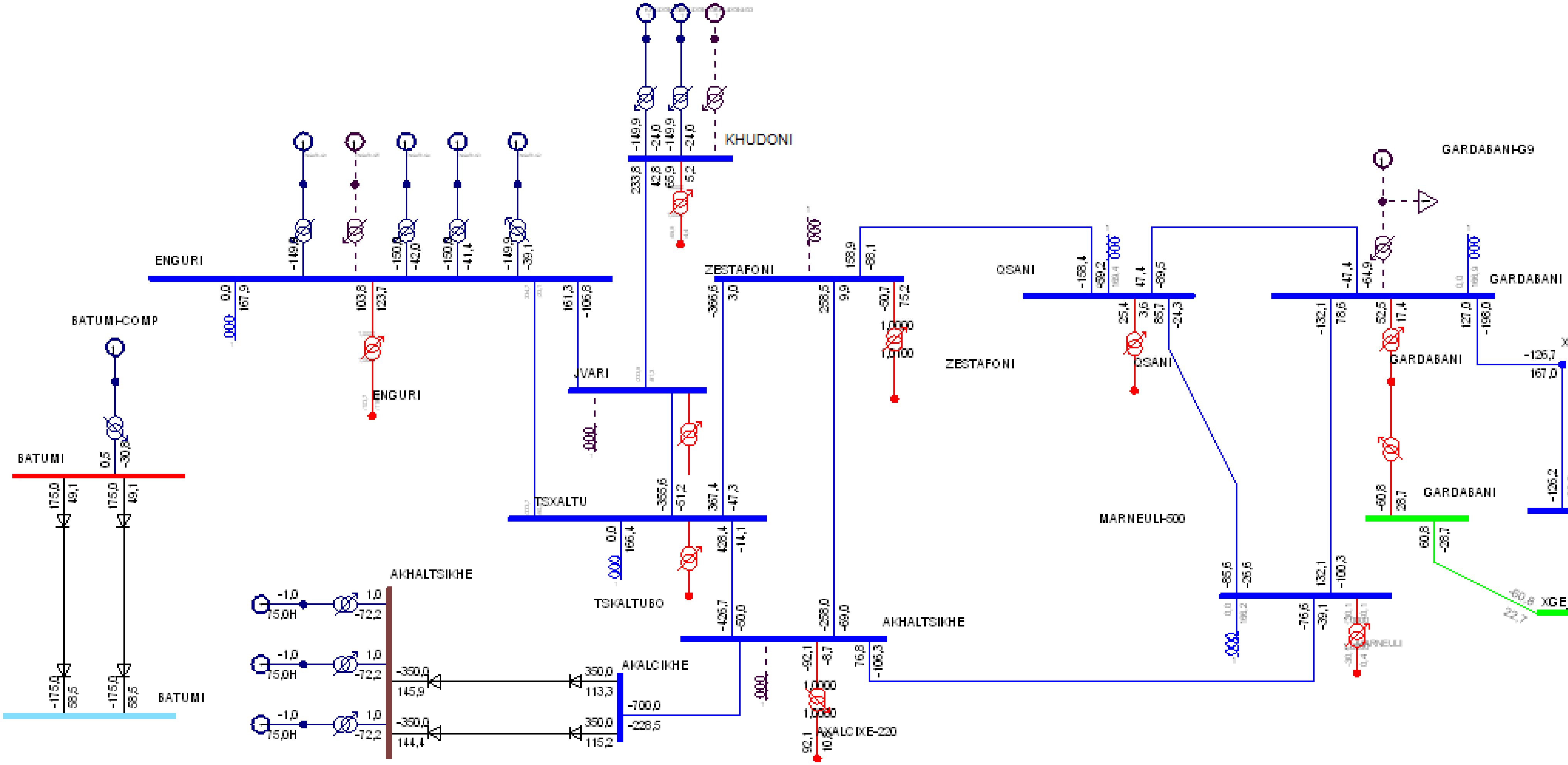


Fig 2.17

2.18 Summer max 2017-1

GENERATION = 2765 MW, LOAD = 1497 MW,
IMPORT = 0 MW, EXPORT (TR) = 1050 MW[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW], EXPORT (AZ) = 179 MW

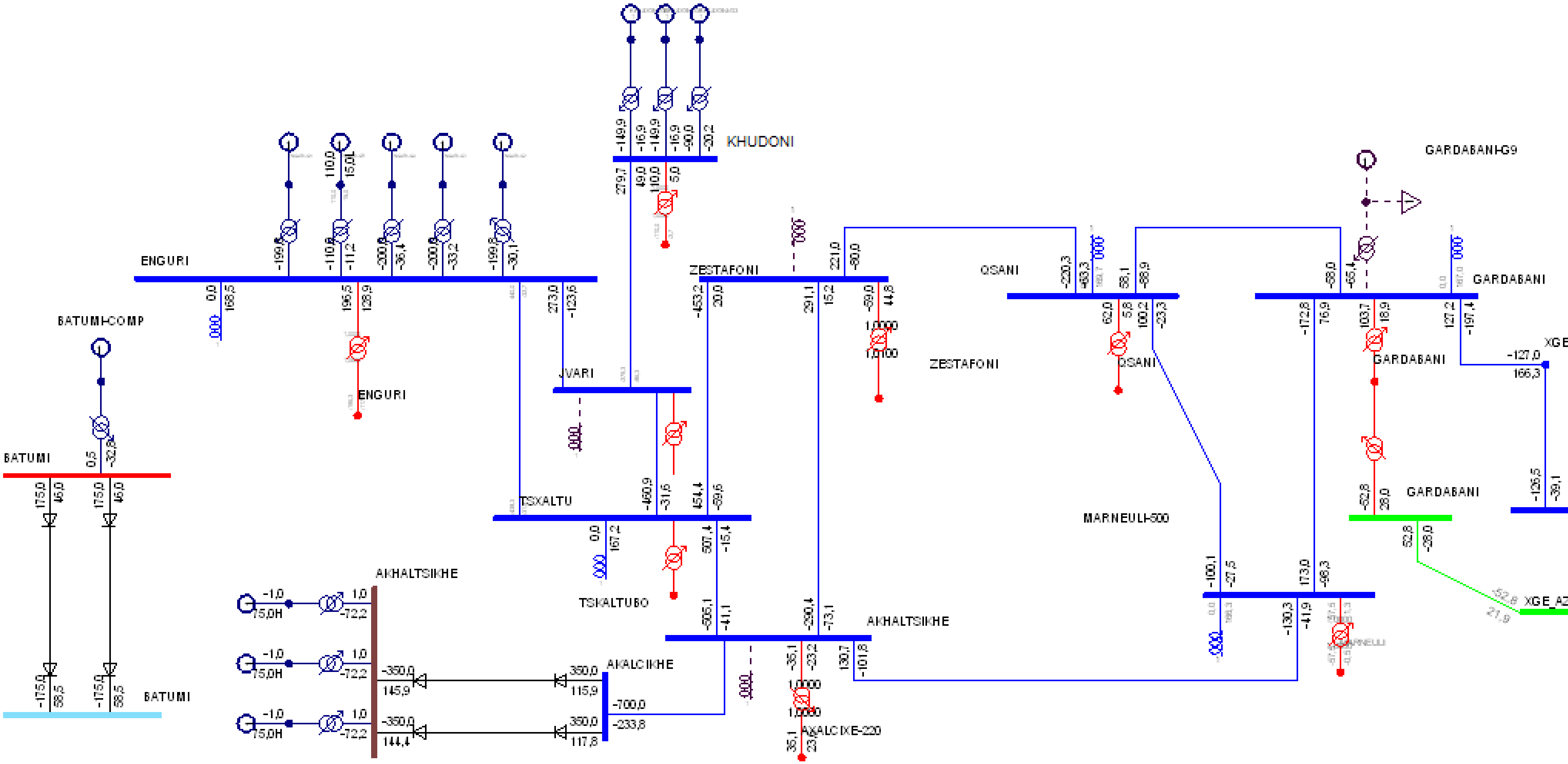


Fig 2.18

2.19 Autumn – min 2017-1

GENERATION = 1802 MW, LOAD = 1028 MW,
IMPORT (AZ) = 302 MW, EXPORT (TR) = 1050 MW[AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW]

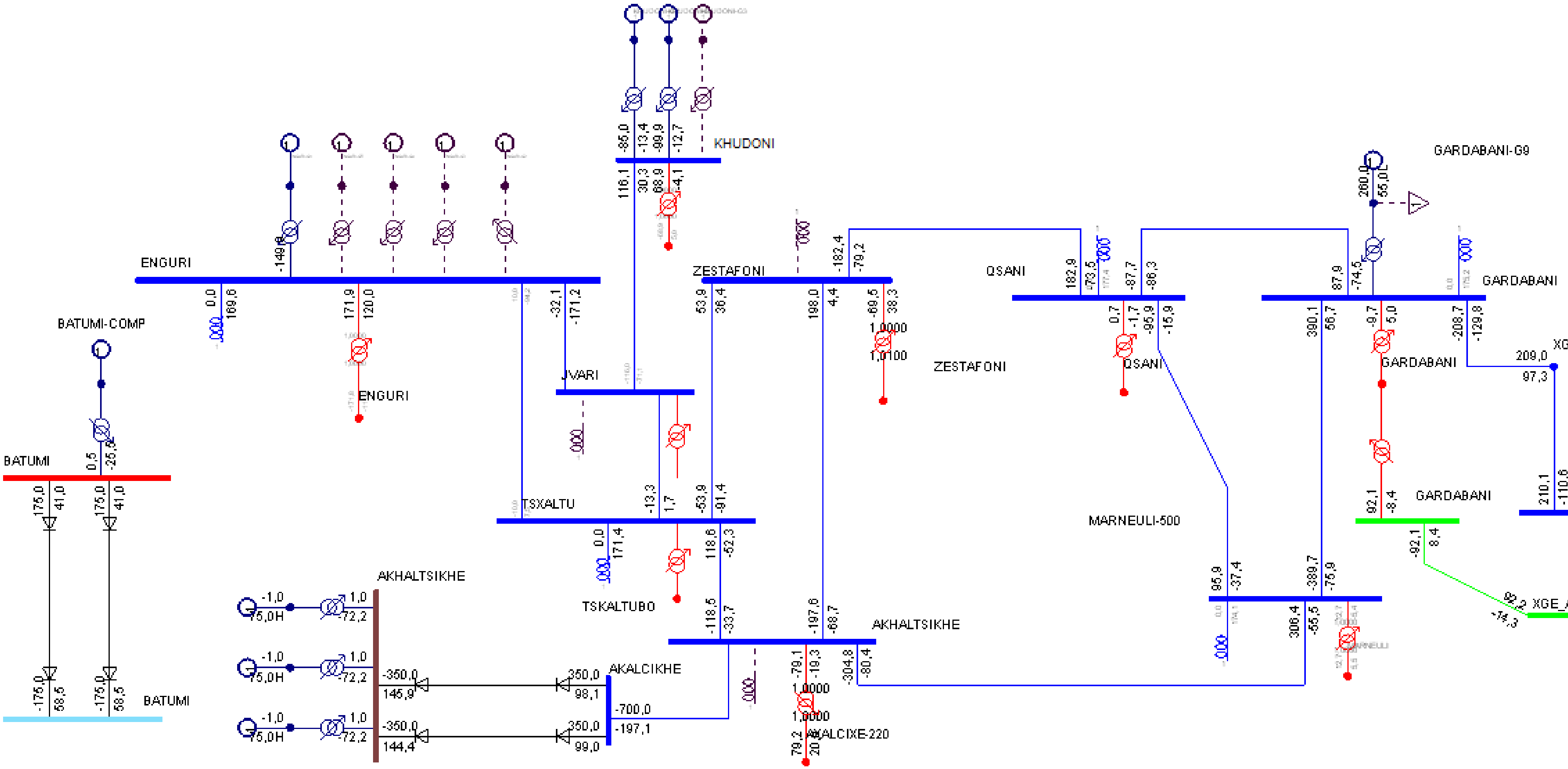


fig 2.19

2.20 winter max 2017-1

GENERATION = 2452 MW, LOAD = 1920 MW,
IMPORT (AZ) = 562 MW, EXPORT (TR) = 1050 MW [AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW]

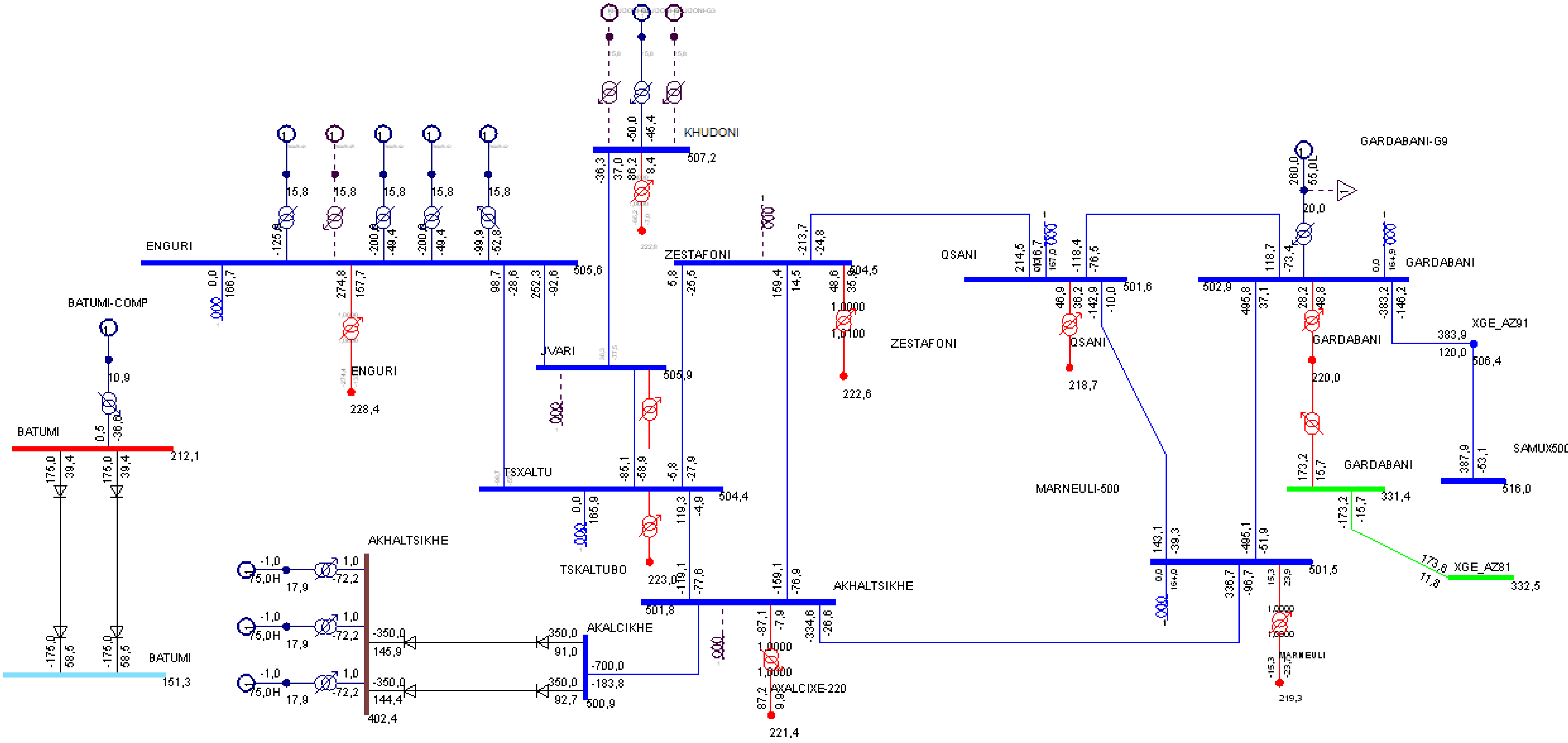


Fig 2.20

2.21 Spring Min 2017-2

GENERATION = 2280 MW, LOAD = 1012 MW,
IMPORT (AZ) = 163 MW, EXPORT (TR) = 1400 MW[AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW]

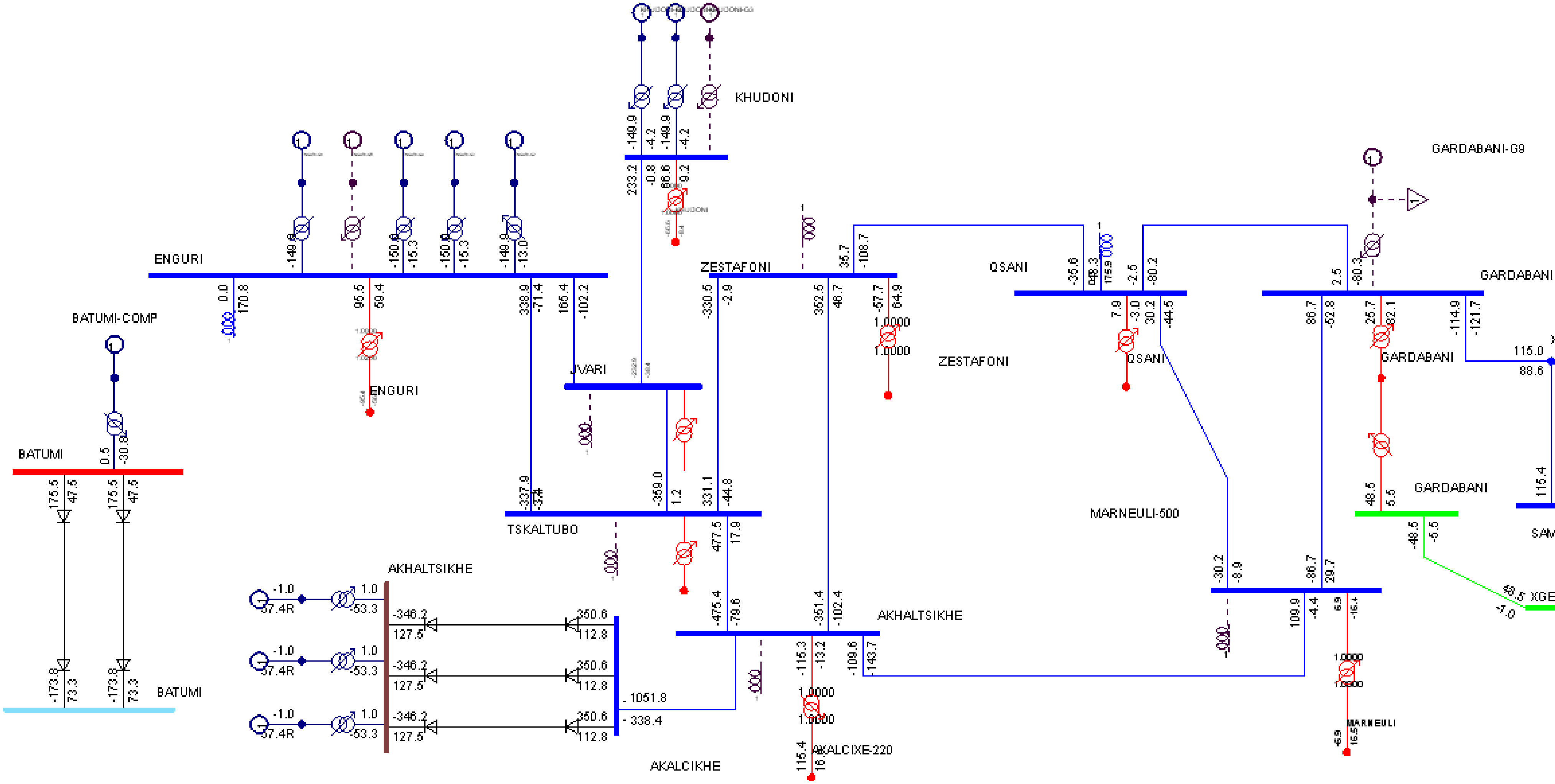


Fig 2.21

2.22 Summer max 2017-2

GENERATION = 2765 MW, LOAD = 1497 MW,

IMPORT (AZ) = 173 MW, EXPORT (TR) = 1400 MW [AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW]

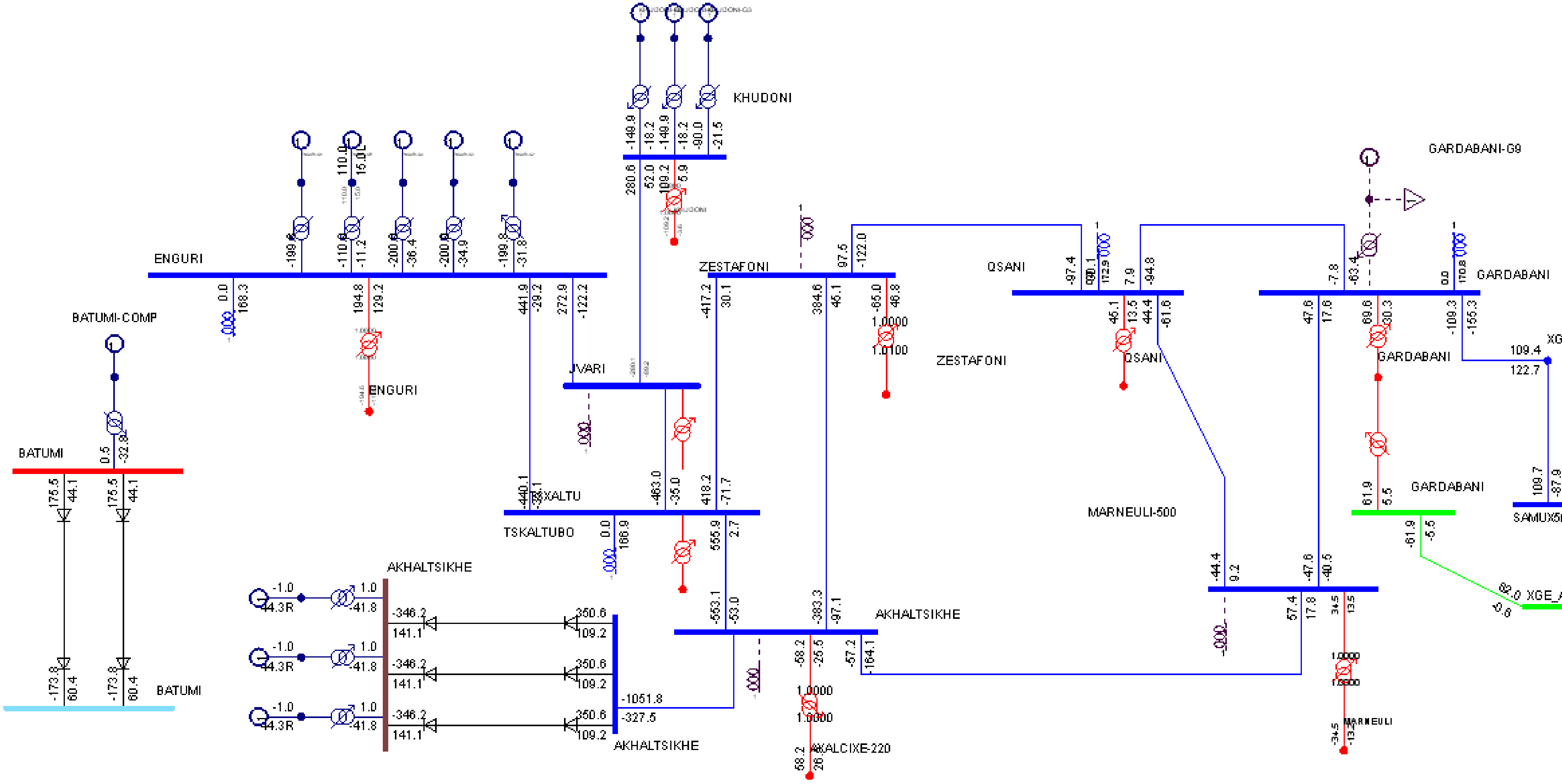


Fig 2.22

2.23 Autumn –min 2017-2

GENERATION = 2022 MW, LOAD = 1032 MW,
IMPORT (AZ) = 448 MW, EXPORT (TR) = 1400 MW [AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW]

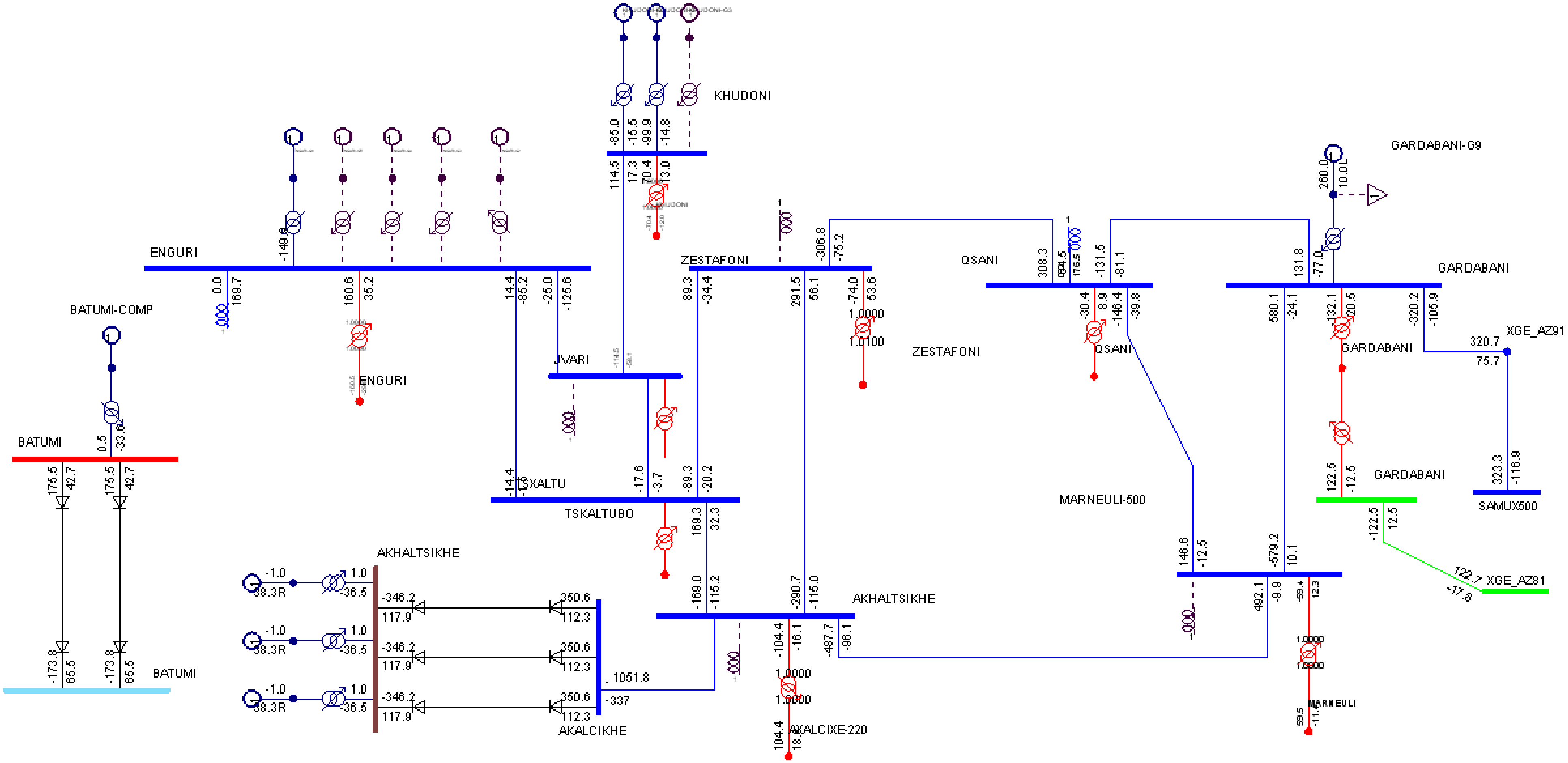


fig 2.23

2.24 winter max 2017

GENERATION = 2739 MW, LOAD = 1920 MW,

IMPORT (AZ) = 633 MW, EXPORT (TR) = 1400 MW [AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW]

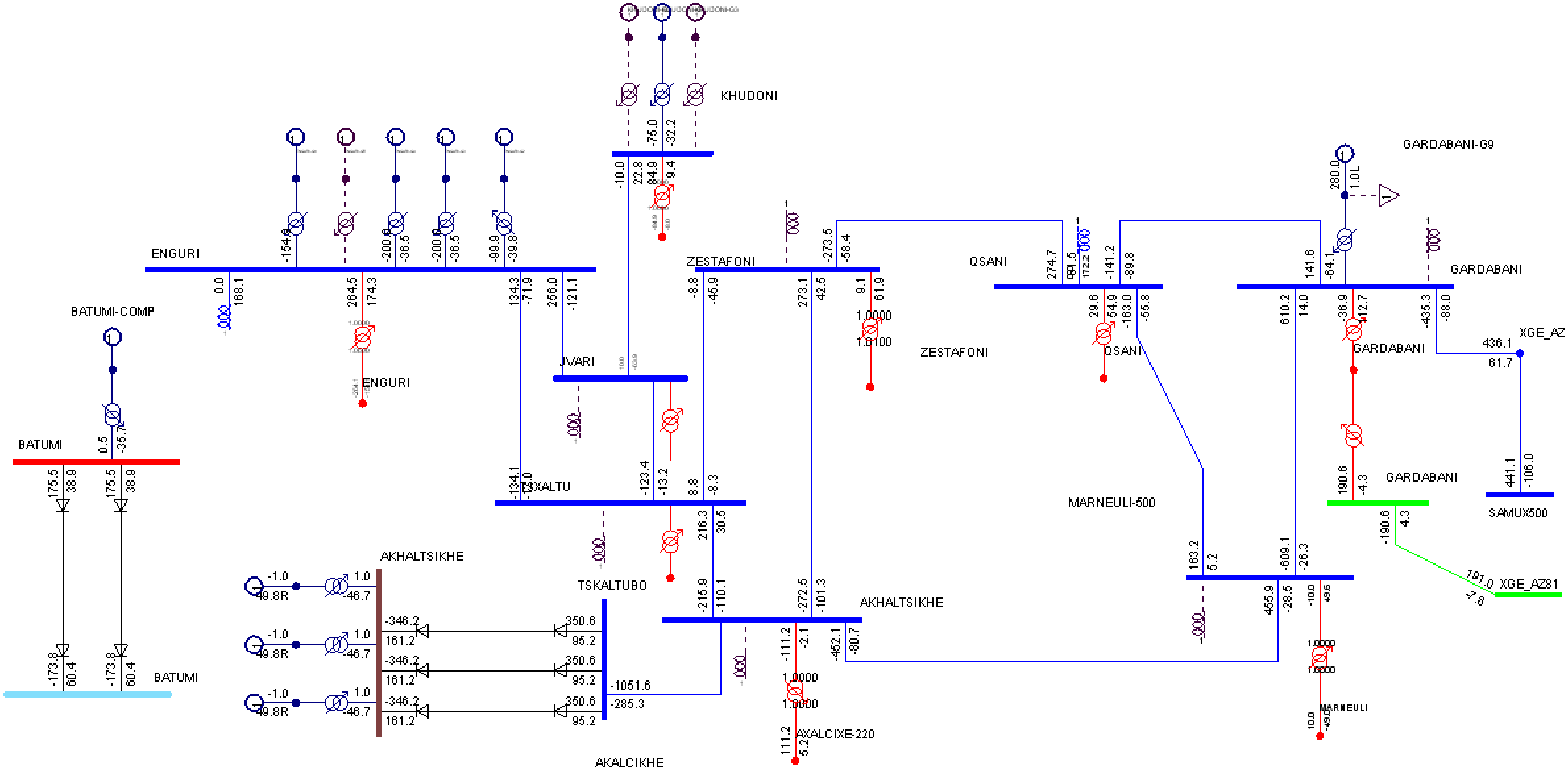


Fig 2.24

Table2.1. **Steady state summary table, for 2013 year with taking in account the system automatic actions**

WINTER MAX GENERATION = 1652 MW LOAD = 1617 MW IMPORT (AZ) = 348 MW EXPORT (TR) = 350 MW ***ONE B2B IN AKHALTSIKHE IS IN OPERATION***	**WINTER MIN** GENERATION = 1021 MW LOAD = 952 MW IMPORT (AZ) = 298 MW EXPORT (TR) = 350 MW ***ONE B2B IN AKHALTSIKHE IS IN OPERATION***
SPRING MAX GENERATION = 1543 MW LOAD = 1549 MW IMPORT (AZ) = 388 MW EXPORT (TR) = 350 MW ***ONE B2B IN AKHALTSIKHE IS IN OPERATION***	**SPRING MIN** GENERATION = 970 MW LOAD = 778 MW IMPORT (AZ) = 170 MW EXPORT (TR) = 350 MW ***ONE B2B IN AKHALTSIKHE IS IN OPERATION***
SUMMER MAX GENERATION = 1340 MW LOAD = 1100 MW IMPORT (AZ) = 490 MW EXPORT (TR) = 700 MW ***TWO B2B IN AKHALTSIKHE ARE IN OPERATION***	**SUMMER MIN** GENERATION = 1220 MW LOAD = 780 MW IMPORT (AZ) = 334 MW EXPORT (TR) = 700 MW ***TWO B2B IN AKHALTSIKHE ARE IN OPERATION***
AUTUMN MAX GENERATION = 1790 MW LOAD = 1410 MW IMPORT (AZ) = 373 MW EXPORT (TR) = 700 MW ***TWO B2B IN AKHALTSIKHE ARE IN OPERATION***	**AUTUMN MIN** GENERATION = 1075 MW LOAD = 761 MW IMPORT (AZ) = 403 MW EXPORT (TR) = 700 MW ***TWO B2B IN AKHALTSIKHE ARE IN OPERATION***

Table2.2 Steady state summary table, for 2015 year

SPRING MIN

GENERATION = 1856 MW, LOAD = 950 MW,
IMPORT(AZ) = 115 MW, EXPORT (TR) = 1000 MW

AKHALTSIKHE B2B = 700 MW,
BATUMI B2B = 300 MW
ENGURI GENERATION = 720 MW

SUMMER MAX

GENERATION = 2303 MW, LOAD = 1366 MW,
IMPORT(AZ) = 96 MW, EXPORT (TR) = 1000 MW

AKHALTSIKHE B2B = 700 MW,
BATUMI B2B = 300 MW,
ENGURI GENERATION = 622 MW

AUTUMN MIN

GENERATION = 1534 MW, LOAD = 897 MW,
IMPORT(AZ) = 333 MW, EXPORT (TR) = 950 MW

AKHALTSIKHE B2B = 700 MW,
BATUMI B2B = 250 MW,
ENGURI GENERATION = 125 MW

WINTER MAX

GENERATION = 2242 MW, LOAD = 1731 MW,
IMPORT(AZ) = 531 MW, EXPORT (TR) = 1000 MW

AKHALTSIKHE B2B = 700 MW,
BATUMI B2B = 300 MW,
ENGURI GENERATION = 700 MW

Table2.3 Steady state summary table, for 2017-1 year

(1050 MW Export to TR)

SPRING MIN

GENERATION = 2280 MW, LOAD = 1012 MW,
IMPORT = 0 MW, EXPORT (TR) = 1050 MW, EXPORT (AZ)=187 MW

AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW
ENGURI GENERATION = 600 MW, KHUDONI GENERATION = 300 MW

SUMMER MAX

GENERATION = 2765 MW, LOAD = 1497 MW,
IMPORT = 0 MW, EXPORT (TR) = 1050 MW, EXPORT (AZ)=179 MW

AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW
ENGURI GENERATION = 910 MW, KHUDONI GENERATION = 390 MW

AUTUMN MIN

GENERATION = 1802 MW, LOAD = 1028 MW,
IMPORT (AZ) = 302 MW, EXPORT (TR) = 1050 MW,

AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW
ENGURI GENERATION = 150 MW, KHUDONI GENERATION = 185 MW

WINTER MAX

GENERATION = 2452 MW, LOAD = 1920 MW,
IMPORT (AZ) = 562 MW, EXPORT (TR) = 1050 MW,

AKHALTSIKHE B2B = 700 MW, BATUMI B2B = 350 MW
ENGURI GENERATION = 625 MW, KHUDONI GENERATION = 50 MW

Table2.4 Steady state summary table, for 2017-2 year

(1400 MW Export to TR)

SPRING MIN GENERATION = 2280 MW, LOAD = 1012 MW IMPORT (AZ) = 163 MW, EXPORT (TR) = 1400 MW AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW, ENGURI GENERATION = 600 MW
SUMMER MAX GENERATION = 2766 MW, LOAD = 1497 MW IMPORT (AZ) = 173 MW, EXPORT (TR) = 1400 MW AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW, ENGURI GENERATION = 910 MW
AUTUMN MIN GENERATION = 2022 MW, LOAD = 1032 MW IMPORT (AZ) = 448 MW, EXPORT (TR) = 1400 MW AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW, ENGURI GENERATION = 150 MW
SUMMER MAX GENERATION = 2739 MW, LOAD = 1920 MW IMPORT (AZ) = 633 MW, EXPORT (TR) = 1400 MW AKHALTSIKHE B2B = 1050 MW, BATUMI B2B = 350 MW, ENGURI GENERATION = 655 MW

3. N-1 Steady State Analysis

3.1 N-1 analysys for 2013 Year. This analyses was conducted for all 8 scenarios (Winter, Spring, Summer and Autumn Maximum and Minimum) considering outages of 500 kV internal lines and 500/220 kV autotransformers of Georgia and for 500 kV line connecting Azerbaijan (s/s Samukh) and Georgia (s/s Gardabani). Summary table is given bellow:

Table 3.1

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								

In this table light green color means that after N-1 outage all system parameters remain in normal ranges; orange color means that after corresponding N-1 outage, some system parameters are deviated from permitted ranges, but so that they may be improved by dispatch actions; red color means that system parameters have inadmissible values or after N-1 system does not converges.

- (1-6) In Summer Minimum scenario, system operation without 500 kV OHL between substations Enguri and Zestafoni, forces overloading of its parallel 220 kV OHLs: Tskaltubo-Kutaisi (117%) and Kutaisi-Zestafoni, circuit 1 (127%);
- (9-3) In Spring Maximum scenario, system operation without 500 kV OHL Samukh-Gardabani, forces overloading of its parallel line Agstafa-Gardabani (112%).
- (9-8) In Autumn Minimum scenario, system operation without 500 kV OHL Samukh-Gardabani, forces overloading of its parallel line Agstafa-Gardabani (113%).
- (12-1), (12-3) In Winter Maximum and Spring Maximum scenarios, system operation without 500/220 kV autotransformer of Enguri, forces voltage reduction in Abkhazia region.

3.2 N-1 Analysis for 2015 Year This analyses was conducted for all 4 scenarios (Winter and Summer Maximum, Spring and Autumn Minimum) considering system operation with out of service 500 kV OHLs of Georgia and Azerbaijan and 500/220 kV autotransformers of Georgia.

Table 3.2. N-1 steady state summary

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	🟩	🟩	🟩	🟩

In this table light green color means that after N-1 outage all system parameters remain in normal ranges; yellow color means that after corresponding N-1 operation, some system parameters are deviated from permitted ranges, but so that they may be improved by dispatch actions orange color means that system converges but the parameters deviation from normal is not permitable and requires intervention of automatics; red color means that system does not converges.

- (12-1) In Winter Maximum scenario, operation without 500 kV OHL Mukhrani (Gardabani –Samukh) causes overloading of 330 kV line Gardabani (Gardabani-Agstafa): Load = 135 % and 330/220 kV transformer of Gardabani: Load = 135 %.
- (15-1) In Winter Maximum scenario, system operation without 500/220 kV autotransformer of Enguri, causes voltage reduction in Abkhazia region.

3.3 N-1 Analysis for 2017-1 (1050 MW Export to TR) Year. This analyses was conducted for all 4 scenarios (Winter and Summer Maximum, Spring and Autumn Minimum) considering system operation with out of service 500 kV OHLs of Georgia and Azerbaijan and 500/220 kV autotransformers of Georgia.

Table 3.3. N-1 steady state summary

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			
Samukh-AzTPP				
AzTPP-Apsheron				
AT-Enguri				
AT-Zestafoni				
AT-Qsani				
AT-Jvari				
AT-Gardabani				
AT-Alhaltsikhe				
AT-Marneuli				
AT-Tskhaltubo				
AT-Knudoni				

In this table light green color means that after N-1 outage all system parameters remain in normal ranges; yellow color means that after corresponding N-1 operation, some system parameters are deviated from permitted ranges, but so that they may be improved by dispatch actions orange color means that system converges but the parameters deviation from normal is not permutable and requires intervention of automatics; red color means that system does not converges.

- (12-1) In Winter Maximum scenario, operation without 500 kV OHL Mukhrani (Gardabani –Samukh) causes overloading of 330 kV line Gardabani (Gardabani-Agstafa): Load = 145 % and 330/220 kV transformer of Gardabani: Load = 146 %.

3.4 N-1 Analysis for 2017-1 (1400 MW Export to TR) Year. This analyses was conducted for all 4 scenarios (Winter and Summer Maximum, Spring and Autumn Minimum) considering system operation with out of service 500 kV OHLs of Georgia and Azerbaijan and 500/220 kV autotransformers of Georgia.

Table 3.4. N-1 steady state summary

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	🟩	🟩	🟩	🟩

In this table light green color means that after N-1 outage all system parameters remain in normal ranges; yellow color means that after corresponding N-1 operation, some system parameters are deviated from permitted ranges, but so that they may be improved by dispatch actions orange color means that system converges but the parameters deviation from normal is not permutable and requires intervention of automatics; red color means that system does not converges.

- (12-1) In Winter Maximum scenario, operation without 500 kV OHL Mukhrani (Gardabani –Samukh) causes overloading of 330 kV line Gardabani (Gardabani-Agstafa): Loading = 167 % and 330/220 kV transformer of Gardabani: Loading = 167 %.
- (12-4) In Winter Maximum scenario, operation without 500 kV OHL Mukhrani (Gardabani –Samukh) causes overloading of 330 kV line Gardabani (Gardabani-Agstafa): Loading = 115 % and 330/220 kV transformer of Gardabani: Loading = 115 %.

4. N-1 Dynamic Analysis

4.1. N-1 Dynamic Analysis for 2013

For 2013 year, power systems of Azerbaijan and Georgia will be connected by two OHLs: Perspective 500 kV "Mukhrani" and Existing 330 kV "Gardabani". Outage 330 kV OHL "Gardabani" does not force problems in N-1 disturbance cases and neither in dynamics. But outage of 500 kV line "Mukhrani" in some cases may force overloading of 330 kV OHL "Gardabani". Hence, in case of outage of above mentioned 500 kV line between Azerbaijan and Georgia, system automatics have to trip loads and reactors in Georgia, so that not reduce power export to Turkey by transfer capability of "Gardabani".

By consideration of action of mentioned automatics, steady state scenarios of Georgia in Summer and Autumn had been changed (Fig 4.1-4.3).

System automatic actions summary in Georgia

WINTER MAX	**WINTER MIN**
NO ACTION IS RE	TRIPPING REACTORS IN S/Ss GARDABANI AND QSANI
SPRING MAX	**SPRING MIN**
TRIPPING REACTORS IN S/Ss GARDABANI AND QSANI	TRIPPING REACTORS IN S/Ss GARDABANI AND QSANI
SUMMER MAX	**SUMMER MIN**
TRIPPING OF 180 MW LOAD	TRIPPING 120 MW LOAD; REACTORS IN S/S GARDABANI AND S/S MARNEULI
AUTUMN MAX	**AUTUMN MIN**
TRIPPING 75 MW LOAD; REACTORS IN S/Ss GARDABANI, QSANI, ZESTAFONI	TRIPPING 100 MW LOAD; REACTORS IN S/Ss GARDABANI, QSANI, ZESTAFONI

Dynamic simulation results, for Summer and Autumn Maximal and Minimal scenarios

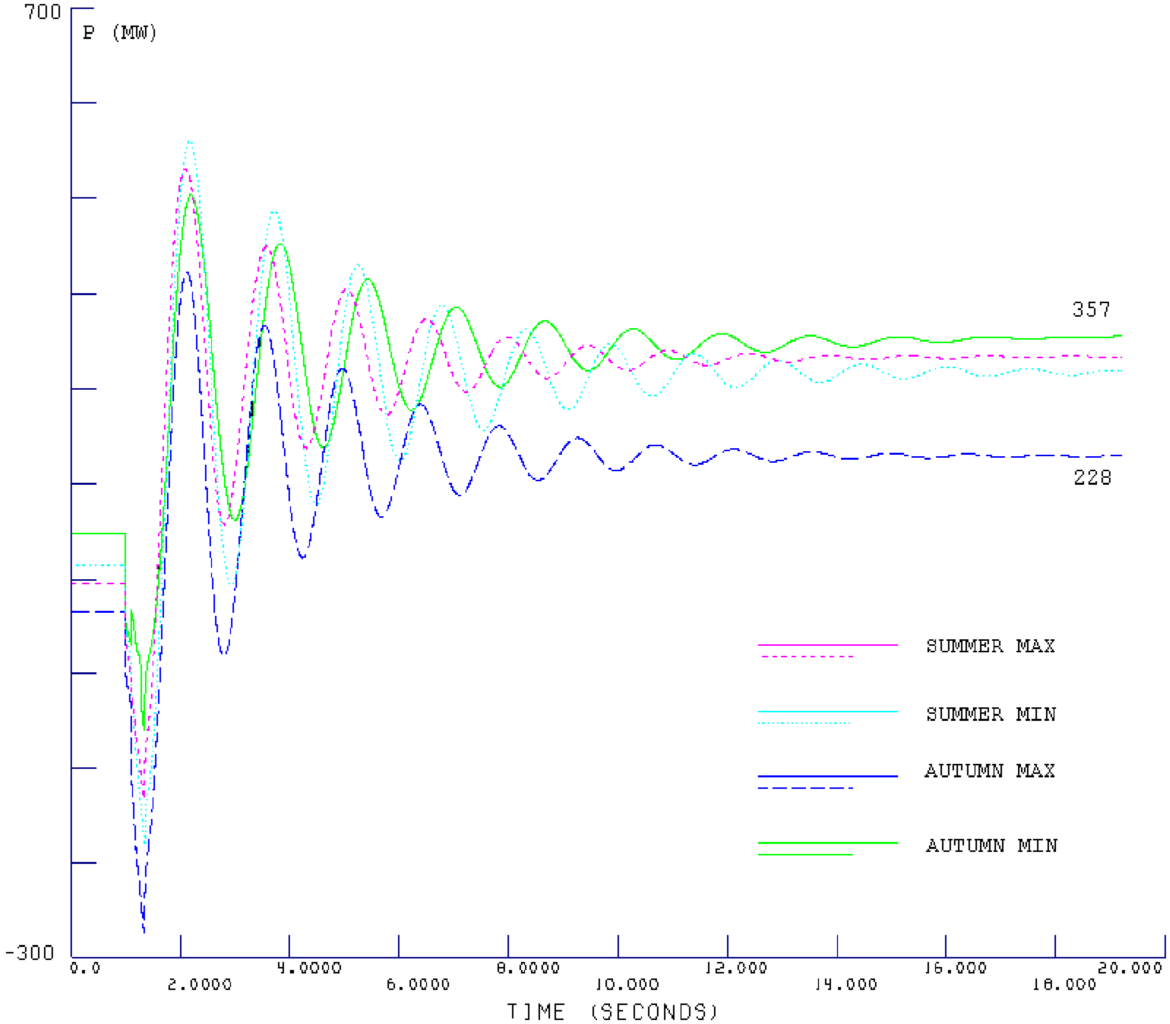


Fig 4.1. Load flow at OHL Gardabani 330 kV

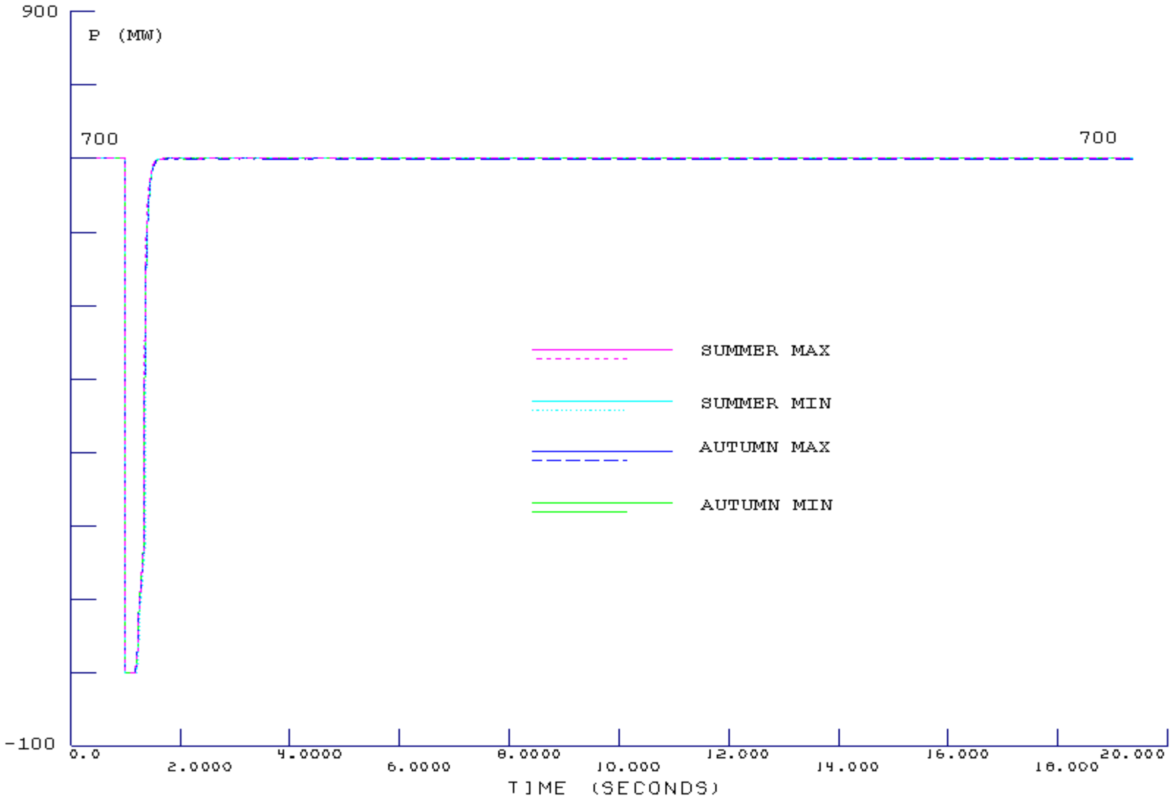


Fig 4.2. Load flow at b2b of Akhaltsikhe

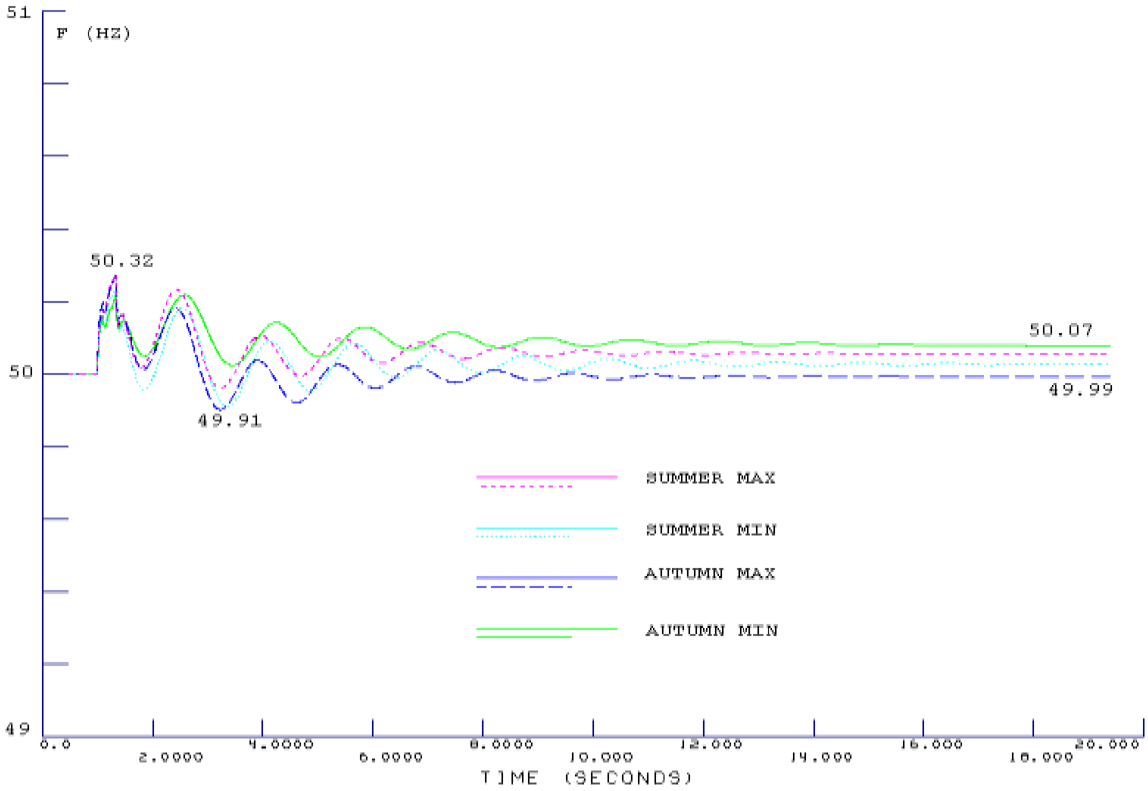


Fig 4.3. Frequency in Menji (Georgia)

4.2 N-1 dynamic analysis and emergency automatics For 2015

Dynamic simulation showed that, each internal 500 kV OHL and 500/220 kV autotransformer outage, like N-1 static analysis, did not force system stability loss or any significant deviation of system parameters from normal. The exclusion was Gardabani – Akhaltsikhe 500 kV OHL, after emercgency outage of witch have to be performed tripping of reactors by system automatics, depending on given system scenario (see table 3).

For 2015 year, as well as for 2013, power systems of Azerbaijan and Georgia will be connected by two OHLs: Perspective 500 kV Mukhrani and Existing 330 kV Gardabani. Outage 330 kV OHL Gardabani does not force problems in N-1 disturbance cases and neither in dynamics. The same is for Mukhrani outage, except Winter Maximum scenario. In this case, outage of Mukhrani have to be accompanied with tripping of about 225 MW loads in Georgian system (see table 3) by system automatics.

Emergency outage of 400 kV OHL between Akhaltsikhe and Borcka or Akhaltsikhhe B2B have to be accompanied with tripping of Generating units in Enguri HPP and/or Gardabani TPP with total loading approximately equal to pre disturbance power flow of mentioned 400 kV line, by system automatics (see table 3) .

Emergency outage Batumi B2B have to be accompanied with tripping of Generating units at Enguri HPP and/or Gardabani TPP with total loading approximately equal to pre disturbance power flow of mentioned B2B, by system automatics (see table 3).

Dynamic simulation results, for outages Akhaltsikhe-Borchka and Mukhrani OHLs are given on fig7-fig10.

4.2.1 Outage of OHL Akhaltsikhe – Borchkha.

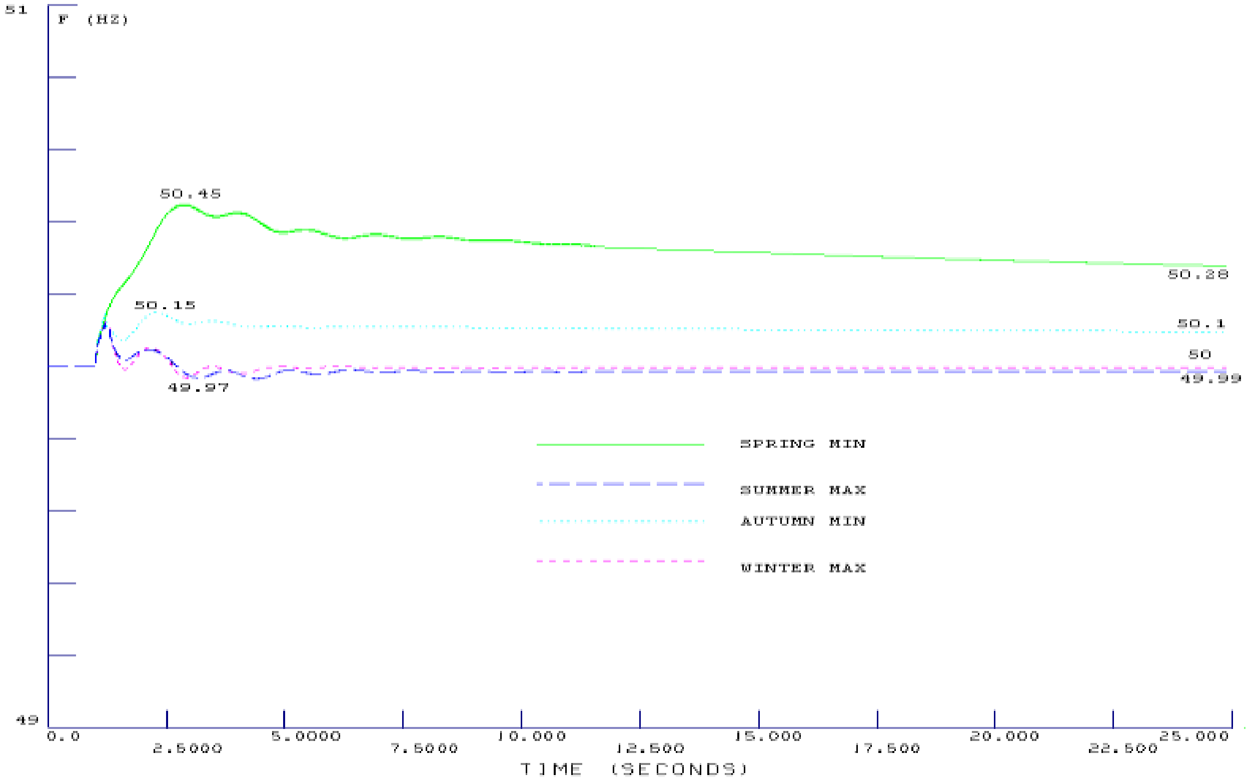


Fig 4.4. Freqency in Menji 220 kV S/S (Georgia)

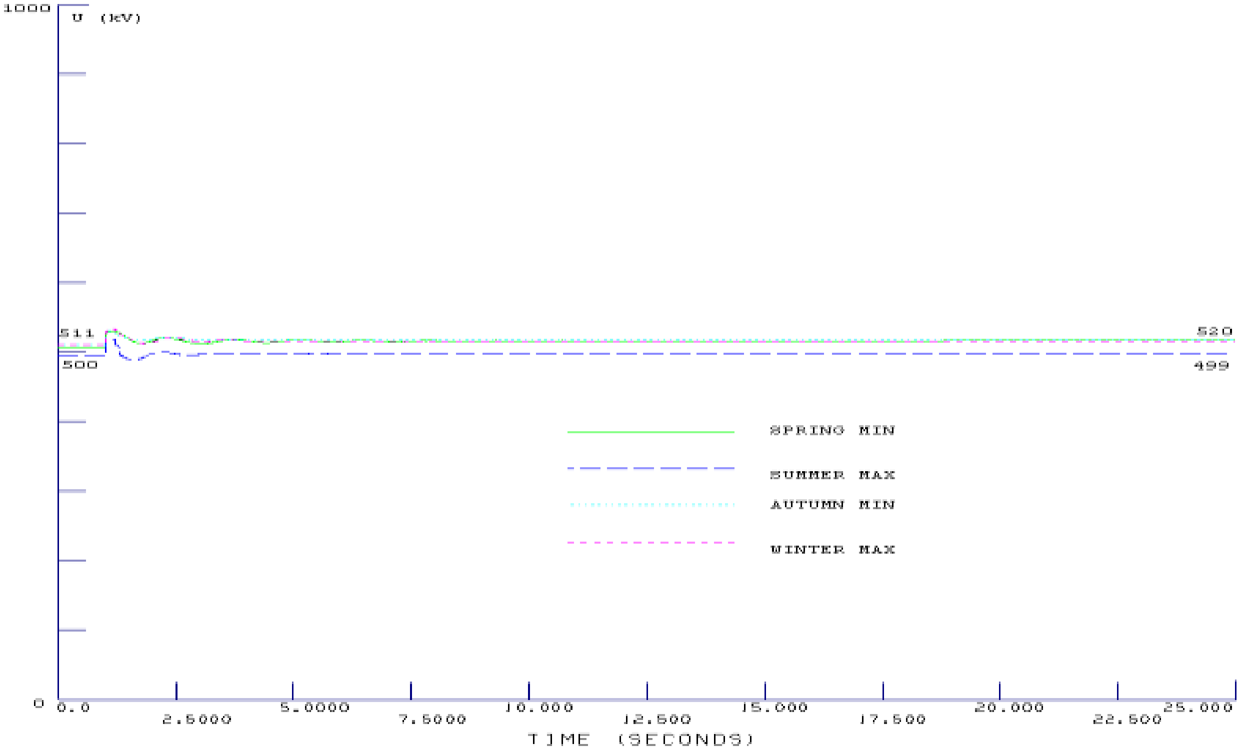


Fig 4.5. Voltage in Zestafoni 500 kV S/S (Georgia)

4.2.2 Outage of Mukhrani 500 kV line (Az-Ge)

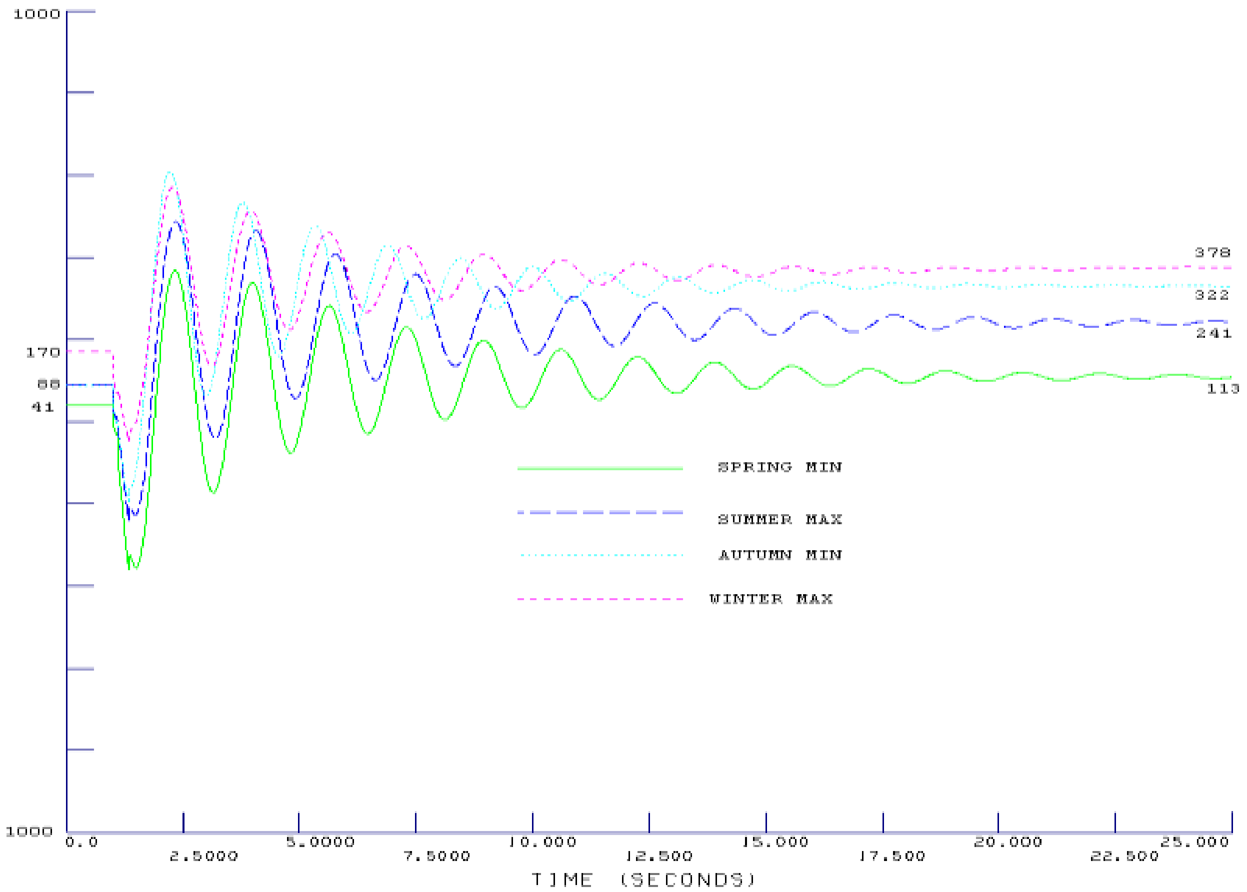


Fig 4.6. Power Flow on Gardabani 330 kV OHL

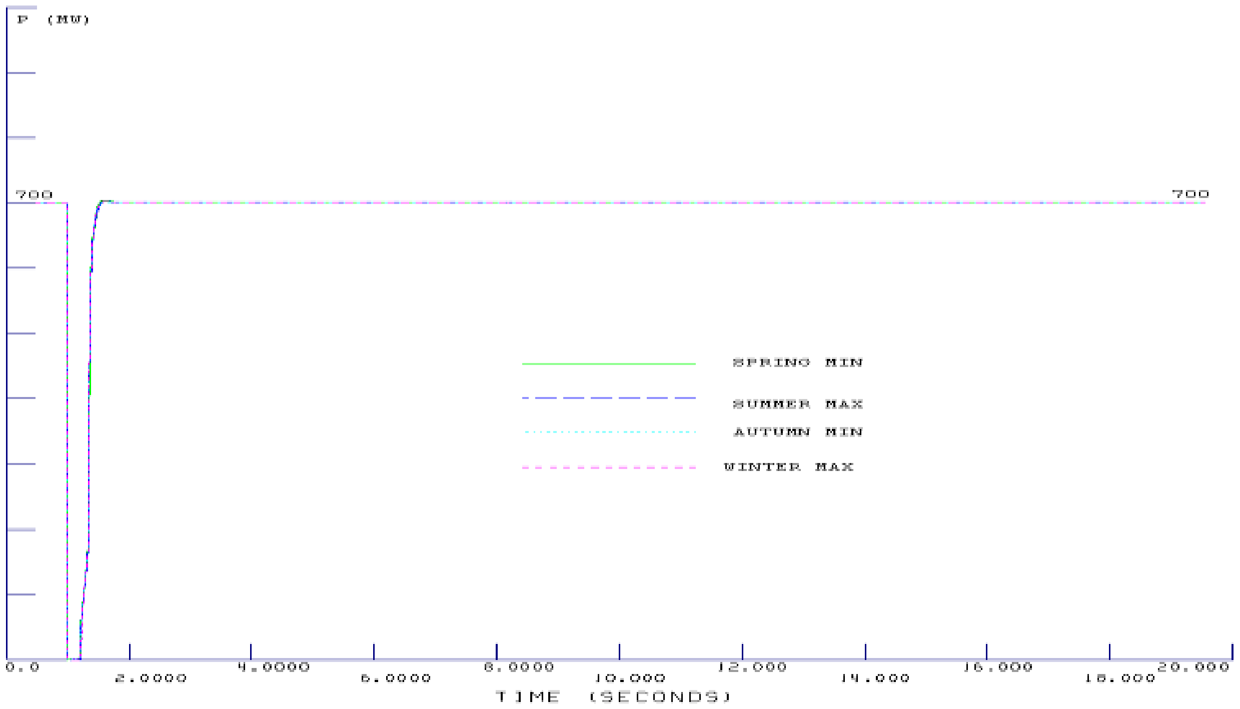


Fig 4.7. Power Flow on Akhaltsikhe B2B

Table 4.2. Emergency automatics summary for 2015 year

SPRING MIN	**SUMMER MAX**
EXPORT (TR) = 1000 MW 1.**AKHALTSIKHE BORCHKA OHL OUTAGE** – 620 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS; 2.**BATUMI B2B OUTAGE** – APPROX 300 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS;	EXPORT (TR) = 1000 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – 720 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS; 2.**BATUMI B2B OUTAGE** – APPROX 300 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS;
AUTUMN MIN	**WINTER MAX**
EXPORT (TR) = 950 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – 225 MW GENERATION ON ENGURI AND 250 MW ON TPP #9 AT GARDABANI HAVE TO BE TRIPPED BY SYSTEM AUTOMATICS; 2.**BATUMI B2B OUTAGE** – APPROX 300 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS; 3.**MARNEULI-AKHALTSIKHE OHL OUTAGE** – REACTORS HAVE TO BE TRIPPED BY SYSTEM AUTOMATICS IN GARDABANI AND QSANI;	EXPORT (TR) = 1000 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – 720 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS; 2.**BATUMI B2B OUTAGE** – APPROX 300 MW GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS; 3.**MARNEULI-AKHALTSIKHE OHL OUTAGE** – REACTORS HAVE TO BE TRIPPED BY SYSTEM AUTOMATICS IN GARDABANI; 4.**MUKHRANI (GARDABANI-SAMUKH) OHL OUTAGE** – 225 MW LOAD HEVE TO BE TRIPPED IN GEORGIAN SYSTEM

4.3 N-1 dynamic analysis and emergency automatics for 2017-1 (1050 MW Export to TR) year

Dynamic simulation showed that, each internal 500 kV OHL and 500/220 kV autotransformer outage, like N-1 static analysis, did not force system stability loss or any significant deviation of system parameters from normal.

For 2017 year, as well as for 2013 and 2015, power systems of Azerbaijan and Georgia will be connected by two OHLs: Perspective 500 kV Mukhrani and Existing 330 kV Gardabani. Outage 330 kV OHL Gardabani does not force problems in N-1 disturbance cases and neither in dynamics. The same is for Mukhrani outage, except Winter Maximum scenario. In this case, outage of Mukhrani have to be accompanied with tripping of about 300 MW loads in Georgian system (see table 3) by system automatics.

Emergency outage of 400 kV OHL between Akhaltsikhe and Borcka or Akhaltsikhhe B2B have to be accompanied with tripping of Generating units in Enguri HPP and/or Gardabani TPP with total loading approximately equal to half (because entering of big number of new power plants increases total inertia constant of united system) of pre disturbance power flow of mentioned 400 kV line, by system automatics (see table 3) .

Dynamic simulation results, for outages Akhaltsikhe-Borchka and Mukhrani OHLs are given on fig6-fig9.

4.3.1 Outage of OHL Akhaltsikhe – Borchkha.

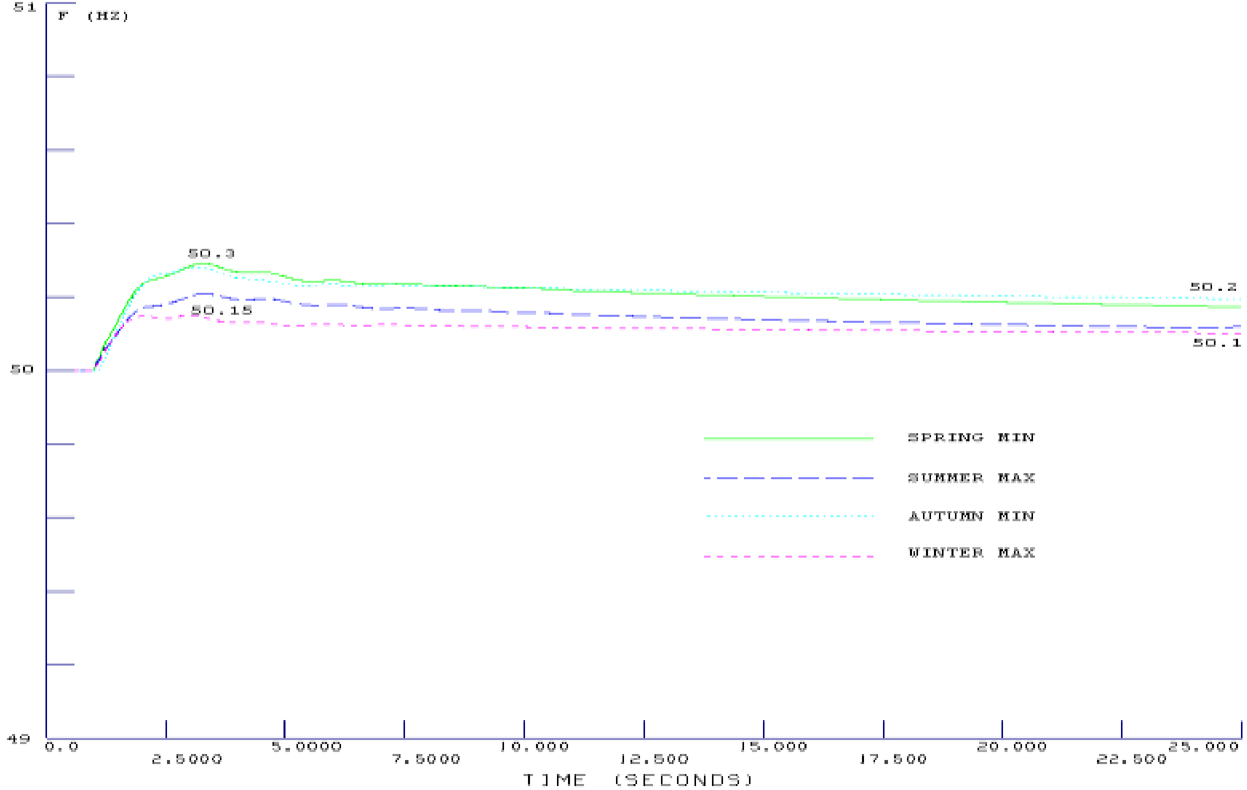


Fig 4.8. Freqency in Menji 220 kV S/S (Georgia)

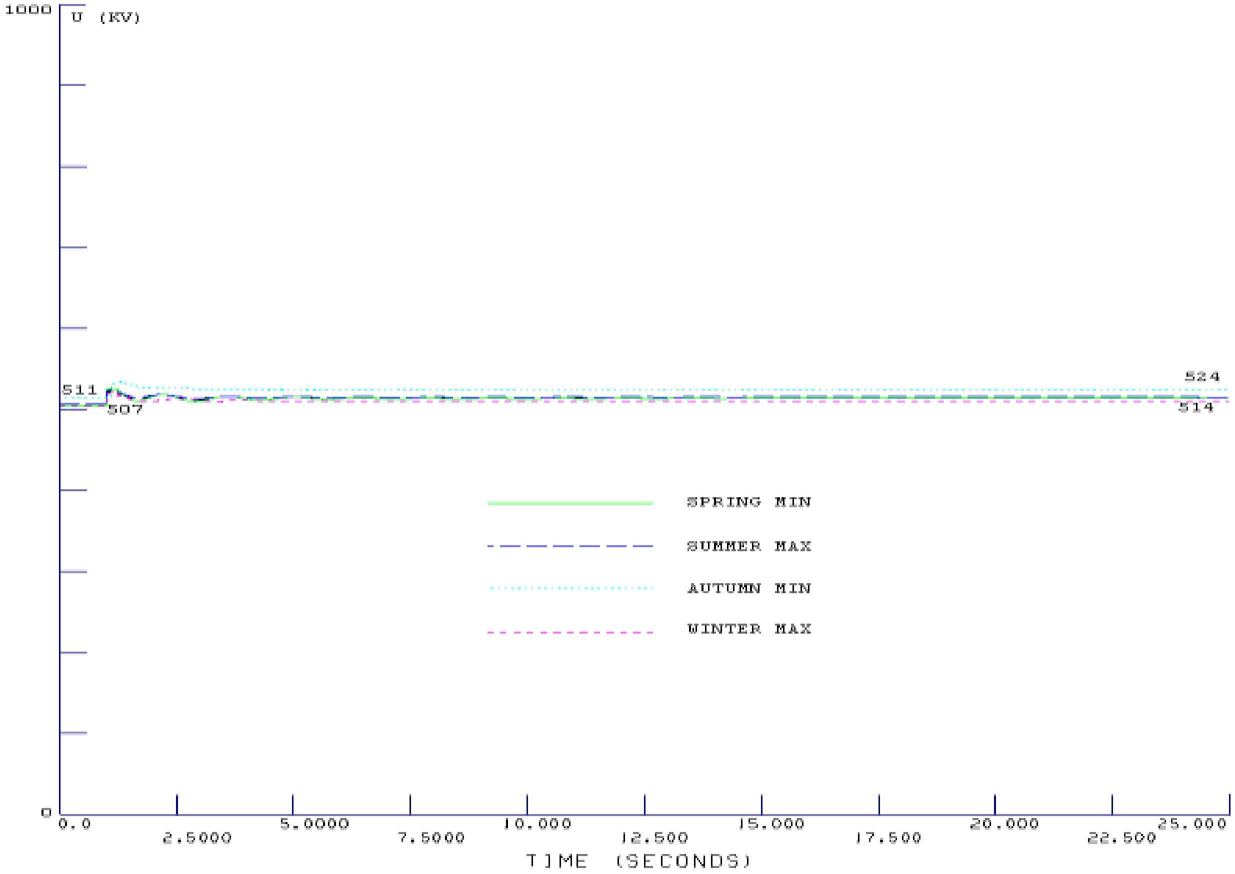


Fig 4.9. Voltage in Zestafoni 500 kV S/S (Georgia)

4.3.2 Outage of Mukhrani 500 kV line

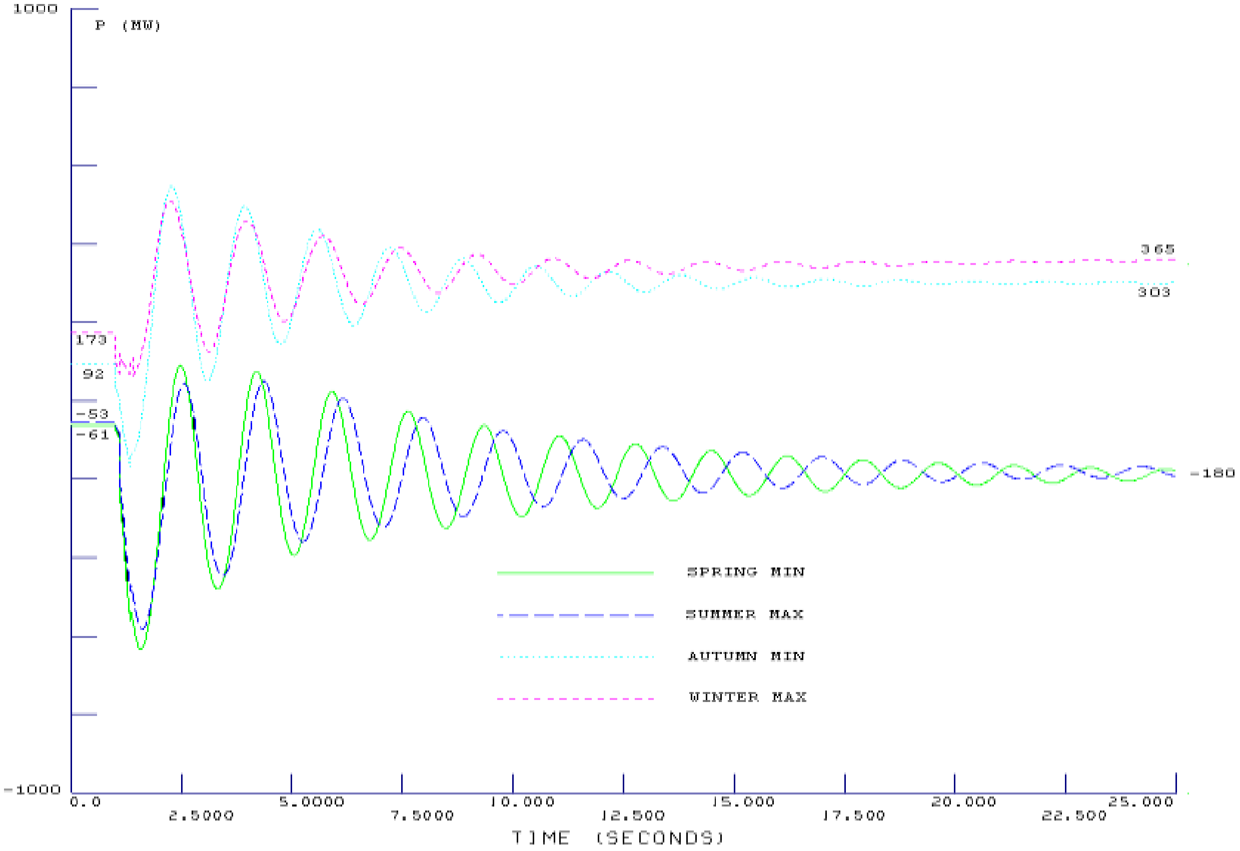


Fig 4.10. Power Flow on Gardabani 330 kV OHL (from AZ to GE)

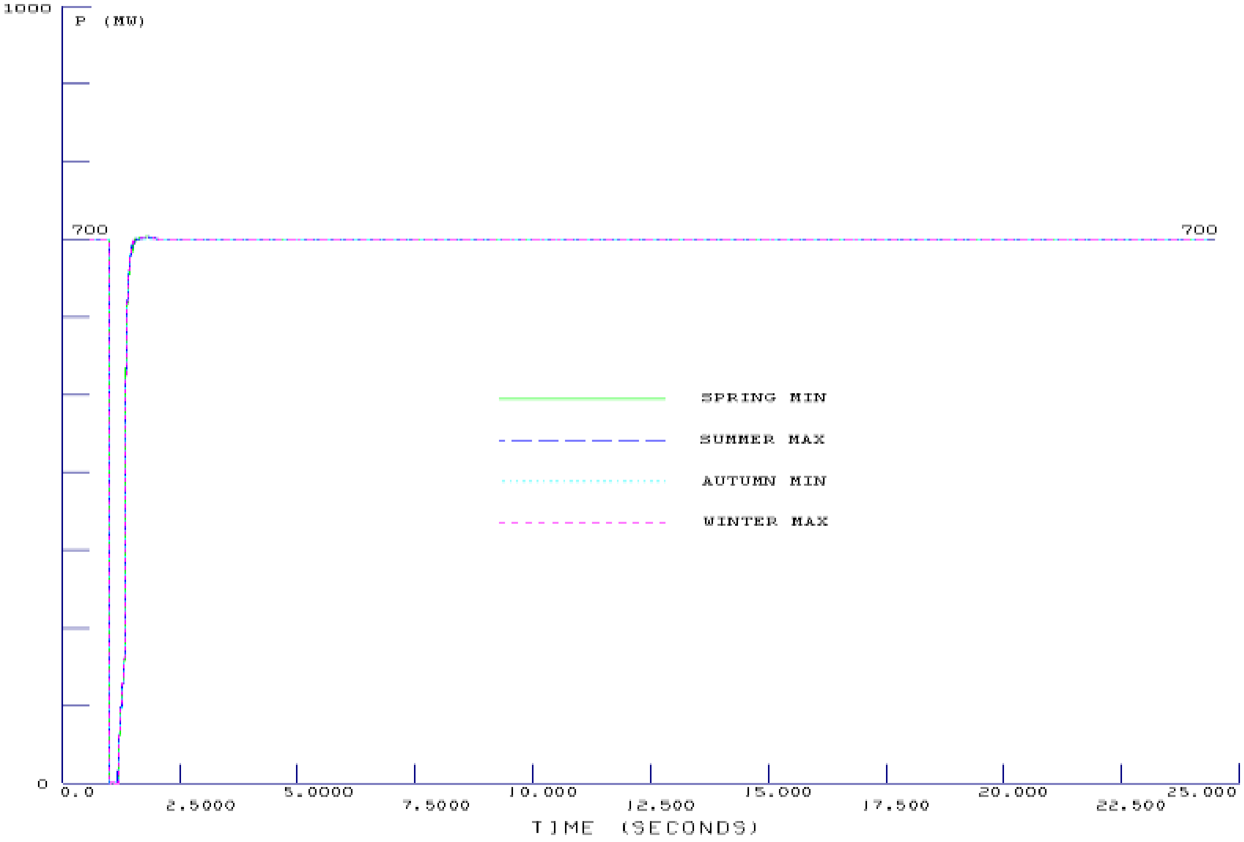


Fig 4.11. Power Flow on Akhaltsikhe B2B

Table 4.3. Emergency automatics summary

SPRING MIN EXPORT (TR) = 1050 MW 1.**AKHALTSIKHE BORCHKA OHL OUTAGE** – GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS;	**SUMMER MAX** EXPORT (TR) = 1050 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS;
AUTUMN MIN EXPORT (TR) = 1050 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – GENERATION ON ENGURI HAVE TO BE TRIPPED BY SYSTEM AUTOMATICS;	**WINTER MAX** EXPORT (TR) = 1050 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – GENERATION HAVE TO BE TRIPPED IN ENGURI HPP BY SYSTEM AUTOMATICS; 2.**MUKHRANI (GARDABANI-SAMUKH) OHL OUTAGE** – 300 MW LOAD HEVE TO BE TRIPPED IN GEORGIAN SYSTEM

4.4 N-1 dynamic analysis and emergency automatics For 2017-2 (1400 MW Export to TR)

Dynamic simulation showed that, each internal 500 kV OHL and 500/220 kV autotransformer outage, like N-1 static analysis, did not force system stability loss or any significant deviation of system parameters from normal.

For 2017 year, as well as for 2013 and 2015, power systems of Azerbaijan and Georgia will be connected by two OHLs: Perspective 500 kV Mukhrani and Existing 330 kV Gardabani. Outage 330 kV OHL Gardabani does not force problems in N-1 disturbance cases and neither in dynamics. The same is for Mukhrani outage, except Winter Maximum And Autumn Minimum scenarios. In this cases, outage of Mukhrani have to be accompanied with tripping of about 300 MW loads in Georgian system (see table 3) by system automatics.

Emergency outage of 400 kV OHL between Akhaltsikhe and Borcka or Akhaltsikhhe B2B have to be accompanied with tripping of Generating units in Enguri HPP and/or Gardabani TPP with total loading approximately equal to half (because entering of big number of new power plants increases total inertia constant of united system) of pre disturbance power flow of mentioned 400 kV line, by system automatics (see table 3) .

Dynamic simulation results, for outages Akhaltsikhe-Borchka and Mukhrani OHLs are given on fig6-fig9.

4.4.1 Outage of OHL Akhaltsikhe – Borchkha.

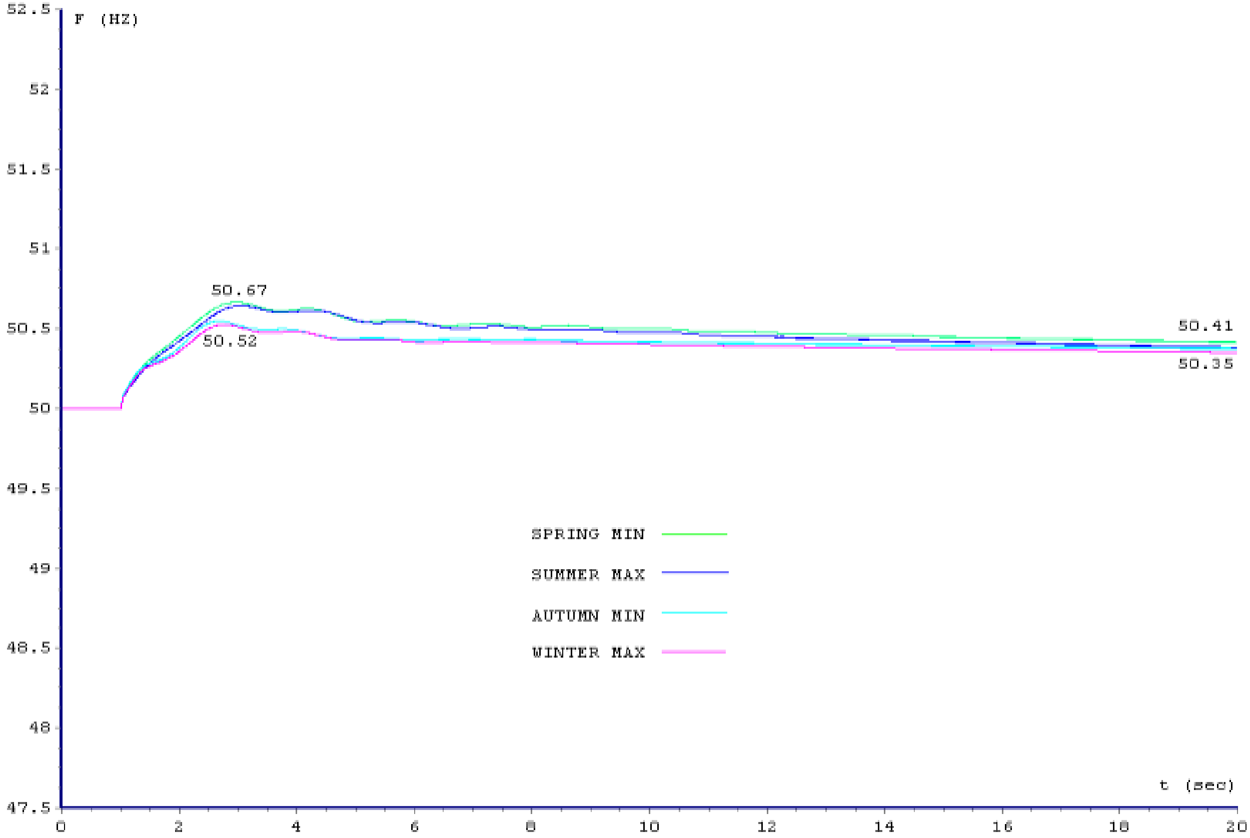


Fig 4.12. Freqency in Menji 220 kV S/S (Georgia)

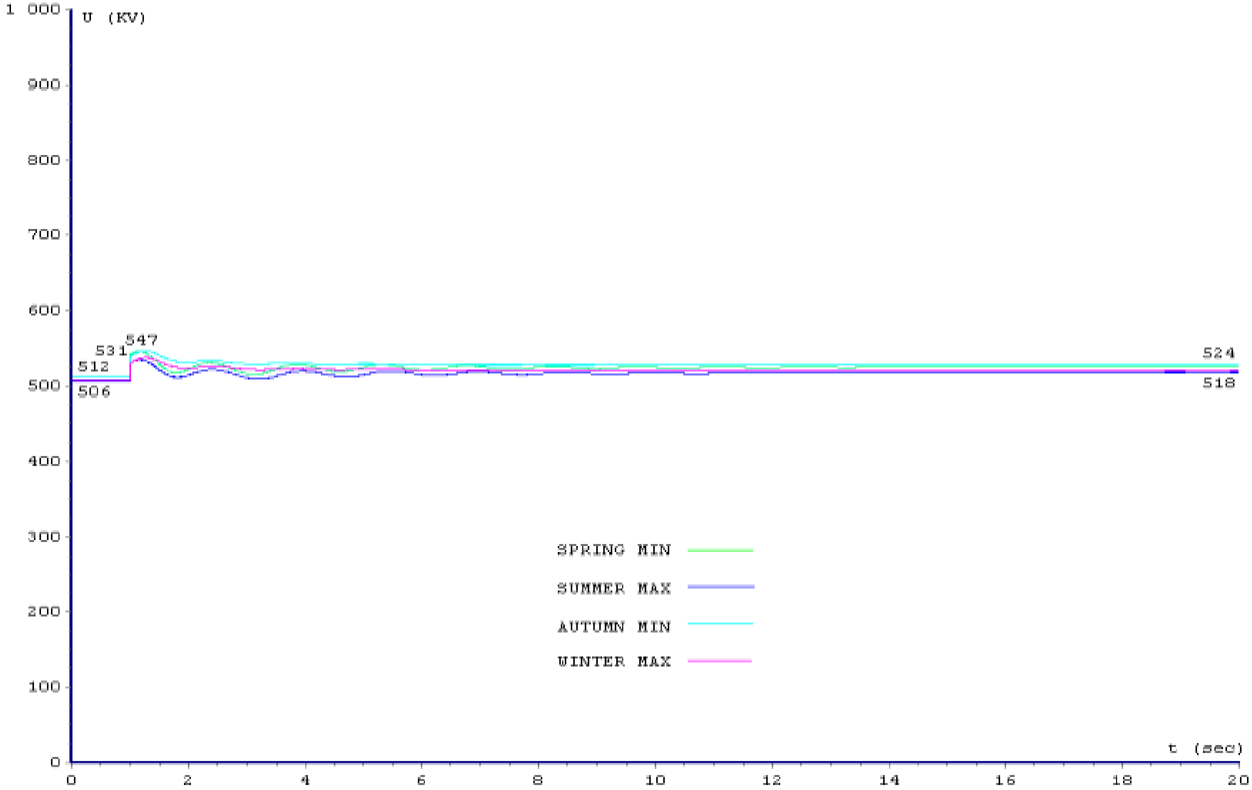


Fig 4.13. Voltage in Zestafoni 500 kV S/S (Georgia)

4.4.2 Outage of Mukhrani 500 kV line

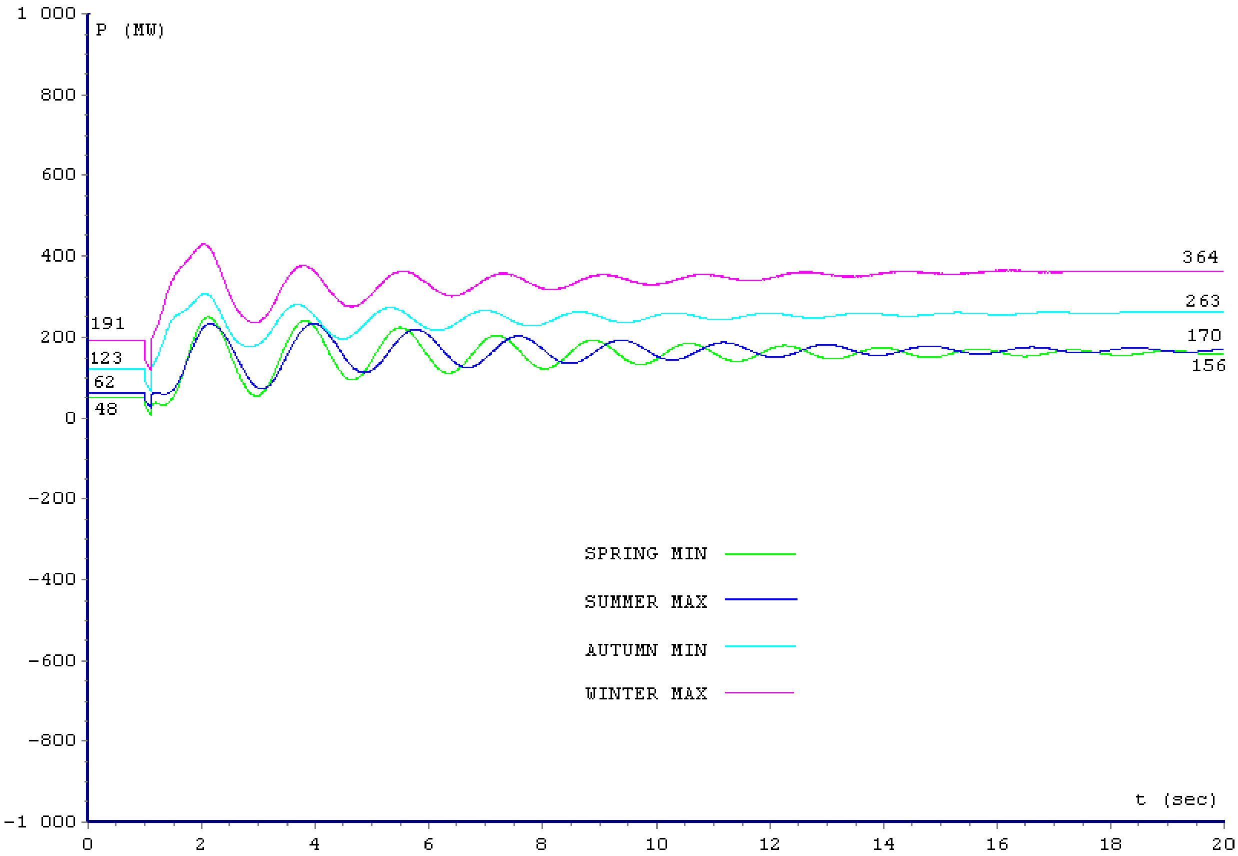


Fig 4.14. Power Flow on Gardabani 330 kV OHL (from AZ to GE)

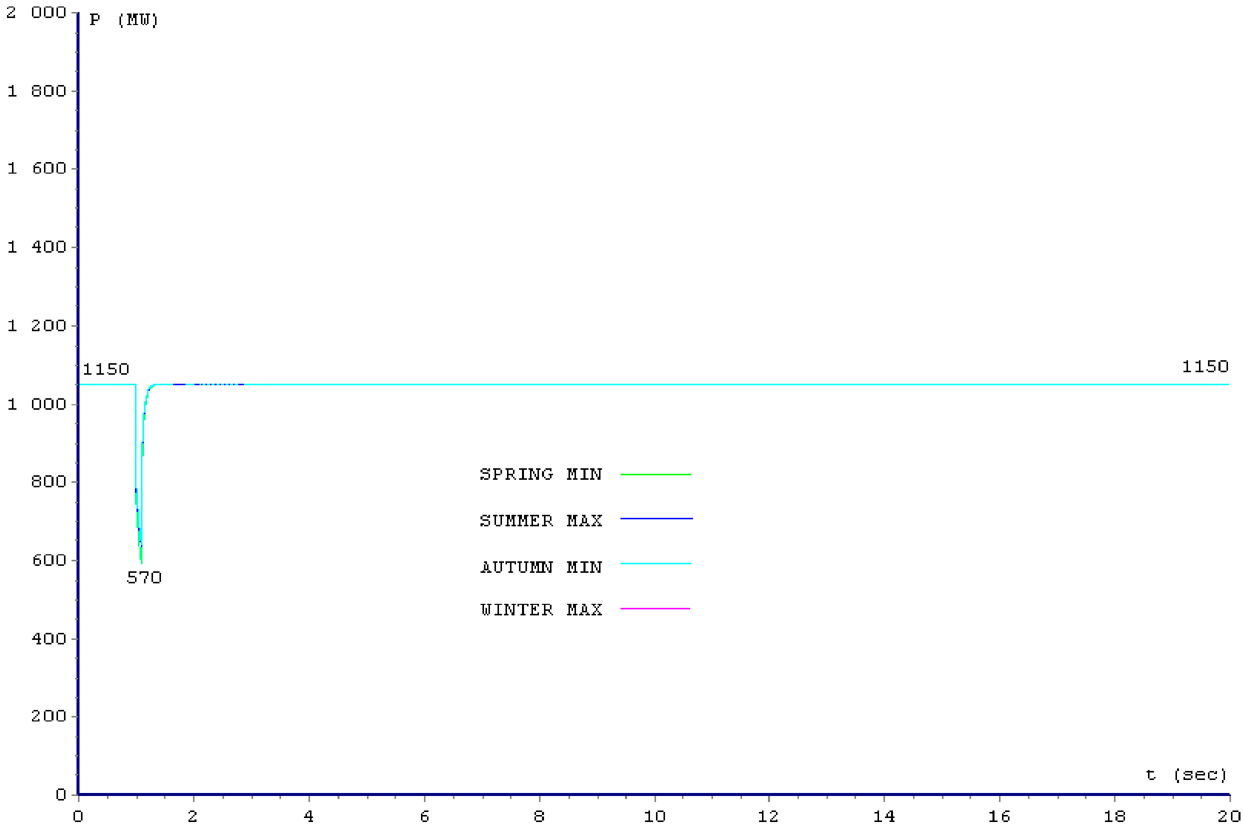


Fig 4.15. Power Flow on Akhaltsikhe B2B

Table 4.4. Emergency automatics summary

SPRING MIN EXPORT (TR) = 1400 MW 1.**AKHALTSIKHE BORCHKA OHL OUTAGE** – NO AUTOMATIC NEEDS	**SUMMER MAX** EXPORT (TR) = 1400 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE – NO AUTOMATIC NEEDS**
AUTUMN MIN EXPORT (TR) = 1400 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – GENERATION ON ENGURI HAVE TO BE TRIPPED BY SYSTEM AUTOMATICS; 2. **MUKHRANI OHL OUTAGE** - LOADS IN GEORGIA HAVE TO BE TRIPPED	**WINTER MAX** EXPORT (TR) = 1400 MW 1. **AKHALTSIKHE BORCHKA OHL OUTAGE** – GENERATION ON ENGURI HAVE TO BE TRIPPED BY SYSTEM AUTOMATICS; 2. **MUKHRANI OHL OUTAGE** - LOADS IN GEORGIA HAVE TO BE TRIPPED

5 Switching analysis results, including N-1

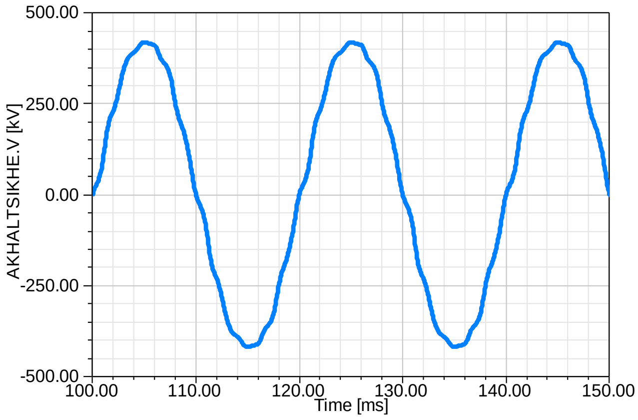
5.1 Switching analysis for 2015

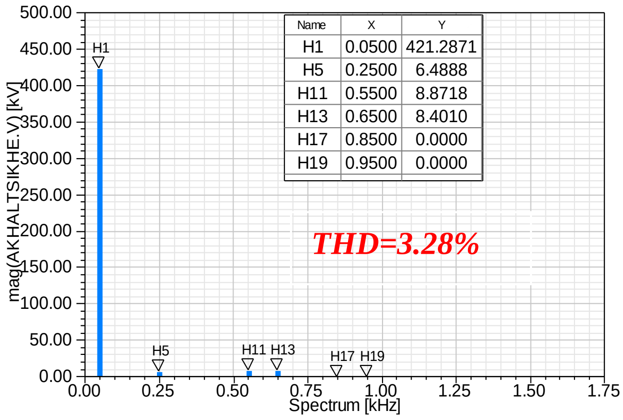
Harmonic analysis had been carried out for two cases. First is the summer max scenario when the export from Georgia to Turkey by b2b station is 500MW. Second one is for n-1 analysis , when happens outage of 500 kV line “Zestafoni – Akhaltsikhe”. Simulations are realized with and without AC filters. Simulated parameters aren’t very exact, because at this moment we don’t have precise data of b2b station. We are waiting for Siemens, in the nearest future they should give us essential information for simulations.

Power flow in B2B ---- 500 MW

AKHALTSIKHE 500

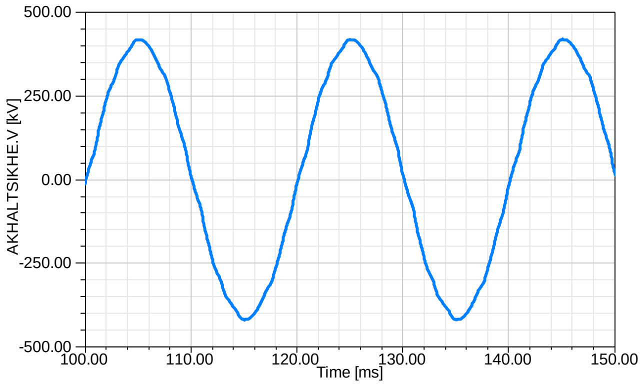
without AC filters

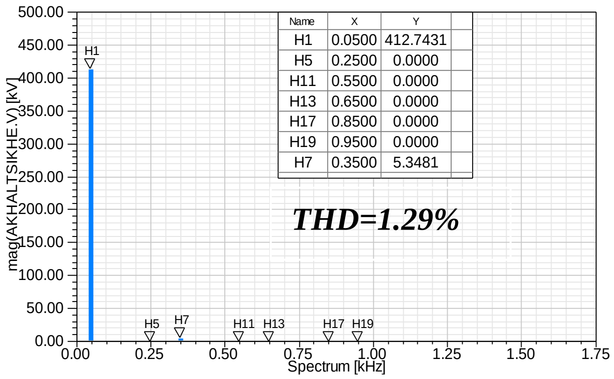




Name	X	Y
H1	0.0500	421.2871
H5	0.2500	6.4888
H11	0.5500	8.8718
H13	0.6500	8.4010
H17	0.8500	0.0000
H19	0.9500	0.0000

with AC filters

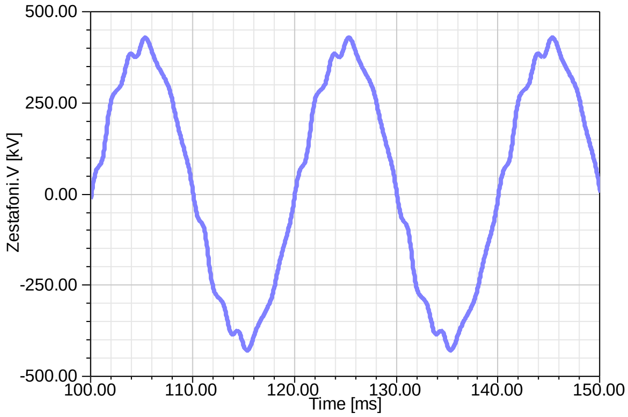


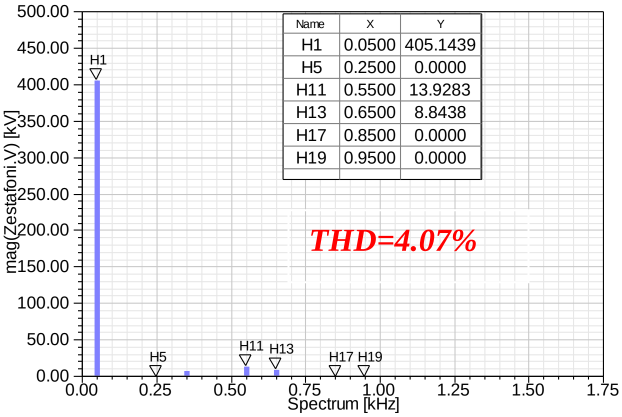


Name	X	Y
H1	0.0500	412.7431
H5	0.2500	0.0000
H11	0.5500	0.0000
H13	0.6500	0.0000
H17	0.8500	0.0000
H19	0.9500	0.0000
H7	0.3500	5.3481

ZESTAFONI 500

without AC filters

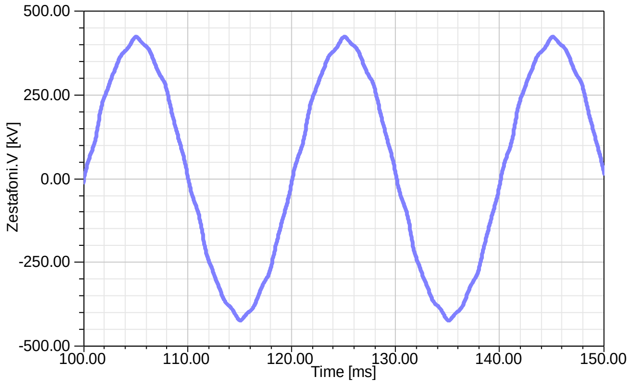


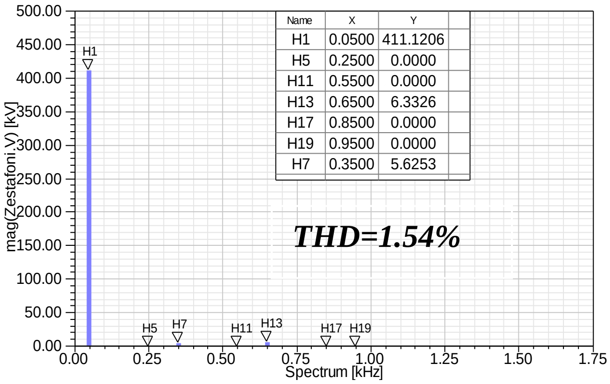


Name	X	Y
H1	0.0500	405.1439
H5	0.2500	0.0000
H11	0.5500	13.9283
H13	0.6500	8.8438
H17	0.8500	0.0000
H19	0.9500	0.0000

THD=4.07%

with AC filters





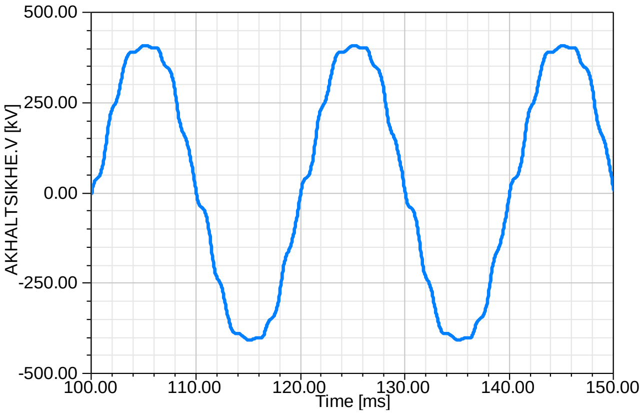
Name	X	Y
H1	0.0500	411.1206
H5	0.2500	0.0000
H11	0.5500	0.0000
H13	0.6500	6.3326
H17	0.8500	0.0000
H19	0.9500	0.0000
H7	0.3500	5.6253

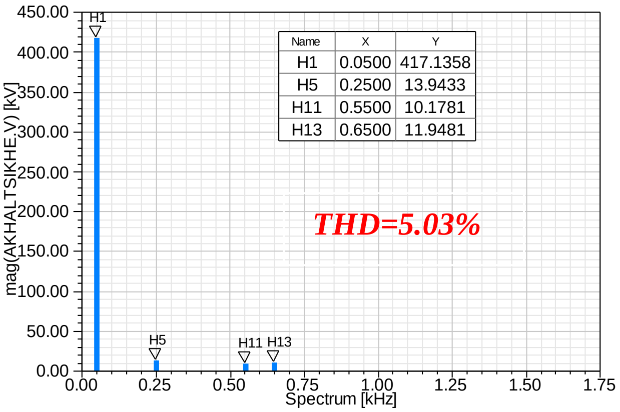
THD=1.54%

N-1, outage of “Zestafoni -Akhaltsikhe”,

AKHALTSIKHE 500

without AC filters

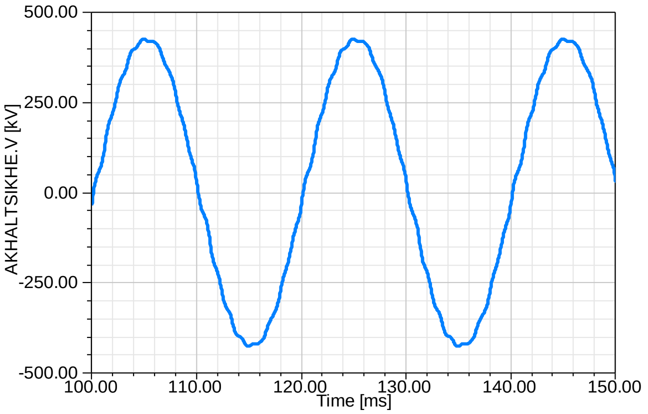


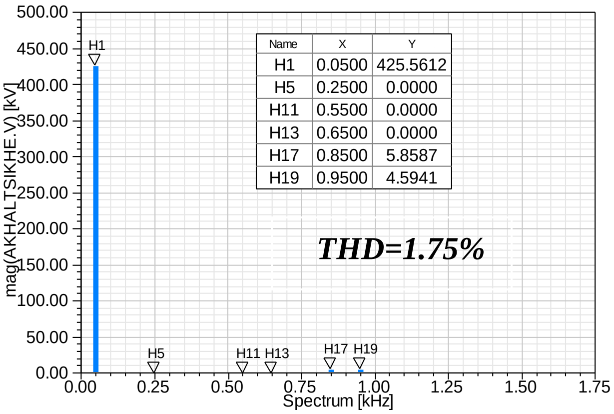


Name	X	Y
H1	0.0500	417.1358
H5	0.2500	13.9433
H11	0.5500	10.1781
H13	0.6500	11.9481

THD=5.03%

with AC filters



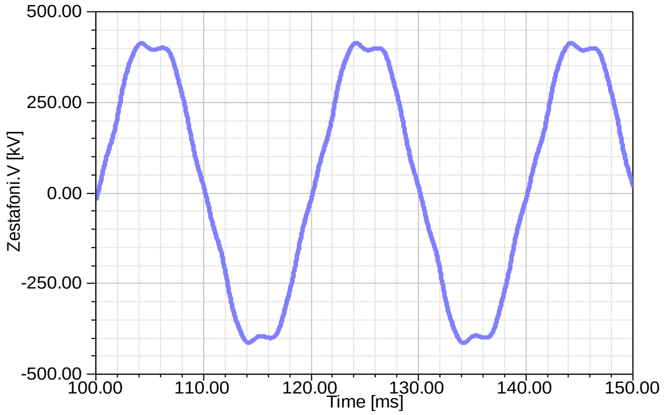


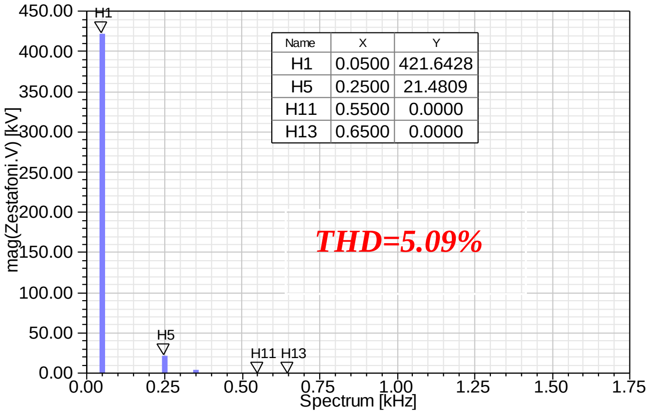
Name	X	Y
H1	0.0500	425.5612
H5	0.2500	0.0000
H11	0.5500	0.0000
H13	0.6500	0.0000
H17	0.8500	5.8587
H19	0.9500	4.5941

THD=1.75%

ZESTAFONI 500

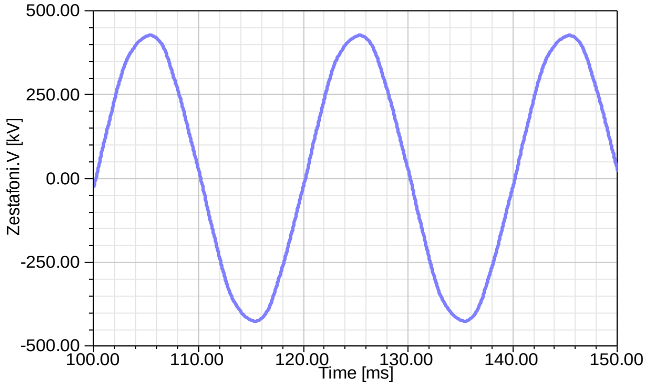
without AC filters

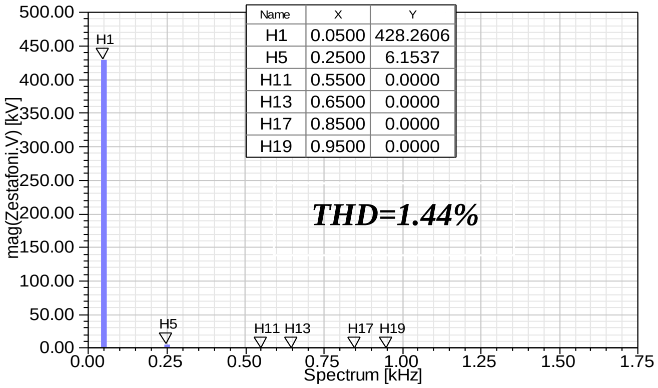




Name	X	Y
H1	0.0500	421.6428
H5	0.2500	21.4809
H11	0.5500	0.0000
H13	0.6500	0.0000

with AC filters





Name	X	Y
H1	0.0500	428.2606
H5	0.2500	6.1537
H11	0.5500	0.0000
H13	0.6500	0.0000
H17	0.8500	0.0000
H19	0.9500	0.0000

As seems form simulation results, at some busburs without ac filters, harmonic contents exceeds of desirable value, but after filters installation even in the worst case, when 500 kV line is out of service, THD reduces to permissible value. The max value of THD is in Akhaltsikhe and it is 1.75%. So, approximate harmonic analysis shows that everything is ok.

5.2 Switching analysis for 2015

Harmonic analysis had been carried out for Akhaltsikhe 500 and Batumi 220 busburs for two cases: with and without AC filters.

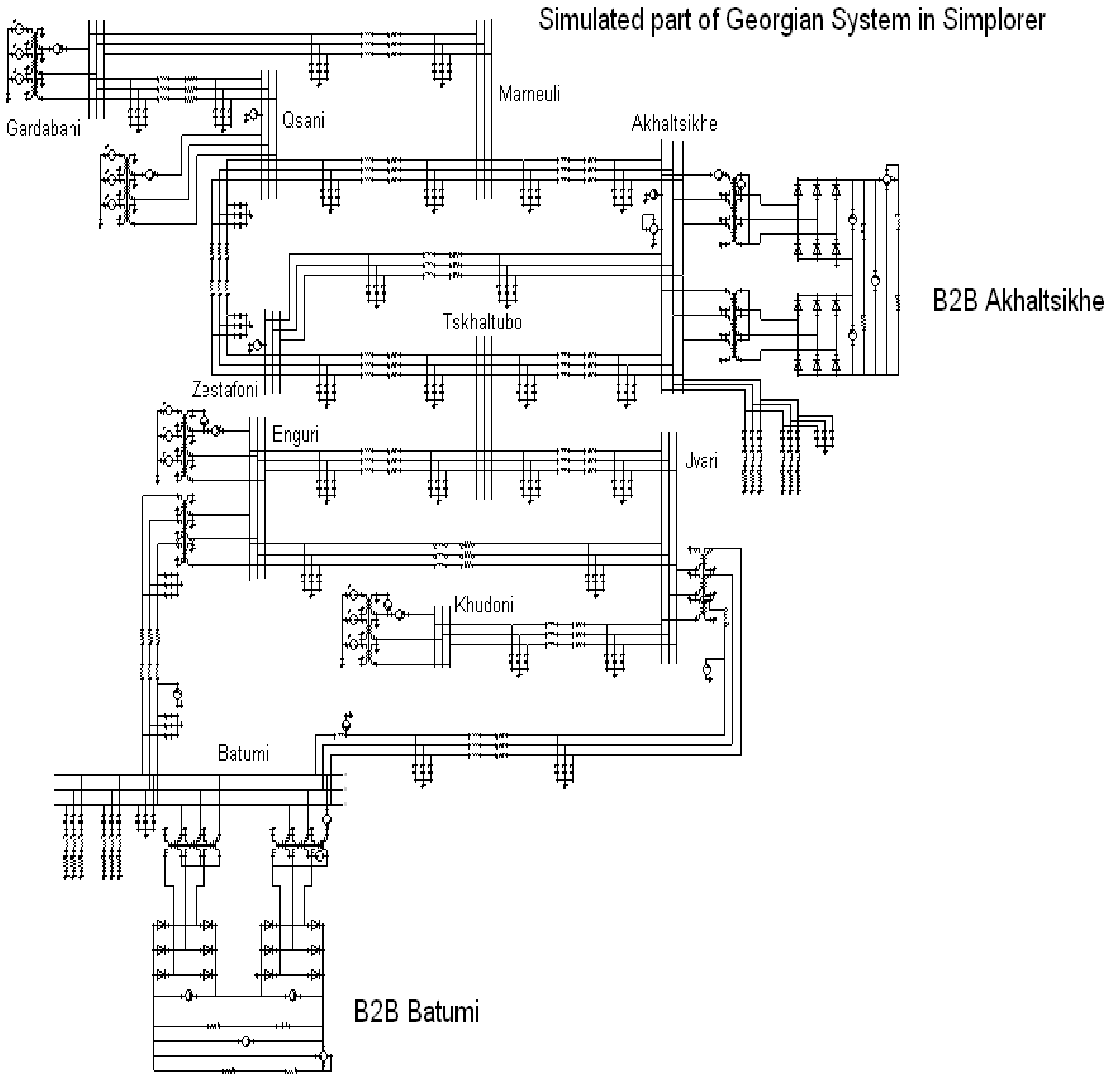
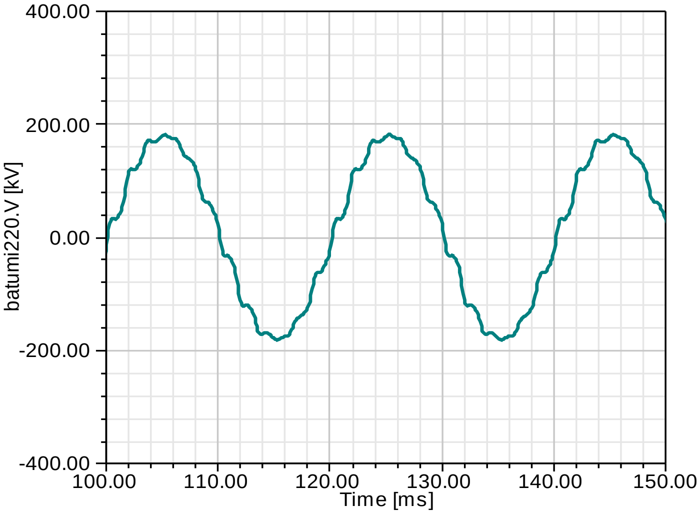


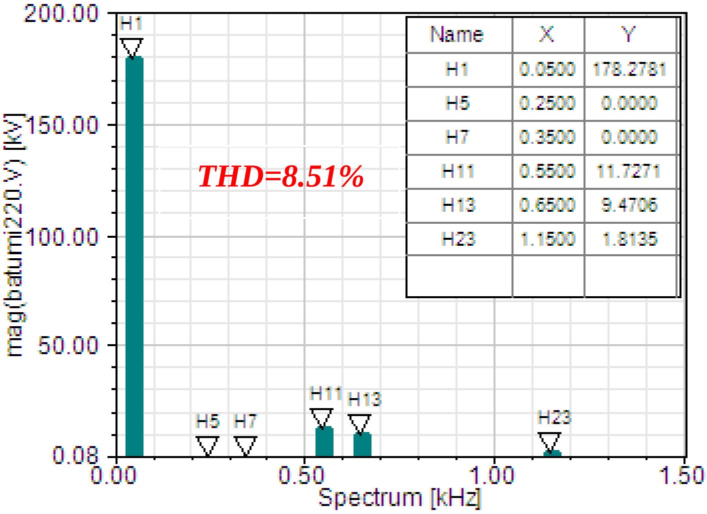
Fig 5.1. Simulated part of Georgian system in “Simplorer” software

5.2.1 Batumi 220 kV (300 MW Export to TR via Batumi B2B)

Calculations are considering that 220 kV OHL connecting substations Batumi and Menji is out of service. Results are shown on the following pictures:

without AC filters

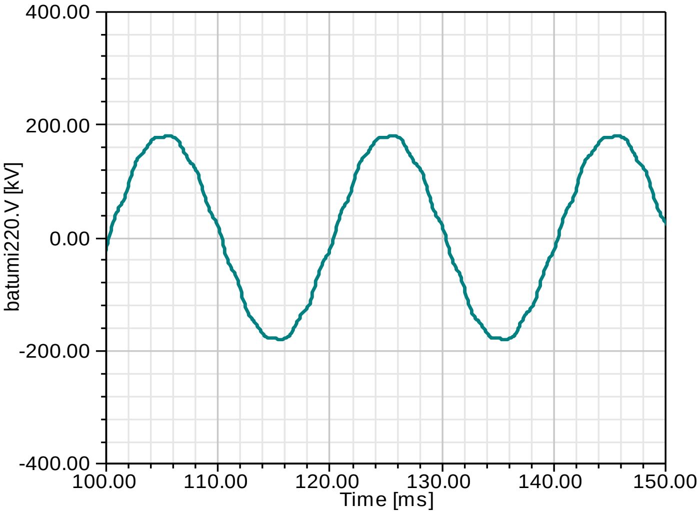


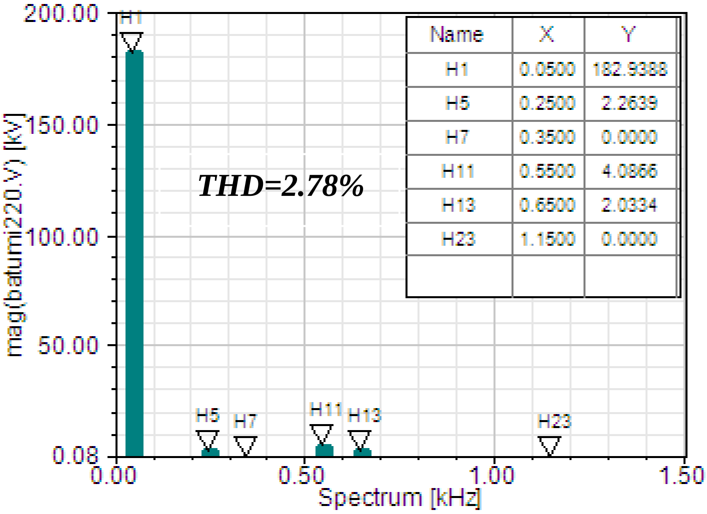


THD=8.51%

Name	X	Y
H1	0.0500	178.2781
H5	0.2500	0.0000
H7	0.3500	0.0000
H11	0.5500	11.7271
H13	0.6500	9.4706
H23	1.1500	1.8135

with AC filters





THD=2.78%

Name	X	Y
H1	0.0500	182.9388
H5	0.2500	2.2639
H7	0.3500	0.0000
H11	0.5500	4.0866
H13	0.6500	2.0334
H23	1.1500	0.0000

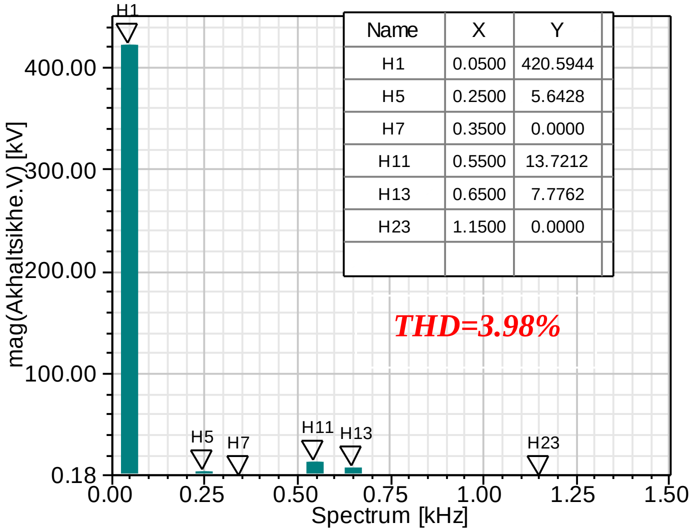
without AC filters the THD factot

At Batumi 220 busbur is 8.51% , and with ac filters it reduces to 2.78% , p range of the THD in our power grid is below 3 %, so it has permitted value .

5.2.2 Akhaltsikhe 500 kV (700 MW Export to TR via Batumi B2B)

Calculations are considering that 500 kV OHL connecting substations Tskaltubo and Akhaltsikhe is in and out of service. Results are shown on the following figures:

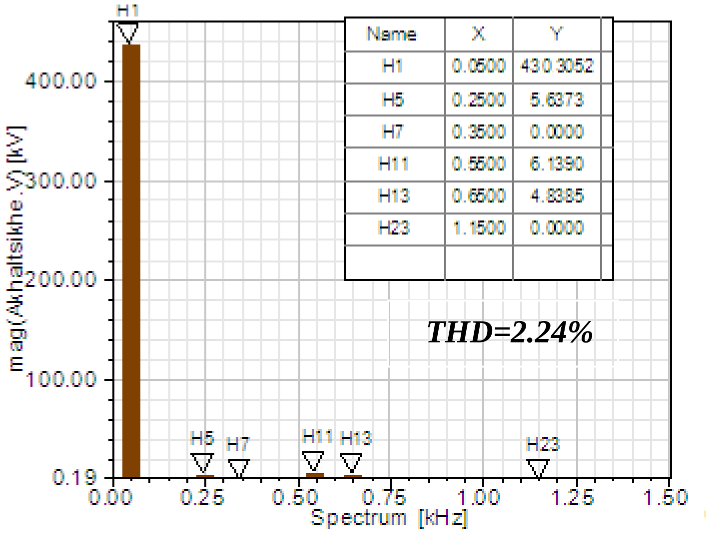
without AC filters



Name	X	Y
H1	0.0500	420.5944
H5	0.2500	5.6428
H7	0.3500	0.0000
H11	0.5500	13.7212
H13	0.6500	7.7762
H23	1.1500	0.0000

THD=3.98%

with AC filters

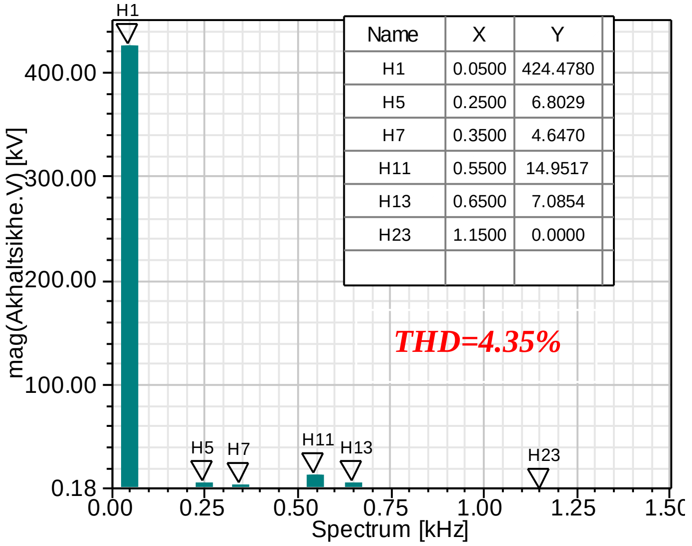


Name	X	Y
H1	0.0500	430.3052
H5	0.2500	5.6373
H7	0.3500	0.0000
H11	0.5500	6.1390
H13	0.6500	4.8385
H23	1.1500	0.0000

THD=2.24%

N-1

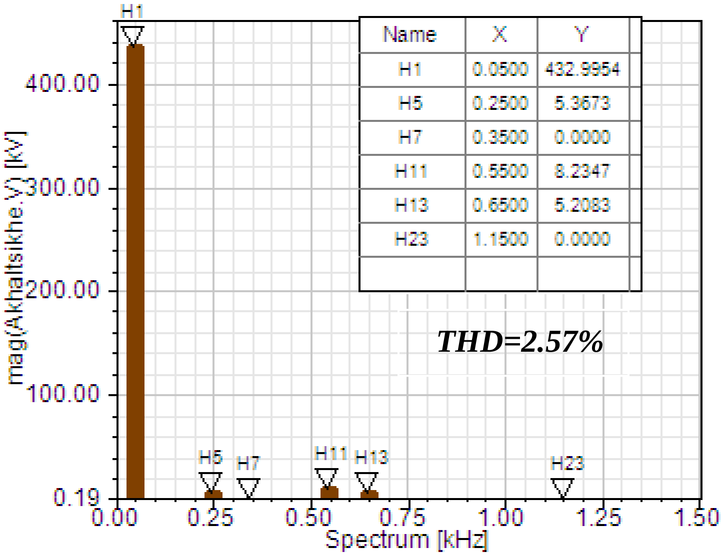
without AC filters



Name	X	Y
H1	0.0500	424.4780
H5	0.2500	6.8029
H7	0.3500	4.6470
H11	0.5500	14.9517
H13	0.6500	7.0854
H23	1.1500	0.0000

THD=4.35%

with AC filters



Name	X	Y
H1	0.0500	432.9954
H5	0.2500	5.3673
H7	0.3500	0.0000
H11	0.5500	8.2347
H13	0.6500	5.2083
H23	1.1500	0.0000

THD=2.57%

At Akhaltsikhe 500 kV busbars in normal and N-1 conditions without filters, THD = 3.98 % and 4.35 % respectively. In case of installed filters in normal condition

THD =2.24% and in N-1 condition THD=2.57. As long as for Georgia 3% and less is treated as permitted, THD values at Akhaltsikhe 500 busbars in case of installed filters in both (normal and N-1 conditions) are OK.

5.3. Switching analysis for 2017

Harmonic analysis had been carried out for Akhaltsikhe 500 and Batumi 220 busburs for two cases: with and without AC filters.

5.3.1 Batumi 220 kV (350 MW Export to TR via Batumi B2B)

In N-1 condition, (Menji – Batumi 220 kV OHL is out of service) at Batumi 220 busburs THD = 7.81 % , and with ac filters it reduces to 2.54%. Permitted range of the THD in Georgian power grid is below 3 %, so 2.54% is OK.

5.3.2 Akhaltsikhe 500 kV (700 MW Export to TR via Batumi B2B)

Calculations are considering that 500 kV OHL connecting substations Tskaltubo and Akhaltsikhe is in and out (in N-1) of service.

At Akhaltsikhe 500 kV busbars in normal and N-1 conditions without filters, THD = 3.44 % and 3.85 % respectively. In case of installed filters in normal condition THD =2.12% and in N-1 condition THD=2.23. As long as for Georgia 3% and less is treated as permitted, THD values at Akhaltsikhe 500 busbars in case of installed filters in both (normal and N-1 conditions) are OK.

5.4. Switching analysis for 2017-2

Harmonic analysis had been carried out for Akhaltsikhe 500 and Batumi 220 busburs for two cases: with and without AC filters.

5.4.1 Batumi 220 kV (350 MW Export to TR via Batumi B2B)

In N-1 condition, (Menji – Batumi 220 kV OHL is out of service) at Batumi 220 busburs THD = 7.89 % , and with ac filters it reduces to 2.64%. Permitted range of the THD in Georgian power grid is below 3 %, so 2.64% is OK.

5.4.2 Akhaltsikhe 500 kV (1050 MW Export to TR via Akhaltsikhe B2B)

Calculations are considering that 500 kV OHL connecting substations Tskaltubo and Akhaltsikhe is in and out (in N-1) of service.

At Akhaltsikhe 500 kV busbars in normal and N-1 conditions without filters, THD = 3.7 % and 3.95 % respectively. In case of installed filters in normal condition THD =2.35% and in N-1 condition THD=2.3. As long as for Georgia 3% and less is treated as permitted, THD values at Akhaltsikhe 500 busbars in case of installed filters in both (normal and N-1 conditions) are OK.

6. Short Circuit Power Calculation Results

6.1. 2013 year

SHORT CIRCUIT POWER (MVA) AT AKHALTSIKHE 500 BUSBURS

	SPRING MAX	SPRING MIN	SUMMER MAX	SUMMER MIN	AUTUMN MAX	AUTUMN MIN	WINTER MAX	WINTER MIN
GE+AZ	2919.75	2469.1	2754.5	2383	2862.75	2388.05	3010.85	2654.25
GE	2441.5	1877.95	2148.65	1814	2333.85	1909.7	2588.2	2226.5

6.2. 2015 year

SHORT CIRCUIT POWER (MVA) AT AKHALTSIKHE 500 BUSBURS

	SPRING MIN	SUMMER MAX	AUTUMN MIN	WINTER MAX
GE+AZ	3586.75	3894.3	3645.55	4221.2
GE	2833.85	3139.1	3145.35	3730.5

SHORT CIRCUIT POWER (MVA) AT BATUMI 220 BUSBURS

	SPRING MIN	SUMMER MAX	AUTUMN MIN	WINTER MAX
GE+AZ	1279.5	1266.0	1128.1	1234.5
GE	1246.3	1237.9	1107.2	1220.6

6.3. 2017 year

SHORT CIRCUIT POWER (MVA) AT AKHALTSIKHE 500 BUSBURS				
	SPRING MIN	SUMMER MAX	AUTUMN MIN	WINTER MAX
GE+AZ	3965.0	4567.0	4213.5	4635.0
GE	3273.1	3920.7	3658.6	4147.5

SHORT CIRCUIT POWER (MVA) AT BATUMI 220 BUSBURS				
	SPRING MIN	SUMMER MAX	AUTUMN MIN	WINTER MAX
GE+AZ	1376.1	1334.1	1304.1	1314.3
GE	1354.1	1320.2	1285.6	1299.3

ANNEX 4

Analysis of Energy Export capabilities from Azerbaijan and Georgia to Turkey “AGT Power Bridge” Project, Report, Azerenerji, Baku-2011

AzərEnerji®

Analysis of Energy Export capabilities from Azerbaijan and Georgiya to Turkey

“AGT Power Brige” Project

REPORT

Baku-2011

Preface

One of the significant factors to increase efficiency (operation security, energy trading, as well as integration of renewable energy) of PG is Interstate Integration. In this respect it is possible to realize the known number of system effects as structural, capacity, frequency, regime, ecological effects and so on.

As Azerbaijan PG is currently an integrated part of “AGT Power Bridge” project.

At present time, there are 21 power plants with a total capacity of 6.5 GW (with a per capita of more than 700 kW) and total length of all transmission lines at all voltage classes (500-35 kV) is 12000 km. About 98 % of the generation source concentrated in the grid and is managed by JSC "Azerenerji".

Thermal power plants (PP) dominate in the structure of the Country Generation system, which forms 84% of the installed generation capacity, therewith share of hydraulic PP is 16%.

Over the past 10 years the economy of Azerbaijan Republic shows positive dynamics of almost all macro indices, the downward trend is also the energy intensity of GDP, which over the past 10 years has fallen almost 4 times and reached the level of 1.28 toe/USA$ thousand. These and other macroeconomic indicators on the one hand many times surpass.

The main strategic direction of development of electric power industry of Azerbaijan is follow:

1. Replacement of technology and equipment for the generation, transport and distribution of electricity by the most advanced and efficient technologies and equipment;

2. The balanced development of power generating facilities and Backboned Networks to provide the necessary level of reliability and efficiency of the electricity consumers;

4. The establishment of an effective system of optimum management of the operation and development of PG countries, i.e. a system capable of reducing

production costs and optimize accordingly, electricity tariffs, so as ensuring reliable power supply;

5. Development of PG and its integration with systems of other countries;
6. Development of renewable energy source and reduce the negative impact of traditional generation on the environment through the use of innovative technologies.

One of the priority directions of development of National Power System is expansion and integration with PG's of others countries.

Azerbaijan PG has extensive work experience in IPG: about 30 years – in the structure of the no longer existing IPG of USSR. At present time, there are interconnection at a voltage level of 330 kV in the PG of the Russian Federation, three interconnection lines of 330, 220 and 110 kV level with PG of Iran. In the South Caucasus region Azerbaijan's PG remains the dominant and rapidly developing. Over the past 10 years, the installed capacity has increased by more than 30% (2000 MW).

In 2015 and 2017, it is planned to connect Azerbaijan PS to Georgia and Turkey PS through "Power Bridge", this parallel work will strengthen the strategic importance of Azerbaijan in the South Caucasus, as well as in the Eurasian Union.

Meanwhile, the development of the High Voltage Interstate connections and as a result creation of bulk power systems may encounter huge black-outs, which originate by increasing complication in monitoring, operating and control large-scale interconnected PG as well as in limited knowledge of the total system state. Therefore, interconnection between Azerbaijan, Georgia and Turkey requires checking its stability, disturbance in any normal and forced modes in each stage of PS development. Such results of the analysis are used to improve the anti-emergency control.

The results of the following calculations processed on PSS-E software are given in the current report.

In the first part, calculations were performed and due to this, the analysis of stability were carried out both for operation mode and draft-scheme covering a connection frame-scale as Azerbaijan PS to Georgia and Turkey, Iran and the North Caucasus (the Russian Federation) through “Power Bridge” for the years 2012-2013

In the second part, the schemes and operation modes of Azerbaijan PS during power transmission to Georgia and Iran PS modeled for the 2015 and 2017 years.

1. The stability of operation modes and schemas of Azerbaijan PS during paralel mode conditions

(The mode and scheme of the years 2012-2013)

1.1. The mode and scheme features.

Azerbaijan PS mode is characterized in the following way:

$P_{\sum gen}$ = 4400 MW;

$P_{\sum load} = P_{load,\ max} + P_{export}$ =3200 + 1144 = 4344 MW;

Here : $P_{load,max}$ – PS specific load,

P_{export} – total load through interconnection lines

thus,

- to Georgia PS 594 MW (500 kV Samukh-Gardabani OHL – 396 MW and 330kV Akstafa-Gardabani OHL – 198 MW);

- to Iran PS 550 MW (330 kV OHL – 350 MW, 230 kV OHL – 100 MW, 110kV OHL – 100 MW);

- to the North Caucasus PS – 0 MW.

In the Table 1-1 - modes of the system in the normal and N-1 modes, the main modifier of 500-330 kV OHL power flows are shown.

AZERBAIJAN POWER SYSTEM OF THE YEAR 2012-2013

P_{gen}=4400 MW, P_{load}=3200 MW (Personal)

Power Transmission:

Georgia – 595 MW:
- **500 kV Samukh-Gardabani OHL – 396 MW**
- **330 kV Akstafa-Gardabani OHL – 198 MW**

Iran – 550 MW,
Russia – 0 MW/

AZERBAIJAN POWER SYSTEM OF THE YEAR 2015

P_{gen}=5320 MW, P_{load}=4031 MW (Personal)

Power Transmission:

Georgia – 594 MW
- 500kV Samukh-Gardabani OHL- 413 MW
- 330kV Akstafa-Gardabani OHL - 181 MW
Iran – 550 MW
Russia – 0 MW

AZERBAIJAN POWER SYSTEM OF THE YEAR 2017

P_{gen}=6777 MW, P_{load}=5505 MW (Personal)

Power Transmission:

Georgia – 588 MW
- 500 kV Samukh-Gardabani OHL - 391 MW
- 330 kV Akstafa-Gardabani OHL - 197 MW
Iran – 550 MW
Russia – 0 MW

Normal conditions and N-1 **Table 1-1**

P, MW		1 st Apsheron 330 kV OHL	2^{n}nd 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

According to the given in the Table 1-1 analysis, in normal mode, the largest part of the load are referred to 500 kV AzTPP-Samukh OHL, 500 kV 2nd Absheron OHL, 330 kV Agjabedi-Goranboy OHL.

In n-1 mode a large load (≥50% P_n) is given:

- 330 kV 1st Absheron OHL (58,3%) 500 kV 2nd Absheron during OHL switch off;

- 330 kV AzTPP-Goranboy OHL (67,4%) 330 kV AzTPP-Goranboy during OHL switch off;

- 330 kV AzTPP-Samukh OHL (110%) 500 kV- AzTPP-Samukh during OHL switch off,

- 330 kV AzTPP-Mingachevir OHL (3-rd Mingachivir) (135%) 500 kV 2nd Absheron during OHL switch off;

- 330 kVt İmishli-Goranboy OHL (82,3%) 330 kV Agjabadi-Goranboy during OHL switch off;

- 330 kV Akstafa-Gardabani interconnection OHL (195%) 500 kV Samukh-Gardabani interconnection OHL switch off.

Load Increasing along the lines are shown relative to normal mode load. During OHL switch off on Samukh-Gardabani 500 kV, interconnection OHL Akstafa-Gardabani 330 kV due to current are overloaded.

The automatic shutdown may lead to 600 MW loss in Georgia PS and pressure drop, this can be proved by the calculations performed below.

1.2. Dynamic stability of Azerbaijan PS during operation conditions

(The mode and the scheme of the years 2012-2013)

The following types of disturbance are considered:

1. Switch off on both interconnection lines on Azerbaijan and Georgia PS. At that time frequency variation in both PS was recorded .

The calculation of results is given in fig.1-2 and fig.1-3.

2. Switch off – in AzTPP (270 MW) and Shimal CCPP (350 MW).

In this case, changes in voltage and power flows on 500 kV Samukh-Gardabani and 330 kV Akstafa - Gardabani OHLs, as well as frequency and generator rotors of Azerbaijan TPP, and relative angles of generators in Azerbaijan and Georgia PSs were recorded.

The calculation of results is given in fig.1-4 ÷ 1-21.

3. Switch off load rejection lines:

500 kV AzTPP-Samukh (421 MW)
500 kV AzTPP -Absheron (356 MW)
500 kV Samukh-Gardabani (396 MW)
330 kV- AzTPP-Goranboy (316 MW)
500 kV- Akhalsikhe-Tskhaltu (562 MW)
0,2 s by means of automatic reclosing .

In this case, changes in voltage and power flows on 500 kV Samukh-Gardabani and 330 kV Akstafa-Gardabani OHLs, as well as frequency in transient mode and generator rotors of Azerbaijan TPP, and relative angles of generators in Azerbaijan and Georgia PSs were recorded.

The calculation of results is given in fig.1-5 ÷ 1-18

4. on the 3rd phase short circuit buses.:

500 kV Samukh
500 kV AzTPP

500 kV Samukh-Gardabani interconnection OHL and voltage and power in 330 kV Akstafa - Gardabani OHL, frequency and Azerbaijan PS-generator rotors

the generators in Azerbaijan and Georgia PS recorded changes of the below relative angles.

The results of the analysis:

1. During Switch off on each two interconnection lines - 500 kV Samukh- - Gardabani and 330 kV Akhstafa-Gardabani OHL, we observe power deficit on Georgia side, as well as frequency reduces to 48.29Hz (fig.1-2). The investigations in Georgia PS shows that in case of power loss as 891 MW, frequency drops to 47.5Hz.

The frequency of the Azerbaijan TPP changes unimportantly (fig.1-3).

2. Switch off on AzTPP and Shimal CCTP leads to reduction of Power flow, Switch off on Inquri HPP leads to increasing of Power flow in Azerbaijan PS (fig.1-5, 1-10, 1-15). It is shown in changes of tension in the interconnection lines - (fig 1-4, 1-9, 1-14). Frequency changes are miserable during transient processes (fig.1-6, 1-11, 1-16). The relative angles in generators of Azerbaijan and Georgia Power Grids and generators of Azerbaijan THPP and among dedicated generators are recorded (fig.1-7, 1-8, 1-12, 1-13, 1-17, 1-18).

The system is stable. Oscillation processes are the same.

3. During switch off on the 500 kV and 330 kV interconnection lines with automatic reclosing, the changes of voltage and power, relative angles shows that the system is stable. (Fig.1-19 ÷ 1-34). The cycle of the first amplitude depends on load rejection scale.

4. The calculation of the 3 phase s.c. shows that the system is stable (fig.1-35÷1-42). Oscillation of the generators between the relative angles in 500 kV AzTPP buses, the initial amplitude of 3-phase s.c is more noticeable (fig.1-37, 1-38, 1-41, 1-42).

Switch off time has been set-up:

500 kv in Samukh busses during s.c. t_h = 0,28 s.

500 kv in AzTPP buses during s.c. t_h = 0,23 s.

The process is given in fig.1-19 ÷ 1-26. After t = 0,12s. the process is stopped.

DISTURBANCE: switch off both high-voltage on Gardabani (Georgia)

500 KV Samukh-Gardabani OHL
330 KV Akstafa-Gardabani OHL

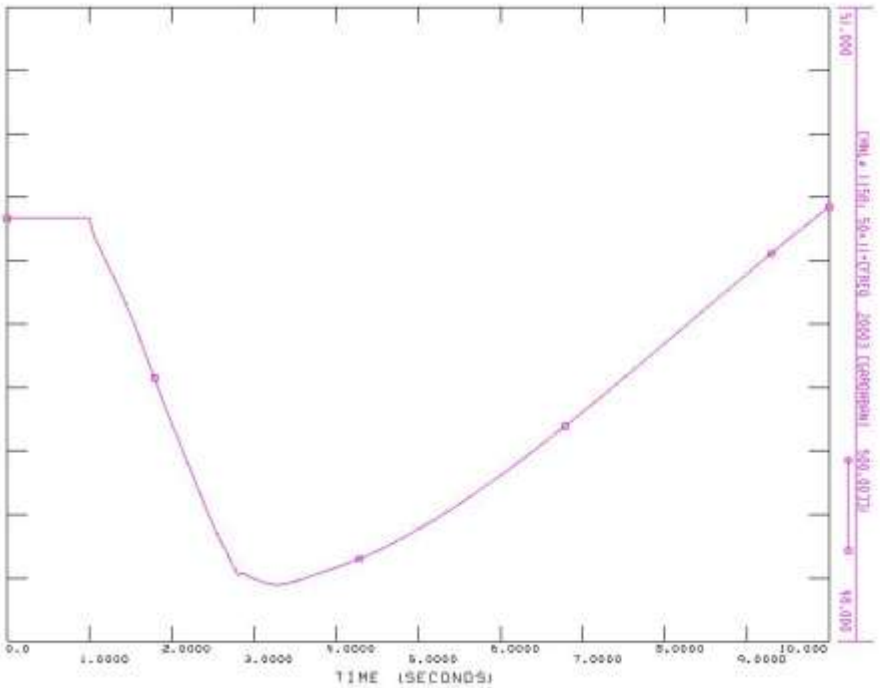


Fig.1-2: Frequency on bus 500 kV Gardabani (Georgia) SS

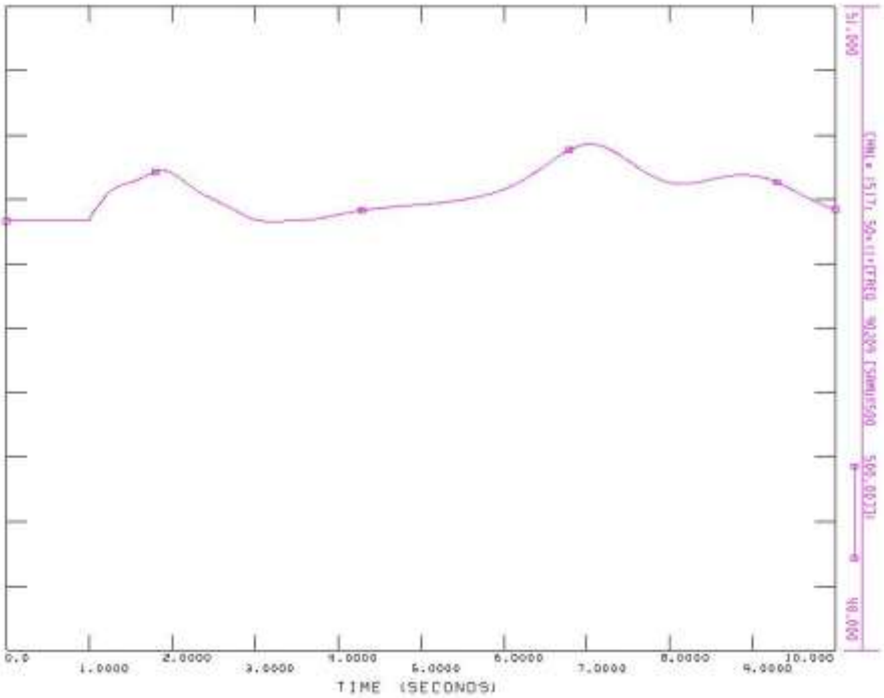


Fig.1-3: Frequency on bus 500 kV Samukh (Azerbaijan) SS

DISTURBANCE : switch off block on AzTPP

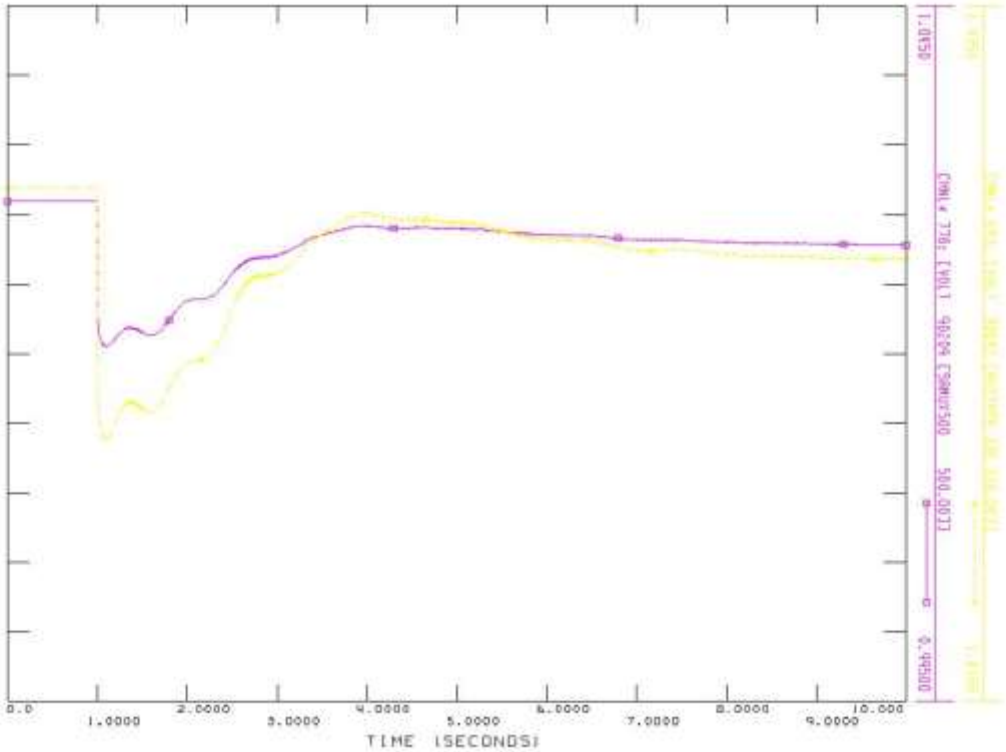


Fig.1-4: Voltage on bus 500 kV Samukh SS, 330kV Akstafa SS

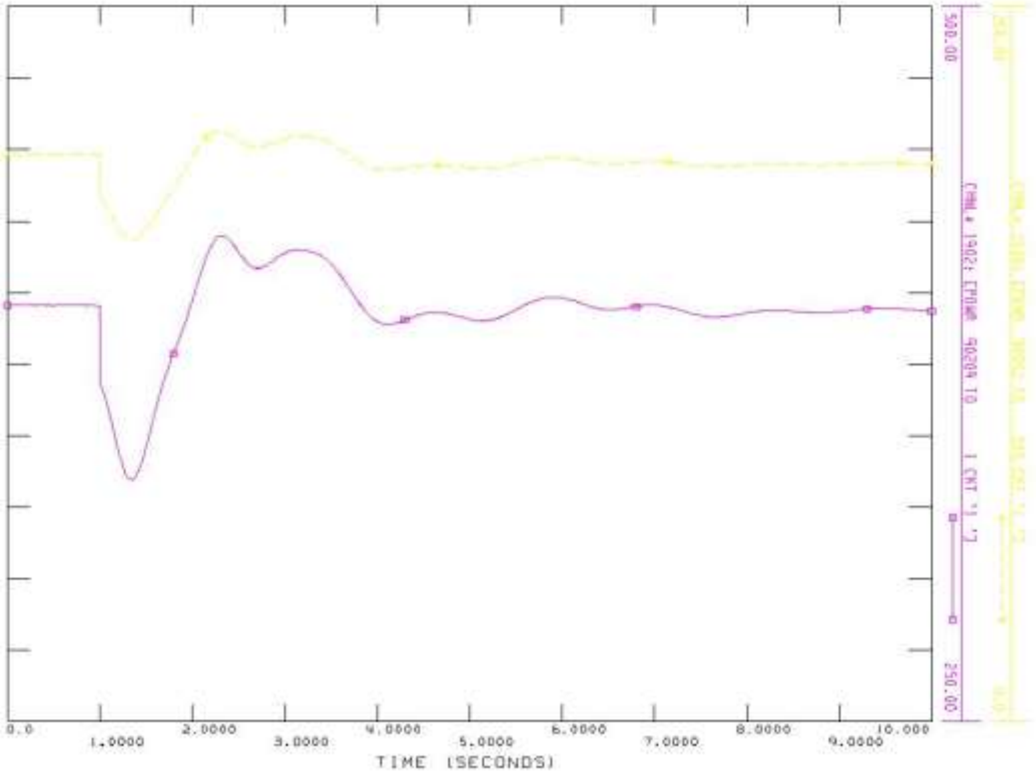


Fig.1-5: Power flow 500 kV Samukh-Gardabani (Georgia) OHL, 330 kV Akstafa-Gardabani (Georgia) OHL

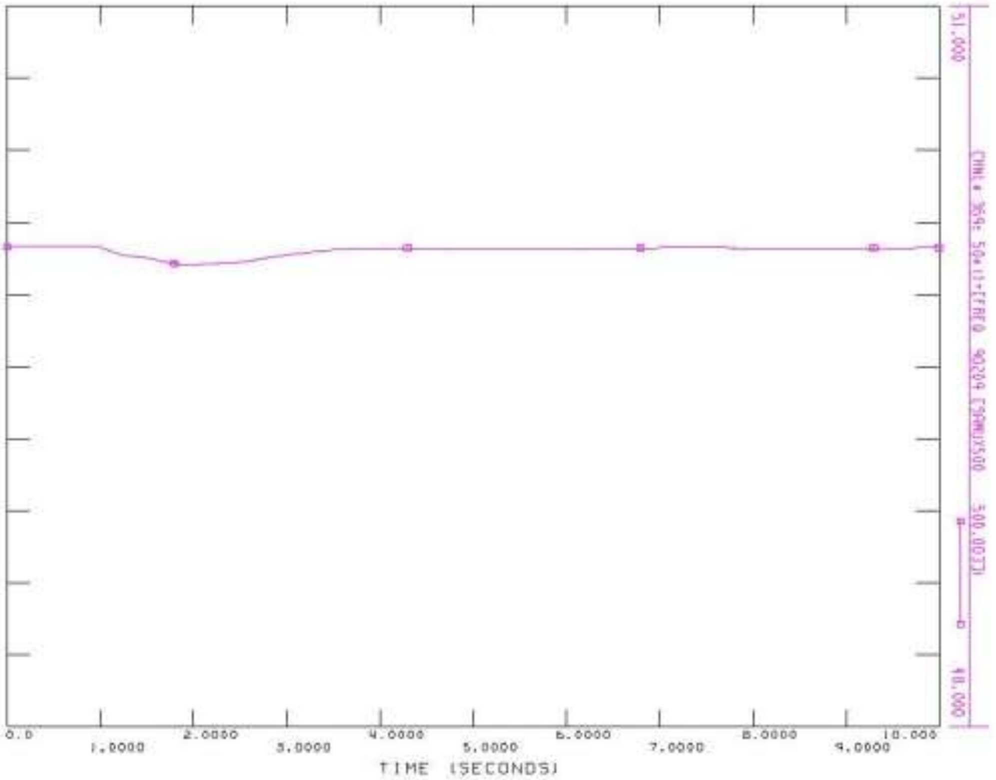


Fig.1-6: Frequency on bus 500 kV Samukh SS

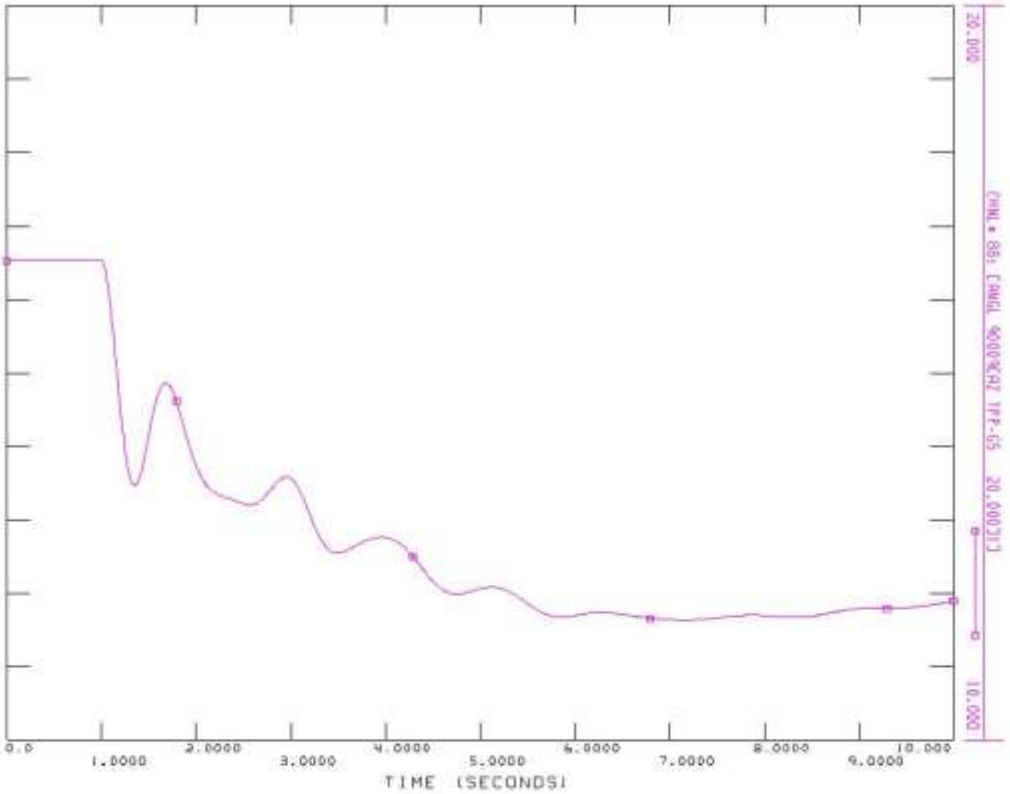


Fig.1-7: Angle of AzTPP Relative to Shimal CCPP

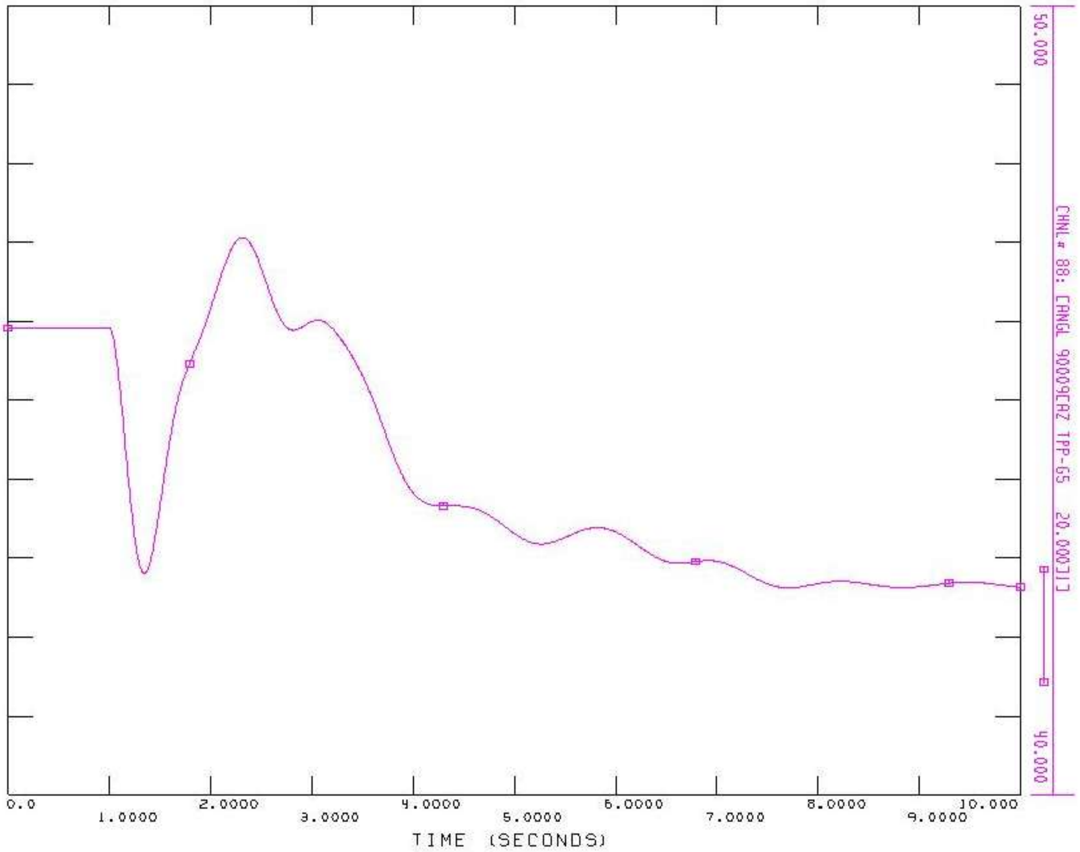


Fig.1-8: Angle of AzTPP Relative to Inguri HPP (Georgia)

DISTURBANCE: switch off block on Inguri HPP (Georgia)

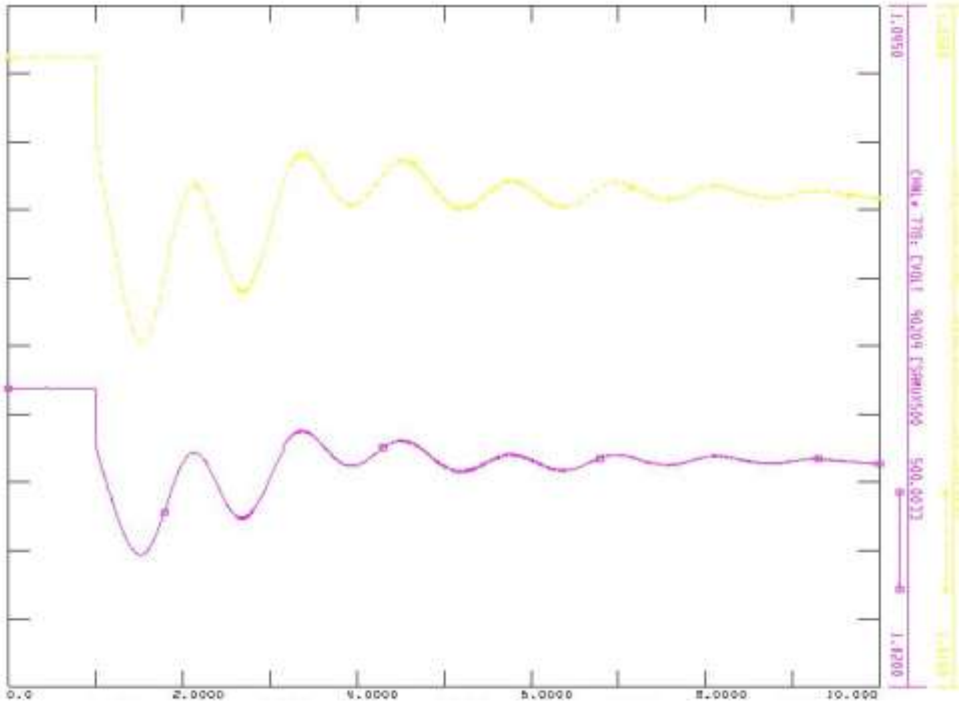


Fig.1-9: Voltage on bus 500 kV Samukh SS, 330 kV Akstafa SS

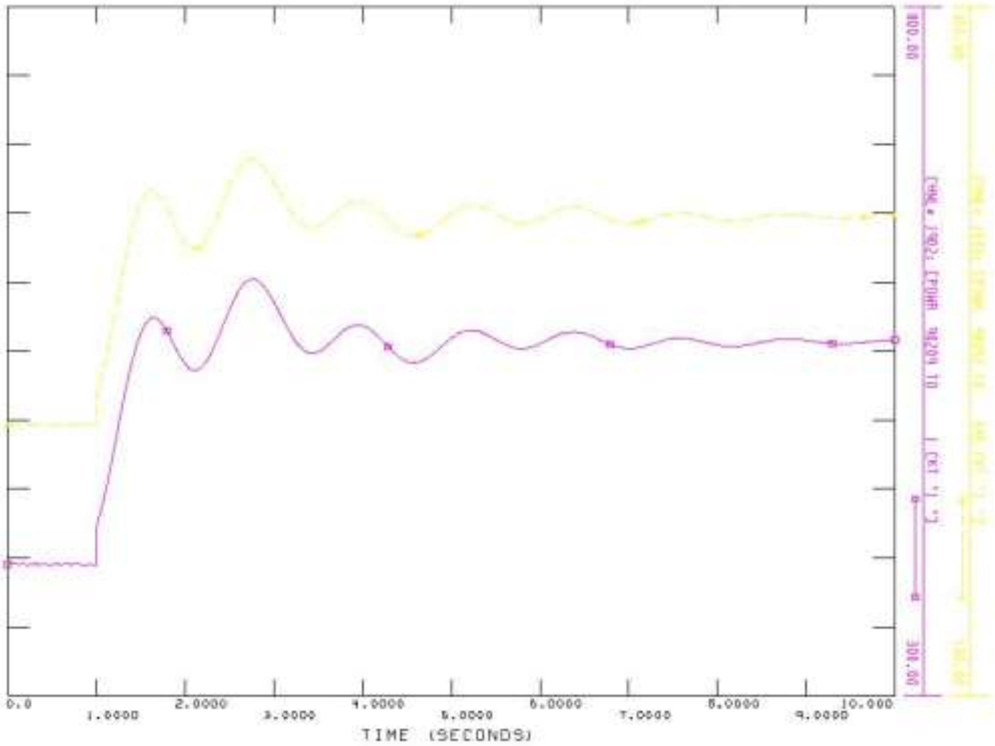


Fig.1-10: Power flow 500 kV Samukh-Gardabani (Georgia) OHL, 330 kV Akstafa-Gardabani (Georgia) OHL

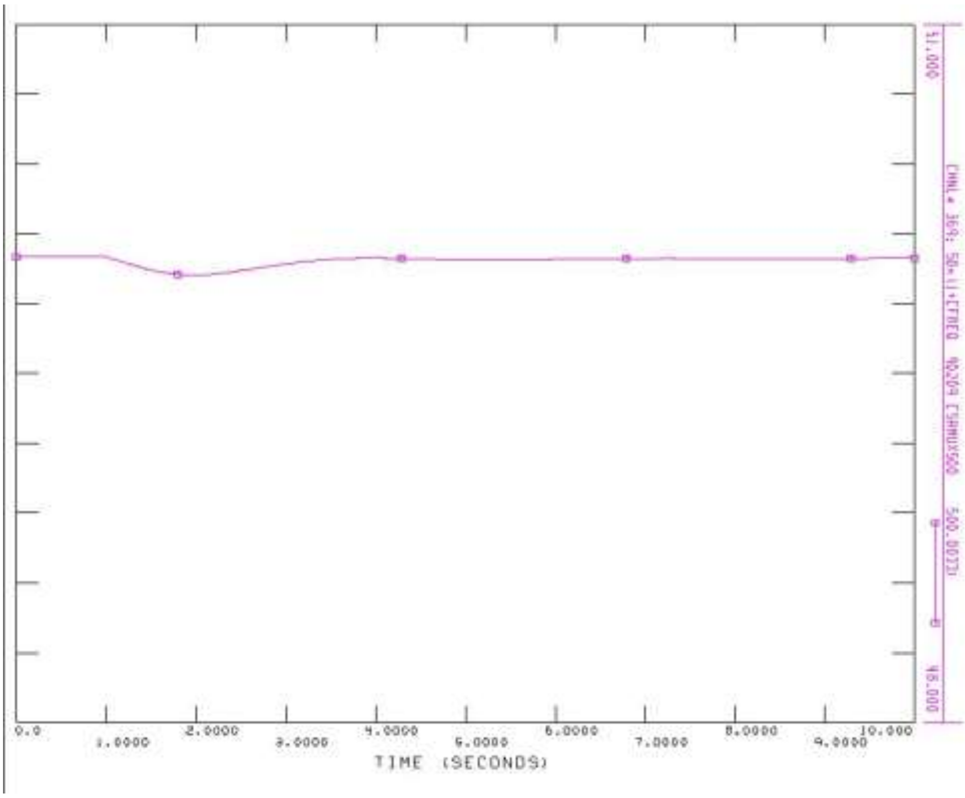


Fig.1-11: Frequency on bus 500 kV Samukh SS

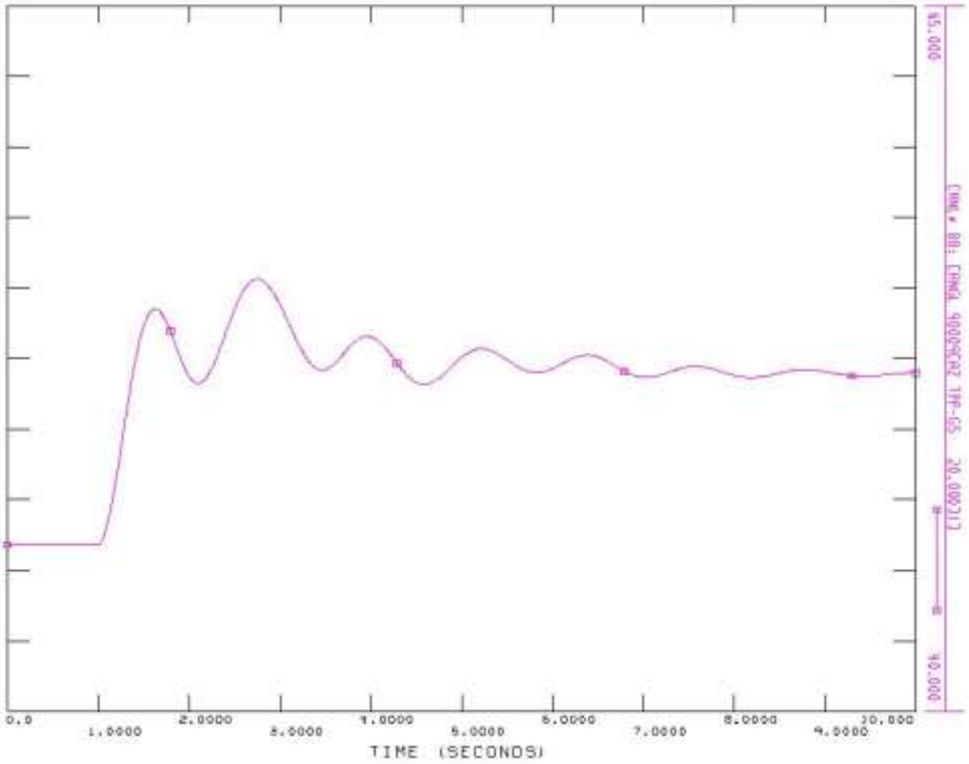


Fig.1-12: Angle of AzTPP Relative to Inguri HPP (Georgia)

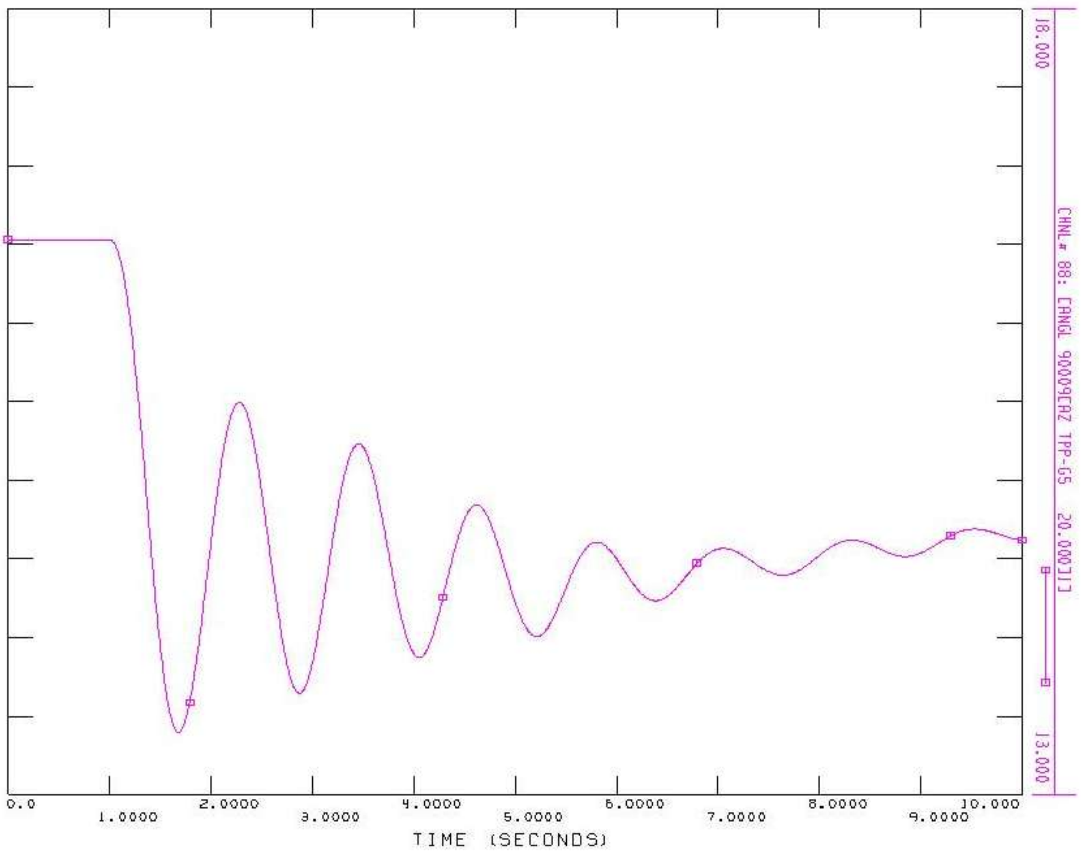


Fig.1-13: Angle of AzTPP Relative to Shimal CCPP

DISTURBANCE: switch off block on Shimal CCPP

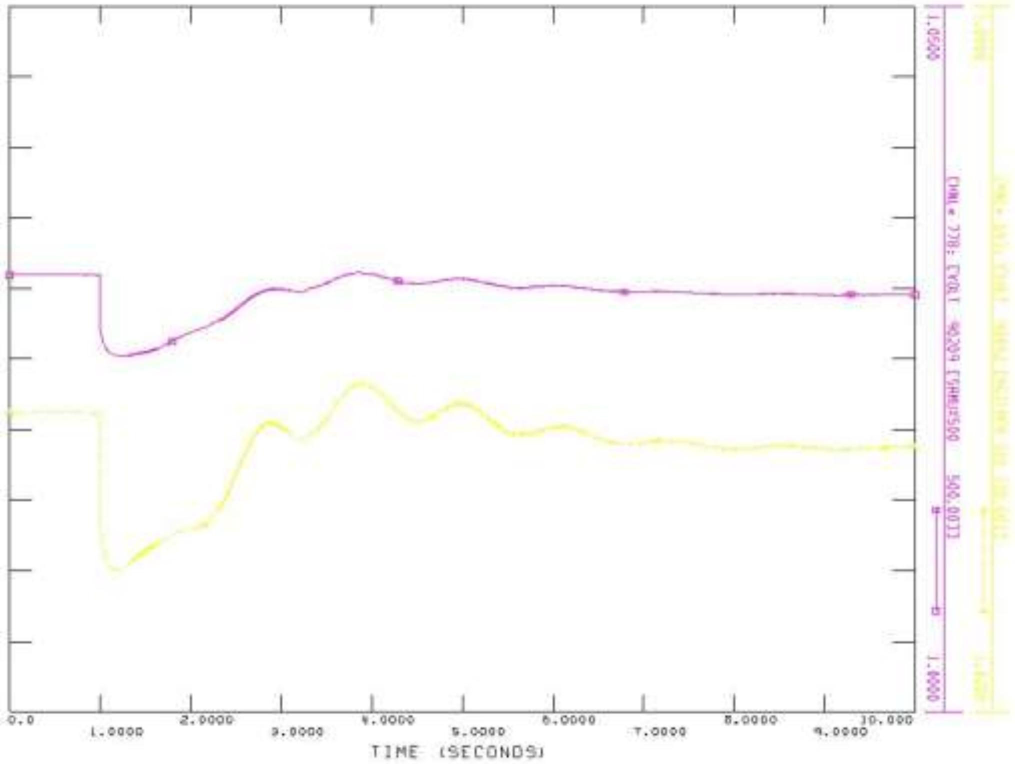


Fig.1-14: **Voltage on bus 500 kV Samukh, 330 kV Akstafa**

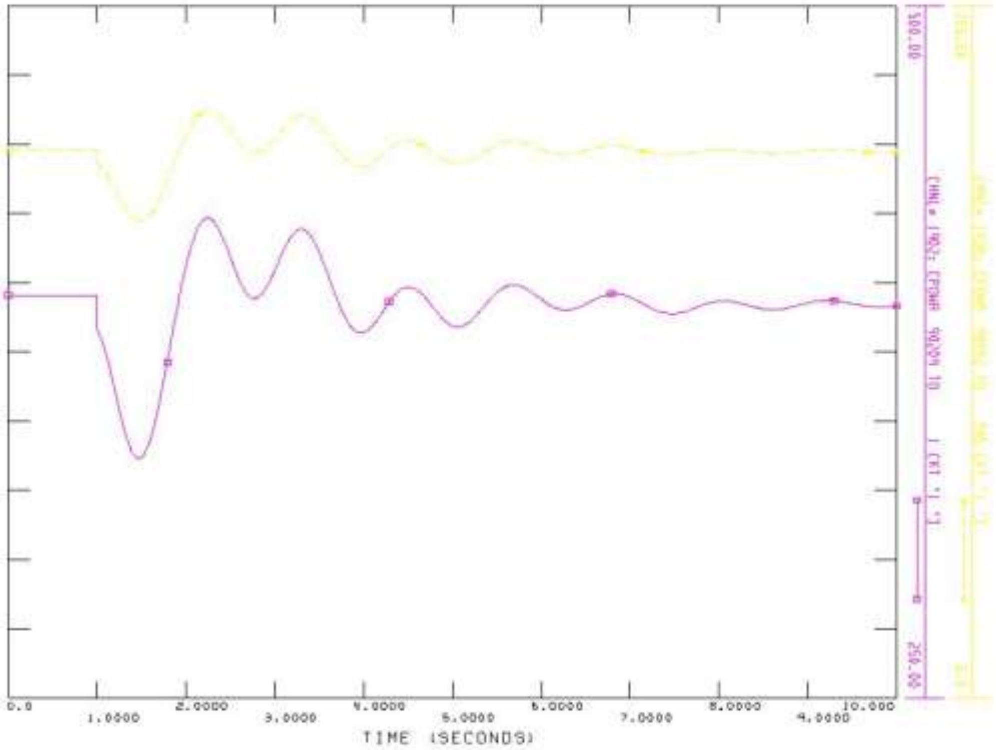


Fig.1-15: Power flow 500 kV Samukh-Gardabani (Georgia) OHL, 330 kV Akstafa-Gardabani (Georgia) OHL

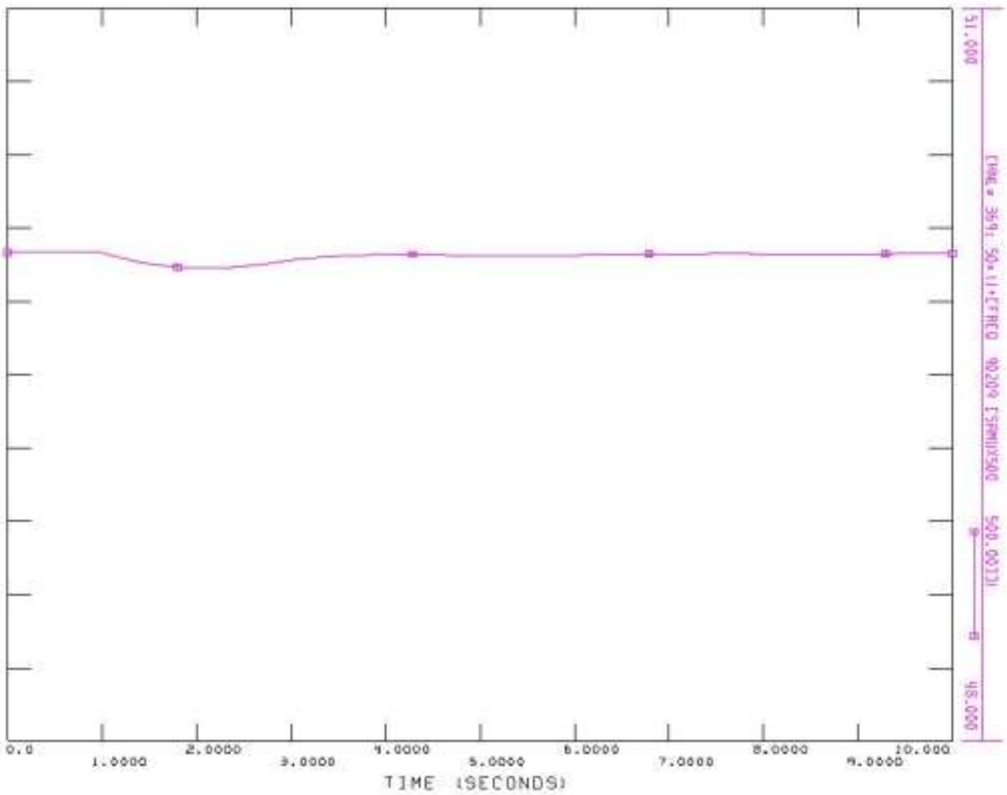


Fig.1-16: Frequency on bus 500 kV Samukh SS

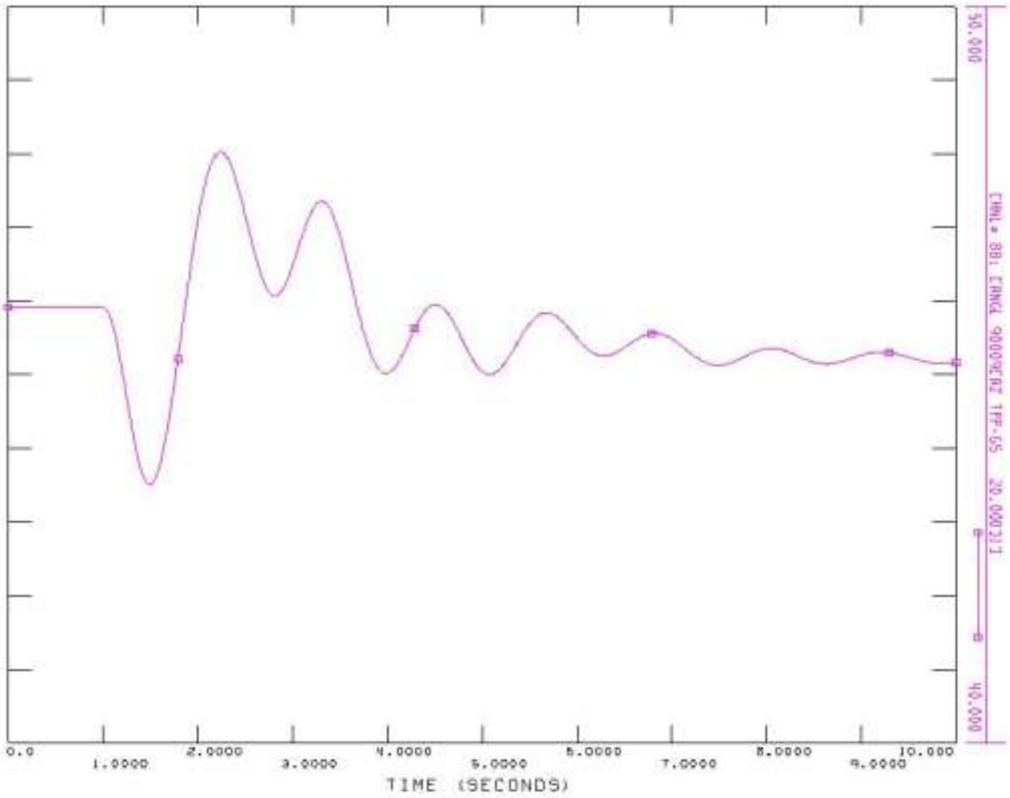


Fig.1-17: Angle of AzTPP Relative to Inguri HPP (Georgia)

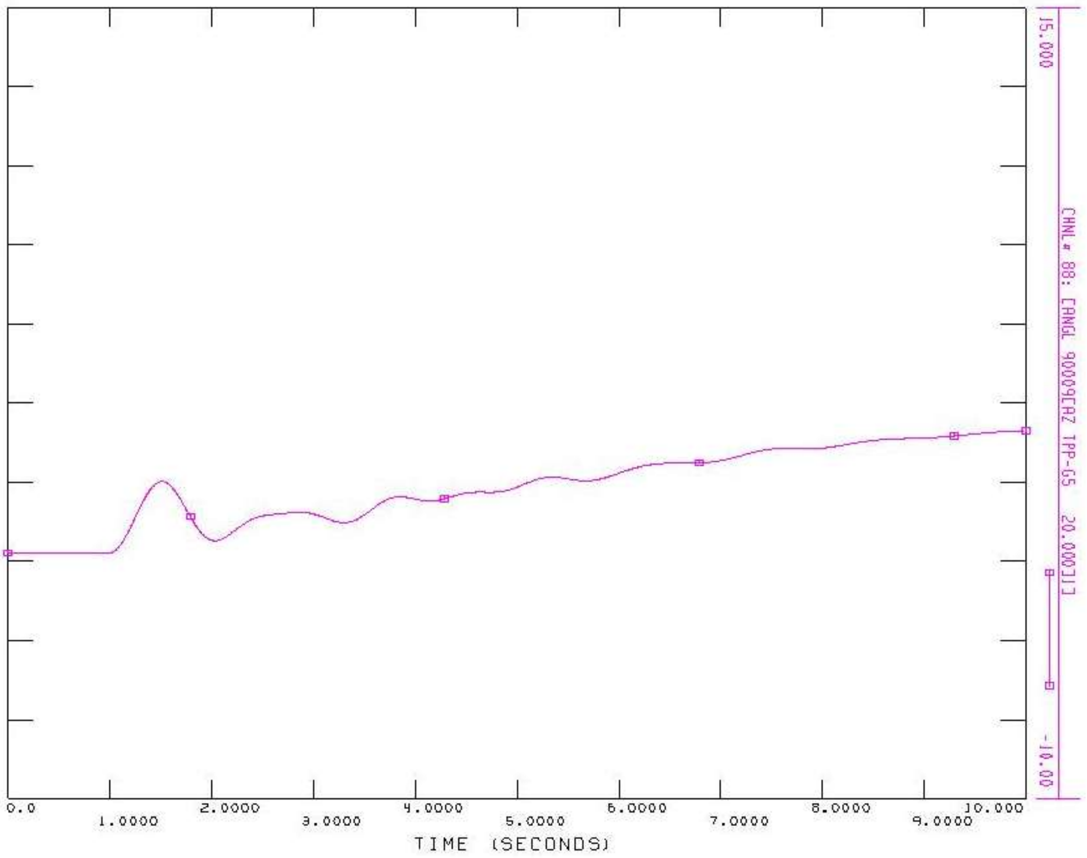


Fig.1-18: Angle of AzTPP Relative to Sumgait CCPP

DISTURBANCE: **switch off high-voltage 500 kV AzTPP-Apsheron (2nd Apsheron) OHL**

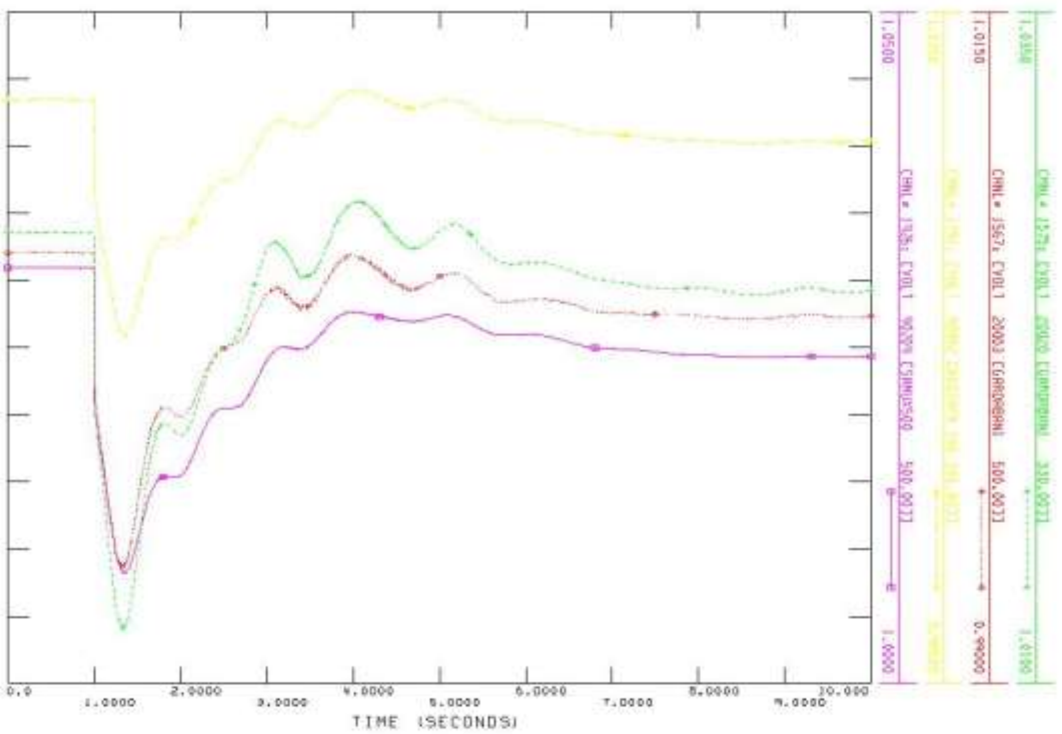


Fig.1-19: **Voltage on bus 500 kV Samukh SS , 330 kV Akstafa SS,**
500 kV Gardabani (Georgia) SS, 330 kV Gardabani (Georgia) SS

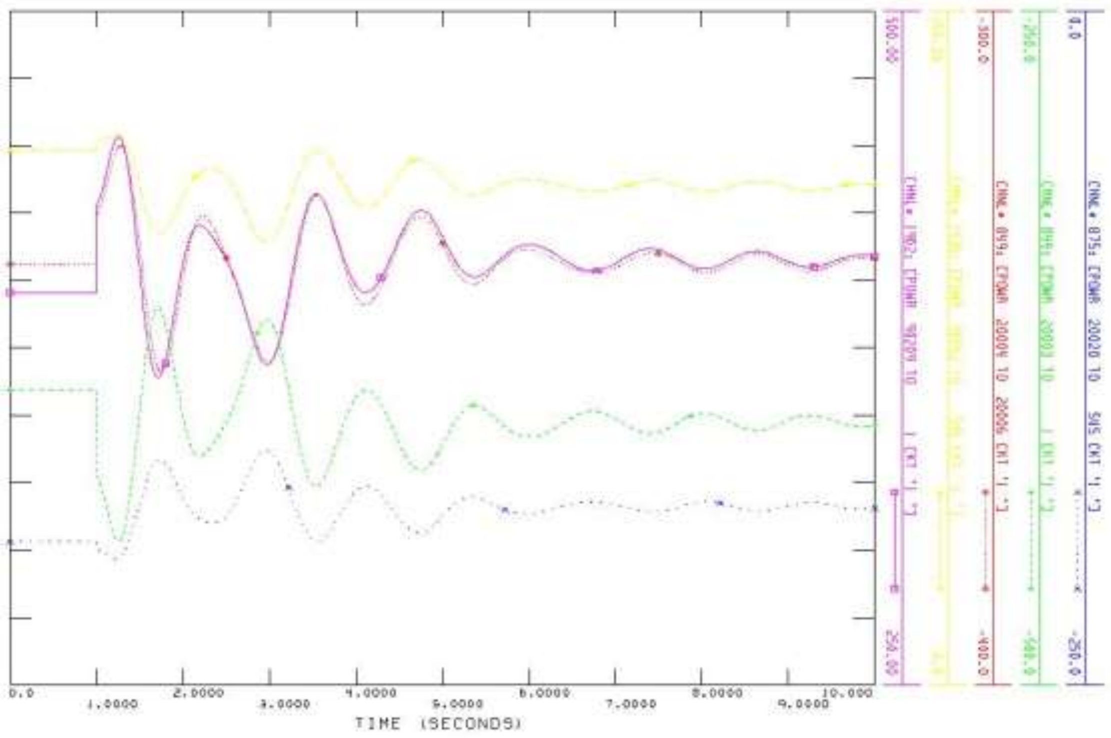


Fig.1-20: Power flow - 500kV Samukh-Gardabani (Georgia) OHL, 330kV Akstafa-Gardabani (Georgia)OHL, 500 kV Akhaltsikhe-Tskaltubo (Georgia) OHL,

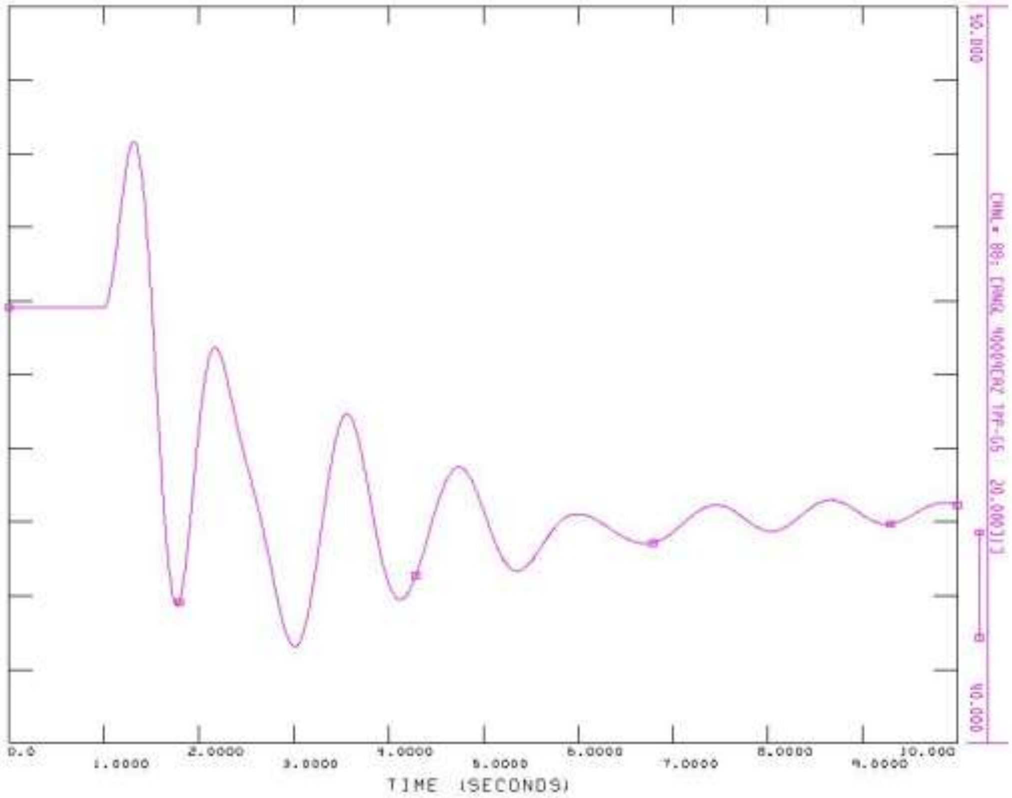


Fig.1-21: Angle of AzTPP Relative to Inguri HPP (Georgia)

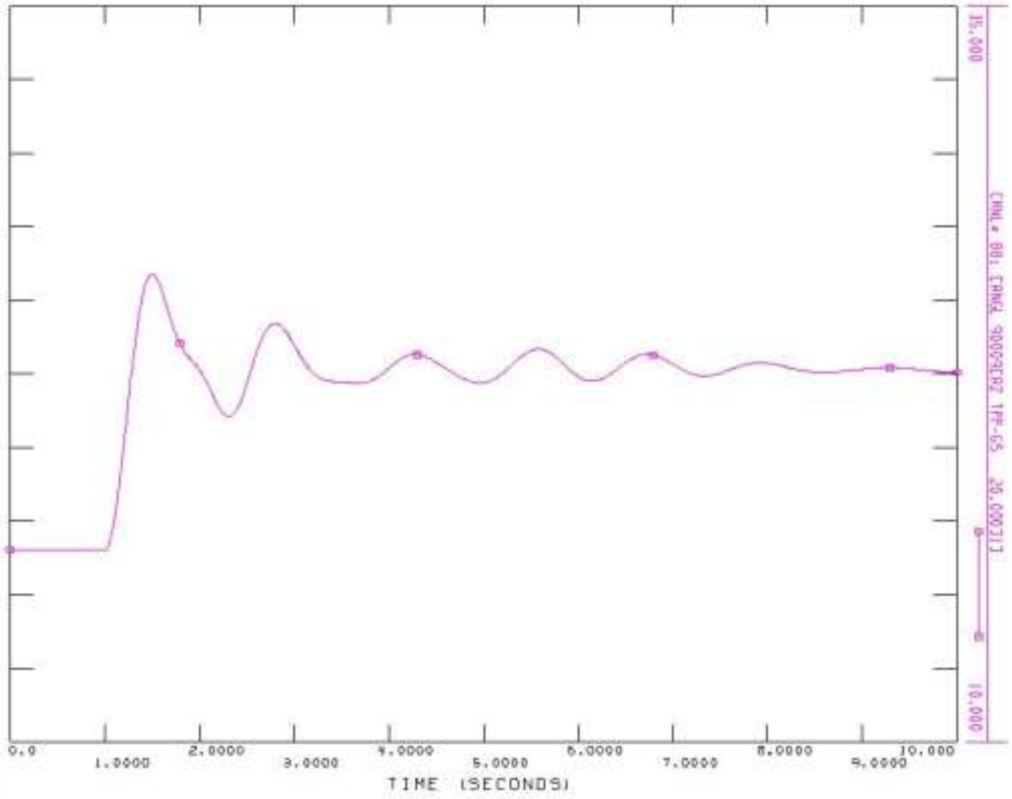


Fig.1-22: Angle of AzTPP Relative to Shimal CCPP

DISTURBANCE: **switch off high-voltage 500 kV Samukh-Gardabani (Georgia) OHL**

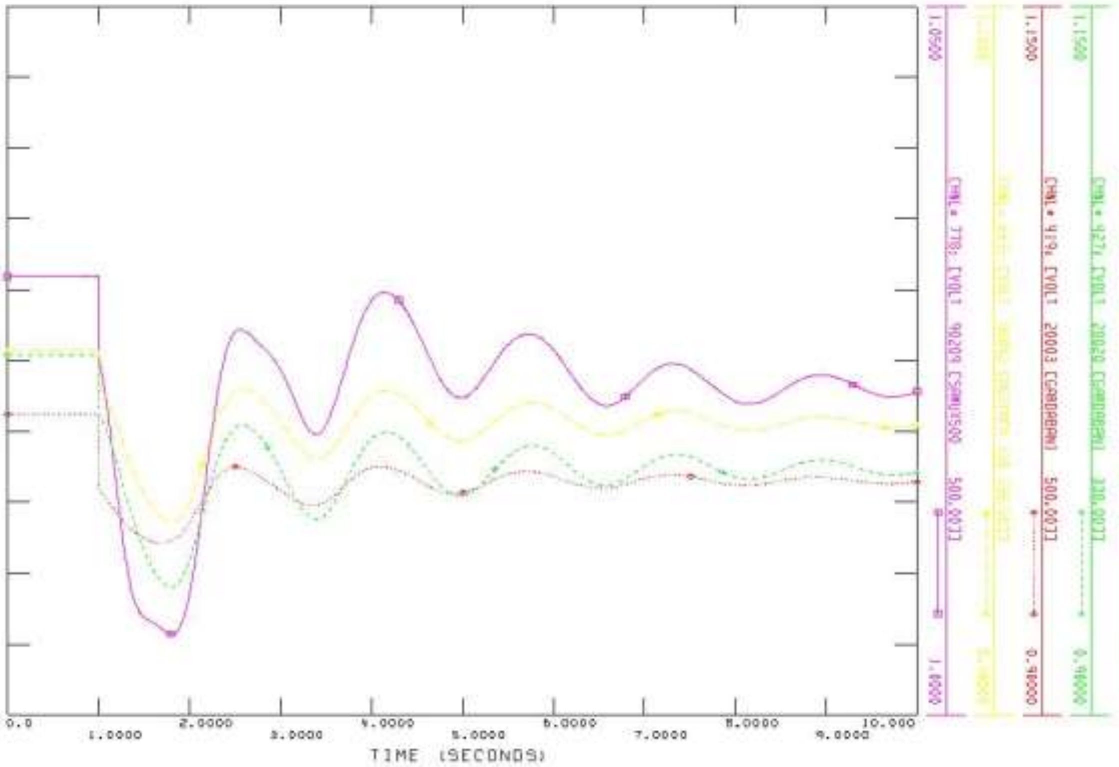


Fig.1-23: Voltage on bus 500kV Samukh SS , 330kV Akstafa SS, 500kV Gardabani SS, 330kV Gardabani SS

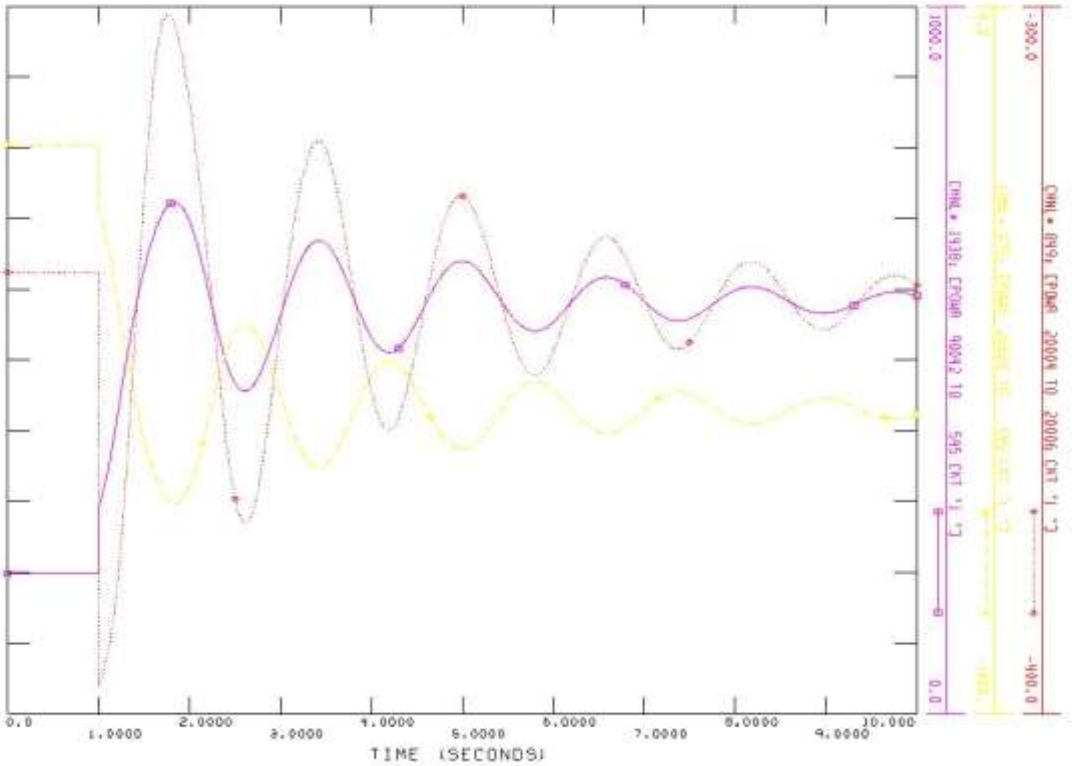


Fig.1-24: **Power flow 500kV Samux-Gardabani OHL, 330kV Akstafa-Gardabani OHL, 500kV Akhaltsikhe-Tskaltubo (Georgia) OHL**

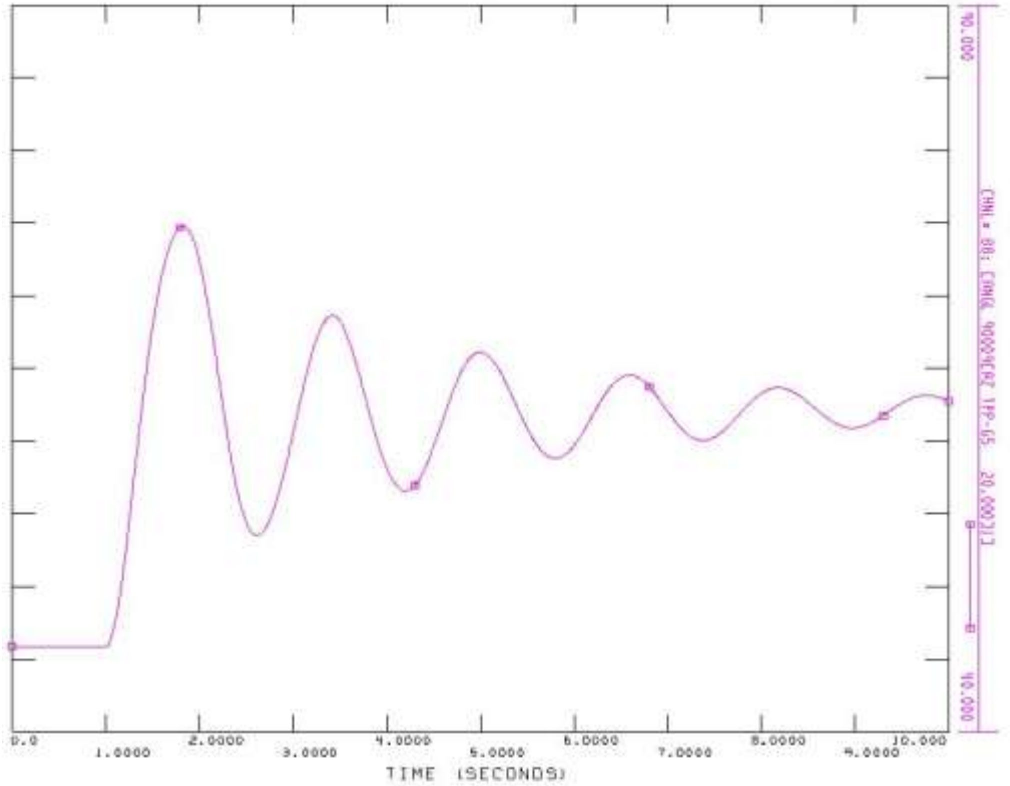


Fig.1-25: Angle of AzTPP Relative to Inguri HPP (Georgia)

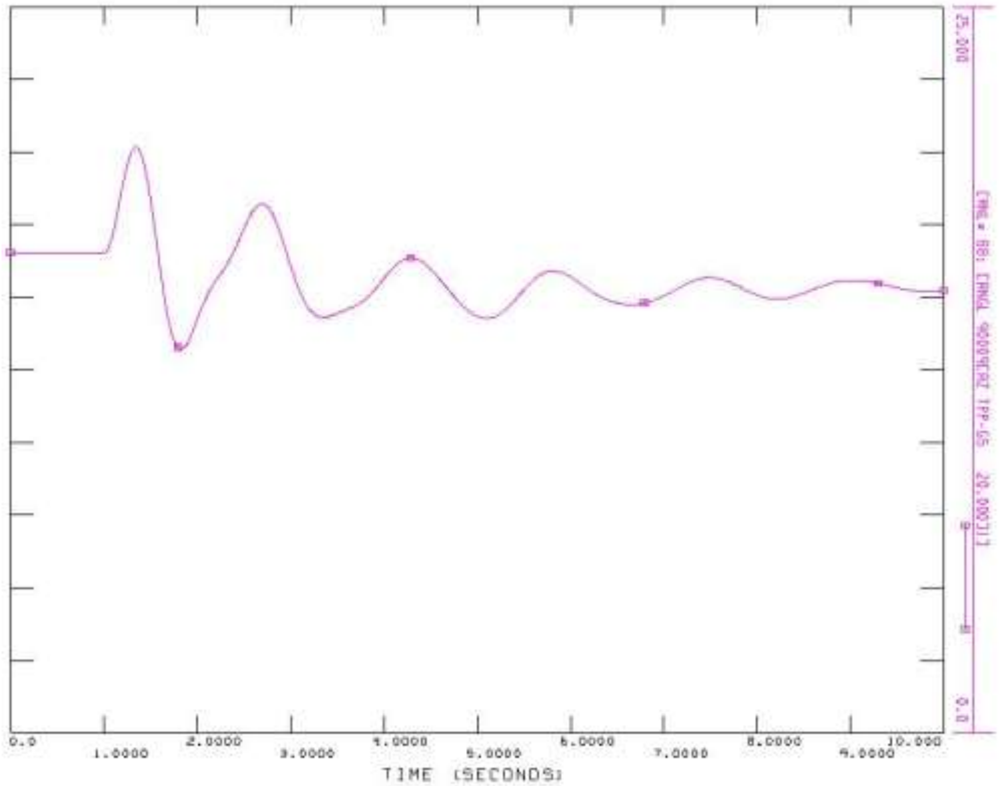


Fig.1-26: Angle of AzTPP Relative to Shimal CCPP

DISTURBANCE: switch off high-voltage 500KV Akhaltsikhe-Tskaltubo

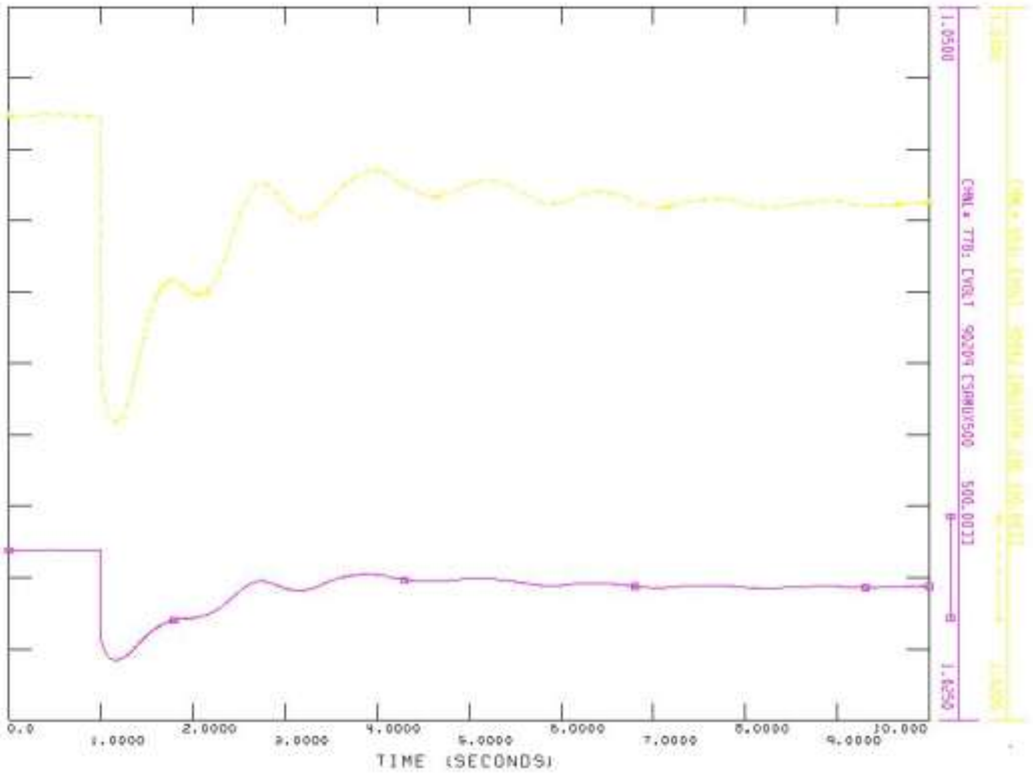


Fig. 1-27: Voltage on bus 500 kV Samukh SS, 330 kV Akstafa SS

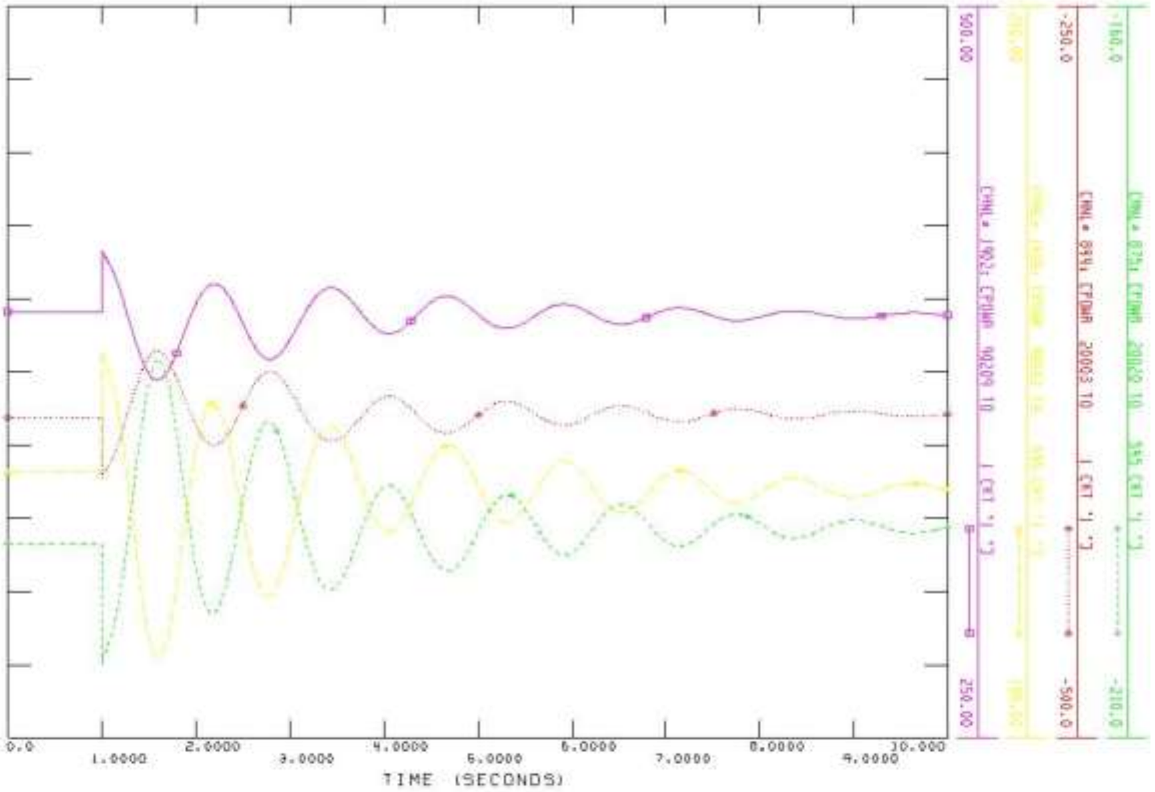


Fig.1-28: Power flow 500kV Samukh-Gardabani (Georgia) OHL, 330kV Akstafa-Gardabani (Georgia) OHL

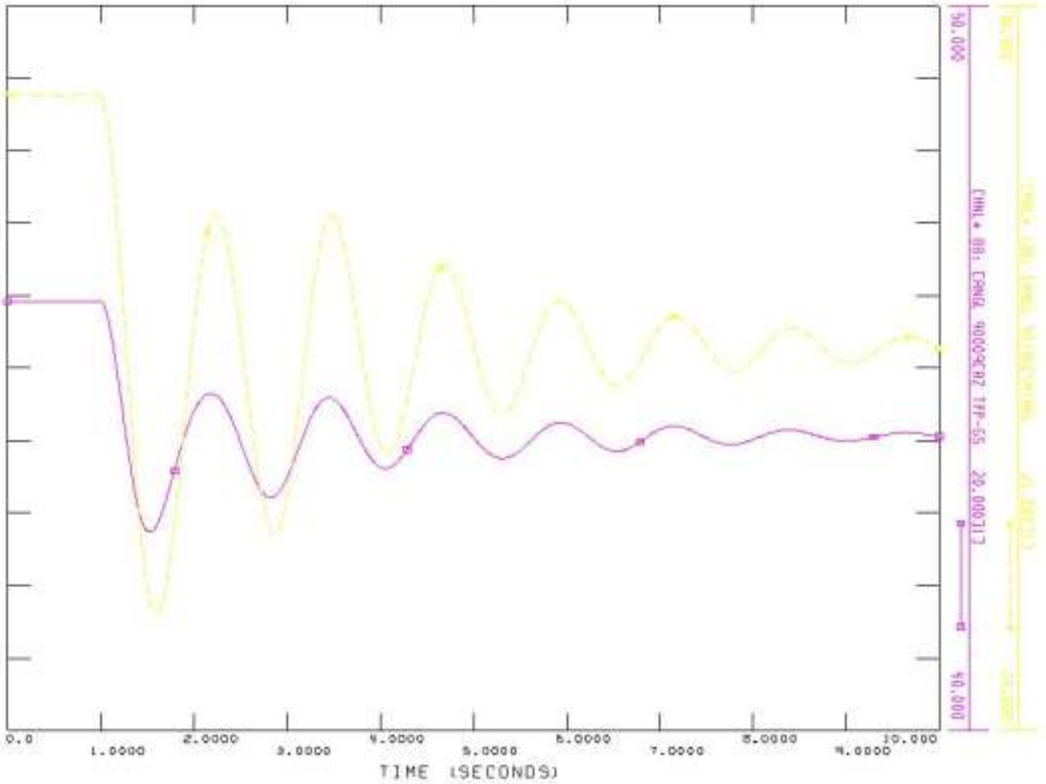


Fig. 1-29: Angle of AzTPP, Shimal CCPP Relative to Inguri HPP

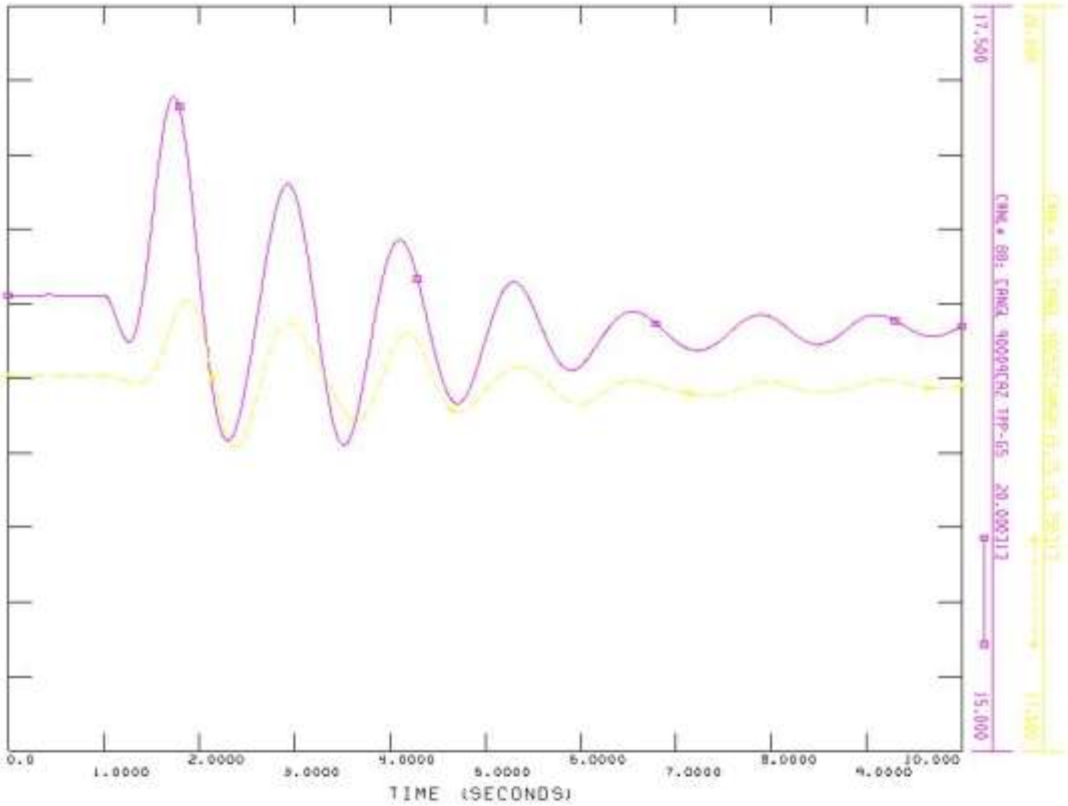


Fig. 1-30: Angle of AzTPP, Sumgayit CCPP Relative to Shimal CCPP

DISTURBANCE: switch off both high-voltage 330 kV AzTPP-Goranboy OHL

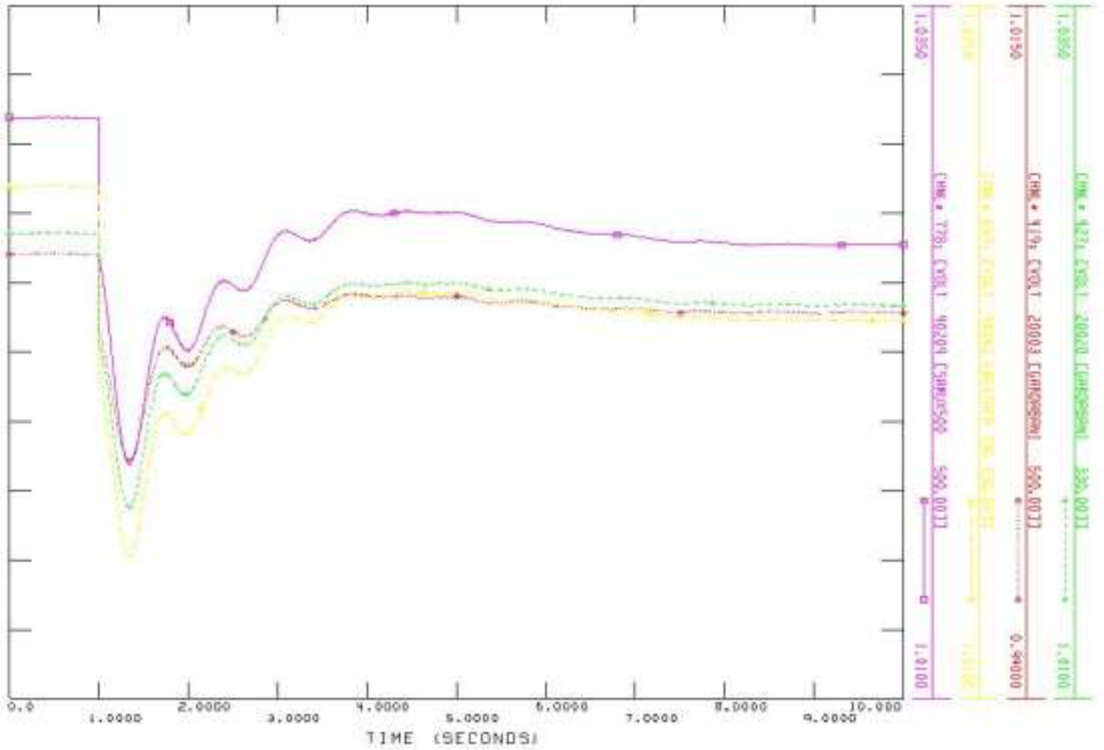


Fig.1-31: **Voltage on bus 500kV Samukh SS, 330kV Akstafa SS, 500kV Gardabani SS (Georgia), 330kV Gardabani SS (Georgia)**

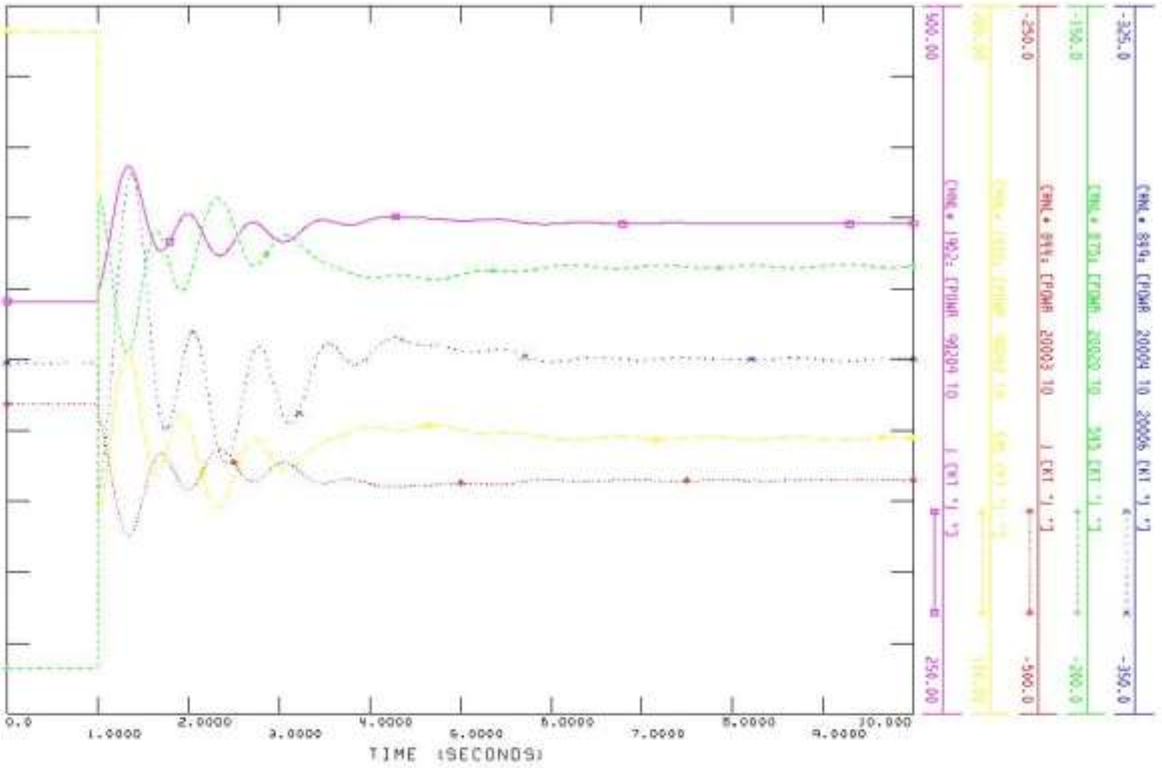


Fig.1-32: Power flow 500kV Samux-Gardabani (Georgia)OHL, 330kV Akstafa-Gardabani (Georgia) OHL, 500kV Akhaltsikhe-Tskaltubo (Georgia) OHL

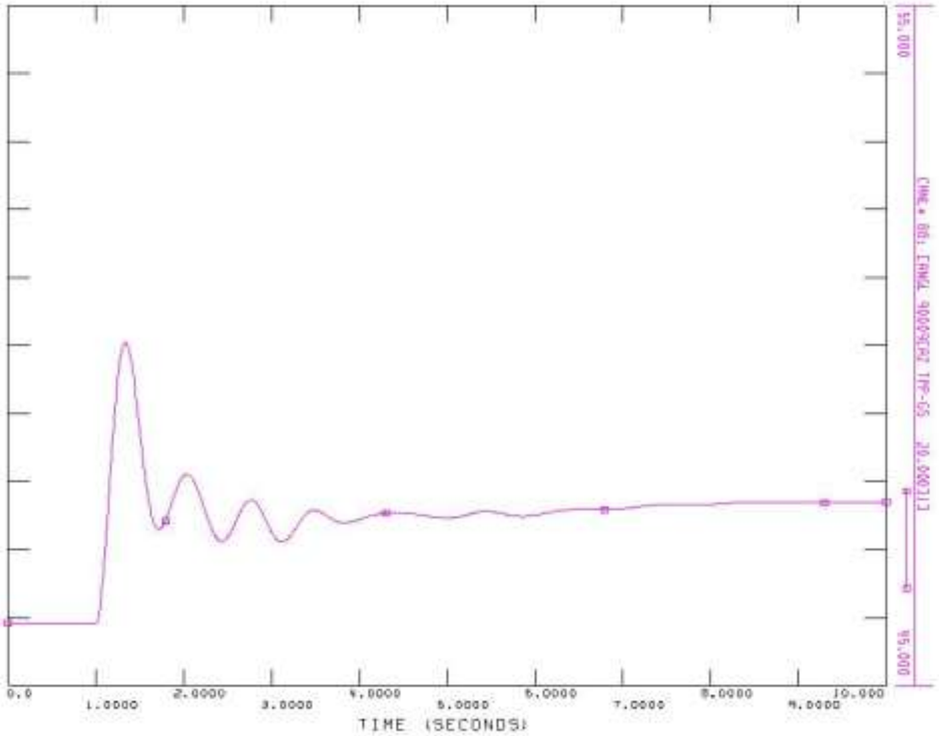


Fig.1-33: **Angle of AzTPP Relative to Inguri HPP (Georgia)**

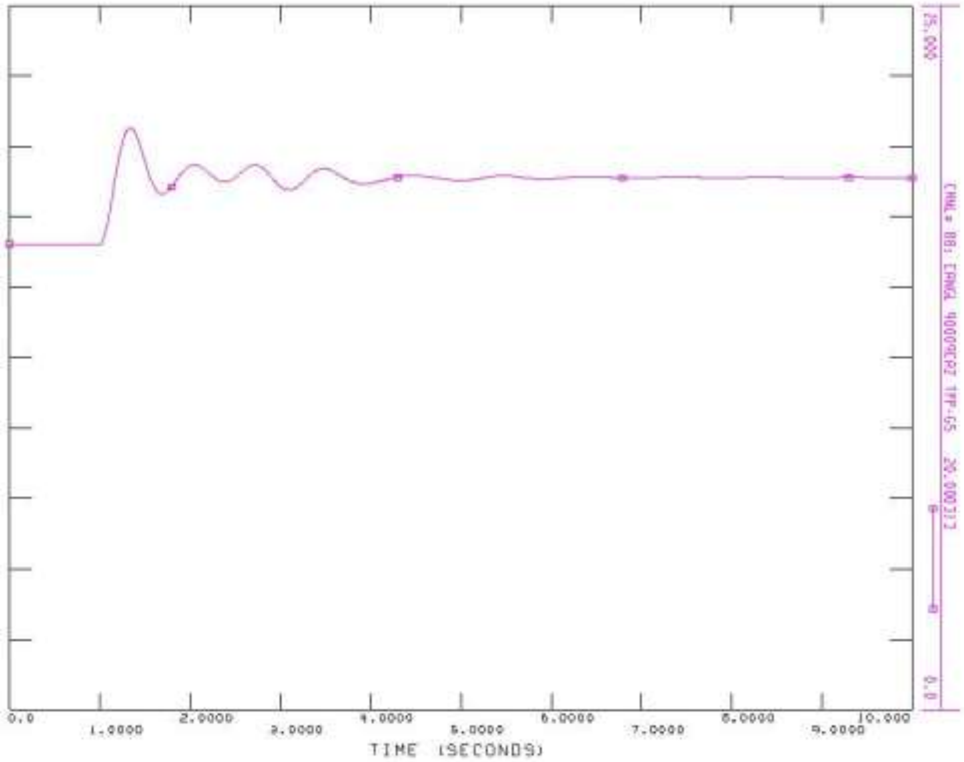


Fig.1-34: **Angle of AzTPP Relative to Shimal CCPP**

DISTURBANCE: **3-phase short circuit on bus AzTPP 500 kV t=0.12sec, t_{limit}=0.23sec**

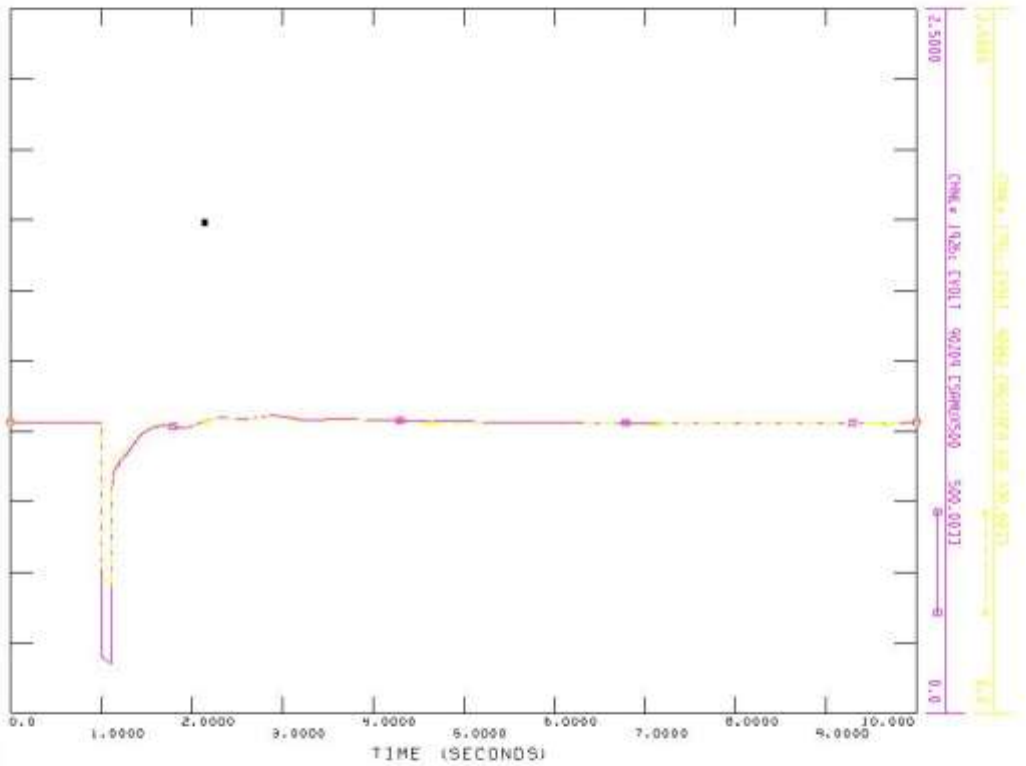


Fig. 1-35: Voltage on bus 500 kV Samukh SS , 330 kV Akstafa SS

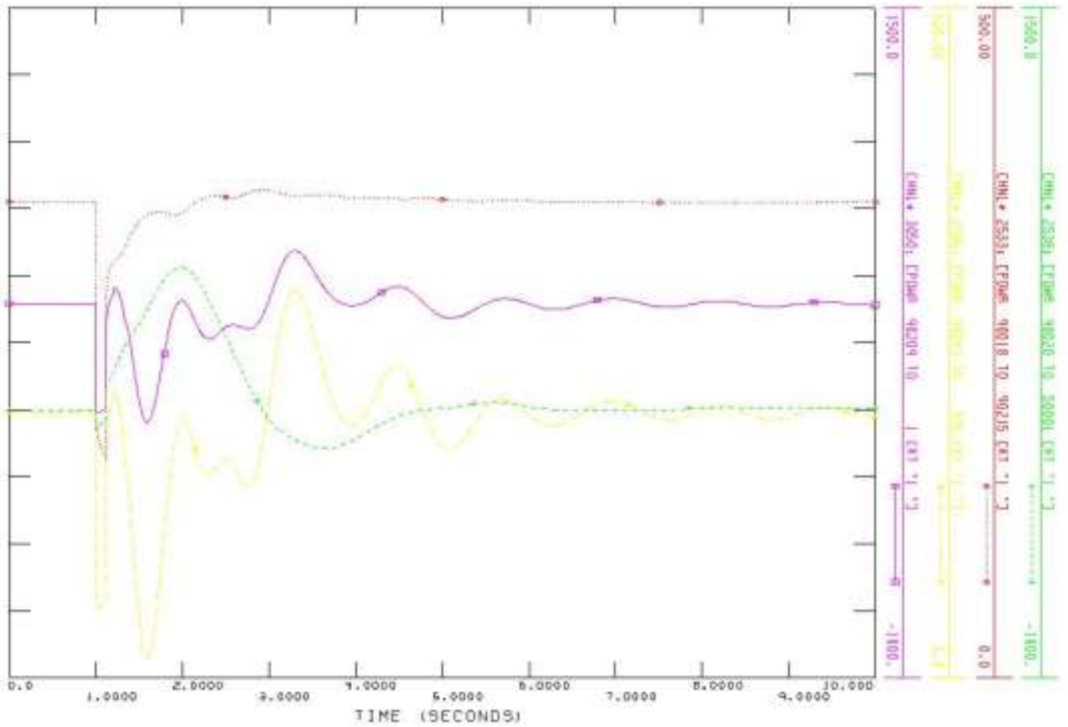


Fig. 1-36: Power flow 500 kV Samukh-Gardabani (Georgia) OHL,
330 kV Akstafa-Gardabani (Georgia) OHL, 330 kV Imishli-Ardabil (Iran) OHL,
330 kV Xachmaz-Derbent (Russia) OHL

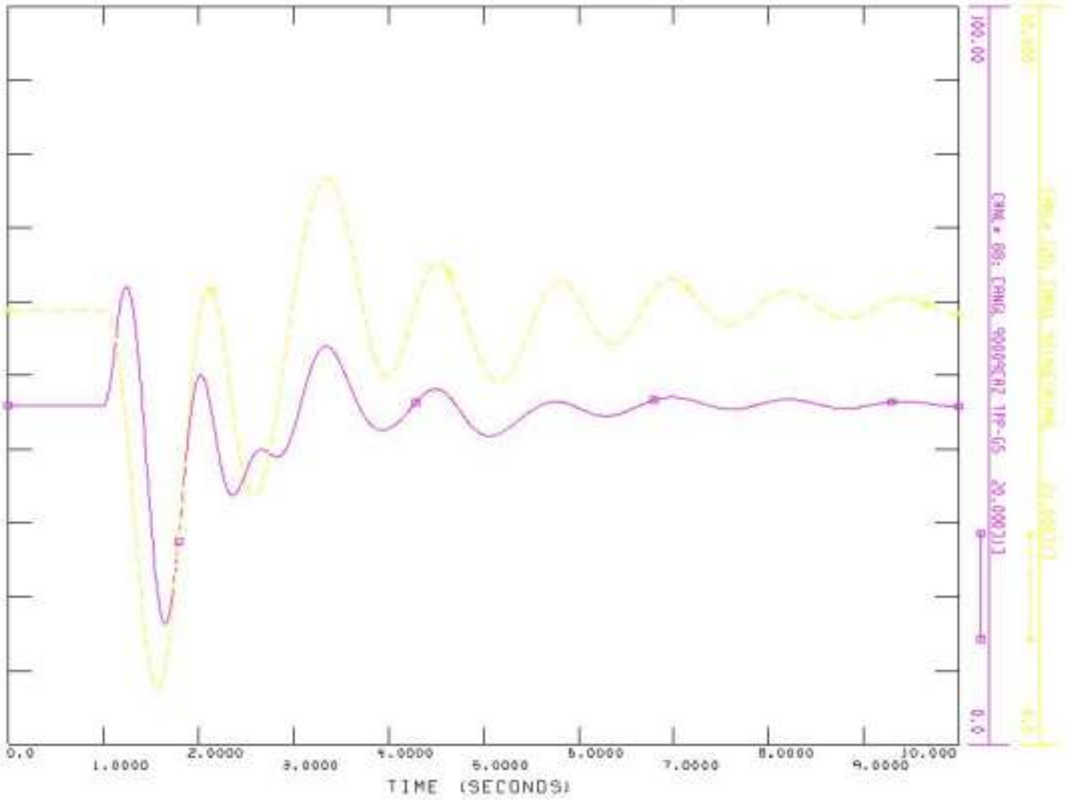


Fig. 1-37: Angle of AzTPP, Shimal CCPP Relative to Inguri HPP

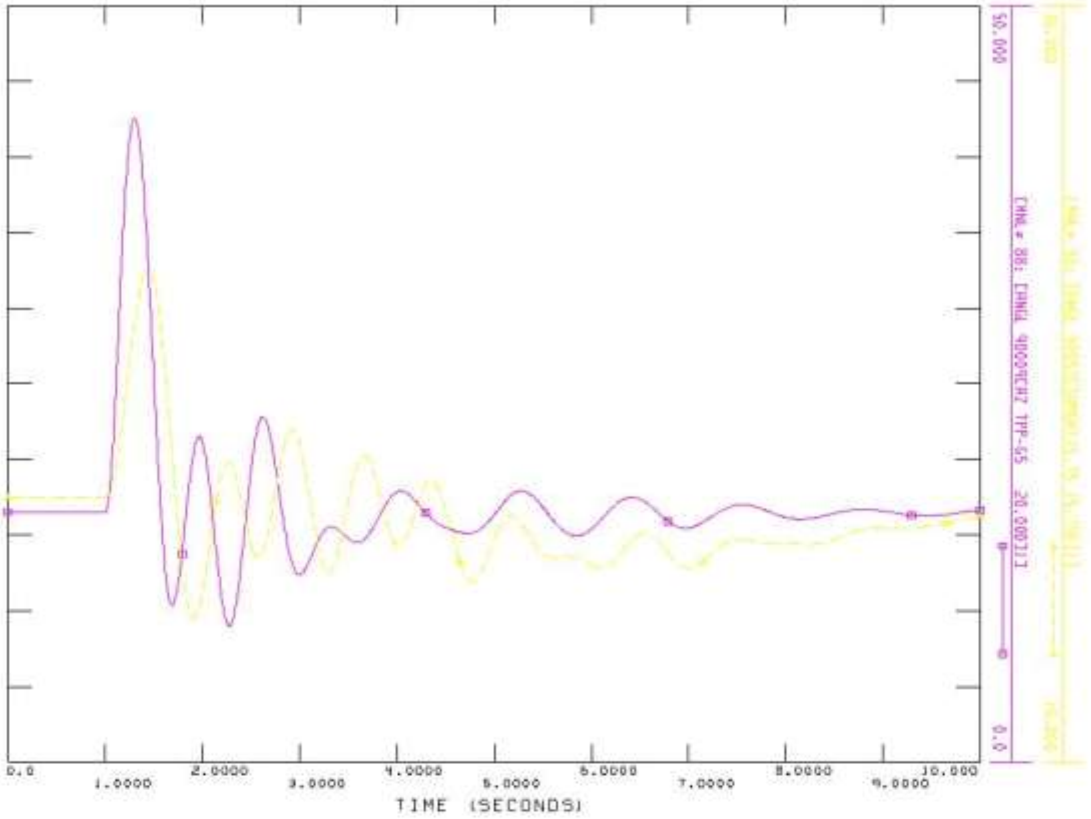


Fig.1-38: Angle of AzTPP, Sumgayit CCPP Relative to Shimal CCPP

DISTURBANCE: 3-phase short circuit on bus 500KV Samukh SS t=0.12sec, T_{limit}=0.28sec

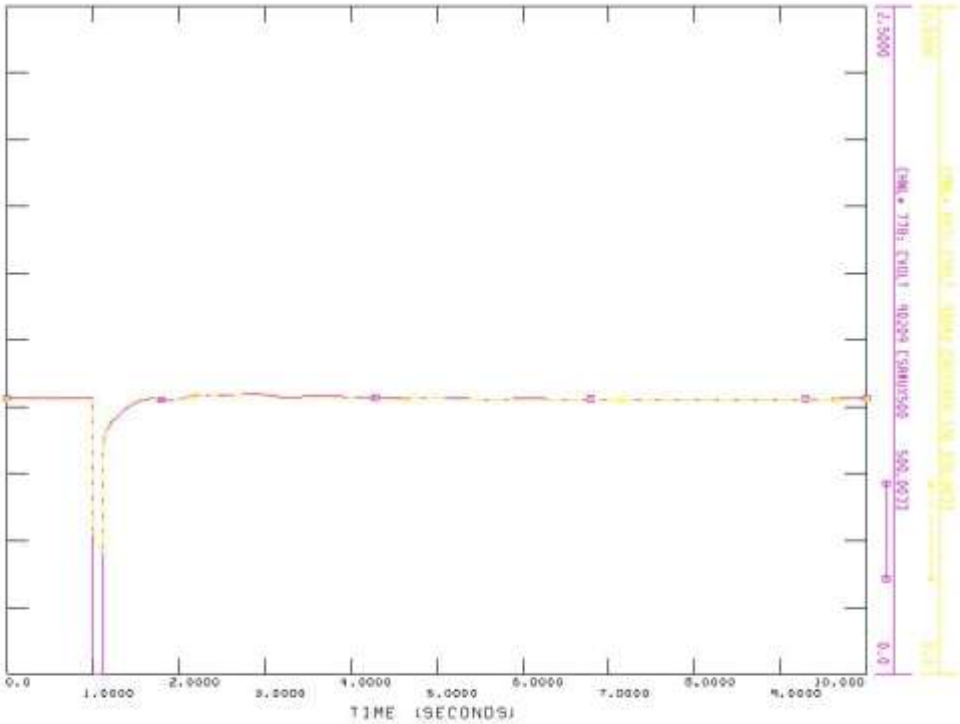


Fig.1-39: Voltage on bus 500kV Samukh SS, 330kV Akstafa SS

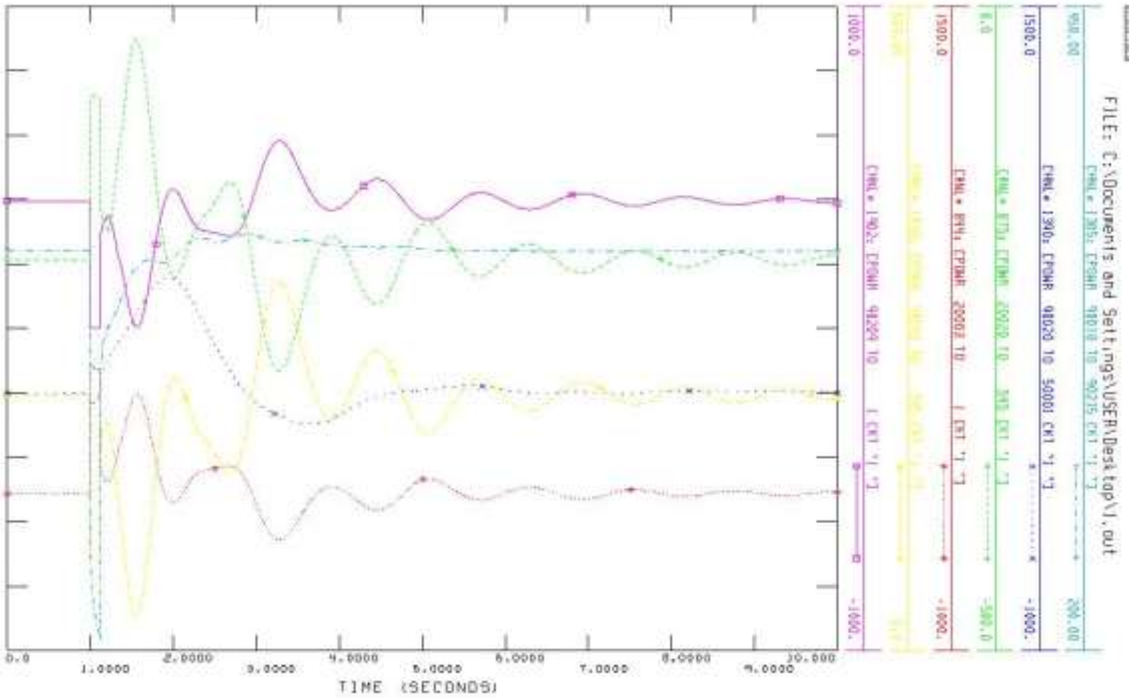


Fig.1-40: **Power flow 500kV Samukh-Gardabani (Georgia) OHL, 330kV Akstafa-Gardabani (Georgia) OHL, 330kV Xachmaz-Derbent (Russia) OHL, 330kV Imishli-Ardabil (Iran) OHL**

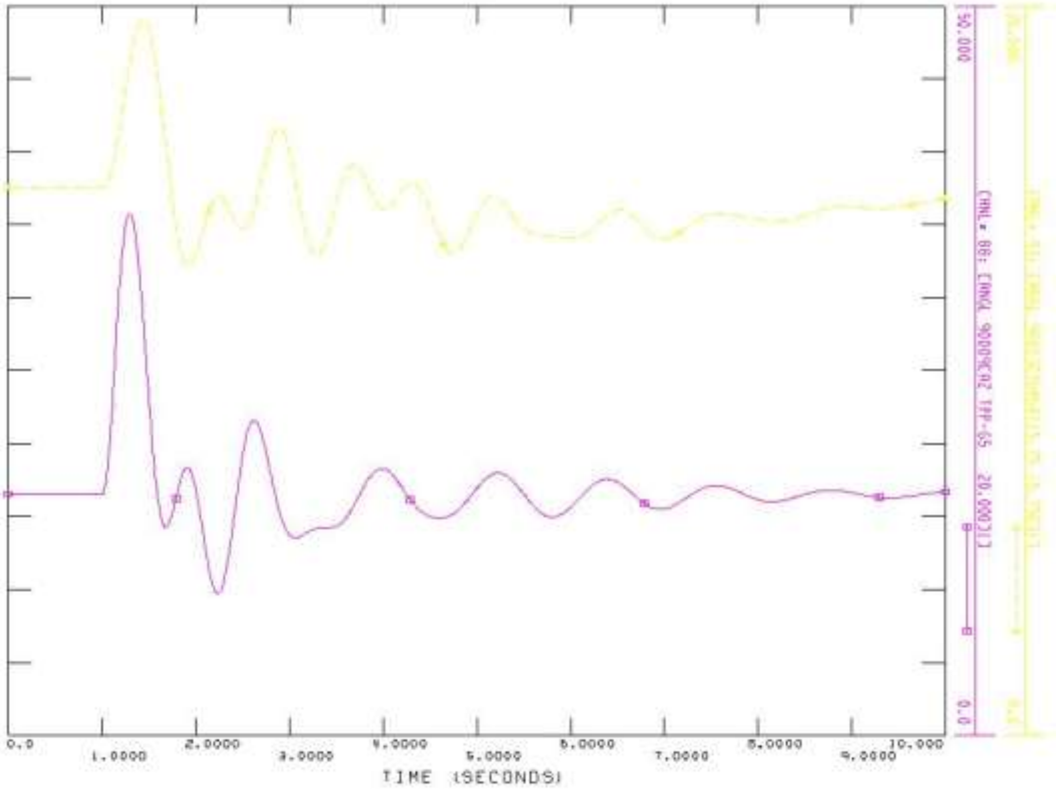


Fig.1-41: **Angle of AzTPP, Sumgayit CCPP Relative to Shimal CCPP**

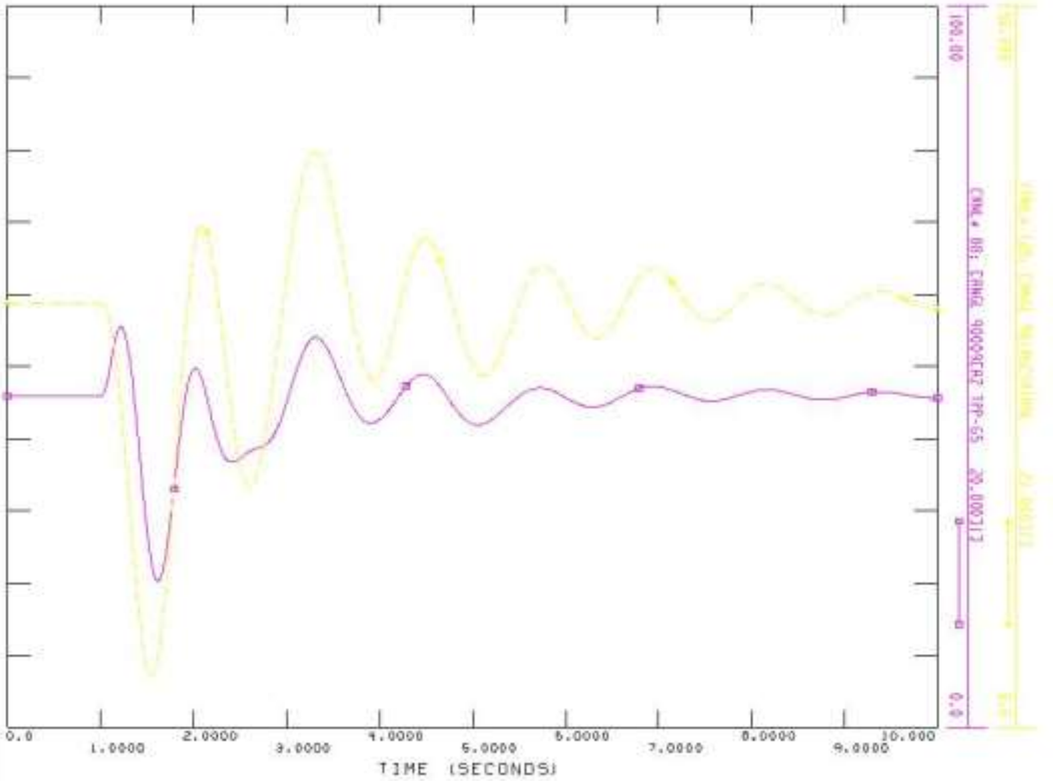


Fig.1-42: **Angle of AzTPP, Shimal CCPP Relative to Inguri HPP**

2. Stability of modes and schemes during operaton process in Azerbaijan PS (the scheme and the mode of the year 2015)

2.1. The characteristics of the mode and scheme:

The followings are taken into consideration in the scheme of development Azerbaijan PS for the year of 2015:

- Connecting 220 kV Shimal CCPP network voltage, inclusion of the 2nd unit with 400 MW;
- 220/110 kV the inclusion of Boyuk Shor SS;
- 220 kV Govsan – Simal OHL (2 cycle);
- 110 kV Boyuk Shor-Binagadi OHL (2 cycle);
- 110 kV Boyuk Shor -205 OHL.

PS modes are characterized in the following way:

$P_{gen.}$ = 5344 MW,

P_{load} = 5175 MW.

The power load consist of 2:

- special load of PS – 4031 MW;
- imitation of the nearest PS load – 1144 MW.

Load to the nearest PS:

Georgia PS: Total - 594 MW:

- 500 kV Samukh-Gardabani OHL – 413 MW;
- 330 kV Agstafa-Gardabani OHL – 181 MW,

İran PS:

- 330 kV İmishli-Parsabad OHL – 550 MW,

North Caucasus PS (RF):

- 330 kV Xachmaz-Derband OHL – 0 MW.

Power flows of the main modifier 500-330 kV in OHL are shown in Table 2-1 N-1 modes.

Normal conditions and N-1 **Table 2-1**

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

The obtained results show that the normal mode of 500 kV AzTPP-Samukh OHL, 500 kV 2nd Absheron OHL and 330 kV 1st Absheron OHL are overloaded.

In N-1 mode the following lines accept more load (≥P_n):

- when 500 kV 2nd Absheron OHL switch off, 330 kV 1st Absheron OHL - 53,3 %;
- when 330 kV 2nd AzTPP-Goranboy OHL switch off, 330 kV 1st AzTPP-Goranboy OHL – 57 %;
- when 330 kV 1st AzTPP-Goranboy OHL switch off, 330 kV 2st AzTPP-Goranboy OHL – 68 %;
- when 500 kV AzTPP-Samukh OHL switch off, 330 kV AzTPP-Samukh OHL – 99 %;

when 330 kV Agcabadi-Goranboy OHL switch off, 330 kV- İmishli-Goranboy OHL – 84 %;

Overload due to current didn’t occur in any modes.

2.2. Dynamic stability of Azerbaijan PS during operation conditions

(The mode and the scheme of the year 2015)

The following types of disturbance are considered:

1. Switch off in power plants:
   - switch off 4 units in Yenikend HPP– 150 MW (fig. 2-2);
   - switch off 2 units in Baku TPP– 110 MW (fig. 2-3);
   - switch off 2 units in AzTPP– 540 MW (fig. 2-4);
   - switch off units in Shimal CCPP– 350 MW (fig. 2-5);
   - switch off 2 units in Simal CCPP – 700 MW(fig. 2-6);
   - switch off units in 330 kV AzTPP buses – 1360 MW (fig. 2-7);
   - switch off in AzTPP – 2170 MW (fig. 2-8).

Frequency in normal mode is f = 49.997 Hz.

The minimum frequency during the process and as well as changes of the relative angles in power plants generators was recorded.

2. the 3rd phase s.c. in PP high voltage buses

In this case, the time of the dynamic stability was defined. The process of is designed for the following cases:

- s.c. 500 kV in AzTPP bus (fig. 2-9);
- s.c. 330 kV in AzTPP bus. (fig. 2-10);
- s.c. 110 kV in Shimal CCPP bus. (fig. 2-11);
- s.c. 220 kV in Shimal CCPP bus (fig. 2-12);
- s.c. 110 kV in JanubCCPP bus (fig. 2-13);
- s.c. 110 kV in Sumgaıt CCPP buses (fig. 2-14, 2-15);
- s.c. 110 kV-in Sangachal TPP buses (fig. 2-16, 2-17).

Relative angles of the PS generators and voltage change in s.c. were recorded

3. Load rejection

Load rejection occured in the following SS:

- Power flow to Georgia in 330 kV Gardabani SS (181 MW) and in 500 kV Gardabani SS (413 MW);

- In Boyuk Shor SS (289 MW).

Frequency, changes of the relative angles and voltage were recorded.

The calculation of the results is given in fig.2-18 and fig.2-19.

4. Load rejection of more than 500 kV and 330 kV OHL:

The following switch offs were considered:

- 500 kV AzTPP-Samukh OHL (fig 2-20)
- 330 kV AzTPP-Samukh OHL (fig. 2-21)

Switched off lines after 0.2 s were connected with automatic reclosing

Frequency, changes of the relative angles and voltage were recorded.

The results of the analysis are given below:

1. The system remains stable in all types of disturbance,
2. The changes of relatime angles can occur during switch off units in Bakı TPP (fig.2-3) and Shimal CCPP (fig.2-6)

Frequency of the power generation change (decrease) depends on the strength of the static characteristics of PS in Azerbaijan PS as it’s given in fig.2-8. It characterize each point of characteristics (Table 2-2). Thus, during power reduction of 1360 MW, i.e. in 330 kV buses AzTPP generator during switch off 5 generators (26,3%) frequency reduces to 48.874 Hz. The consistent equals coefficient K = 11.679.

3. During the 3rd phase s.c. switch off was calculated according to the following values:

- 500 kV in AzTPP bus - 0,35s;
- 330 kV in AzTPP bus - 0,3s;
- 110 kV in Shimal CCPP bus - 0,55s;
- 220 kV in Shimal CCPP bus - 0,65s;
- 110 kV in Janub CCPP bus - 0,55s;
- 110 kV in Sumgaıt CCPP bus - 0,6s;
- 110 kV in Sangachal TPP bus - 0,15s.

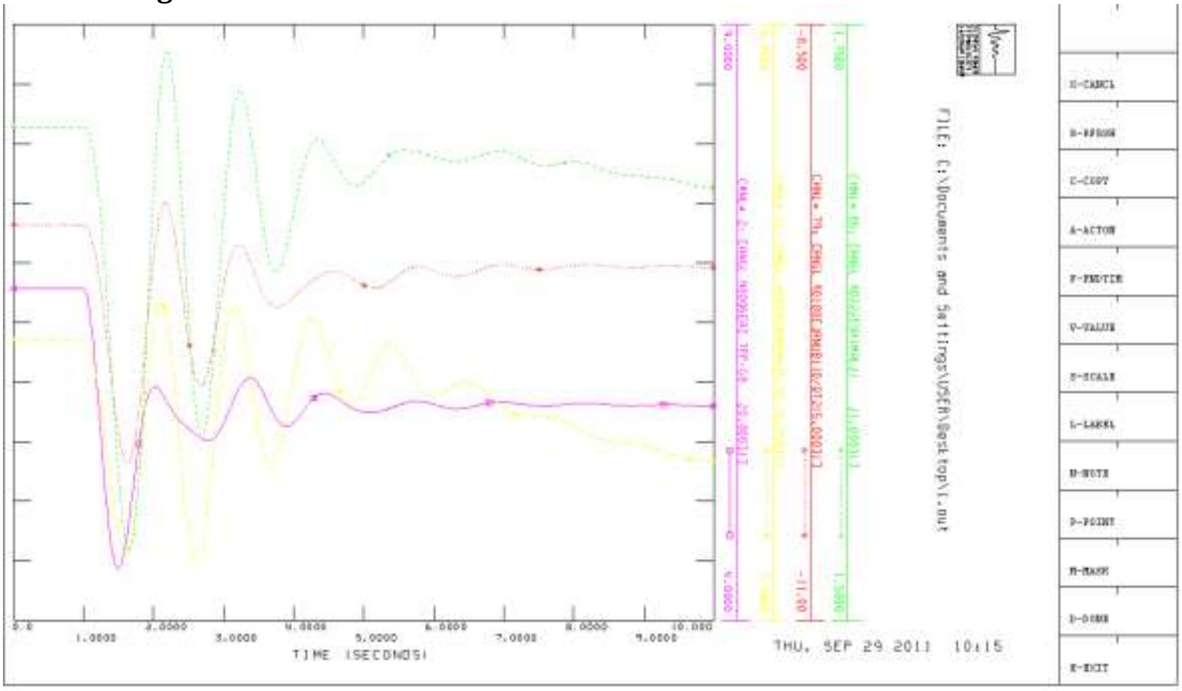
In Sumgait CCPP 110 kV bus within t_h = 0,6s , 110 kV Sangachal TPP changes are shown in fig.2-15. At the same time, the changes in 110 kV Sangachal buses during s.c. and within t_h = 0.2s are given in (fig.2-17). In Sangachal buses within t_h – the value is 0,15s. The reason for this is the stability of plants which makes t_h = 2,74s

4. In Gardabani OHLs of 330 kV and 500 kV, in 600 MW load buses switch off In Azerbaijan PS increases in value up to 50.248 Hz (fig.2-18). Generators in the Shimal CCPP lead to the 330 kV Samukh SS (fig.2-19).

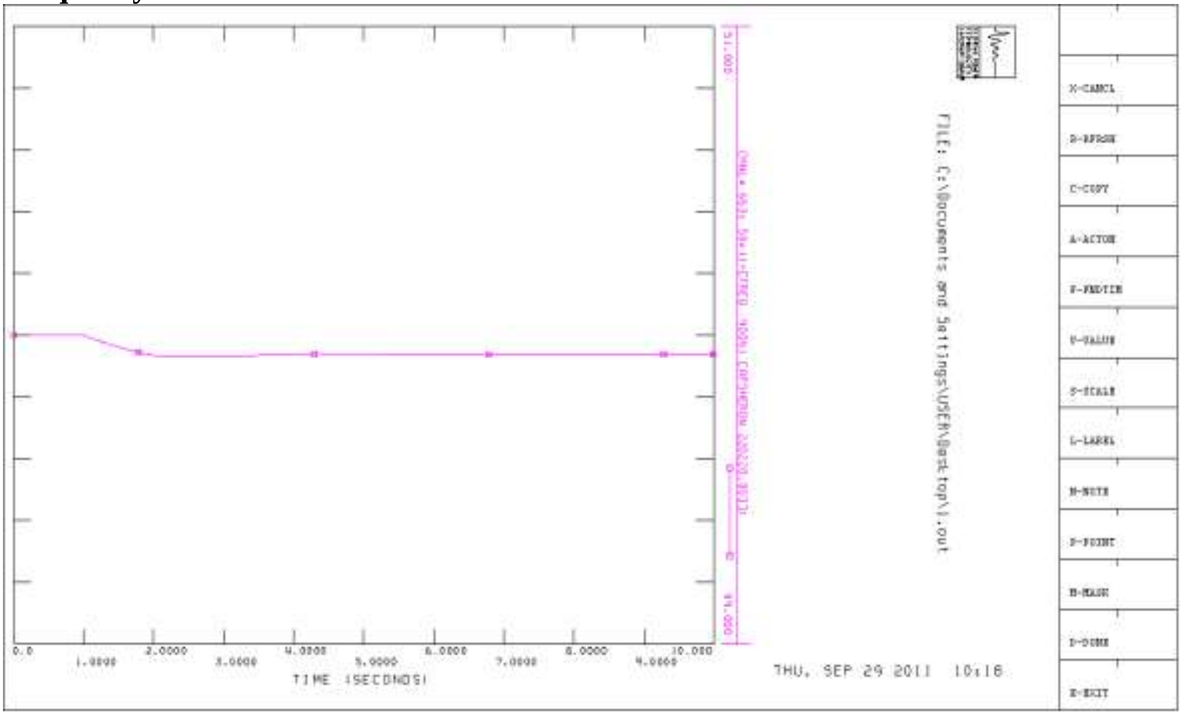
5. During switch off interconnection lines with automatic reclosing (t = 0.2 s) of 500 kV and 330 kV voltage and power, the process of the changes of the relative angles, are given in fig.2-20÷2-21.

DISTURBANCE: switch off each 4 blocks on Yenikand HPP

Relative angels to 110 kV Shimal CCPP



Frequency

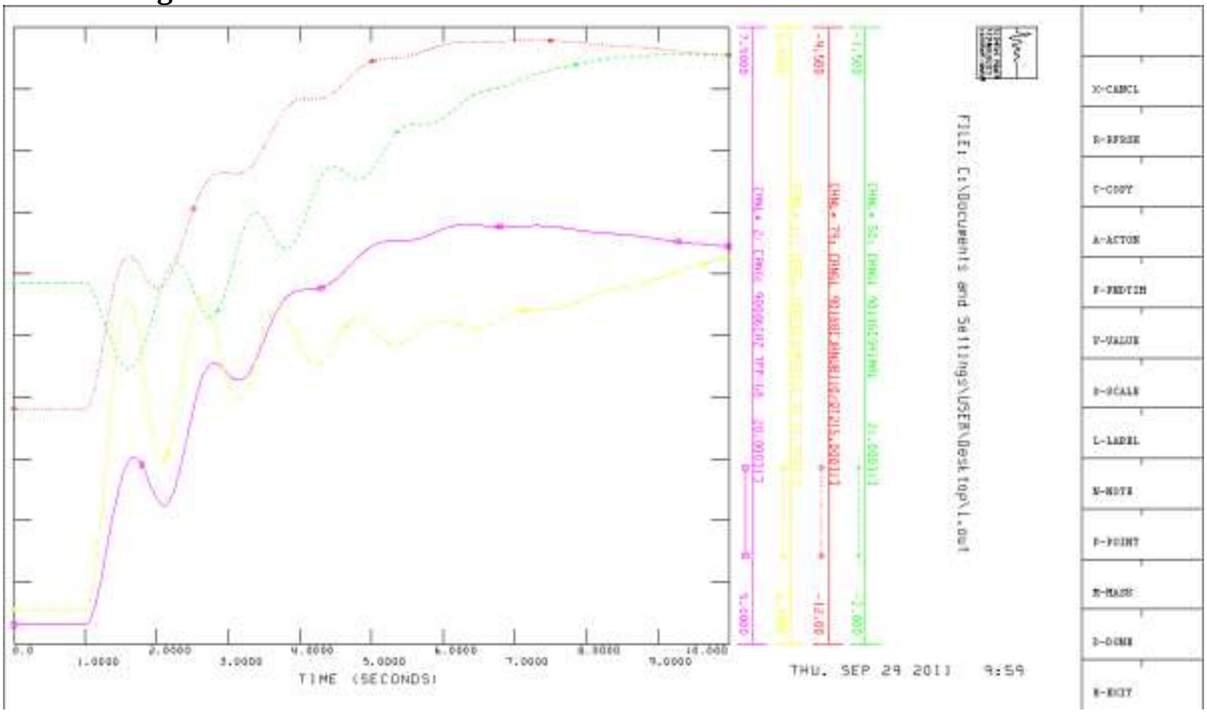


F_0=49,998Hz
F_∞=49,945Hz

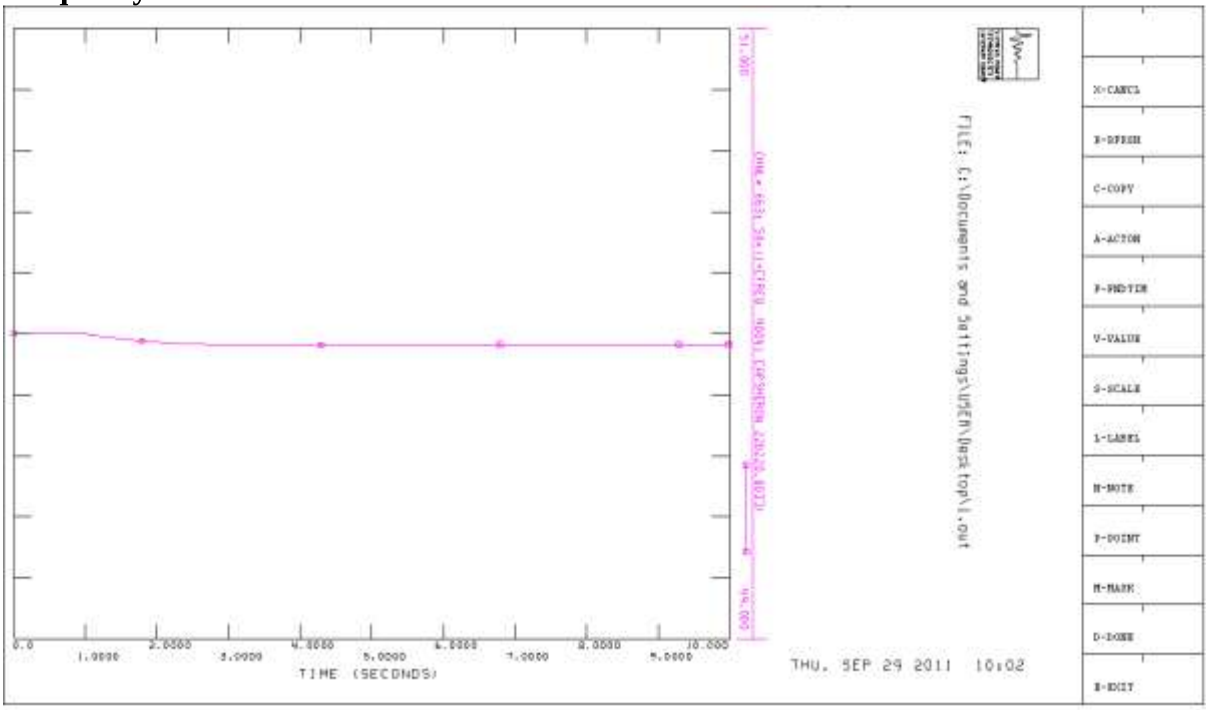
Fiq. 2-2

DISTURBANCE: switch off on both BAKI TPP

Relative angels to 220 kV Shimal CCPP



Frequency

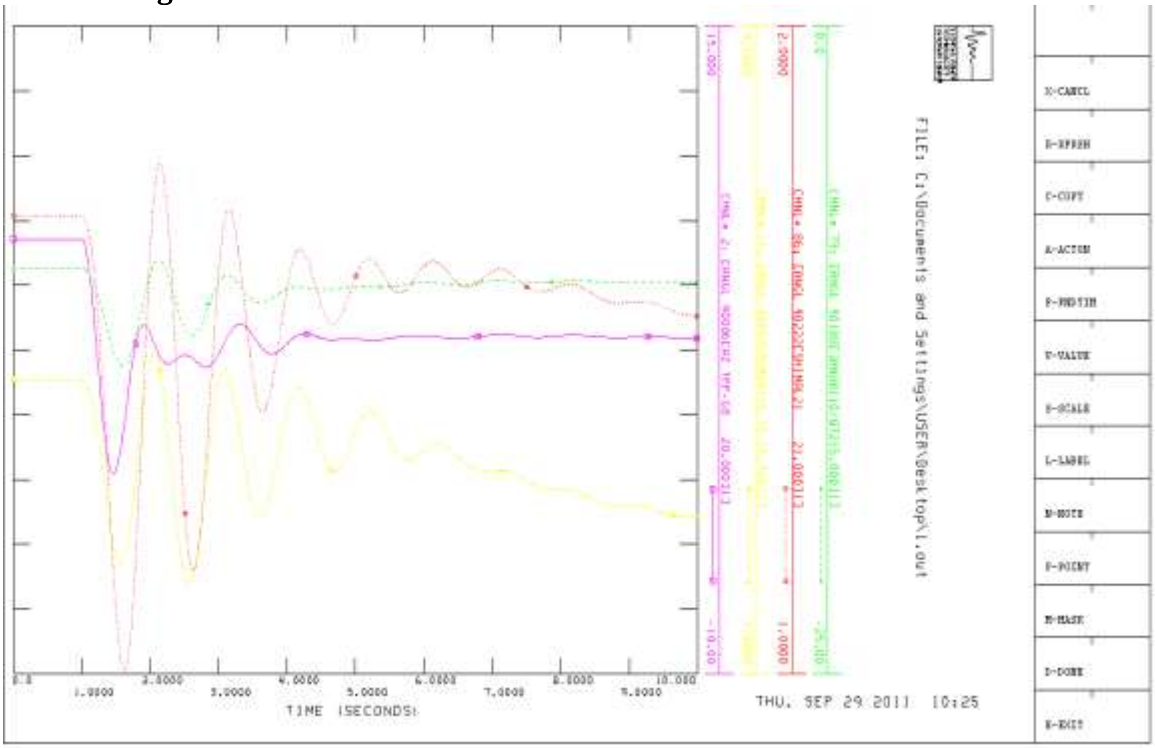


F_0=49,997Hz
F_∞=49,968Hz

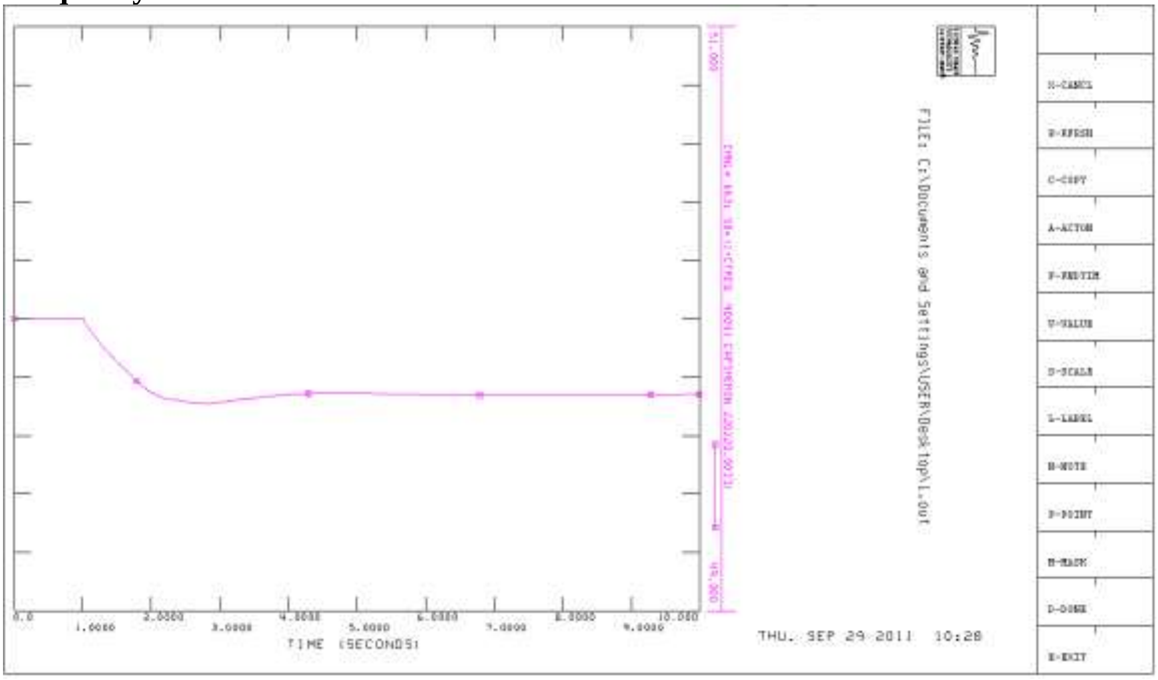
Fig. 2-3

DISTURBANCE: switch off 2 units on 330 kV AzTPP

Relative angels to 110 kV Shimal CCPP



Frequency

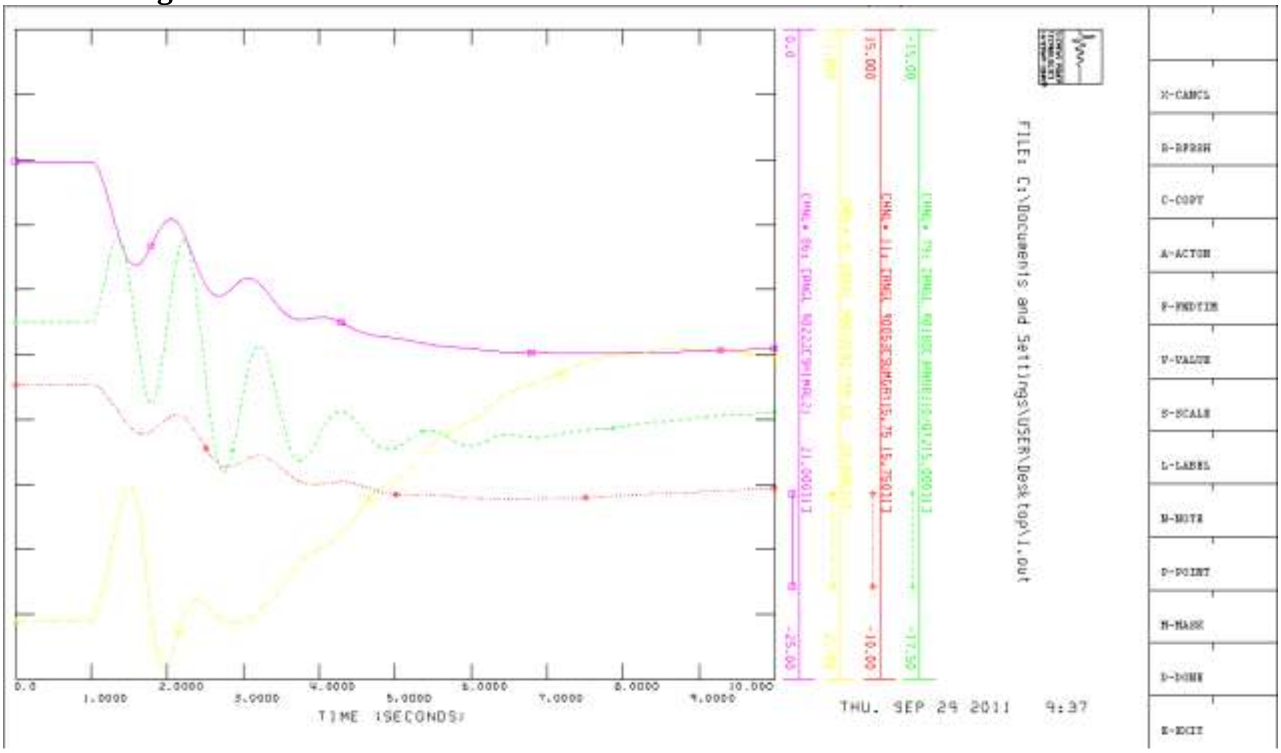


F_0=49,998Hz
F_∞=49,744Hz

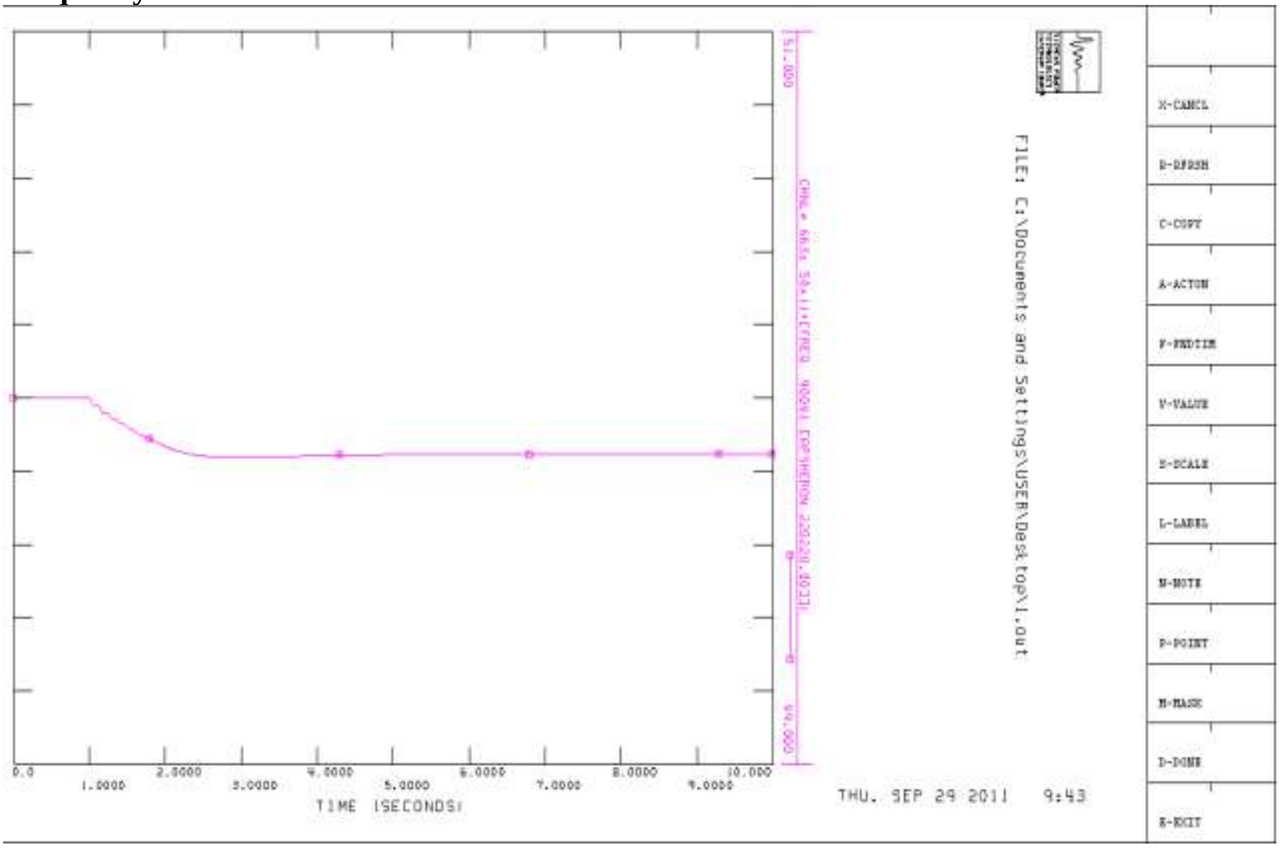
Fiq. 2-4

DISTURBANCE: switch off on 110 kV Shimal CCPP

Relative angles to 500 kV AzTPP



Frequency



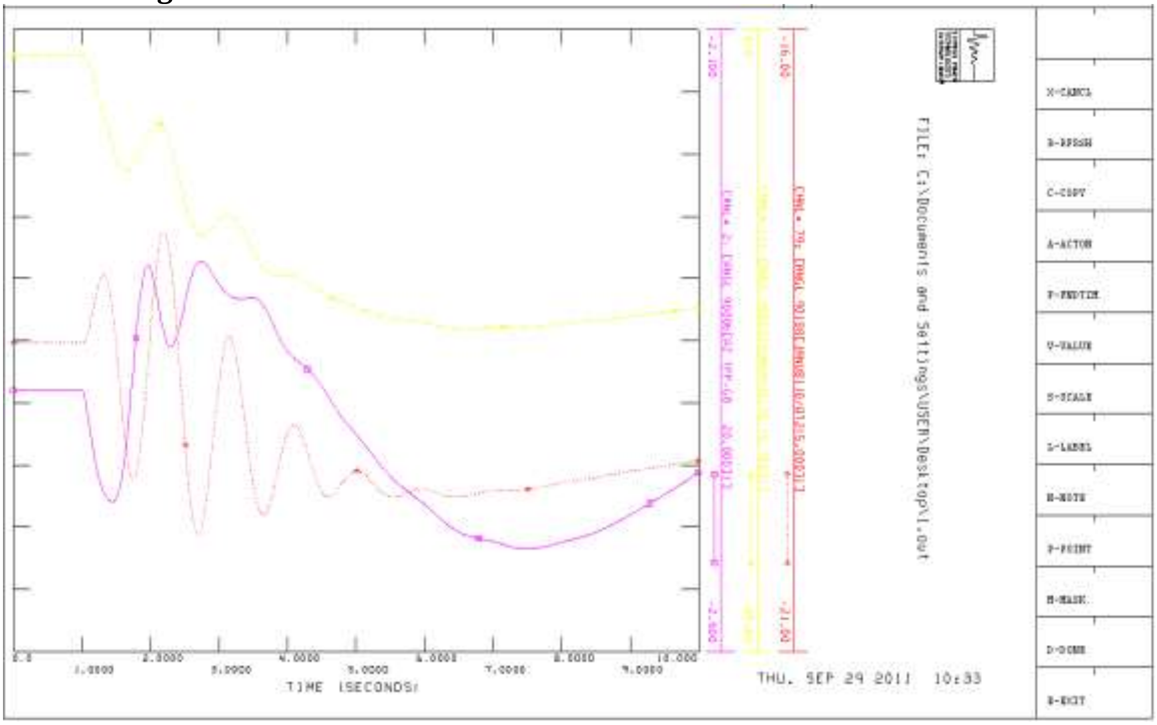
F_0=49,998Hz

F_∞=49,858Hz

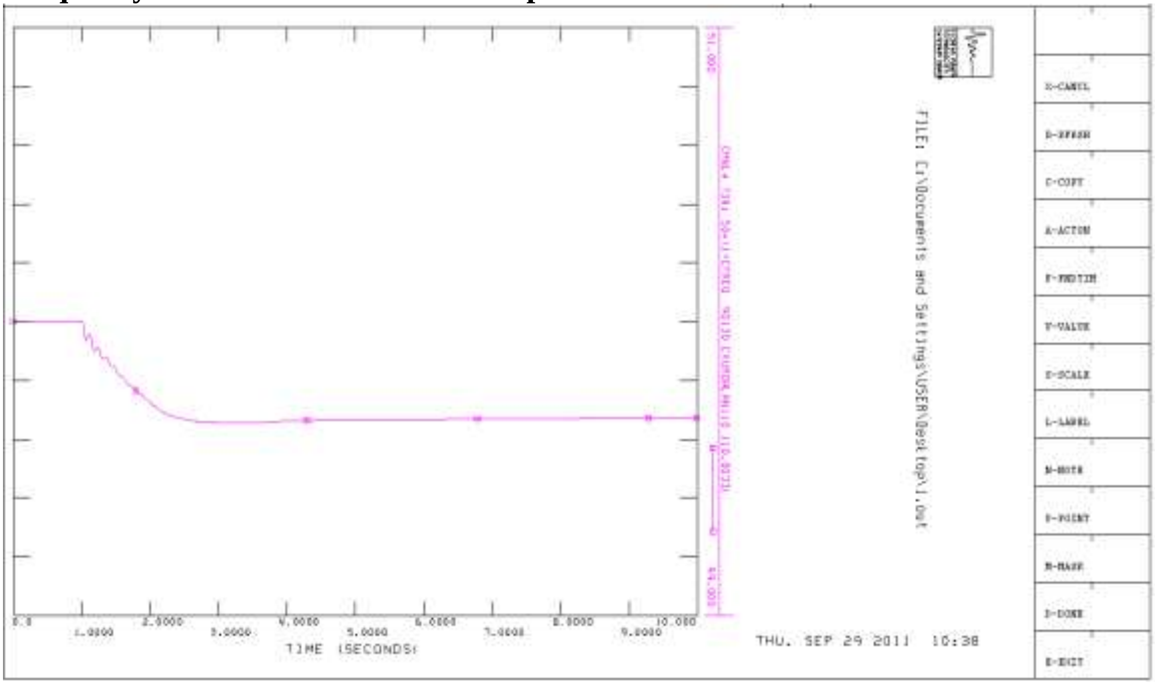
Fig. 2-5

DISTURBANCE: switch off 2 units on Shimal CCPP

Relative angels to 330 AzTPP



Frequency on 110 kV Khirdalan semi-plant

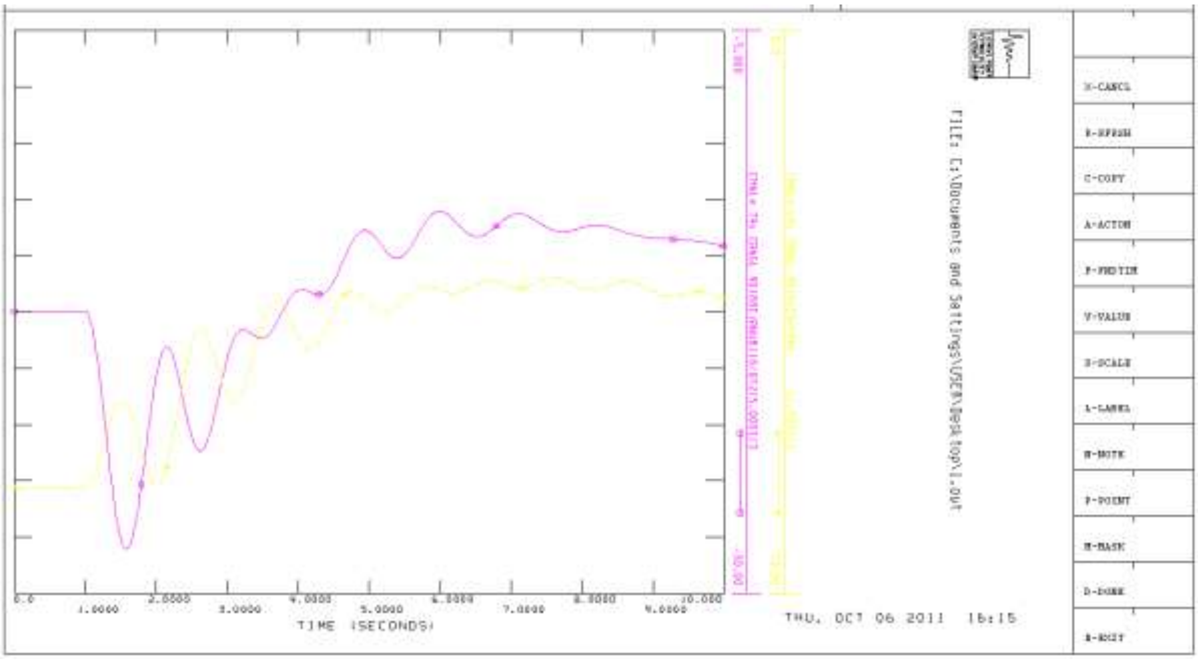


F_0=49,997Hz
F_{min}=49,671Hz
F_∞=49,676Hz

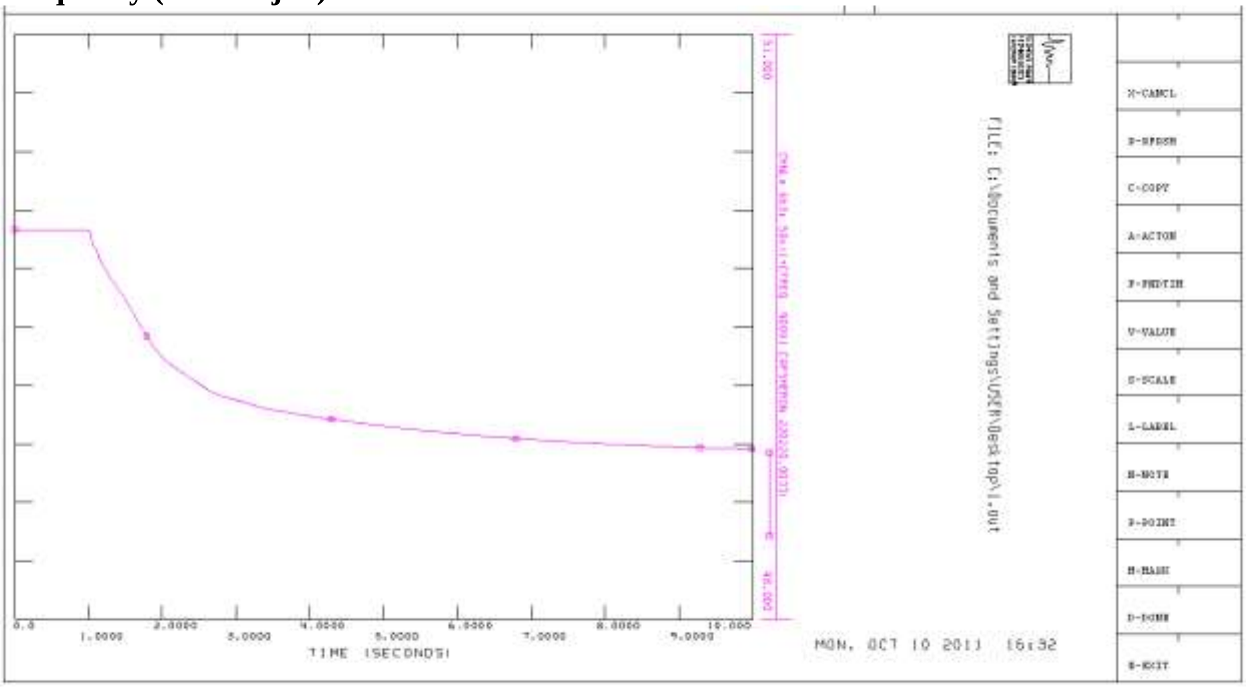
Fiq. 2-6

DISTURBANCE: switch off blocks on AzTPP (1360MW)

Angles relative to 110 kV Sumgait CCPP



Frequency (Azerbaijan)



f_{0v}= 49,998 Hz
$f_{\infty v}$= 48,874 Hz

Fig. 2-7

DISTURBANCE: 3-phase short circuit on AzTPP 500 kV buses (t=0,35s)

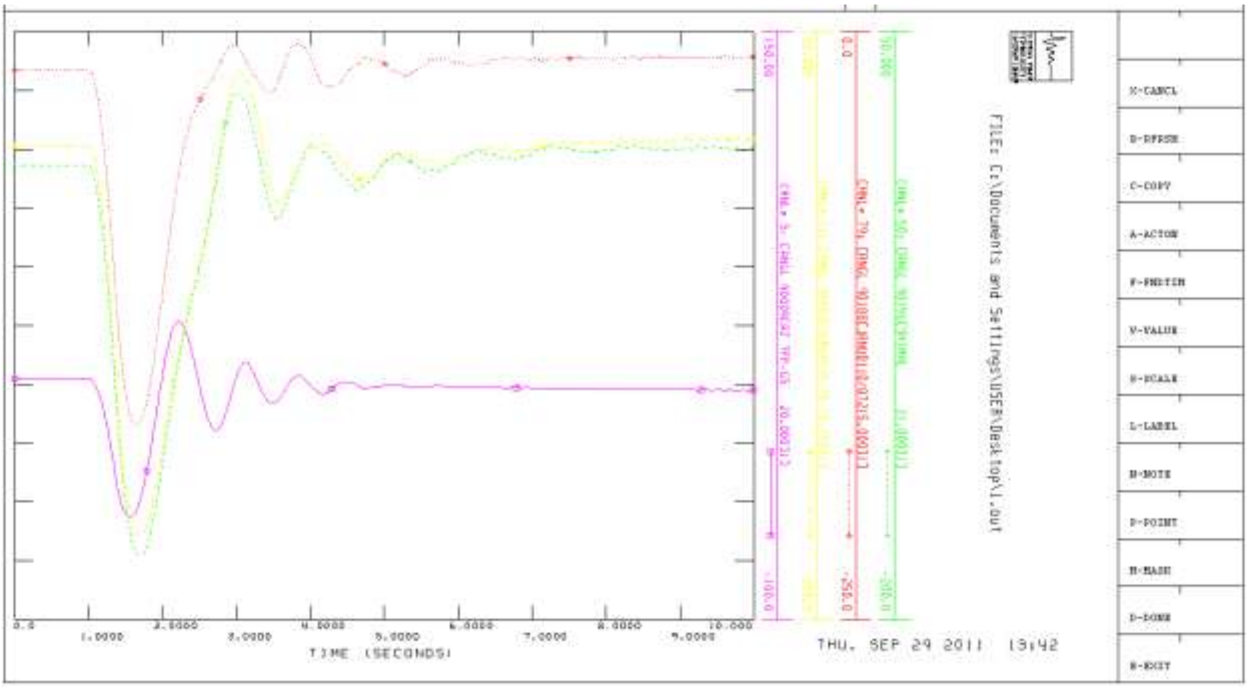


Fig.2-9 Relative angels to 500 kV AzTPP

DISTURBANCE: 3-phase short circuit on AzTPP 330 kV busses (t=0,3s)

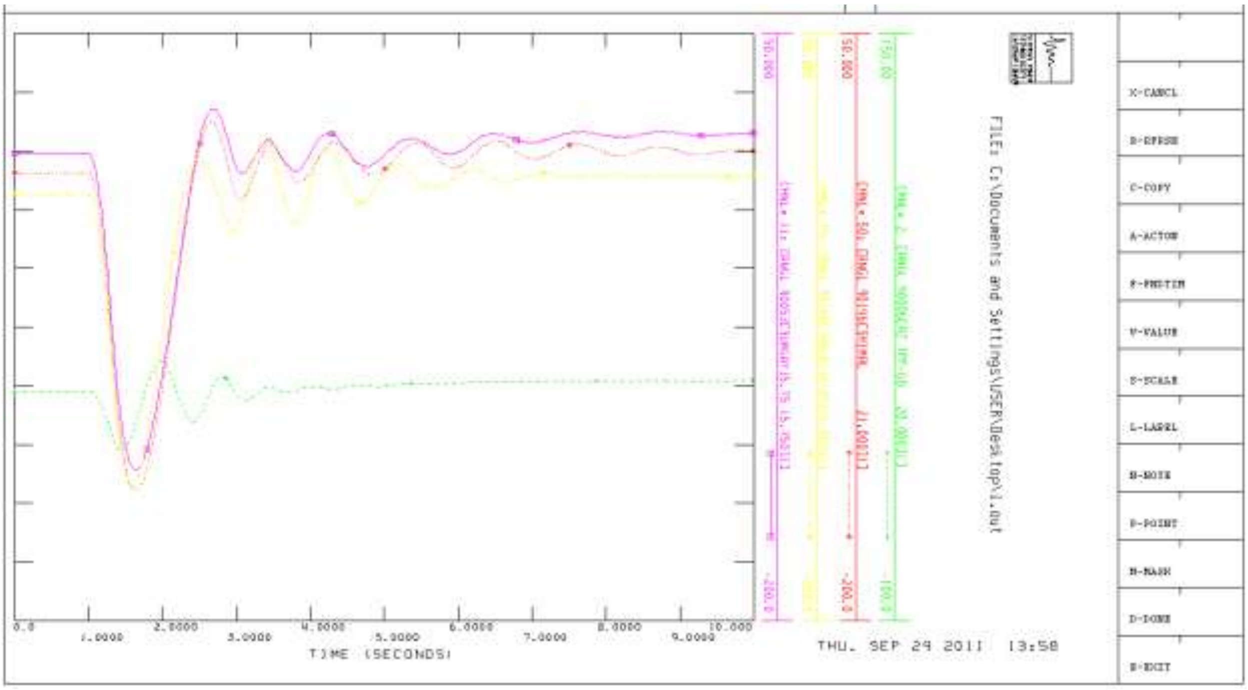
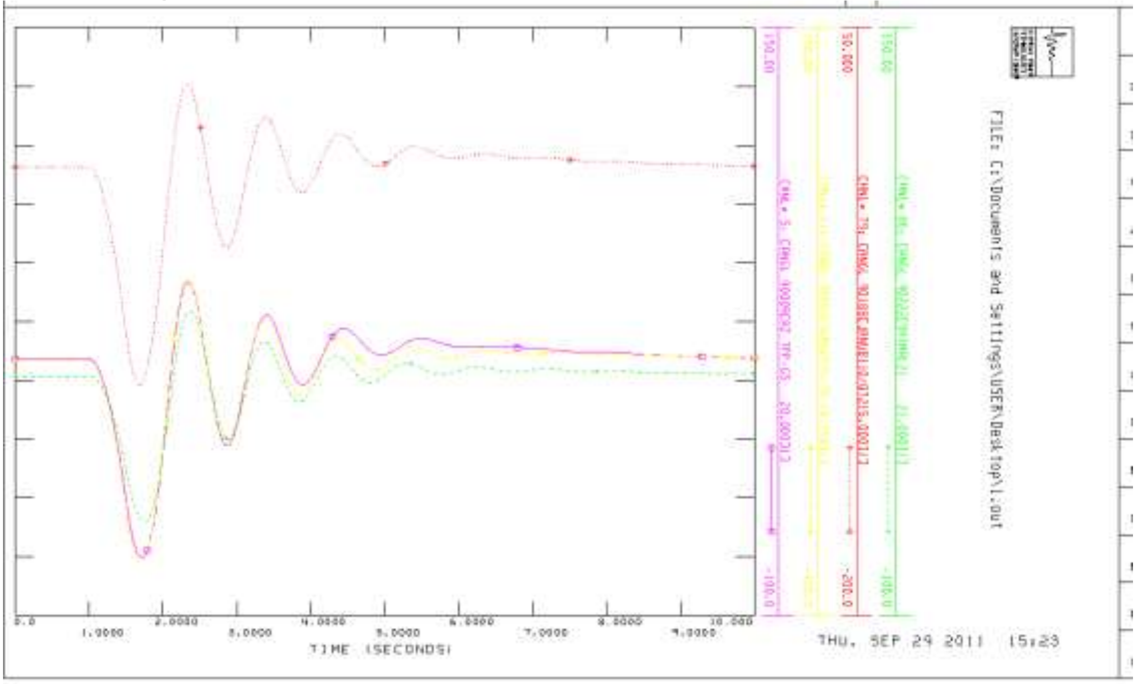


Fig. 2-10. Relative angels to 330 kV AzTPP

DISTURBANCE: 3-phase short circuit on 110 kV buses Shimal CCPP (t=0,55s)

Relative angels to 110 kV Shimal CCPP



Voltage on 110 kV bus Shimal CCPP

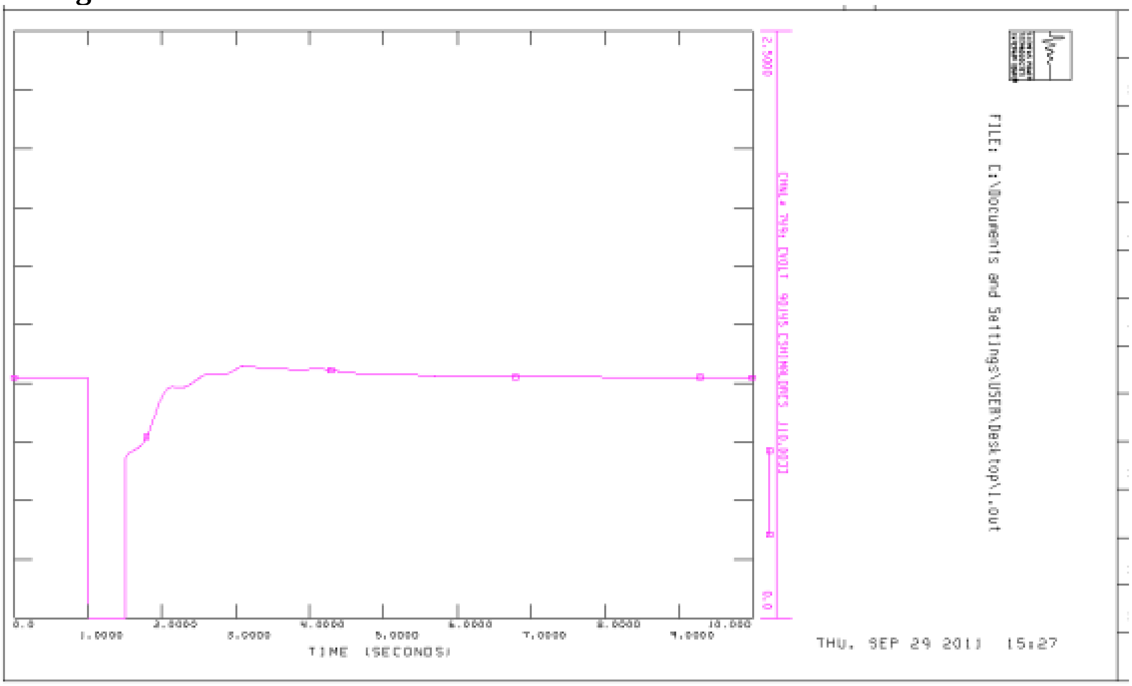
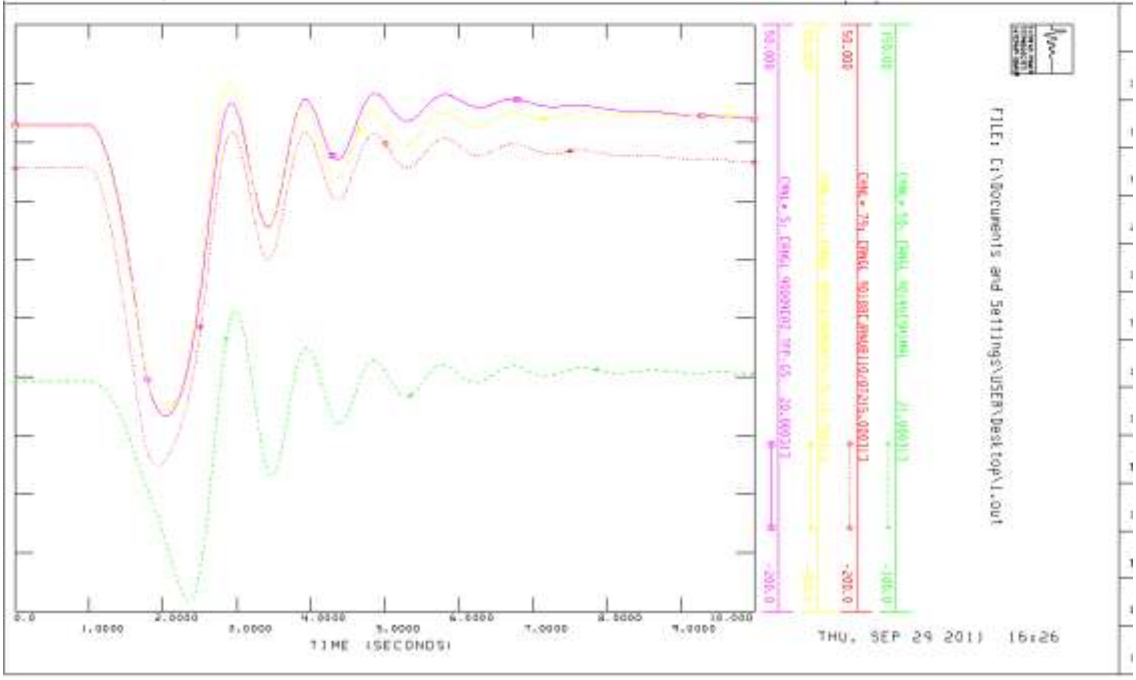


Fig. 2- 11

DISTURBANCE: 3-phase short circuit on 220 kV buses Shimal CCPP (t=0,65s)

Relative angels to 220 kV Shimal CCPP



Voltage on 220 kV Shimal CCPP bus

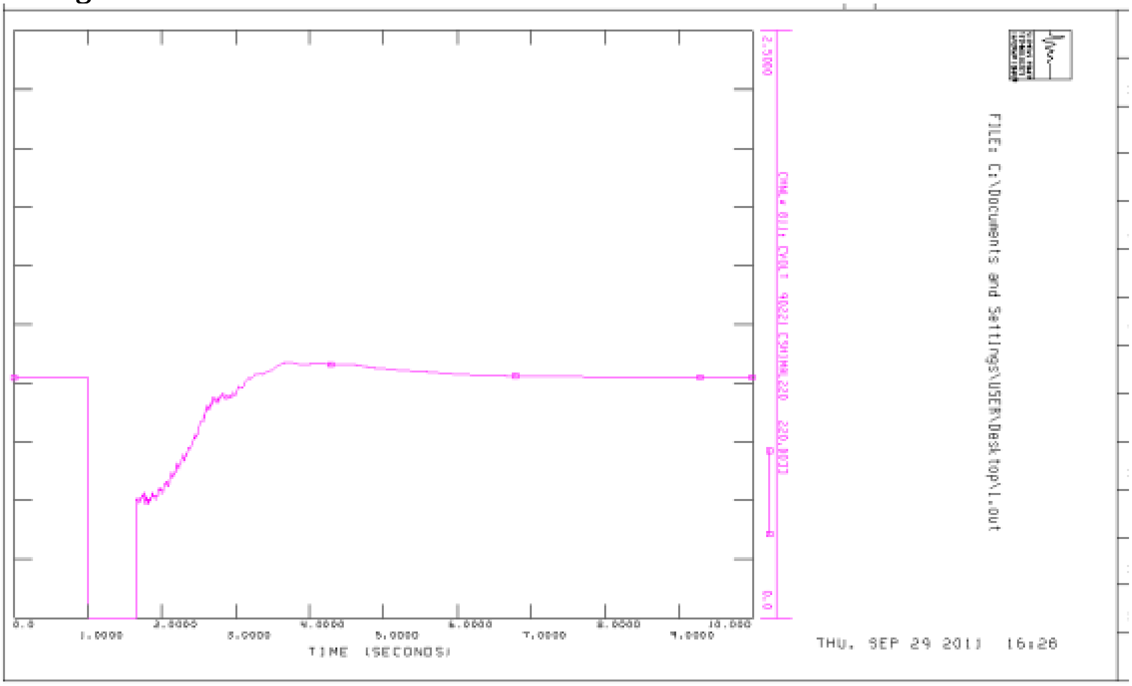
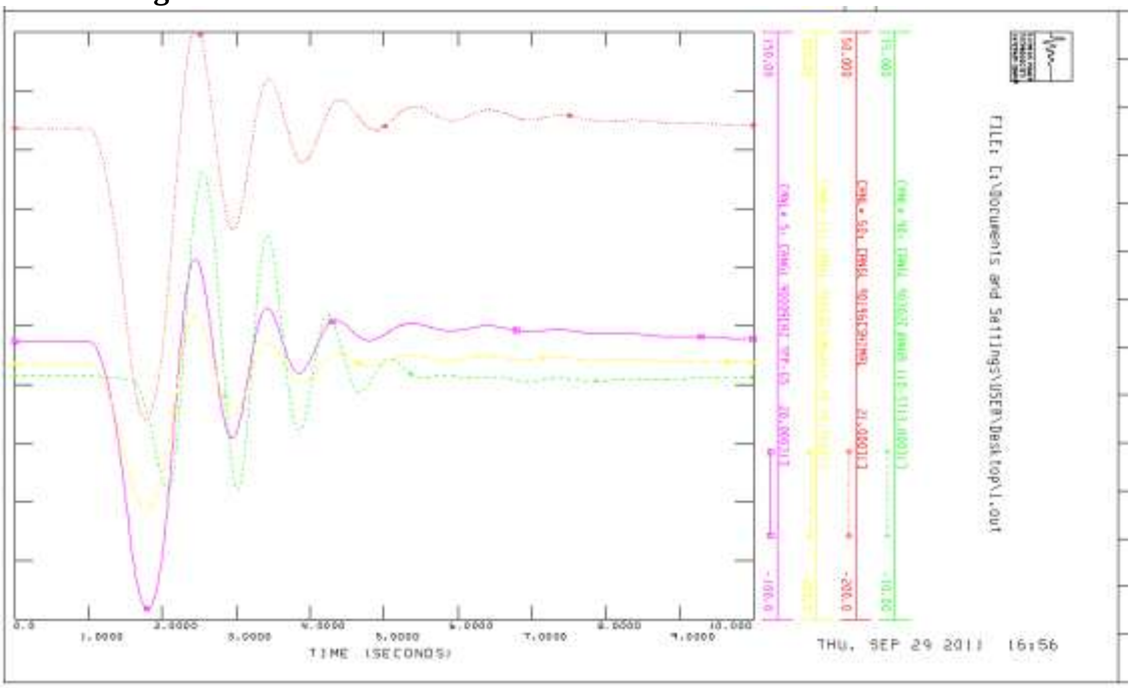


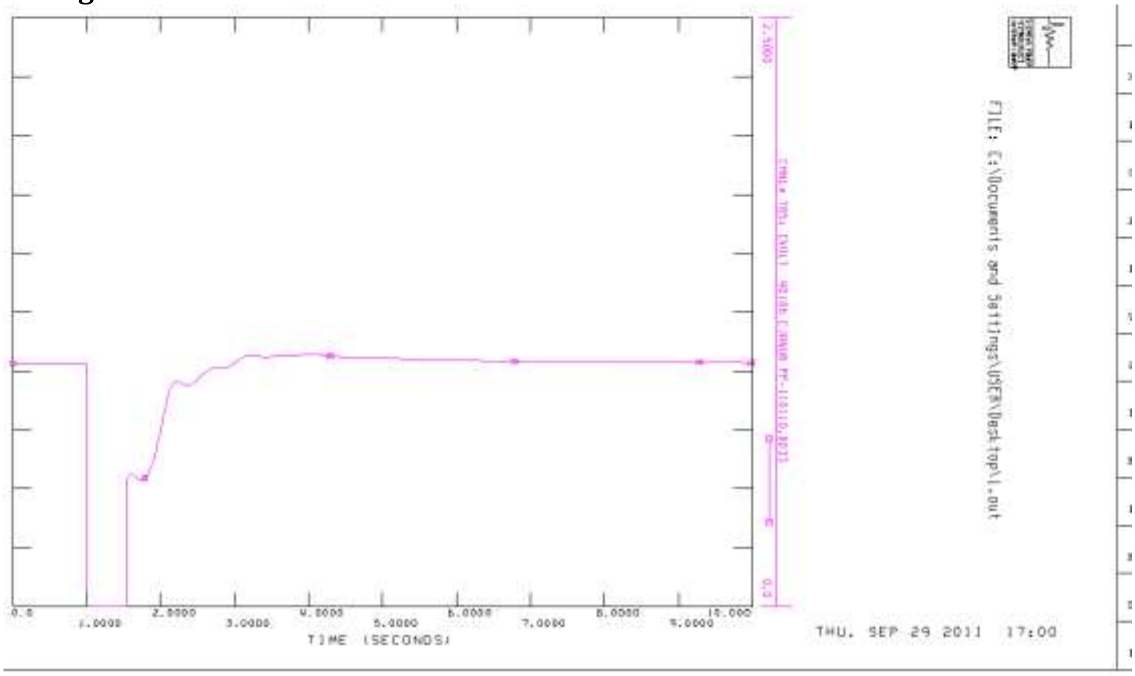
Fig. 2-12

DISTURBANCE: 3-phase short circuit on 110 kV Janub CCPP buses (t=0,55s)

Relative angels to 110 kV Janub CCPP



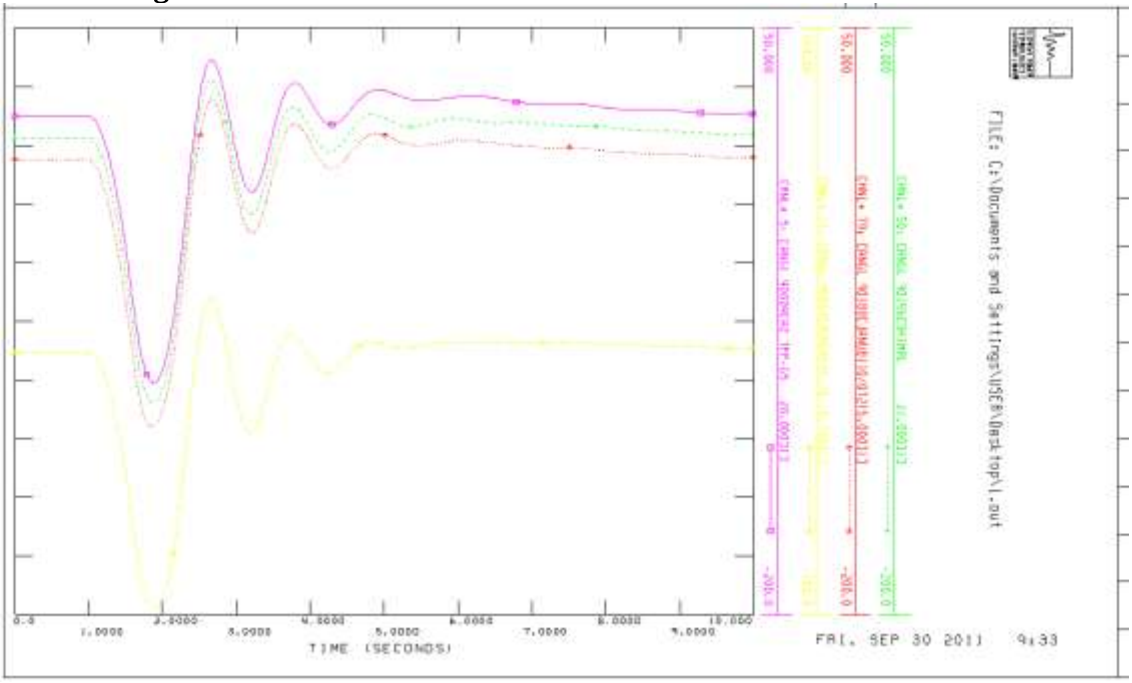
Voltage on 110 kV Janub CCPP bus



Fiq. 2-13

DISTURBANCE: 3-phase short circuit on 110 kV busses Sumgait CCPP (t=0,6s)

Relative angels to 110 kV Janub CCPP



Voltage on 110 kV Sumqait CCPP bus

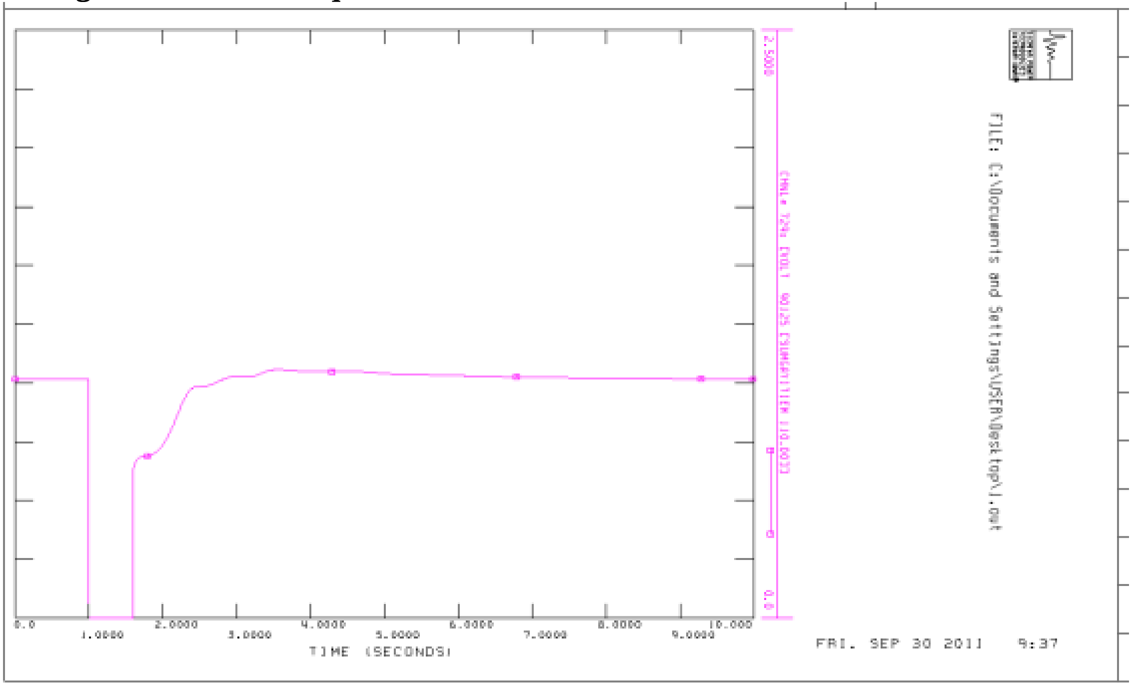


Fig. 2-14

DISTURBANCE: 3-phase short circuit on 110 kV Sangachal TPP (t=0.2s,t=0,15s)

Relative angels to 110kV Sangachal TPP

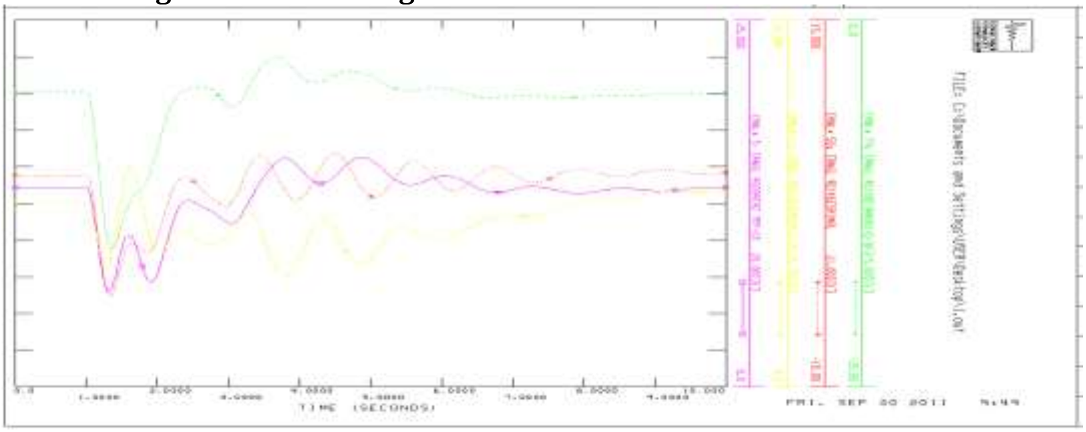


Fig. 2-15: 3-phase short circut on 110 kV Sumgait CCPP buses (t=0,6s)

Relative angels to 110 kV Sumgait CCPP

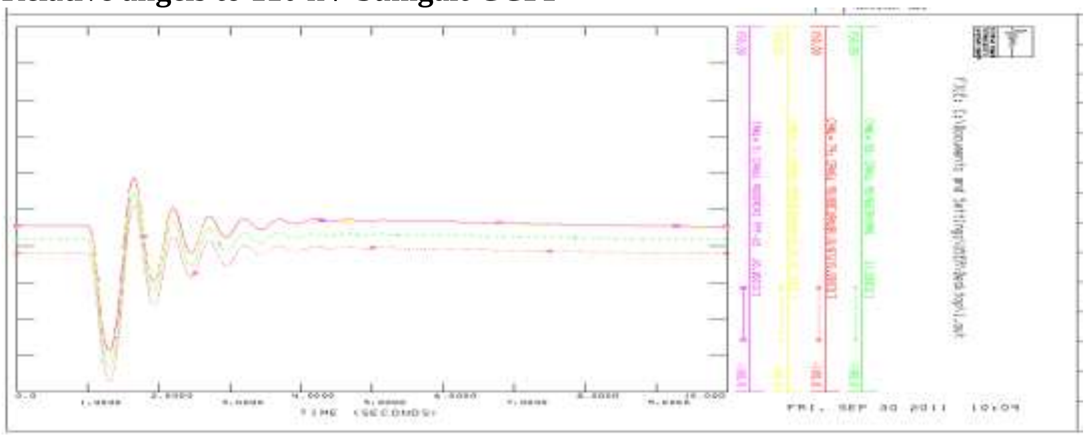


Fig. 2-16 3-phase short circut on 110 kV Sangachal TPP buses (t=0,15s)

Relative angels to 110 kV Shimal CCPP (instability to Sangachal TPP)

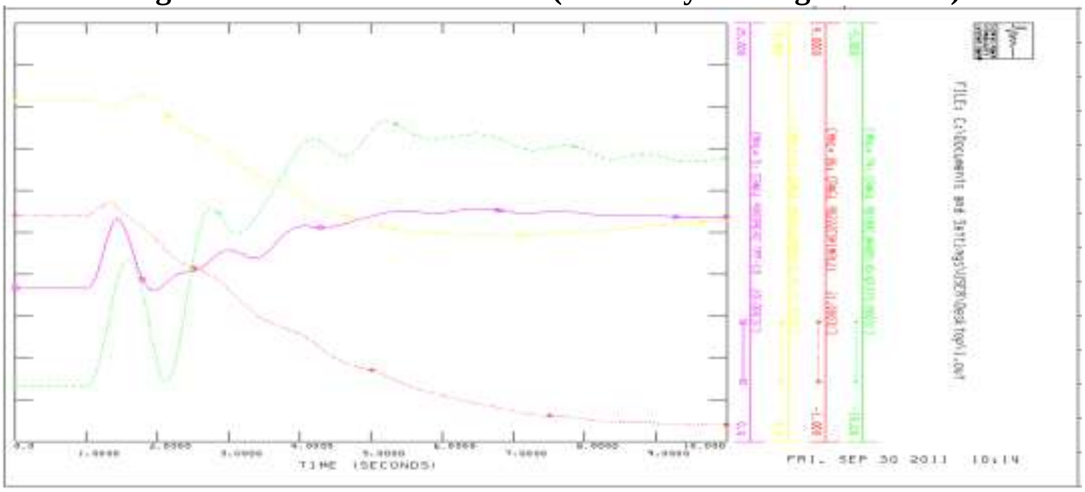
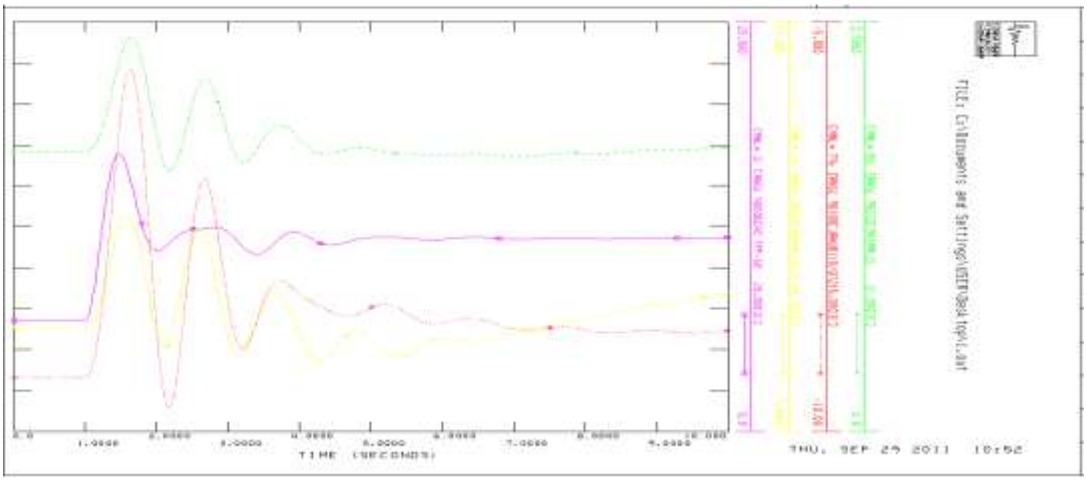


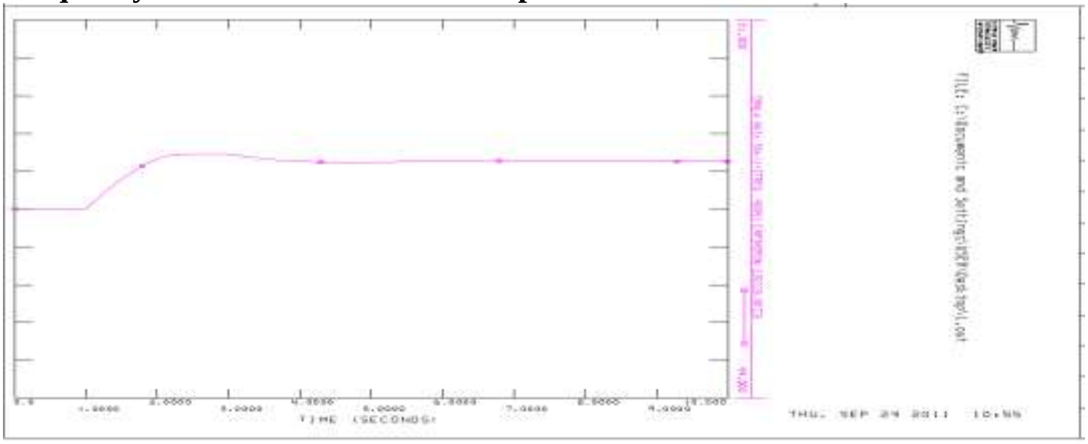
Fig. 2-17

DISTURBANCE: load rejection on 330 KV Gardabani OHL and 500 kV Gardabani OHL

Relative angels to 110 kV Shimal CCPP



Frequency on 220 kV Absheron semi-plant



F_0=49,997Hz
F_{max}=50,292Hz
F_∞=50,248Hz

Voltage on bus 330 kV, 500 kV Samukh SS

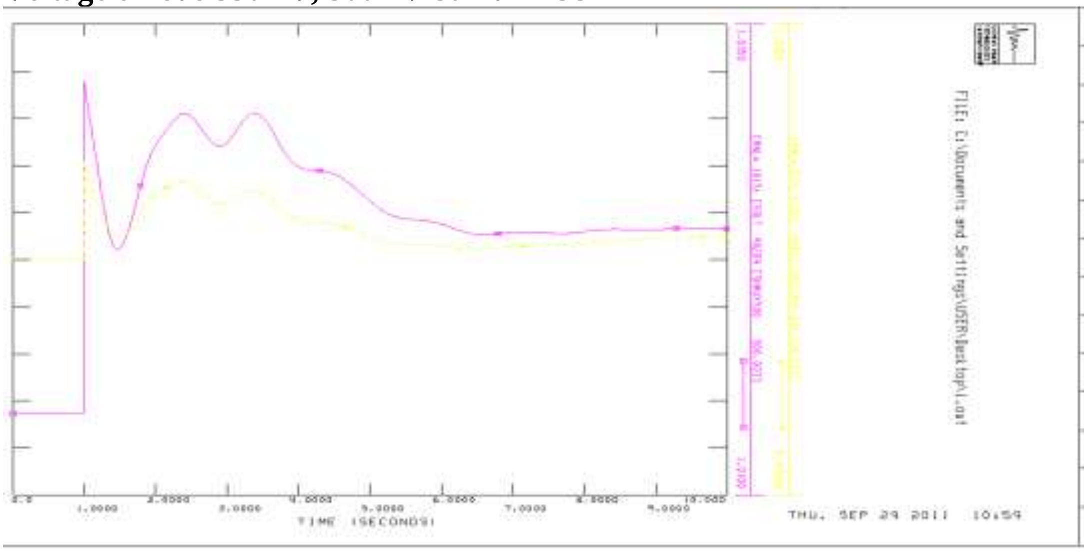
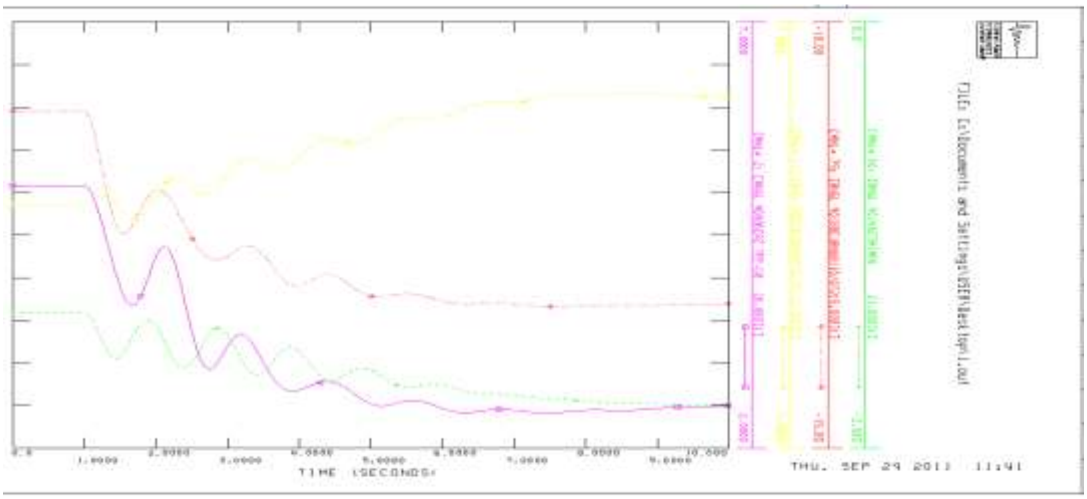


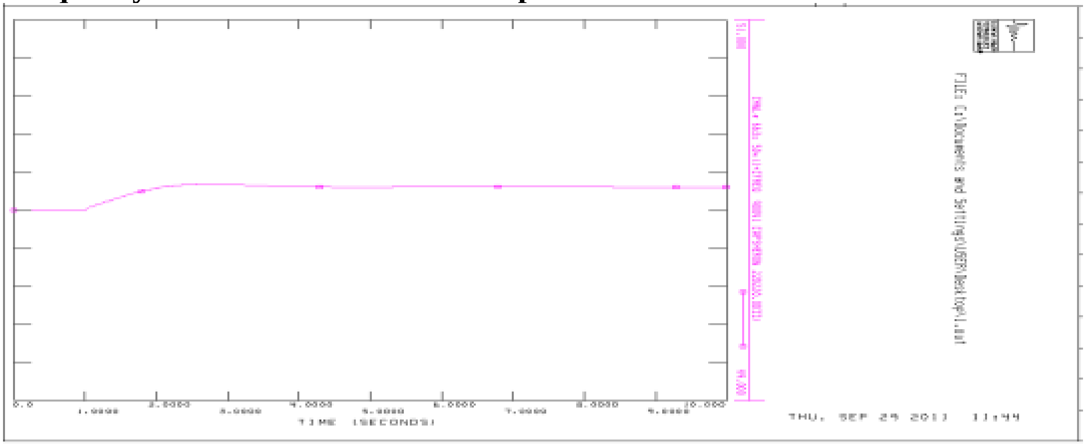
Fig. 2-18

DISTURBANCE: load rejection on 290 MW Boyuk-Shor SS

Relative angels to 220 kV Shimal CCPP



Frequency on 220 kV Absheron semi-plant



F_0=49,997Hz
F_{max}=50,135Hz
F_∞=50,124Hz

Voltage on bus 220 kV Boyuk-Shor SS

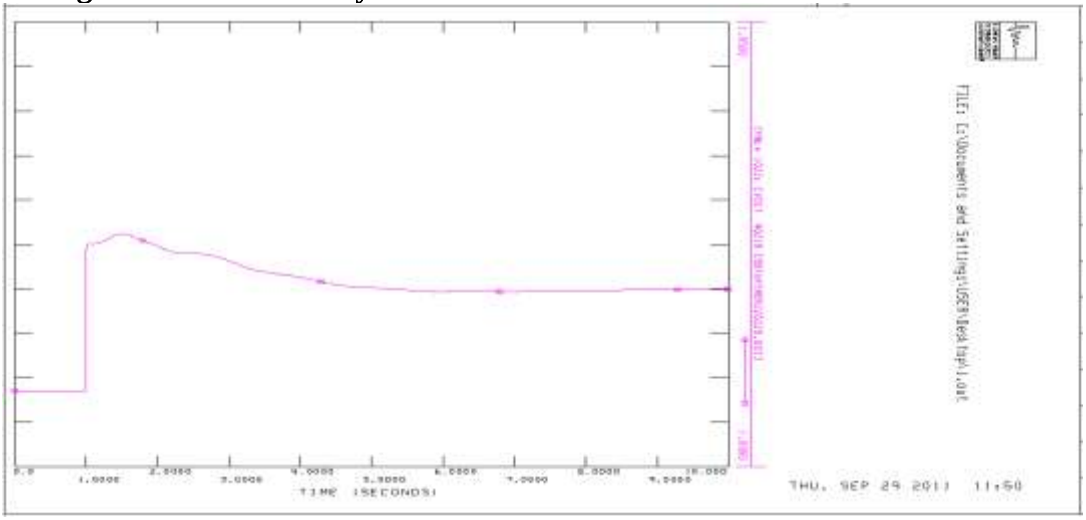
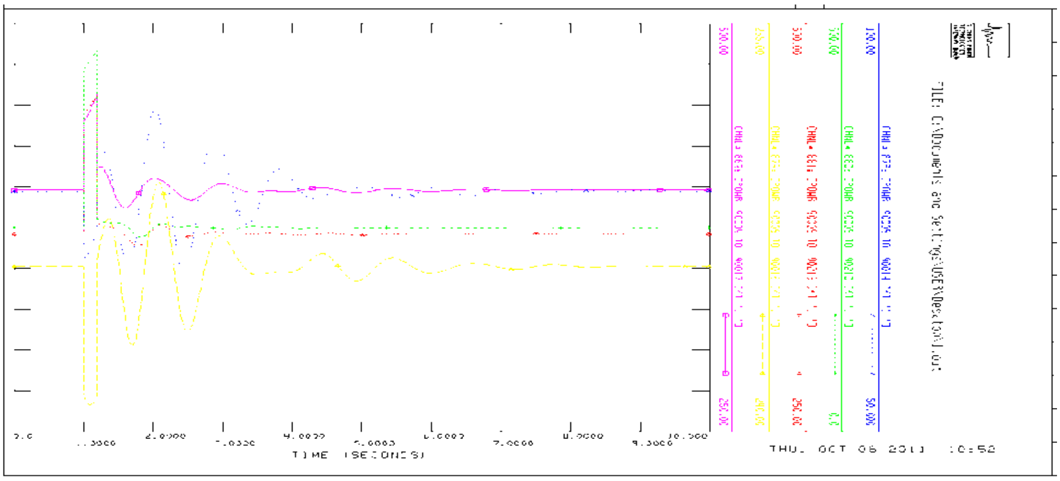


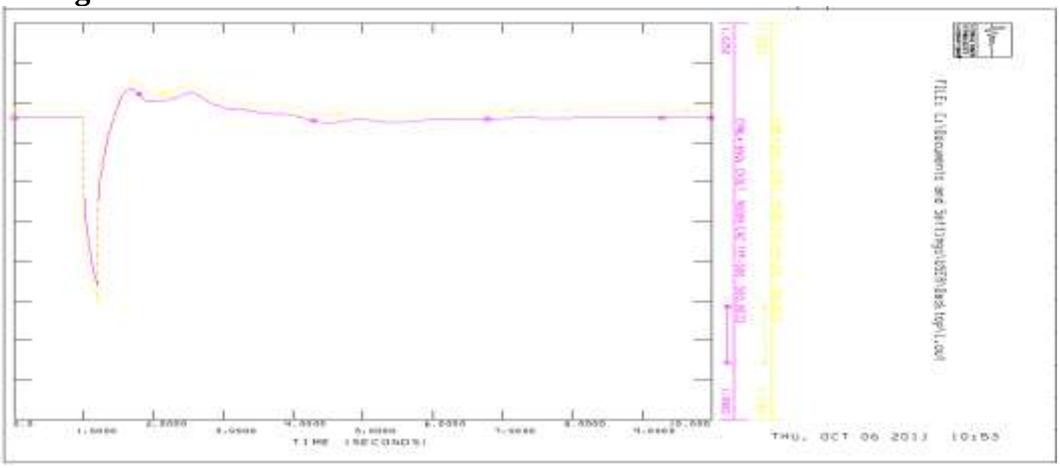
Fig. 2-19

DISTURBANCE: switch off high-voltage 500 kV AzTPP-Samukh OHL (t=0,2 sec switch on)

Power flow 330 kV AzTPP-Mingechaur OHL, 330 kV AzTPP-Samukh OHL, 330 kV AzTPP-Goranboy OHL, 500 kV 2ndAbsheron OHL



Voltage on bus 500 kV and 330kV AzTPP



Angles relative to 500 kV AzTPP

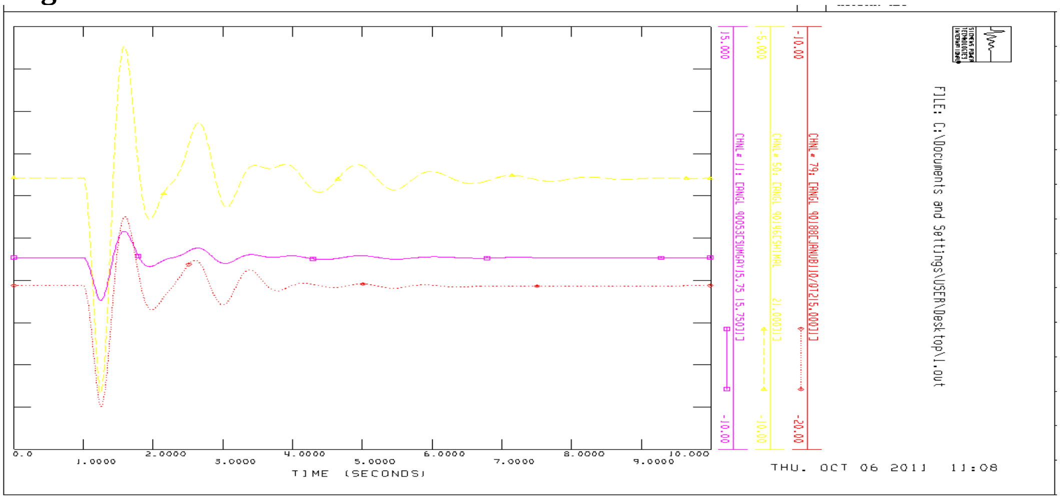
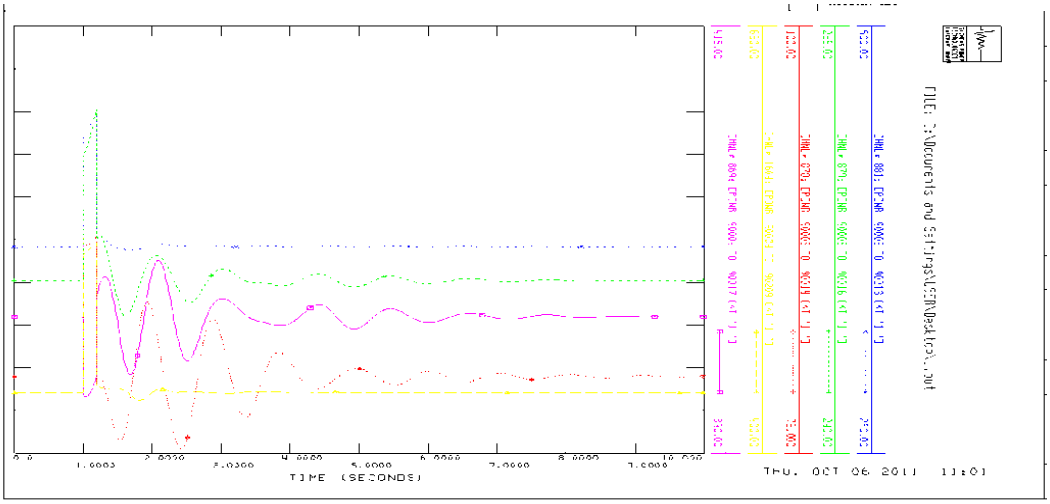


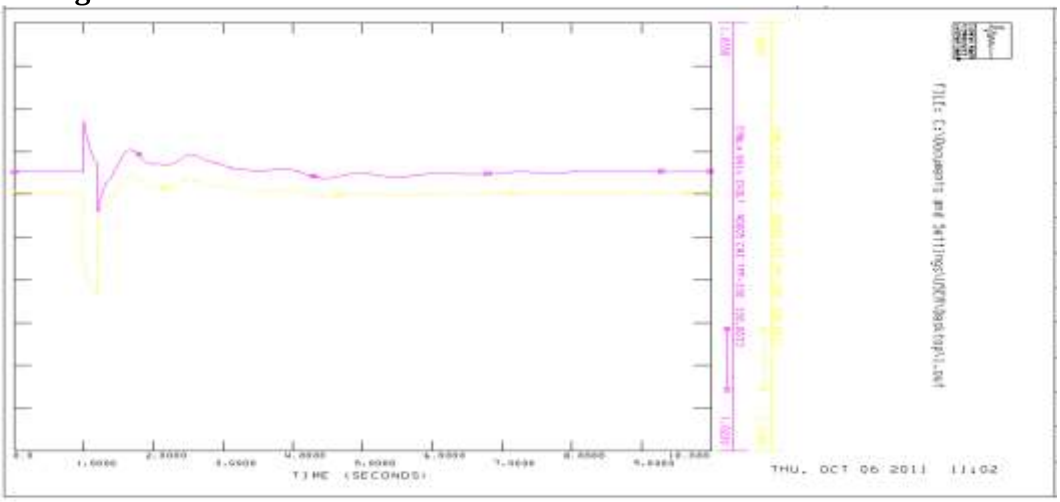
Fig. 2-20

DISTURBANCE: switch off high-voltage 330 kV AzTPP-Samukh OHL (t=0,2 sec switch on)

Power flow on 330 kV AzTPP-Mingechaur OHL, 330 kV AzTPP-Samukh OHL, 330 kV AzTPP-Goranboy OHL



Voltage on bus 500 kV and 330 kV AzTPP



Angles relative to 330 kV AzTPP

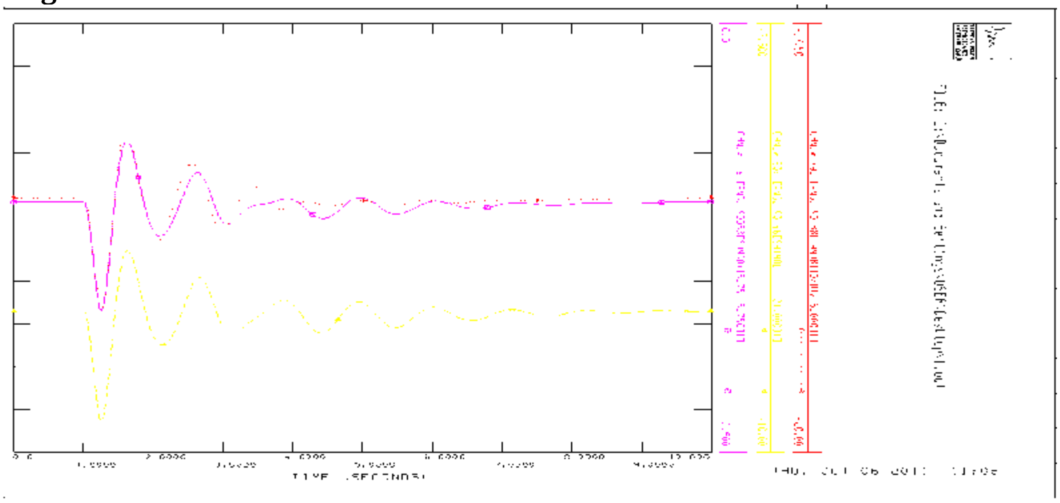


Fig. 2-21

2.3. Dynamic stability of Azerbaijan PS during operation conditions

(The mode and the scheme of the year 2017)

AZERBAIJAN POWER SYSTEM OF THE YEAR 2017

P_{gen} = 6777 MW, P_{lod}=5505 MW (Personal)

Power Transfer

- **Georgia – 588 MW:**
  - **500 kV Samukh-Gardabani OHL – 391 MW,**
  - **330 kV Akstafa-Gardabani OHL – 197 MW,**
- **Iran – 550 MWt,**
- **Russia – 0 MW.**

DISTURBANCE: 3-phase short circuit on 110 kV bus JANUB CCPP

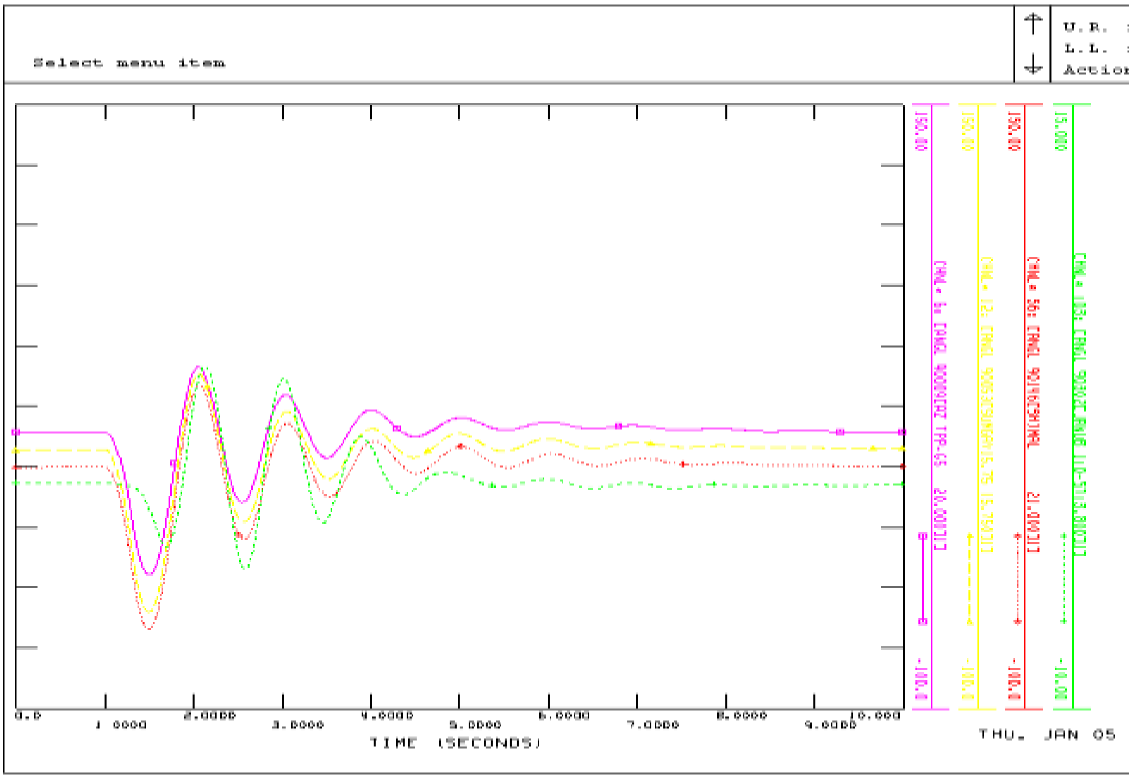


Fig. 2-22: Angles relative to Janub CCPP (t=0.3s)

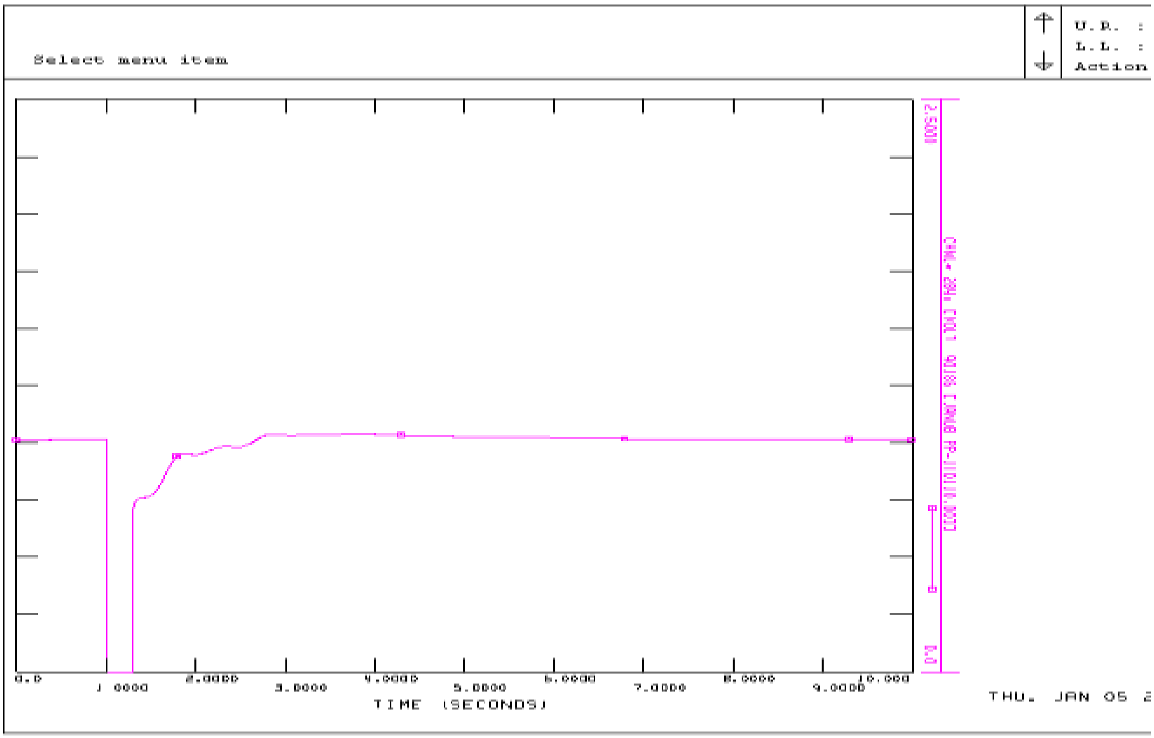


Fig. 2-23: Voltage on 110 kV bus Janub CCPP

DISTURBANCE: 3-phase short circuit on 110 kV bus SUMGAIT CCPP

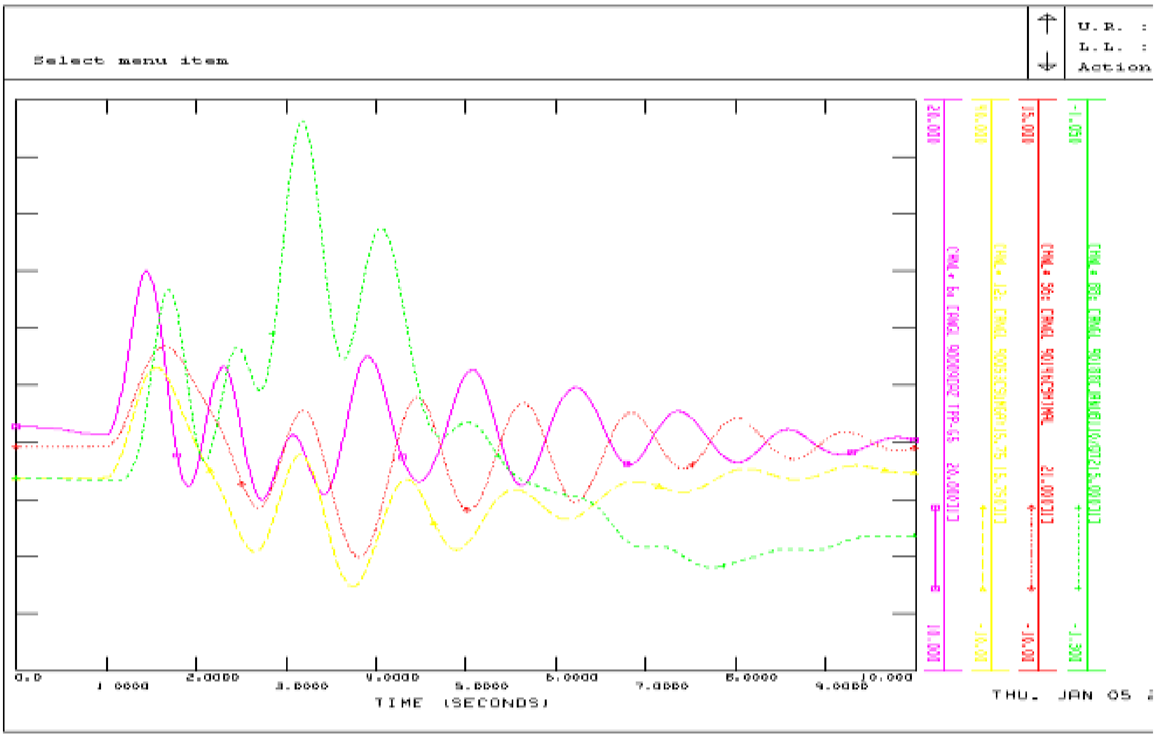


Fig. 2-24: Angles relative to Janub CCPP

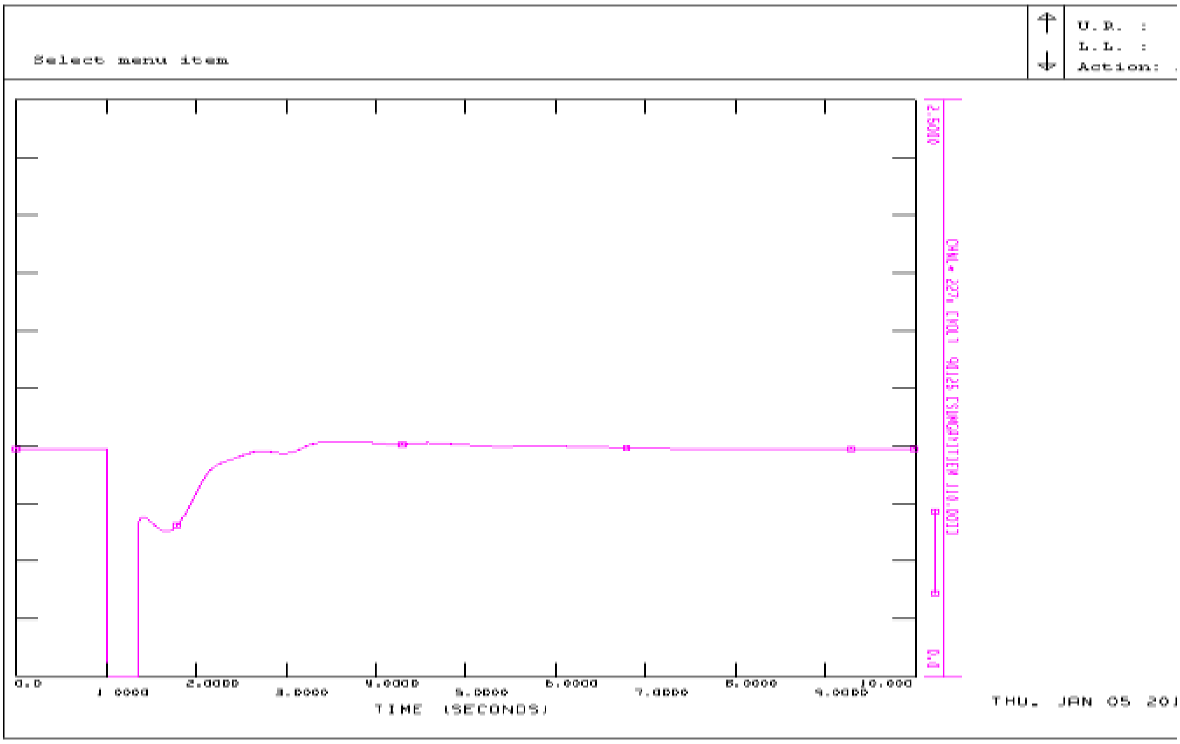


Fig. 2-25: Voltage on 110 kV bus Sumgait CCPP

DISTURBANCE: switch off block on AzTPP

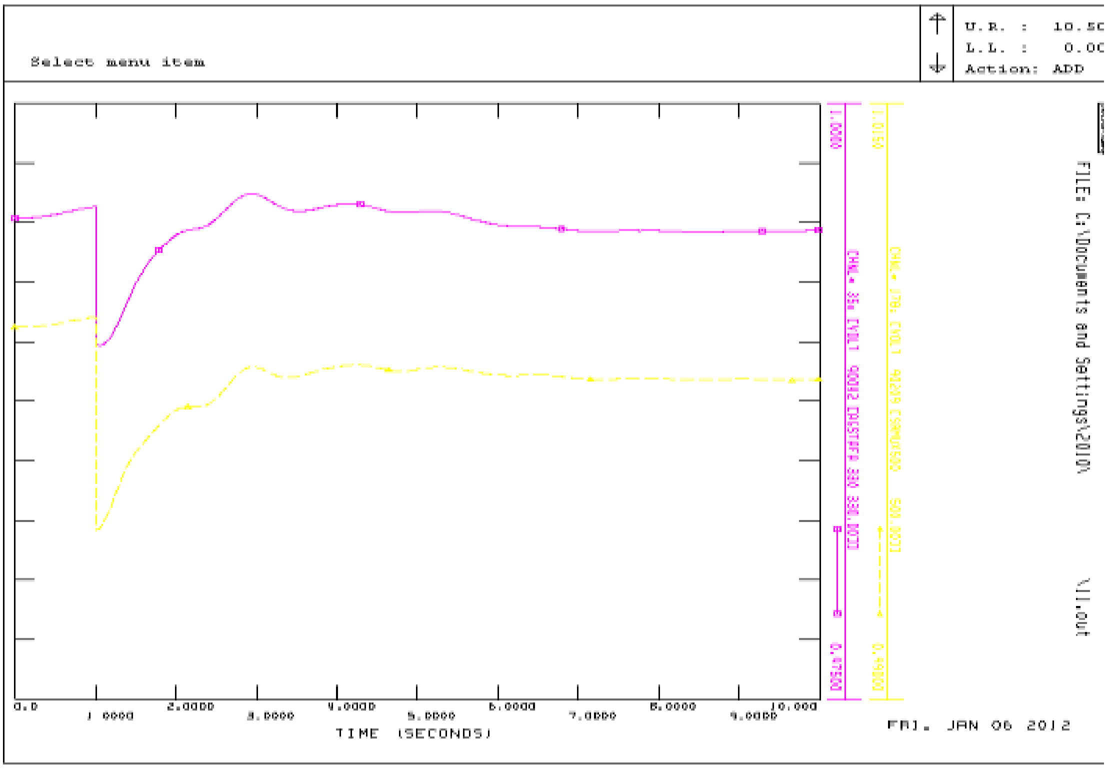


Fig. 2-26: Voltage on 500 kV Samukh SS , 330 kV Akstafa SS busses

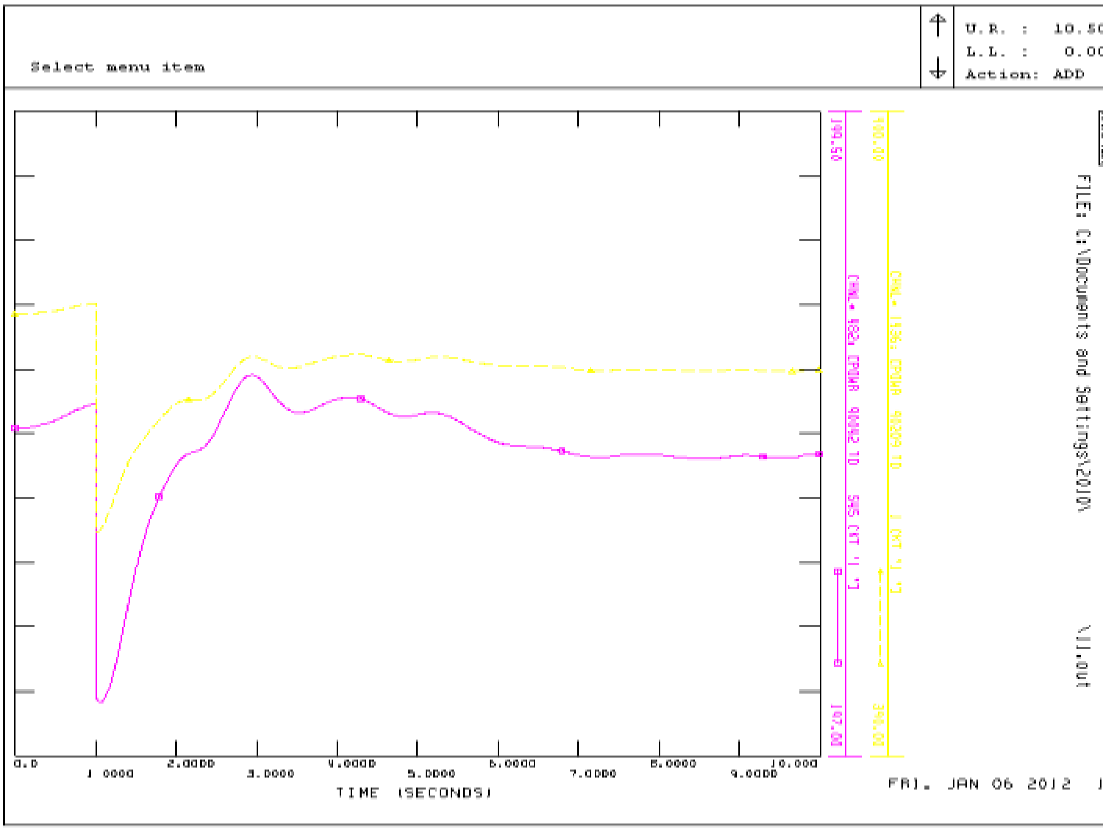


Fig. 2-27: Power flow 500 kV Samukh-Gardabani OHL, 330 kV Agstafa-Gardabani OHL

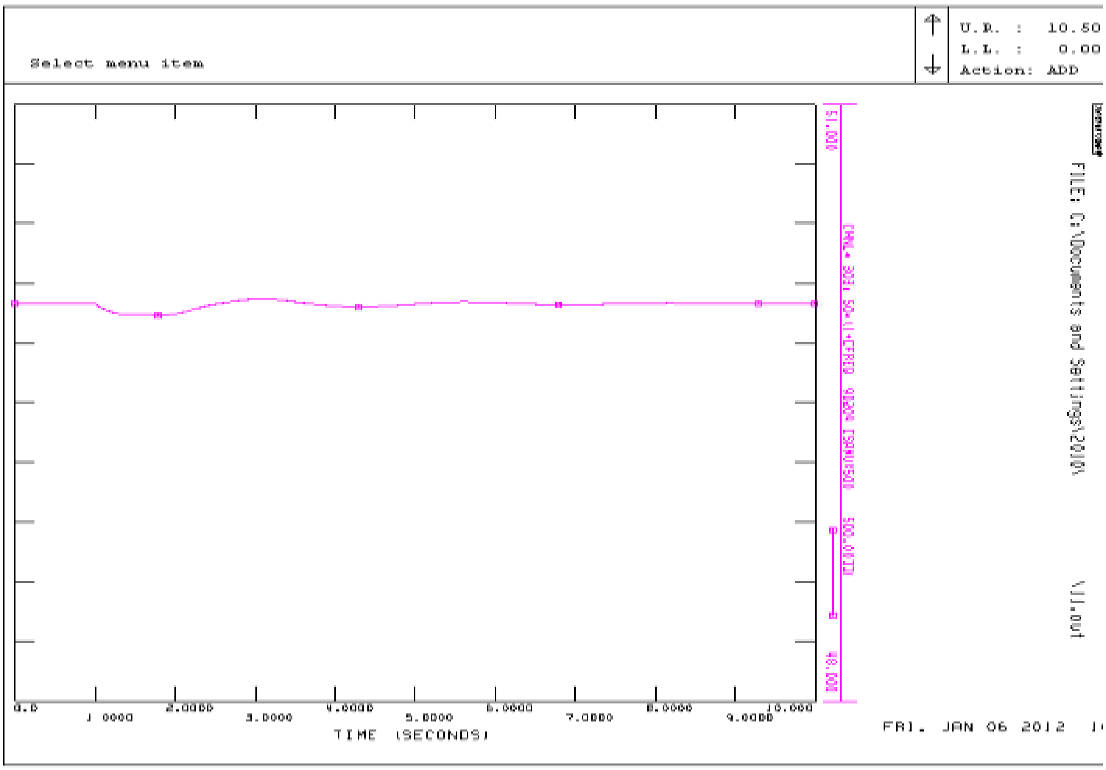


Fig. 2-28: Frequency on 500 kV bus Samukh SS

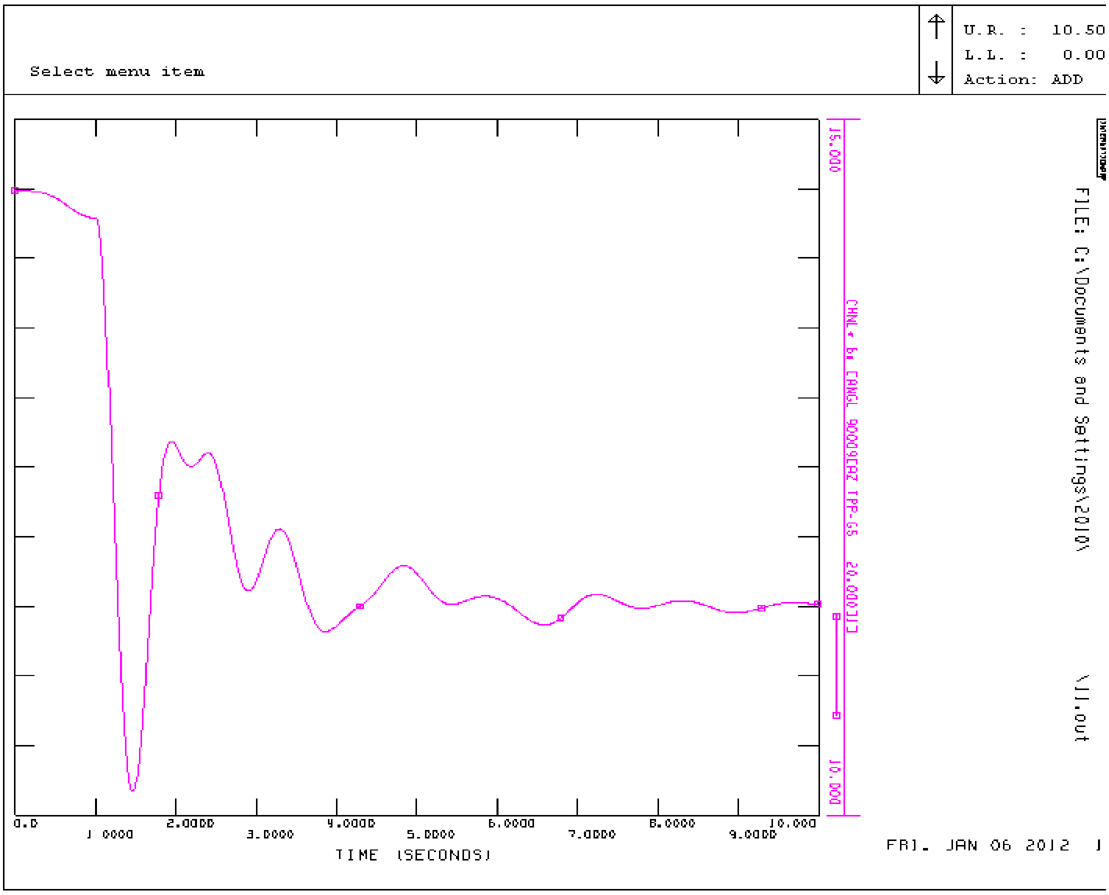


Fig. 2-29: Angle of AzTPP relative to Shimal CCPP

DISTURBANCE: switch off high-voltage 500 kV Samukh-Gardabani OHL

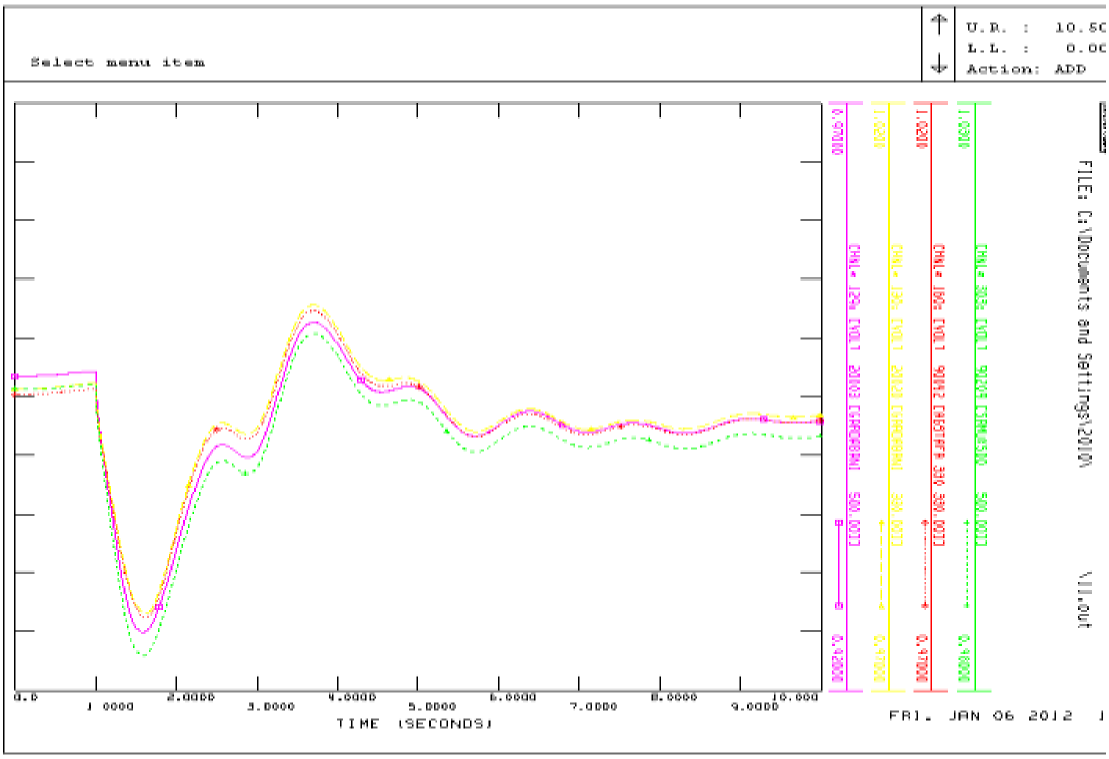


Fig. 2-30: Voltage on 500 kV Samukh , 330 kV Akstafa, 500kV Gardabani, 330 kV Gardabani SS buses

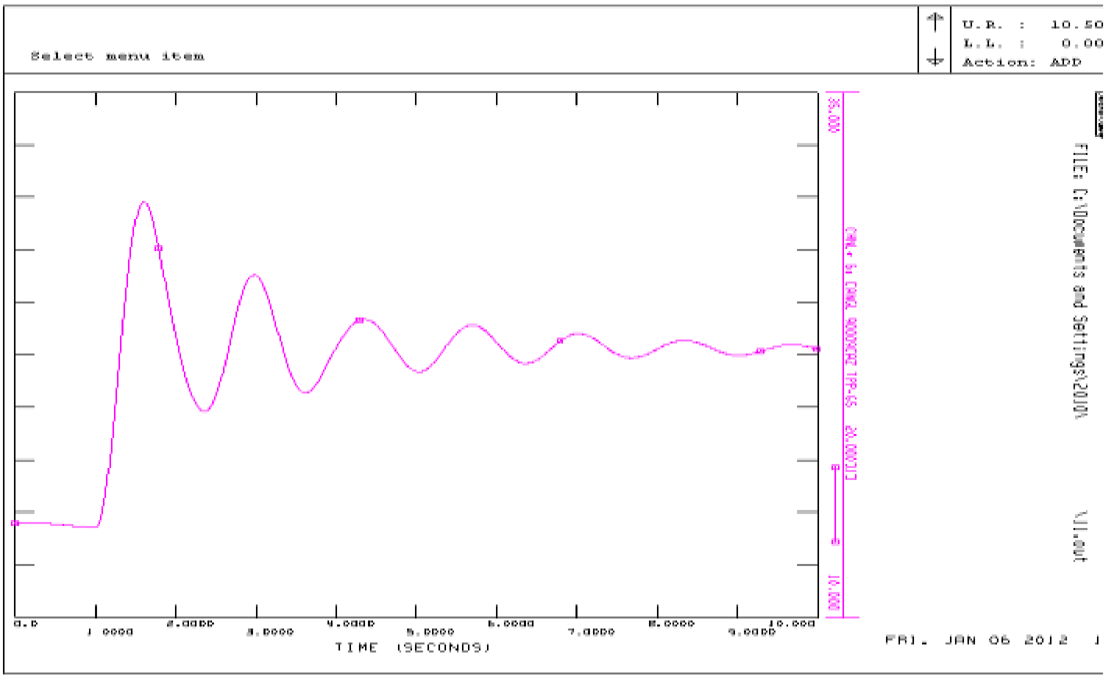


Fig. 2-31: Angle of AzTPP Relative to Shimal CCPP

Conclusion

The modes and the schemes of Azerbaijan PS for the years 2013, 2015 and 2017 was carried out by PSS-E software.

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

The following types of disturbance were considered: units, switch off most overloaded 500 kV and 330 kV OHLs, 3rd phase s.c. in plant buses.

Power flow, frequency, voltage, and the processes of the relative angle change were presented in drawings collection.

The obtained results can be used for to solve emergency control issues in power unions (pools) in the future where Azerbaijan PS playing both importer and exporter functions.

Effective “Anti - Emergency Management” is important for the solution of the problem optimal location of hardware intellectual technology, in particular, 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.