Legal basis of Ten Year Network Development Plan

Ten Year Network Development Plan of Georgia is elaborated according Article 3^2 of "Law Of Georgia On Electricity And Natural Gas" and the amendment in paragraph 3 of Article 2 of "Law Of Georgia On Electricity And Natural Gas" (12 December 2014).

Author of Ten Year Network Development Plan

Ten Year Network Development Plan of Georgia is elaborated by the TSO of Georgia JSC Georgian State Electrosystem (GSE) by agreement with agreement of transmission licensees Energotrans LTD and JSC Sakrusenergo.

The consultations regarding use of information, materials and analysis given in in Ten Year Network Development Plan, also about the implementation of requirements of this plan may be provided by TSO. Tel.: +(99532) 2 510 202.

Email: archil.kokhtashvili@gse.com.ge;
giorgi.vakhtangadze@gse.com.ge.
The responsible persons:
Archil Kokhtashvili, Chief of Electrical Regimes and Development Service;
Giorgi Vakhtangadze, Chief of Transmission network planning and development section.

The discussion and approval of Ten Year Network Development Plan

The plan discussed and agreed by the Government on December 8 of 2017 session.

The plan approved by the Minister of Energy on December 28, 2017 by # 1-1/579 order.

Ministry of Energy, Georgian National Energy and Water Supply Regulatory Commission the transmission system operator, electricity transmission licensees, other agencies and interested took part in discussions of Ten Year Network Development Plan.

Action of Ten Year Network Development Plan

Ten Year Network Development Plan is obligatory implemented act.

The plan is designed for the period 2018 to 2028 (inclusive).

Licensees/subjects responsible for implementation of the plan are shown in Annex D-5.

The implementation of Ten Year Network Development Plan is controlled by the Ministry of Energy.

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Annexes:

1 Executive Resume

Electric power sector composes an important part of the national economy having enormous influence on the social status of Georgia's population, and therefore development of the energy infrastructure constitutes the countrywide strategic goal.

The emerged cross-border electricity trade opportunities, high electricity demand growth and need for evacuation of the energy generated by the planned power plants, call for investments in the transmission infrastructure for ensuring adequate development of the network. Such objective targets availability of the transmission network capable ensuring of the consistent response to generation and demand growth by reliable and safe transportation of electricity, without any interruptions caused by outage of any single network element.

This Ten-Year Plan presents the time-tagged program designed for reinforcing infrastructure of the national transmission system, addressing the existing problems, responding to the future challenges and implementing the opportunities. It assumes adequate evolution of Georgian power system considering realistic scenarios and projects relevant to 2017-2027 time span.

The Ten-Year Plan aims at presentation and analysis of the future environment and reduction of uncertainties to obtain plausible projections and establish unified and well-structured vision about transmission grid development.

In general, development of the transmission system is a long-term process targeting reinforcement, expansion and upgrading of the network in line with generation and demand growth.

This document covers all components relevant to the development of Georgian power system. However, other projects that are not included in this Ten-Year Plan may also be reviewed in current and/or subsequent years. In addition, some projects described herein may be modified, implemented in shorter timeframes or delayed. All such changes will be accounted for in 2018-2028 version of this plan.

The goal of GSE is development of stable, reliable, cost-effective and efficient transmission system ensuring at any development stage:

- Security of Supply, network reliability, Power quality;
- Sufficient transfer capacity for both integration of renewable energy sources into the network and power exchange with neighbouring countries;
- Preparedness for integration into ENTSO-E's Ten-Year Network Development Plan.

The reason of long-term development planning is explained by the need for the future transmission network satisfying all applicable design requirements, main from which is **single contingency (N-1) criterion**.

In case additional reasonable projects will be identified, they will be considered in the next Ten-Year Network Development Plan of Georgia.

The planning process shall consist of the following major stages:

a) Data collection;

b) Data processing;

c) Modelling;

d) removing or mitigating any deficiencies;

e) Preparation of the unified transmission grid development plan.

Fig. 1.1 Preparation stages of Unified Georgian Transmission Network Development Plan

1.1 Data Management

Inputs for Ten year Plan include: Information on installed capacities, outputs, geographical locations, categories and their commissioning years of the planned hydropower plants as well as decommissioning dates of aged power plants represent; forecasted characters of consumption growth in power system; agreements with neighboring countries about construction of cross-border infrastructure; Assignments from Ministry of Energy and memorandums of Georigan government, based on which changes in projects are implemented; Minimal technical requirements on power plants and their units and specific requirements on back-to-back stations.

By support of the Ministry of Energy preliminary design data of above generation facilities required for dynamic stability and harmonic analyses have been provided. Whenever such data were not available, the standard values were applied using typical generators' characteristics given in the databases developed by GSE's specialists.

Power flow, losses, system stability and short circuit analyses were performed using the model developed by PSS/E (Power System Simulator for Engineers) software, for Harmonic analysis – Digsilent PowerFactory software.

1.2 Planning Period

The planning period was divided into the following three time spans:

1. **Short-Term Planning Period** extended over 3 years after the base year (2016), i.e. the period of 2017-2019. Consulting companies have already been performing or they have already completed feasibility studies for the projects planned for such period. Required investments are clarified and new ones are identified. Three year Investment Plan for these three-year period is shown in Annex-5.

2. **Mid-Term Planning Period**, covering 4th and 5th years from the base year (2016), i.e. the period of 2020-2021. Feasibility studies of the projects envisaged for such period have not started yet, however the major project features and estimated technical and economical data have already been specified. It is expected that technical feasibility studies for these projects will commence shortly and in result forecasted features may be changed in some extent.

3. **Long-Term Planning Period**, including 6th to 10th years from the base year (2016), i.e. the period from 2022 to 2027. Feasibility studies of the projects planed for this period have not been started yet, however necessity for these projects have already been identified, and it is expected that their feasibility studies will commence within 2-3 years. In result of such studies certain project parameters may be changed.

1.3 Operating strategy, security of supply and adequacy level of Power system

Operation strategy. For purposes of analyzing power system security and designing appropriate control systems, it is helpful to conceptually classify the system-operating conditions into five states: normal, alert, emergency, in extremis and restorative.

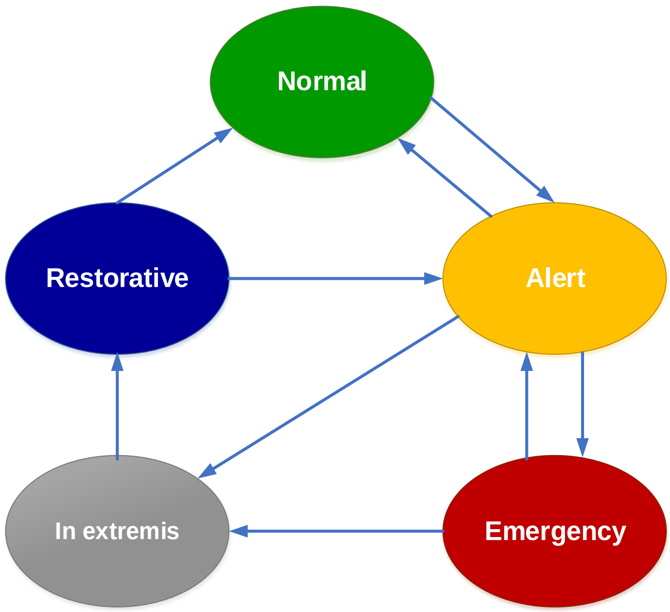


Fig. 1.2 Power system operating states

In the normal state, all system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand a contingency without violating any of the constraints. This means there are enough reserves of generation in power system as well as enough reserves of transmission system capacity. System meets N-1, G-1 and N-G-1 conditions.

The system enters the alert state if the security level falls below a certain limit of adequacy, or if the possibility of a disturbance increases because of adverse weather conditions such as the approach of severe storms. In this state, all system variables are still within the acceptable range and all constraints are met. However, the system has been weakened to a level where a contingency may cause an overloading of equipment that places the system in an emergency state. If the disturbance is very severe, the in extremis (or extreme emergency) state may result directly from the alert state.

Preventive action, such as generation shifting (security dispatch) or increased reserve, can be taken to restore the system to the normal state. If the restorative steps do not succeed, the system remains in the alert state.

The system enters the emergency state if a sufficiently severe disturbance occurs when the system is in the alert state. In this state, voltages at many buses are low and/or equipment loadings exceed short-term emergency ratings. The system is still intact and may be restored to the alert state by the initiating of emergency control actions: fault clearing, excitation control, fast-valving, generation tripping, generation run-back, HVDC modulation, and load curtailment. If the above measures are not applied or are ineffective, the system is in extremis; the result is cascading outages of possibly a shut-down of a major portion of the system. Control actions, such as load shedding and controlled system separation, are aimed at saving as much of the system as possible from a widespread blackout.

The restorative state represents a condition in which control action is being taken to reconnect all the facilities and to restore system load. The system transits from this state to either the alert state or the normal state, depending on the system conditions.

Whenever all elements are in normal state as well as all parameters are within their normal range, operation of Georgian transmission network corresponds to the “alert state”. Therefore, **the most critical problem of Georgian transmission network is security of supply and leitmotif of transmission network development within next ten years will be security of supply** and **its improvement as well as upgrade of system reliability.**

In order to improve network reliability and stability, construction of tie-lines from 220 kV OHLs to power plants below 100 MW is maximally avoided due to two reasons:

1) Substation of power plant will be constructed on transmission route which will complicate harmonization of modern relay protection and automatic and the rest systems.
2) Both ends of overhead lines are being switched off in case of short circuit in power plant.

3/2 (1.5) scheme is used for 500 kV substation, as for 220 kV substations – double system with bypass bus bars.

1.4 Bottlenecks and Development Drivers of Georgian Transmission Network

Main network bottlenecks. Georgian transmission network is predominantly oriented from west to east (except SS Batumi located at the south and connected to the West Georgia’s system via long 220 kV OHLs that causes one more system wide problem). The most of the energy is generated in the west part of the country (total installed capacity of the HPPs located at the west amounts to 2080 MW), with the main consumption in the east part (Tbilisi-Rustavi node). Such imbalance is especially explicit during spring and summer, when due to the high water flows available in Georgian rivers, the thermal power units located at the east (near Gardabani) are not operated, and the power flows in the west-to-east direction.

The problem is faced in the west part of the system (500/220 kV mains along Enguri-Zestaponi route) during tripping of 500 kV OHL Imereti, because 220 kV mains are unable to transfer full load flow.

Cross border lines of Georgian transmission network are not basically backed-up and their outages create risk of emergency. Furthermore, there are several 220 kV dead-end lines trip of which is some threat for system stability. Additional supply of Batumi region is performed by long 220 kV lines what makes it difficult to keep parameters of power quality in permitable ranges.

Below are listed weaknesses experienced along this route:

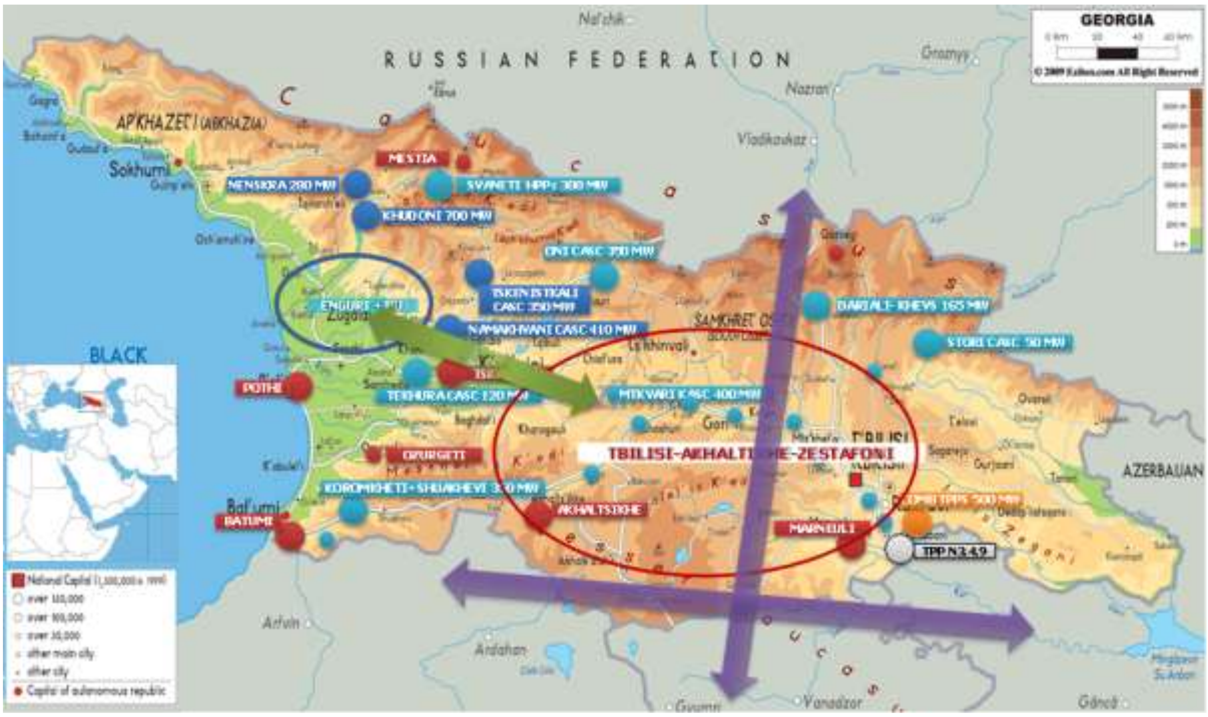
- Interconnetion lines
    - Kavkasioni, 500 kV
    - Gardabani, 330 kV
    - Alaverdi, 220 kV
    - Meskheti, 400 kV
    - Adjara, 220 kV
- Radial Network of West Georgia
    - Imereti, 500 kV
    - Zekari, 500 kV
    - Autotransformer at Enguri, 500/220 kV
    - Egrisi 1,2
    - Kolkhida 2a
    - Kolkhida 2
- Batumi supply grid
    - Paliastomi 1,2
- 220 kV dead end transmission lines
    - Kolkhida 3
    - Derchi
    - Lomisi
    - Manavi
    - Paravani

Development Drivers. A large majority of Georgian transmission network elements were designed/installed during Soviet era and assumed parallel operation with the North Caucasus and Armenian/Azeri power systems. Specifically, generation of the HPPs located in the West Georgia was transmitted to Russia, while the power plants located in the East Georgia were supplied with fuel from Azerbaijan.

After Georgia re-gained independence, prices for fuel supply for thermal units of Georgia grew much, and currently eastern part of Georgia is supplied with power from the HPPs located at the west. Meanwile, Turkish energy markets becomes steadily attractive entailing construction of the HVDC back-to-back station in Akhaltsikhe, as well as encouring the majority of the greenfield projects that are under development in Georgia. Due to its geographical location, Georgian transmission network may be used for energy transit between 1) Russia and Armenia/Iran, 2) Azerbaijan and Turkey, 3) Russia and Turkey, and 4) Armenia/Iran and Turkey.

It should also be noted that automatic governors and regulators of the existig hydro power plants are obsolete or inoprable, and the most of thermal power units are fully depreciated. Therefore, the governorsr/regulators shall be rehabilitated, and thermal power units shall be replaced with the new cost-efficient analogs.

Georgian power system endures acute shortage of operating reserves resulting in law power quality in isolated regimes. In addition, when any large power unit fails, emergency control system initiates load shedding. For dealing with such situation, sufficient operating reserves shall be provided by both construction of regulated hydro power plants (with water storage) and Thermal power plants as well as rehabilitation of the existing generation facilities.



- ● Prospective regulated HPPs
- ● Prospective seasonal HPPs
- ● Prospective demand growth
- ● Thermal power plants scheduled for decommissioning
- ● New combined cycle thermal power plants
- ⇔ Necessary upgrades of cross-border (inter-system) links
- ⇔ Necessary upgrades of internal network links
- O Existing bulk generation region
- O Existing bulk demand region

Fig. 1.3 Map illustrating development drivers of Georgian electric power network

Assuming above, the main development drivers of Georgian transmission network development drivers will be targeted to:

- Uninterruptable transmission of the existing generation;
- Fulfillment of single contingency (N-1) criterion (improvement of reliability)
- Reclamation of the new energy resources / integration of new HPPs into the network;
- Increasing network potential with respect to power transit;
- Establishment of reliable power supply centres for promoting development of potential production/tourist centres;
- Responding to the (naturally) growing demand in the power system;
- Replacement of the aged thermal units with flexible and cost-effective combined cycle thermal power plants;
- Provision of sufficient operating reserves;
- Improvement of the power quality.

1.5 Forecasted Energy and Capacity Balances

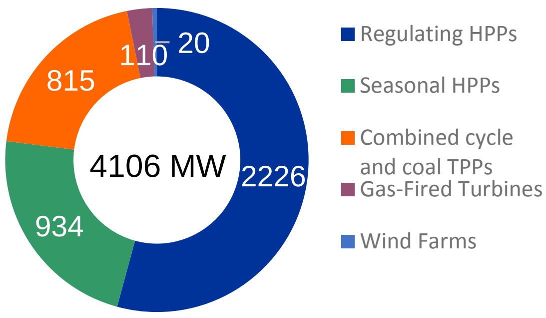


Fig. 1.4 Installed capacities of the existing power plants

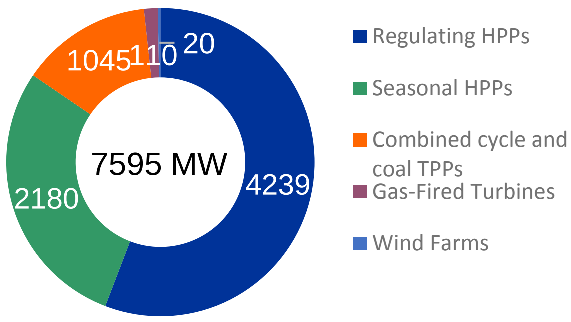


Fig. 1.5 Installed capacities of power plants as for 2027

At present, total installed capacity of electric power plants operated in Georgia amounts to 4106 MW. From this, 2226 MW is generated by the so called "regulated" HPPs (with water storage), 934 MW by "seasonal" (run-of-river) HPPs, 110 MW by Gas Turbines and 815 MW by thermal power plants (Fig. 1.4). Roughly 77% of the total in-country installed capacity is provided by HPPs, including 54% generated by regulated hydro power plants.

For 2027, the total installed capacity available in Georgian power system will grow to 7595 MW (Fig. 1.5). From this, 4239 MW will be attributed to regulated HPPs, 2180 MW to seasonal HPPs, 20 MW to Wind Power Plants, 110 MW to Gas turbines and 1045 MW to high efficiency combined cycle as well as coal thermal power plants, which will replace the older Gardabani TPP's Units Nos. 3, 4 and 9. For 2027, percentage share of hydropower in total national installed capacity will grow to 85%, including 56% regulated hydro power plants. This will ensure use of the water stored during flood season for low flow periods, thus reducing dependence on import of electricity and fossil fuels necessary for operation of thermal power plants.

The annual electric energy balances have been developed based on forecasted growth of generation and demand for all considered scenarios (table 1.1, fig. 1.6). Energy balance for basic scenario (Table 1.1, Picture 1.6) is shown below, which includes timely integration of all generation objects into the network, as well as annual 5% growth of consumption.

Table 1.1. Forecasted annual energy balances of Georgian electric power system (bln kWh)

Year	Generation	HPPs	TPPs	Wind Farms	Consumption	Export
2016	11.37	9.08	2.29	-	11.25	0.12
2017	12.9	10.23	2.58	0.093	11.64	1.26
2018	12.97	10.76	2.12	0.093	12.05	0.92
2019	14.61	11.99	2.53	0.093	12.47	2.14
2020	17.61	14.12	3.4	0.093	12.9	4.71
2021	18.3	15.37	2.84	0.093	13.35	4.95
2022	19.51	17.08	2.34	0.093	13.82	5.69
2023	20.15	17.63	2.43	0.093	14.3	5.85
2024	23.84	21.2	2.55	0.093	14.8	9.04
2025	25.66	22.96	2.61	0.093	15.32	10.34
2026	26.15	22.96	3.09	0.093	15.86	10.29
2027	26.3	22.96	3.24	0.093	16.4	9.9

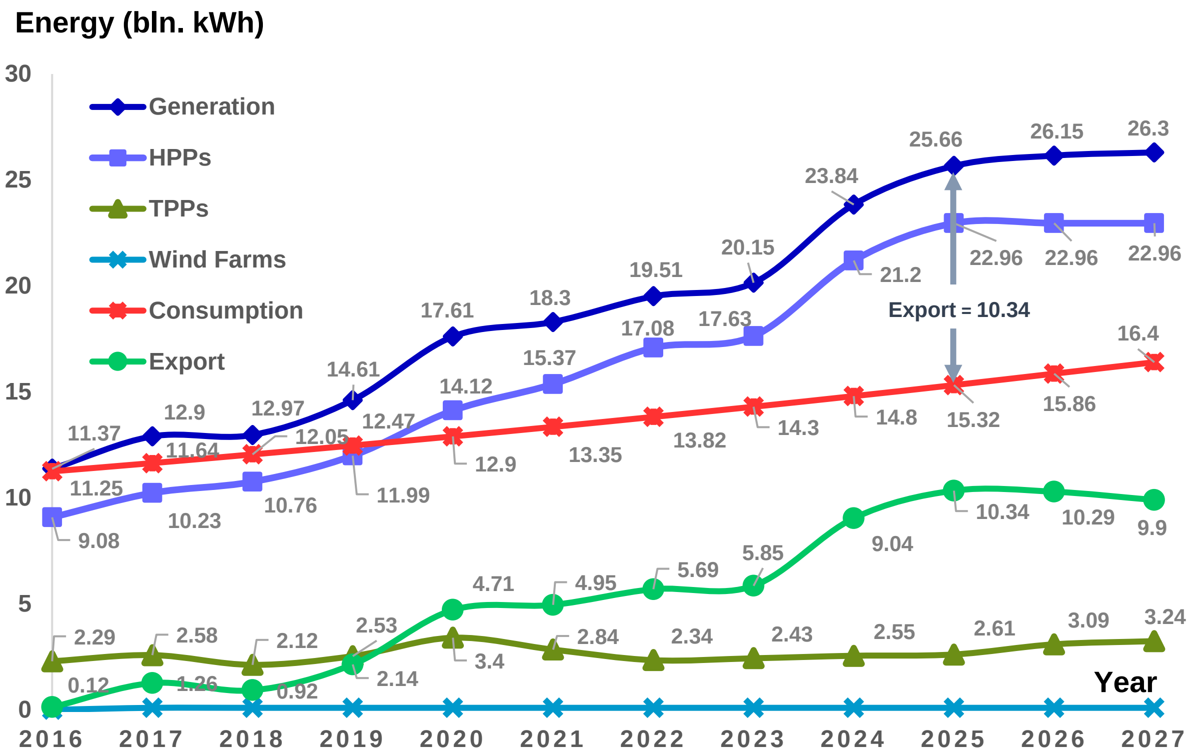


Fig. 1.6 Georgian generation, consumption and export graphs

Summary. Based on forecasted balances presented above, it may be concluded that construction of the new cross-border lines with neighbouring states is necessary. The most critical period in terms of intensity of the power export is flood season, including so called Summer Maximum and Summer Minimum regimes. According to capacity balances, 2100 MW should be available for export in 2020, that will grow to 3100 MW in 2021 and 4100 MW in 2022.

1.6 Development Scenarios and Methodology

Planning scenarios are defined to represent the future environment. Scenario analysis is necessary to obtain realistic picture of a future. Scenarios are means to approach the uncertainties and acknowledge interaction between these uncertainties.

Each scenario encompasses several planning cases, i.e. particular situations that may occur within the framework of the specific planning scenario.

At least the following three time horizons shall be considered:

- Short-term horizon (typically 1-3 years);
- Mid-term horizon (typically 4-5 years);
- Long-term horizon (typically 6-10 years).

Investments encompassed for transmission network reinforcement which correspond transmission network development plan should include all the represented cases and should encompass commissioning dates of new network elements.

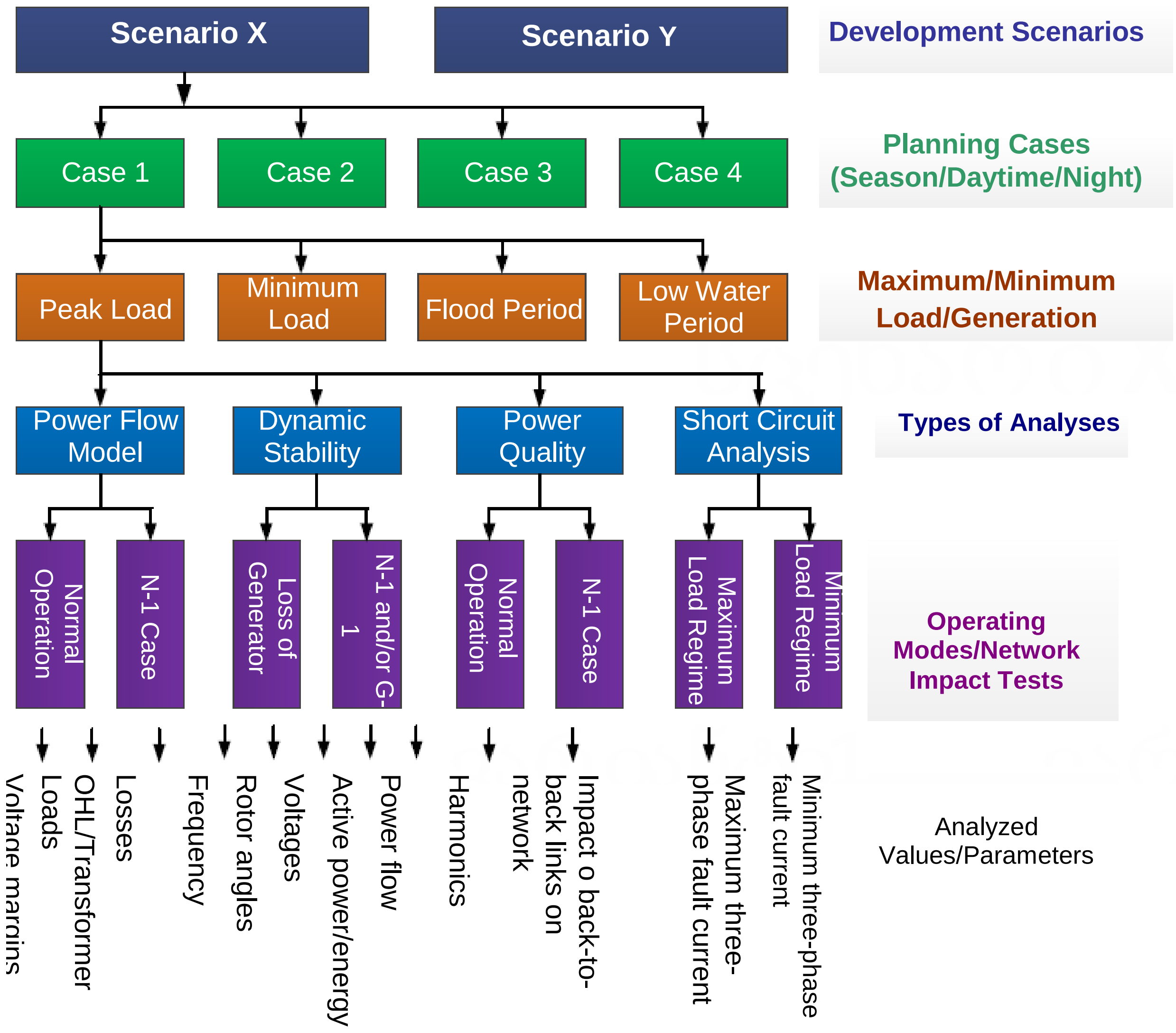


Fig. 1.7 Process of technical analysis of the scenarios

Analysis and network impact tests shall be performed for each design case to identify future problems and adequate technical requirements for network reinforcements. **The line of critical importance for the country is selected based on requirement of fulfilling N-1 criterion without the need of shedding the customer loads.**

The following studies have been performed for checking the planned network reliability status:

- Power flow analysis
- Short circuit analysis
- Voltage analysis
- Stability analysis
- Harmonic analysis

Several scenarios of Georgian transmission network development were reviewed. Information about prospective generation facilities to be integrated into the network was used as the input data for planning. Such facilities were divided into the following categories:

Category 1 Power plants under construction, which are provided with relevant executed Memorandums;

Category 2 Power plants that are objects of interests formally expressed by reputable investor companies, which feasibility studies have been commenced;

Category 3 Large strategic power plants of country wide importance, which feasibility studies will commence in the nearest future.

The estimated annual demand growth rate of 3.5% approved by the Ministry of Energy was applied for the base scenario, along with 1% and 5% growth rates for "optimistic" and "pessimistic" cases.

Table 1.2

GROWTH OF LOAD | GENERATION	"G1" 100% K1, 50% K2	"G2" 100% K1, 50% K2, 25% K3	"G3" 100% K1, 100% K2, 100% K3
1 % growth "L1"	L1G1	**L1G2**	L1G3
3.5 % growth "L2"	L2G1	L2G2	**L2G3**
5 % growth "L3"	L3G1	L3G2	L3G3

The table above shows various cases with different growth rates regarding demand (load) and generation, L2G3 scenario has been selected as general one which means 3.5% growth of load and commissioning 100% of all three categories of new power plants. Calculations presented in this plan are based on L2G3 scenario.

Generally, development of transmission grid depends on scenario of integration of new generation and power demand growth rate. Anyway, in case of development by any scenario until 2027-2031 all three categories of new hydro power plants will be integrated into the grid. As for demand – it represents combination of internal demand and power export. In other words, if internal demand is being less increased, then power export will be icreased more and vise-versa. Hence, **in case of development of generation and demand by any scenario, transmission grid shall be developed by the same option which corresponds timely integration of generation – L2G3.**

1.7 Generation Adequacy

Adequacy – ability of the electricity system to uninterruptedly satisfy the consumers' requirements on electricity, taking into account the both scheduled and unscheduled outages of system elements.

Adequacy of power generation is determined by 2 methods:

1. Deterministic - minimizes time required for calculations (although based on just a few scenarios). This requires deep knowledge of the system and may not cover all accidents;

2. Probabilistic – requires software with mathematical equipment; Requires more time for calculations (a second, or tenths of seconds), although reflects the influence of reliability of each element of the system on the adequacy of generation.

Adequacy may be expressed as the ability of Power System's generation to satisfy 100% of peak load with 95% probability. If less than 100% of peak load is satisfied, than the system treated as inadequate and installation of new generation sources and reinforcement of cross border transmission is required.

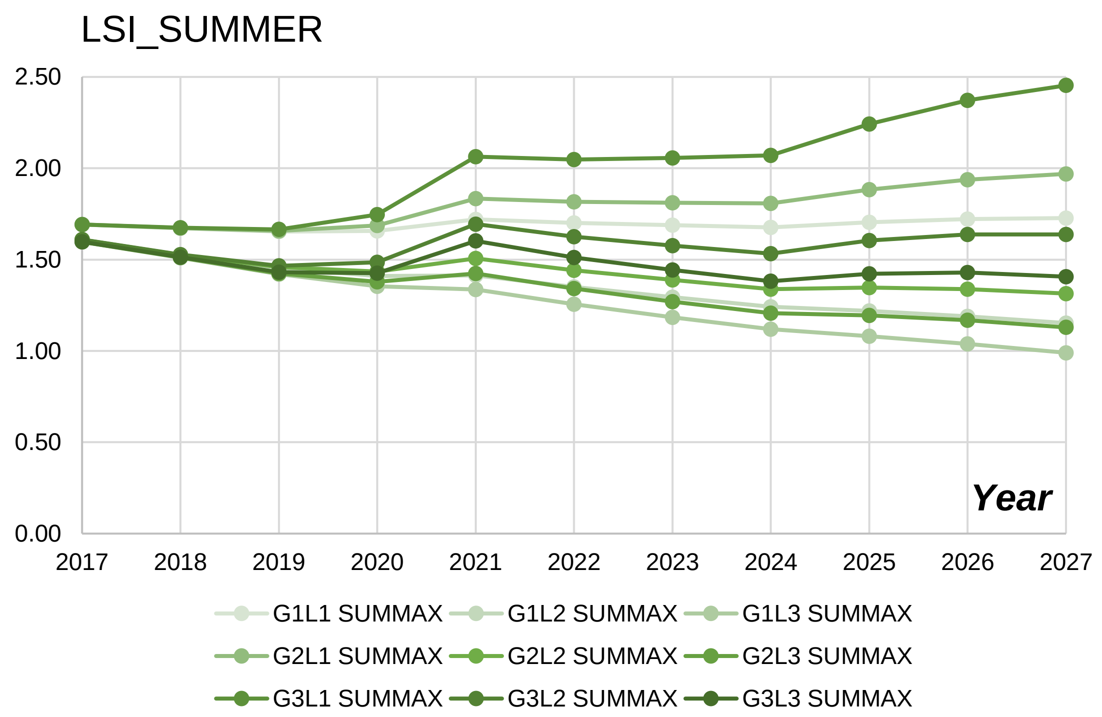
In addition, by adding of generation, 10% of total transfer capacity (NTC) of cross-border overhead lines can be used.

LSI Index (Load Supply Index) shows correlation between generation capacity and peak load capacity of the Coutry.

For the estimation of Generation Adequacy LSI (Load Supply Index) was estimated, which shows the ratio between generation capacity (generation availability plus 10% of NTC) and peak load of country.

If LSI>1.0 than the generation and interconnection capacity of power system is treated as adequate otherwise system is inadequate and new generation sources and the reinforcement of transmission capacity is required.

LSI levels for L2G3 base scenario for summer and winter seasons are given on fig. 1.8



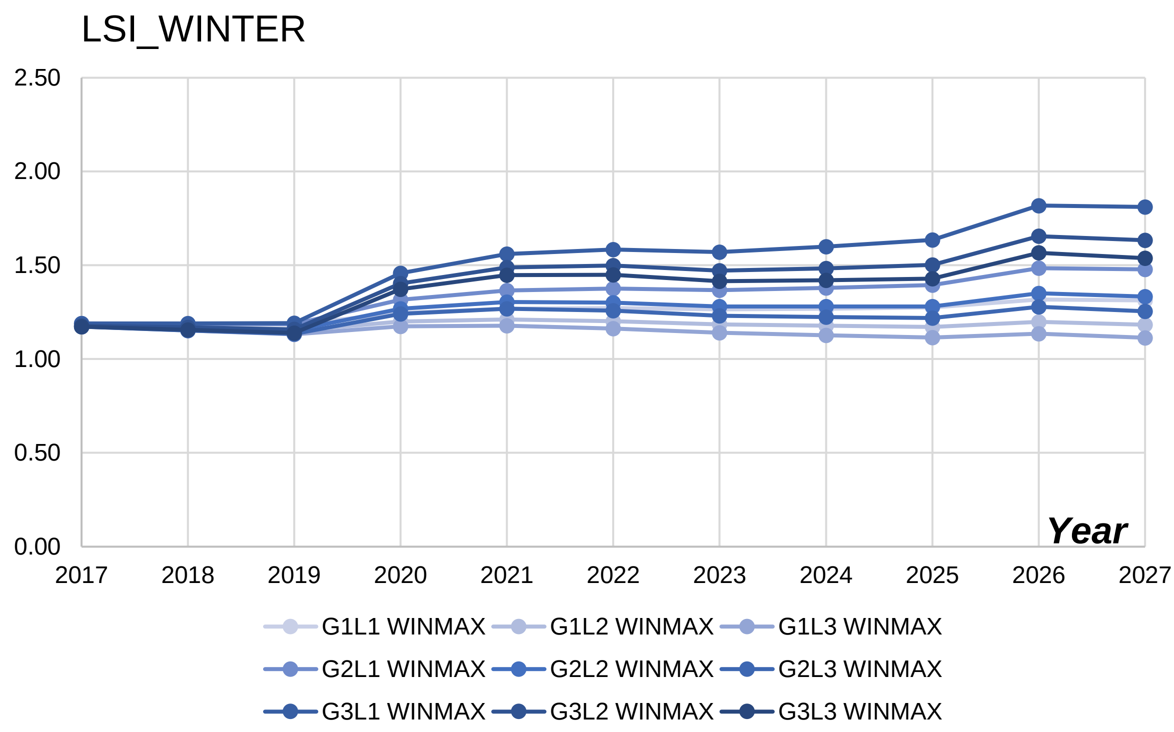


Fig. 1.8-b LSI for winter period

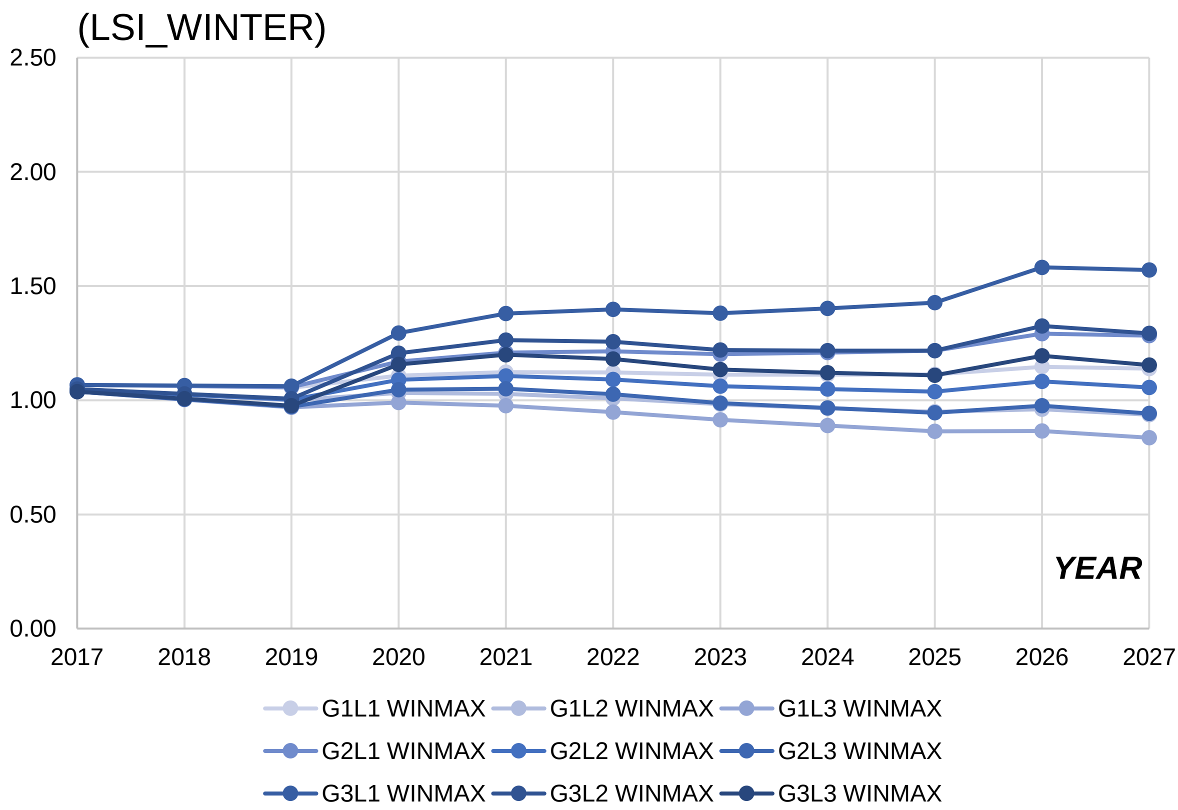


Fig. 1.8-c LSI for winter period (corrected)

() – Corrected data based on the information obtained in January 2017

Hence, in order to avoid the abrupt reduction of security of supply and the adequacy of power system, following recommendations have to be take in account:

1. Increase the reliability of power transfer from Enguri Pool to the consumption centers which are located in Eastern Georgia by construction of parallel 500 kV OHL for 500 kV OHL “Imereti”;
2. Interconnection transmission lines have to be commissioned at list on time;
3. Avoiding postponing of commissioning of prospective generation objects;
4. Full technical reconciliation of existing generation objects;
5. HPPs with Reservoirs (for example Khudoni and Nenskra HPPs, Namakhvani, Tskhenistskali cascade) have to be commissioned on time in order to “save energy” in summer period for winter one.
6. It’s recommended to construct pumped-storage HPPs which will increase system adequacy, stability, flexibility as well as will create opportunity to integrate variable energy sources (Sun and Wind) into the grid.
7. Other measures to ensure power efficiency and mitigate consumption growth.

1.8 Identified Projects and Required Investments

The projects planned for implementation have been divided into the following three groups:

1. ***Internal Projects,*** including the projects affecting power transit and reliability;
2. ***Cross-Border Projects***, i.e. the projects affecting capacity and reliability of the transit flows among the power systems of Georgia and its neighbouring states;
3. ***Local Projects,*** comprising 220 kV and 110 kV dead-end feeder lines.

Transmission Licensee does not implement local projects. The direct affect on development of the transmission network is provided only by Cross-Border and Internal Projects. Therefore 15 of such projects were selected for detail review.

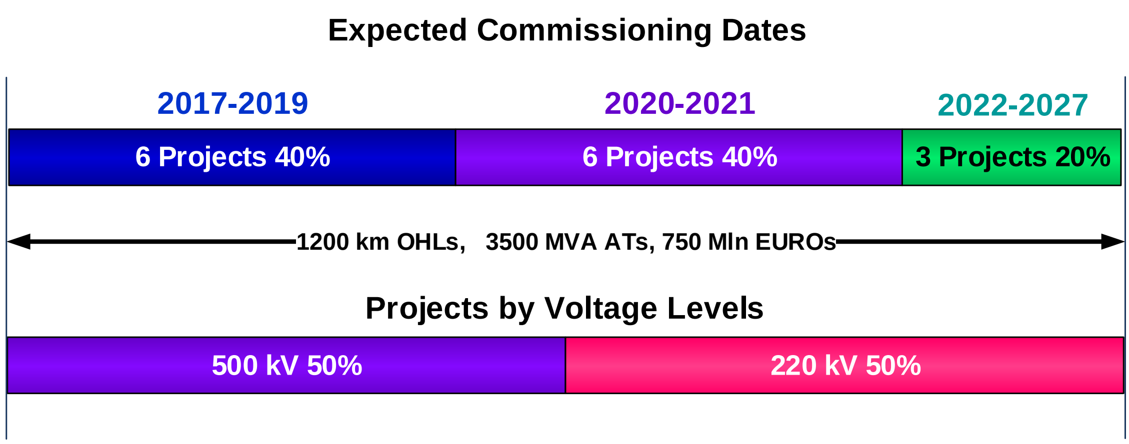


Fig. 1.9 Summarized Data of internal system and cross-border importance Projects

The Cost-Benefit Analysis (CBA) has been performed for the foregoing 15 projects planned for implementation in the transmission network during 2017-2027. Applying the CBA methodology, expected benefits where weighted against estimated investment costs and environmental impacts individually for each project.

According to appraisal of the planned projects applying CBA methodology, the highest ranked interconnection projects (implying the most needs) are: 1) **Jvari-Tskaltubo-Akhaltsikhe** integrating more than 2100 MW hydropower into the network, increasing network transfer capacity and reliability and ensuring compliance with N-1 criteria; 2) **Ksani-Stepantsminda-Mozdok** which will improve reliability of the parallel operation with Russian power system and stability of Georgian network, as well as will integrate up to 170 MW hydropower generation; 3) **Jvari-Khorga**, improving security of supply, implementing power evacuation of Khobi HPP cascade, upgrading flexibility of OHL Kavkasioni, ensuring power supply of Poti Industrial Zone, redusing amount of consumers to be tripped by system automatic.

The nameplate capacity of 500/400/330/220/110 kV autotransformers installed in Georgian transmission network will increase by about 3500 MVA, and the total length of 500/400/330/220/110 kV overhead transmission lines by 1200 km. This will ensure improved reliability of the network along with satisfying the single contingency (N-1) criterion at each development stage, allow Georgia to undertake transit hub function, provide for more than 1000 MW exchange in both east-west and north-south directions, and integration of additional 3500-4000 MW hydropower into the network. Total forecasted investment value of the foregoing projects amounts to about 750 million Euros.

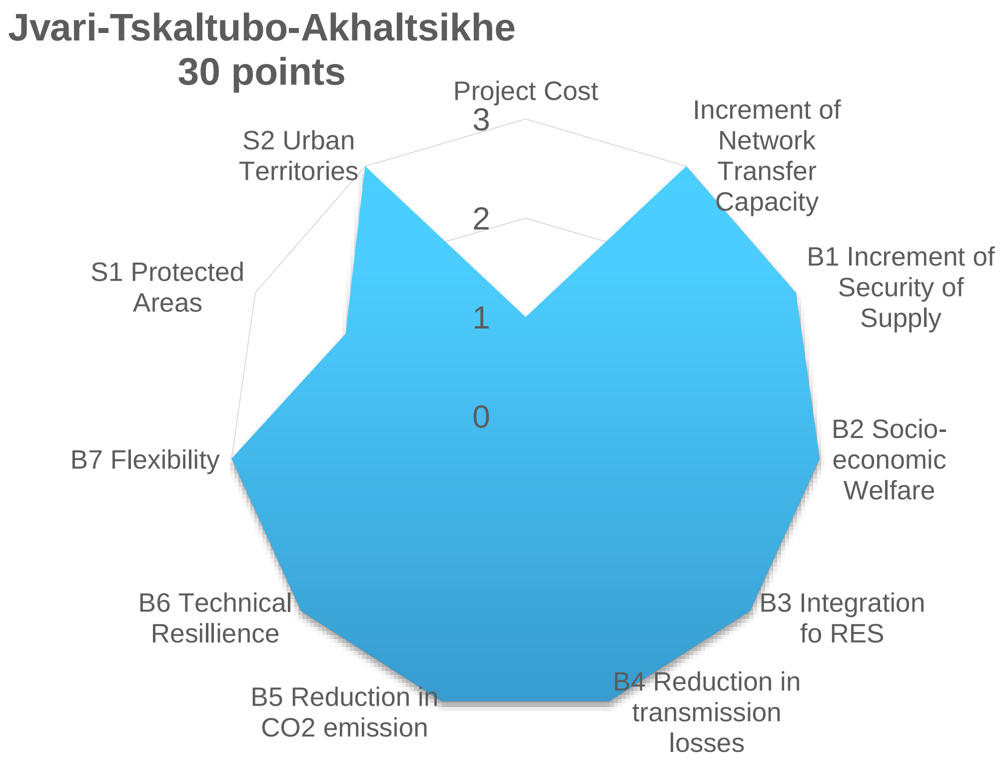


Fig. 1.10 Jvari-Tskaltubo-Akhaltsikhe Project; Total score: 30

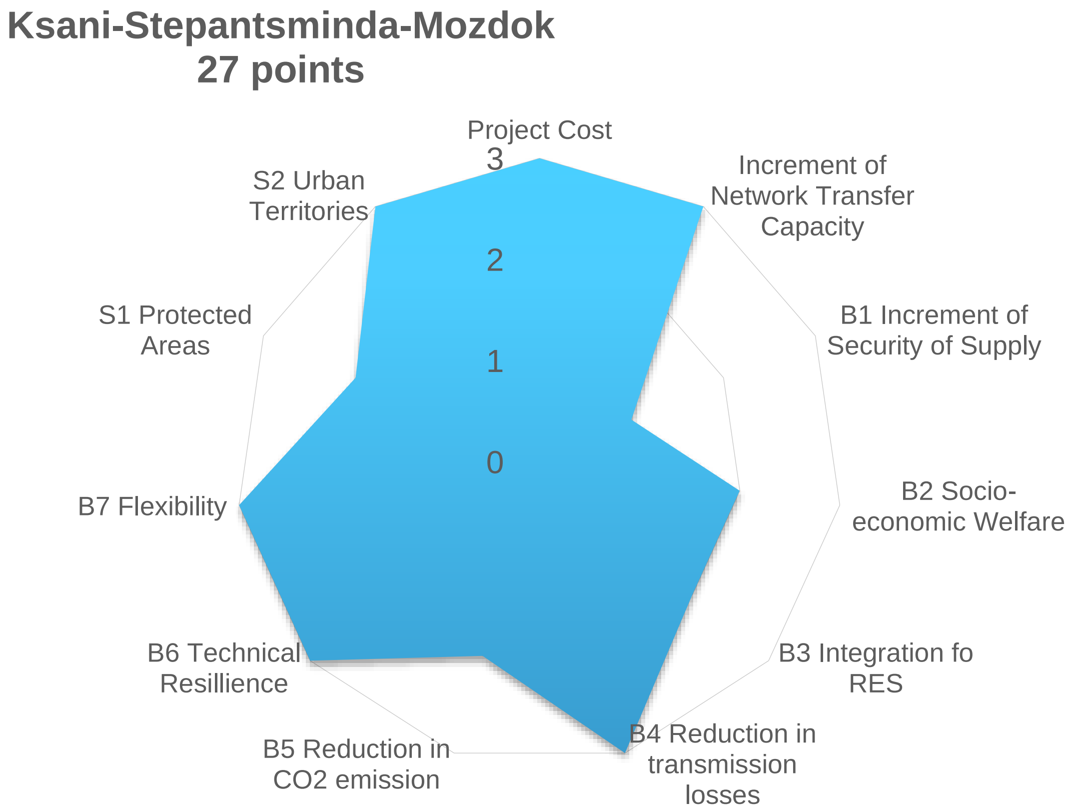


Fig. 1.11 Ksani-Stepantsminda-Mozdok Project; Total score: 27

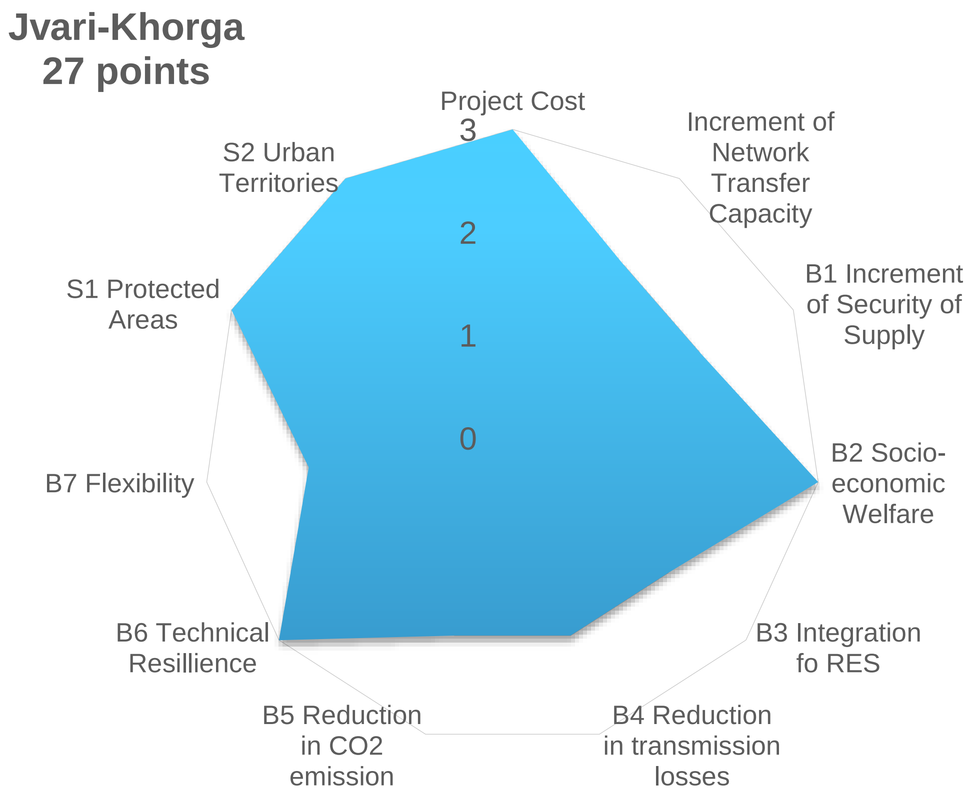


Fig. 1.12 Jvari-Khorga Project; Total score: 27

1.9 Major Calculation Results

Power flow analysis. In the base case, nodal voltages and power flows in the transmission remain within acceptable limits for the total planning horizon of 10 years. Meantime, during 2017-2019 (i.e. prior to the planned construction of 500 kV OHL Jvari-Tskaltubo), 220 kV network in the West Georgia is overloaded under single contingency (N-1) case, namely if 500 kV OHL Imereti is lost. In result, ECS initiates shedding of 200-300 MW load in the eastern part of Georgia along with adequate generation reduction in Enguri-Vardnili node to remove surpass load from transmission system.

Power losses. Power losses in Georgian transmission network at 500/400/330/220 kV voltage levels very in the range of 2.27-4.76 percent.

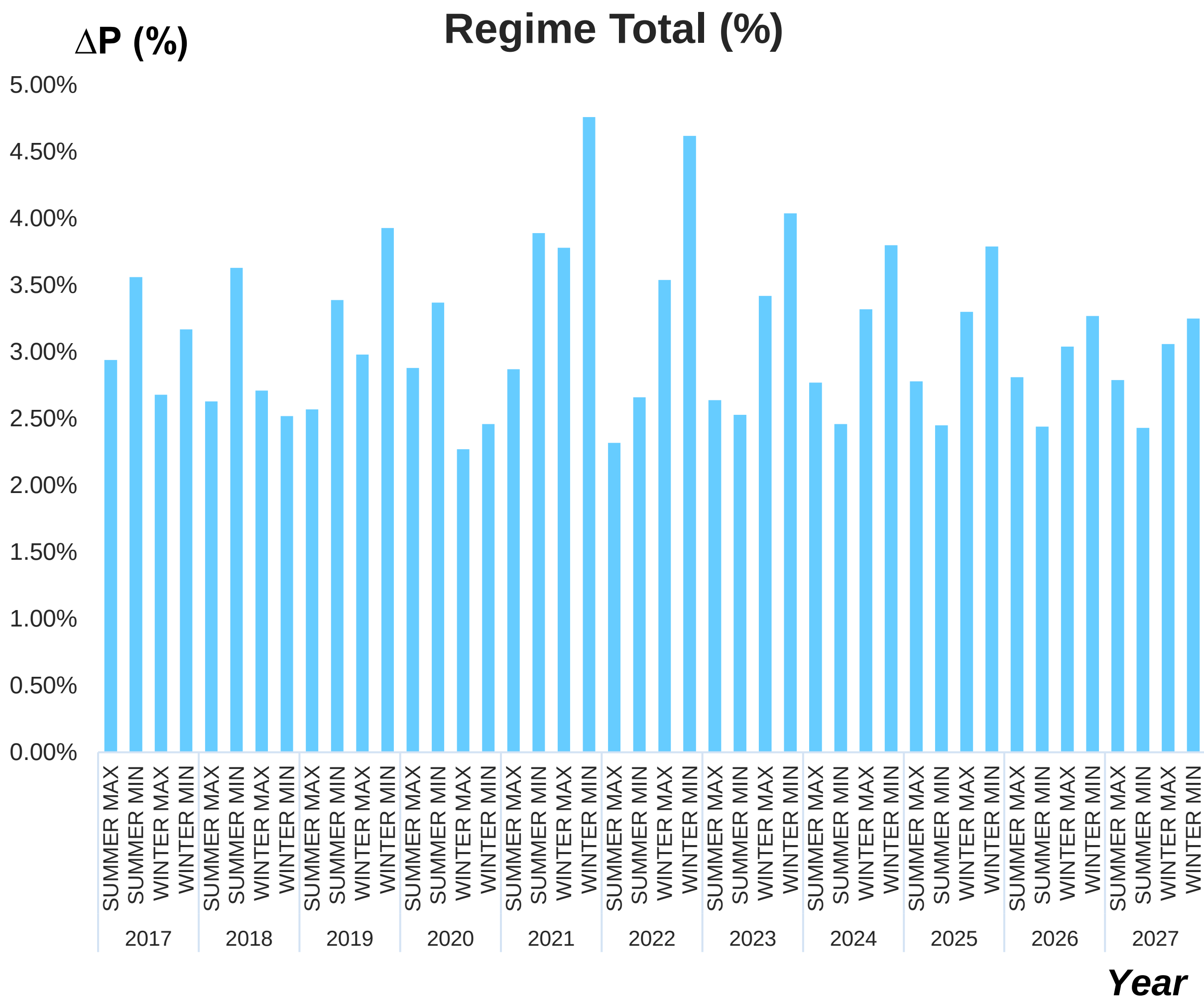


Fig. 1.13 Dynamics of transmission losses during 2017-2027 by seasons

Short circuit analysis. For the Ten-Year Network Development Plan of Georgia, the maximum and minimum short circuit currents have been calculated for the most critical and characteristic years (2017, 2019, 2023, 2027). The maximum short circuit currents were calculated assuming operation of all generators and cross-border lines of Georgian electric power system, while the case when the fewer number of generators appropriate to the summer minimum regime are operated, and all cross-border OHLs are switched off was considered when calculating the minimum short circuit current values. As calculations showed, in certain substations, the estimated short-circuit currents for 2027 are 70%-80% higher than for 2019 and may two times exceed the current values. Therefore, electrodynamical and thermal ratings of the equipment installed in power plants and substations should be verified to timely make relevant replacements.

Dynamic Stability Analysis studies power system behaviour and ability of maintaining synchronous operation of the generators during limited contingencies. Such analysis was performed for maximum summer demand mode of Georgian power system for 2020, 2023 and 2027, considering the following disturbances: Emergency tripping of 500 kV OHLs; Outage of 500/220 kV autotransformers; Tripping of back-to-back link or 400 kV Georgia-Turkey line; Shutdown of the power units of Enguri HPP, 9th Thermal Unit and Khudoni HPP.

According to results of the analysis, Georgian transmission network (power system) maintains stability during any disturbances, subject to the following preconditions: During 2017-2019, in cases involving tripping/shutdown of 500 kV OHL Imereti, 500 kV OHL Kavkasioni, power unit of Enguri HPP or 9th Thermal Unit, ECS should intervene for shedding of the appropriate customer loads and/or generation facilities. During 2020-2027, system stability is naturally maintained in case of any disturbances.

Harmonic analysis. The most powerful source of harmonics in Georgian electric power system is 700 MW Akhaltsikhe HVDC back-to-back station. In near future new HVDC links will be added to Georgian transmission network, such as 350 MW HVDC station planned at Batumi, and additional 350 MW link scheduled at SS Akhaltsikhe. In addition, construction of 700 MW HVDC back-to-back station in Armenia near to Georgian border is planned. For the base case (N), analysis included calculation of individual and summarized harmonic distortion factors, while for single contingency (N-1) cases (considering failure of 220 kV or 500 kV lines), only the Total Harmonic Distortion (THD) was calculated. According to derived results, all THDs, for both N and N-1 modes are within the standard limits. However, certain deviation from standard value of 13th harmonic has been observed that should not have any negative effect on the network, but still needs performance of more accurate calculations.

Summary: based on results of above analyses, the planned transmission network is reliable, provides stability of the power system and maintains system parameters within the limits set forth in the Grid Code.

1.10 Georgian Transmission System Development Indicators

Future constructions of 500/400/220/154/110 kV OHLs and substations planned during next ten year are mainly intended for integration of the new hydro power plants, necessity of improving reliability and security of supply as well as increment of transit potential.

Table 1.3

Overhead Lines		Substation autotransformers and Back-to-Back Links	
Rated Voltage (kV)	Length (Km)	Rating (kV)	Capacity (MVA)
500	841	500/400	875
400	32	500/330	0
330	21	500/220	2800
220	1616	330/220	400
110	3528	220/110	5145
Sum	**6081**	**Sum**	**9220**

The following diagram illustrates dynamics of total generation capacity (MW), installed apparent capacity of 500/400/330/220/110 kV transformers and autotransformers (MVA) and total length of transmission lines expressed in 500 kV OHL equivalent (km).

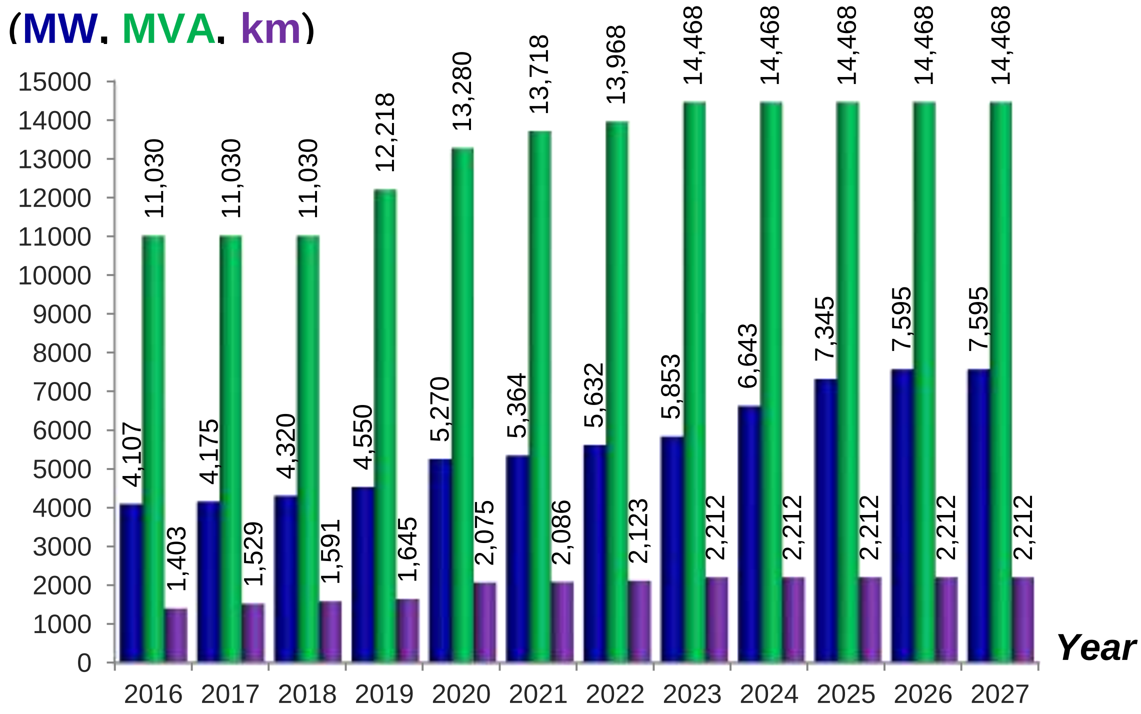


Fig. 1.14 Dynamics of Georgian generation and 500/400/330/220/154/110 kV transmission infrastructure development during 2016-2027

Several indicators describing development of Georgian transmission network were calculated from the diagram given on Fig. 1.14, such as length of overhead line needed for evacuation of 1 MW installed generation capacity (in 500 kV OHL equivalents) and total installed capacity of 500/400/330/220/110 kV (auto)transformers.

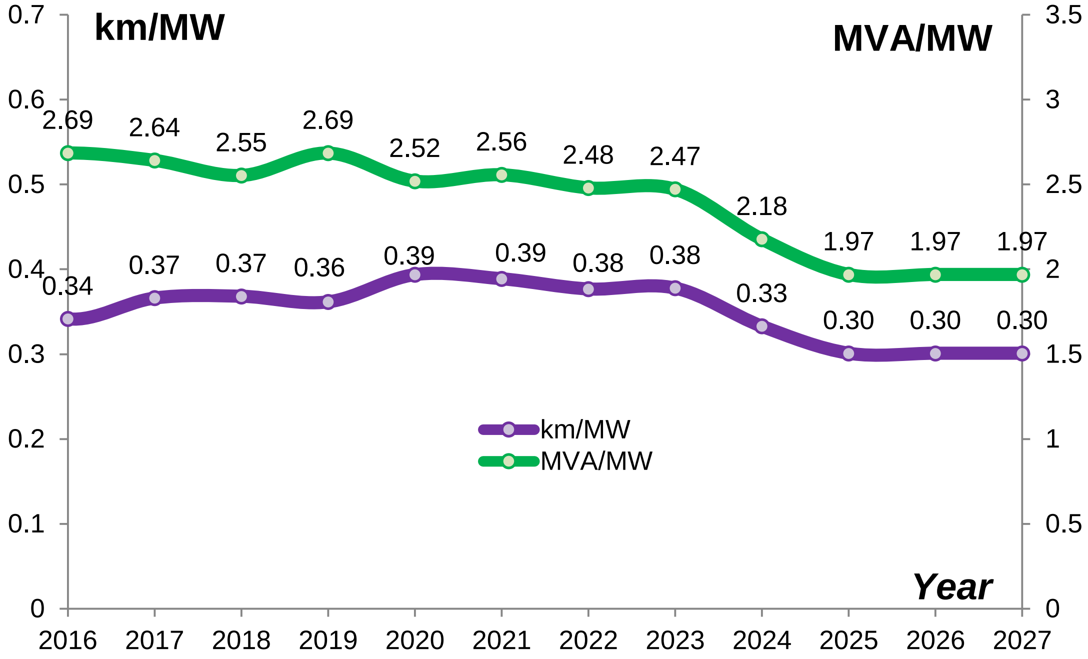


Fig. 1.15 Relationship between development of Georgian transmission network and generation infrastructure

Summary: Despite reduction of unit equivalent length of the transmission network and specific capacity of (auto)transformers per evacuated 1 MW generation, the calculations show that during 2024-2027, Georgian power system will be more stable comparing to 2017-2019 time span. Therefore, it is apparent that improvement of the reliability is accompanied by improvement of network effectiveness and cost-efficiency.

1.11 Capabilities of Power Exchange with Neighbouring States in 2022-2027 Time Span

The existing cross-border links serve for power exchange between Georgia and Russia and transit from Russia and Azerbaijan to Turkey, as well as for bidirectional power exchange between Georgia and Turkey, Azerbaijan and Armenia. However, such power flows are restricted due to both limitations stemmed from the acceptable operating modes of national power system and physical capacities of above cross-border OHLs (tab. 1.4and fig. 1.17).

For 2022-2027 horizon, Georgia, due to its geographical location, will gain an important role in the planned regional integration of the power systems of the Caucasian (and Black Sea) countries assuming promotion of energy trading between these countries and development and use of Georgian hydropower resources.

For 2022-2027, cross-border links between Georgian and its neighbouring power systems will significantly advance, allowing 1400 MW power exchange with Turkey, 1400 MW with Russia and 700 MW with Armenia. There is already possibility of 700-1000 MW power exchange between powers systems of Georgia and Azerbaijan.

Table 1.4 Power exchange capabilities with neighbouring power systems

Country	Cross-border line, conductor	Nom. Voltage (kV)	Exchange	TTC (MW)	Mode
Russia	,,Kavkasioni" AC-3x300	500	Export	700	≈
			Import	700	≈
	,, Stepantsminda" (Ksani-Stepantsminda-Mozdok) AC-3x300, 2021	500	Export	1000	≈
			Import	1000	≈
	,,Salkhino" AC-400	220	Export	50	Isl
			Import	150	Isl
Azerbaijan	,,Mukhranis Veli" AC-3x300	500	Export	700	≈
			Import	700	≈
	,,Gardabani" AC-480	330	Export	320	≈
			Import	320	≈
Armenia	,,Alaverdi" AC-300	220	Export	150/100	≈/Isl
			Import	150/100	≈/Isl

	„Marneuli“ (Marneuli-Ayrum) AC-3x330,[2018]	400	Export	700	B2B *
			Import	700	B2B
Turkey	„Meskheti“ AC-3x500	400	Export	1050	B2B *
	„Tao“ (Akhaltsikhe-Tortum) AC-3x500,[2019 (2020)]		Import	1050	B2B *
	Batumi-Muratli [2020]	154	Export	350	B2B *
			Import	350	B2B *
	„Adjara“ AC-400	220	Export	150	Isl (res)
			Import	150	Isl (res)

≈ synchronous mode

Isl isolated mode

B2B operation with Back-to-back station

In particular, each of the 400 kV OHLs “Tao” and “Meskheti” can transfer up to 1500 MW but their total transfer capacity is limited by the ones of Akhaltsikhe HVDC back-to-back units, value of which will equal to 1050 MW after 2021.

Fig. 1.16 Cross-border transfer capacities between power systems of Georgia and its neighbouring countries as for 2027

1.12 Opportunities of integration of renewable energy sources into the transmission network of Georgia

Georgian power system is a small size one. More than 80% of consumption is covered by “Green energy” produced by HPPs. On the other hand, due to the small size (low intertia constant) and radial layout of

Georgian system, security of supply is important challenge. Fulfil of this is possible by constructing powerful seasonal regulating HPPs which will ensure both power reserves and stability (inertia constant). As for integration of renewables (Solar, wind), it's restricted. Total capacity of 100 MW is acceptable for Georgian power system till 2021, in 2025-2030 (with the consideration of commissioning of all planned regulating HPPs and cross-border lines) this value equals to 400 MW but not more than 45 MW for each geographic region (9 regions in total).

1.13 Ten-year development plan of SCADA and information technology (IT)

Georgian State Electrosystem (GSE) is the transmission system operator serving the function to maintain system stability and reliability for short-term and long-term periods. Especial challenge is to balance the system usage-supply and export-import in real time (online) so that to maintain power quality parameters within normal limits. Another challenge is to manage energy system, and to maintain stability and integrity in emergency modes. In order the company to be able to generate and exchange all required accurate data for energy management, it is necessary to integrate a variety of information technology platforms applied to GSE system, which should correspond to the Ten-Year Network Development Plan of Georgia. This is the basis for SCADA and Information Technology (IT) Development Plan.

1.14 New challenges and relevant solutions

1. **Electromobiles –** Possible drastic increase of peak load; "prosumers" – system decentralization and nonpredictability and customers with changing requirements. *Solution/mitigation*: construction of Hydro Power Plants (HPPs) with reservouis, enhance energy efficiency, introduce power storage stations and batteries, construct thermal plants and inter-system power transmission infrastructure. Complete control and operation system, introduce "smart networks", introduce dynamic patency of transmission lines, optimal integration of wind and solar power stations (possibly with storage batteries), introduce VSC PLUS and FACTS equipment, utilize up-to-date planning and modelling devices. **Challenges associated with the construction of new transmission lines, by the end of next decade:** *solution/mitigation*: visual-friendly constructions, installation of multiple current towers and, under some exceptions, construction of cable transmission lines.
2. **Challenges associated with market liberalization.** *Solution/mitigation*: renewal of system control program and readiness for the trade with the Europe's domestic power market before-day and within-day, as well as rehabilitation of existing power stations as per "systemic service concept".
3. **Possible cyber attack risks and informational safety challenges.** *Solution/mitigation*: GSE conducts personnel awareness and introduction of ISO 27001 safety standard. Besides, foreign cyber security experience is adopted and relevant GSE staff ensures cyber security at all times.

1.15 Strategic Environmental Assessment

GSE aims for the construction of transmission infrastructure, which will provide reliable consumption, as well as minimal adverse enironmental effect. This 10-year plan envisages strategic environmental assessment of all main projects.

1.16 Conclusion

Transmission system operator, together with transmission licensee strives to provide reliable and high quality services to its customers and develop its own infrastructure that is necessary for supporting to economical development of Georgia. The projects presented and discussed in this Ten-Year Plan represent an adequate response to the changes in economical and energy environment. GSE believes that implementation of these projects will meet wishes of Georgian society as well as will allow the national economy to effectively address the challenges and ensure the better future.

2 Introduction

Power transmission system of Georgia operates at 500/400/330/220/110 kV voltage levels and undertakes a vital role in provision of power supply, ensuring reliable and safe transportation of electrical energy from the generation facilities to the customers, as well as energy export/import with neighbouring countries.

Electric power sector composes important part of the national economy having enormous influence on the social status of Georgia's population, and therefore development of the power infrastructure constitutes the countrywide strategic goal.

This Ten Year Network Development Plan of Georgia (hereinafter "Ten-Year Plan") specifies challenges and drivers relevant to development of the grid, and describes projects and investment needs for the period of 2017-2027.

The planning period subject of review has been divided into the following three time spans:

Short-Term Planning Period extended over 3 years after the base year of 2016, i.e. the period of 2017-2019. Consulting companies have already been performing or they have already completed feasibility studies for the projects planned for such period. Required investments are clarified and new ones are identified. Three year Investment Plan for these three-year period is shown in Annex-5.

Mid-Term Planning Period, covering 4th and 5th years from the base year of 2016, i.e. the period of 20120-2021. Feasibility studies of the projects envisaged for such period have not started yet, however the major project features and estimated technical and economical data have already been specified. It is expected that technical feasibility studies for these projects will commence shortly and in result forecasted features may be changed in some extent.

Long-Term Planning Period, including 6th to 10th years from the base year, i.e. the period from 2022 to 2027. Feasibility studies of the projects planed for this period have not been started yet, however necessity for these projects have already been identified, and it is expected that their feasibility studies will commence within 2-3 years. In result of such studies certain project parameters may be changed.

Network components and projects discussed in this Ten-Year Plan have been divided into the following three groups:

1. ***Internal Projects****,* including the projects affecting power transit and reliability;
2. ***Cross-Border Projects***, i.e. the projects affecting capacity and reliability of the transit flows among the power systems of Georgia and its neighbouring states;
3. ***Local Projects****,* comprising 220 kV and 110 kV dead-end feeder lines.

2.1 Legal Compliance

This Ten-Year Plan has been prepared by Georgian State Electrosystem with due account of the situation prevailing in Georgian power sector and applicable best European practice.

The underlying statutory base for this Ten-Year Plan is provided by "Georgian Law on Electricity and Natural Gas" and the Grid Code approved by Georgian National Energy and Water Regulatory Commission ("GNERC").

- According to 3[2] article (**Ten-Year Network Development Plan of Georgia**) of Georgian Law about "Electricity and Natural Gas":

1. The purpose of working out the Ten-year Transmission Network of Georgia Development Plan shall be the reliability, safety, and sustainable development of the transition network, provision of electricity of adequate quality, and raising the transit capacity of the electricity network of the country.

2. The Ten-year Transmission Network of Georgia Development Plan implies:

a) information on the present and future (forecast) electricity requirements and supply;

b) rational forecast of electricity generation, transmission, consumption, and the volume of exchange of electricity with other countries;

c) information on the transmission network infrastructure to be built or improved in the next 10 years, with the indication of concrete timeframes for implementing investment;

d) information on agreed investment and on identifying the new investment that is to be implemented in the next 3 years;

e) information on integrating new generation facilities (including, renewable energy sources) in the network;

f) information on transmission capacity of each node of the future network for the purposes of integration of new generation facilities;

g) defining short circuit currents for the purposes of selecting power equipment for the units to be planned;

h) information on the development of the internal network of generation facilities.

3. The state agencies and organizations in the field of economy, finance and statistics, and the organizations in the field of energy, shall, within the sphere of their respective authority, according to the legislation of Georgia, provide the information, data and forecast that are to be considered in the Ten-year Transmission Network of Georgia Development Plan.

4. The transmission system operator shall, in agreement with electricity transmission licencees, annually, during the next 10 year, work out/update a draft Ten-year Transmission Network of Georgia Development Plan (this process shall involve carrying out all necessary research and assessment). The draft plan shall be forwarded to the Ministry and the Commission not later than 1 October of the respective year. The Commission shall consider the Ten-year Transmission Network of Georgia Development Plan within 1 month after receiving the draft, and shall present to the Ministry its Notes and Recommendations on the draft plan.

5. The Ministry shall consider the Ten-year Transmission Network of Georgia Development Plan and the submitted Notes and Recommendations together with the Commission, the transmission system operator, and the electricity transmission licensees. The Ministry shall, based on the consent of the Government of Georgia, not later than the completion of the respective year, ensure the approval of the Ten-year Network Development Plan of Georgia.

6. Introducing ad hoc amendments to the Ten-year Transmission Network of Georgia Development Plan shall be possible, observing the procedures provided for by this Article. The draft ad hoc amendments to the plan may be worked out and submitted for consideration at any time during the calendar year.

- According to Article 29 of the Grid Code (**"Transmission Grid Planning"**):

1. Dispatch Licensee shall prepare Transmission Network Development Plan, as well as complete all required studies and assessments.

2. Dispatch Licensee (GSE) shall provide for collection and coordination of the data from Transmission Licensees, Transmission Grid Users and Transmission Applicants, as well as ensure information exchange with power system operators of neighbouring states.

3. Dispatch Licensee (GSE) shall prepare the unified transmission grid development plan for 10-year period, and submit it to Georgian National Energy and Water Regulatory Commission and the Ministry of Energy of Georgia.

- According to Article 30 of the Grid Code (**"Major Principles"**):

1. Inter alia, the following shall be taken into account during planning process:

a) Technical reliability requirements;

b) Issues related to economic and operative control, maintenance, relay protection and automation;

c) Issues related to coordination with electricity generation, consumption and distribution facilities;

d) Issues related to information technologies and environmental protection.

2. The unified transmission grid development plan shall consider the issues related to planning of system reliability, cost effectiveness, environmental protection, forecasted development, intersystem links and local transmission network.

3. The following two criteria are used in this Code for assessing reliability of the transmission grid:

a) Adequacy – Ability of the power system to satisfy the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of system elements;

b) Stability – Ability of the electric systems to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

4. Above planning criteria shall be taken into account during assessment of various development scenarios and likelihood of contingencies.

5. The long-term plans shall be reviewed annually.

6. The planning process shall consist of the following major stages:

a)Data collection;

b)Data processing;

c) Modelling;

d)Drafting the optimal plan for removing or mitigating any deficiencies;

e) Preparation of the unified transmission grid development plan.

7. *The planning process shall include:*

   a) Assessment of electric power system performance by individual seasons;

   b) Detail study of electric power system performance anticipated for short-term period;

   c) Requirements for strategic planning applicable to medium and long-term periods.

8. *The planning process shall begin with assessment of power system performance.*

   Any identified potential risks shall be analyzed in detail to ensure their elimination or mitigation.

9. *The power system development plan shall allow elimination and/or reduction of identified risks.*

- According to Article 35 of the Grid Code (**"Transmission Network Planning Criteria"**):

1. *Planning of the transmission network shall be based on maintaining the standard power quality parameters ..., under forecasted load and generation values..*

2. *Transmission network development planning shall provide avoidance of system emergencies and implementation of system stability measures during expected contingencies that may be caused by:*

   a) Failure of a single system element (N-1);

   b) Failure of any system element plus emergency outage of one thermal/hydro power unit (N-

   G-1);

   c) Failure of any system element during maintenance outage of other element (N-1-1).

2.2 Process of Preparation of the Unified 10-Year Network Development Plan

This Unified 10-Year Network Development Plan has been prepared by GSE based on information received by support of the Ministry of Energy of Georgia (generation, consumption growth). Preliminary network development plan has been drafted, which specified:

- Planned OHLs, including rated voltages, lengths and estimated investments;
- Planned substation capacities, rated voltages and estimated investments.

The important dates from preparation process of TYNDP document are represented below:
May 2017 – Obtain inicial information from the Ministry of Energy of Georgia regarding changes in the utilization of prospecive HPPs.
June 6, 2017 – Obtain informaction from the Ministry of Energy of Georgia regarding date commissioning of potential HPPs – "Namakhvani" cascade, "Khudoni" HPP and "Guria" HPP.
June 2017 – Modification of "North Ring" Project.

July 11,2017 – Clarification of prospective HPP commissioning and dynamics of consumtion growth. Correction of 2017-2027 data.
Untill August 25, 2017 – Completion of technical estimates and influence tests of prospective scheme.
August 25, 2017 – Discussion of initial draft of 10-year plan within GSE;
August 25-29, 2017 – Refinement of initial draft of 10-year plan;
August 29, 2017 – Submission of draft 10-year Plan to licensees for approval;
August 31,2017 – Agreement of 10-year plan by “Energotrans Ltd”;
September 1, 2017 - Agreement of 10-year plan by “Sakrusenergo”;
September 1, 2017 – Submission of initial draft 10-year Plan to the Ministry of Energy and Energy and Water Supply Regulatory Commission.
September 1, 2017 – Notes and recommendations from the Ministry of Energy;
September 29, 2017 – Obtain recommendations from Energy and Water Supply Regulatory Commission;
November 28, 2017 – Submit final revised version of 10-year plan to the Ministry, for approval;
December 8, 2017 – Agreement of 10-year Network Development Plan of Georgia 2018-2028 with the Government of Georgia;
December 28, 2017 – Approval of “Network Development Plan of Georgia 2018-2028 by the Ministry of Energy.

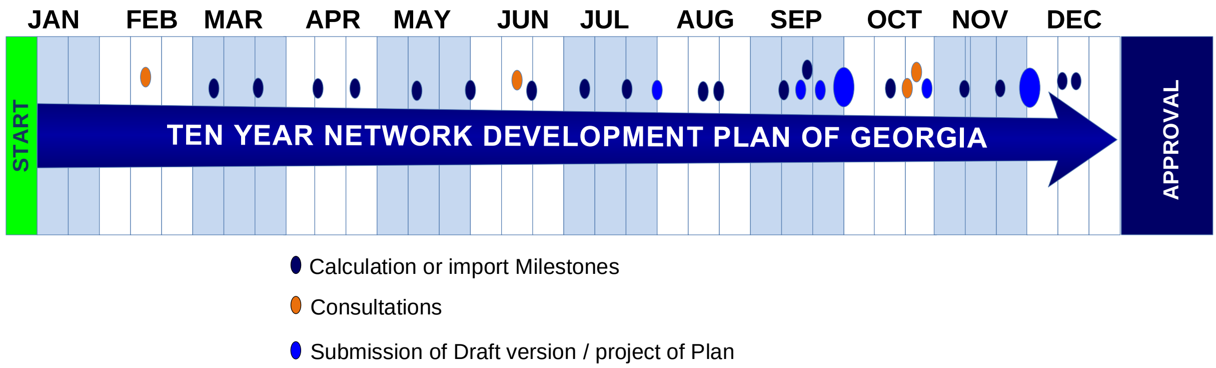


Fig. 2.1 Timeline of preparation of the Unified Georgian Power Network Development Plan

Fig. 2.2 Preparation Stages of Unified Georgian Transmission Network Development Plan

2.3 Data Management / Softwares used for calculations

Transmission system undergoes continuous development in line with modifications and changes made to power network development projects. The projects envisaged in this Ten-Year Plan (2017-2027) represent the ones considered in previous 2016-2016 years, their modification or the projects existing of which become necessary due to the network security and new reality.

Information on installed capacities, outputs, geographical locations, categories and commissioning years of the planned hydropower plants was received by support of the Ministry of Energy (in August 2016). In addition, annual 3.5% growth of demand was assumed. These data have been used in the power flow analysis.

Also, by support of the Ministry of Energy design data of above generation facilities required for dynamic stability and harmonic analyses has been obtained. Whenever such data were not available, the standard values were applied using typical generators' characteristics given in the databases developed by GSE's specialists.

The most recent available and regularly updated information maintained by GSE was used for obtaining data and conditions of the existing OHLs, substations, transformers, reactors, HVDC links and power plants/generators.

GSE specialists collected standard data from feasibility studies of relevant projects, regaring prospective transmission lines, substations, transformer units, HVDC back-to-back stations and reactors.

The analyses were conducted by GSE's specialists.

Power flow, system reliability and short circuit analyses were performed using the model developed by PSS/E (Power System Simulator for Engineers) software, including the following elements:

- 500/400/330/220/110 kV voltage elements of Georgian power network, as well as part of the lower voltage network used for interconnection of the generation facilities with 110 kV and higher voltage grid.
- Models and/or equivalents covering Azeri, Armenian, Turkish and South Russian electric power systems.
- Synchronous generators with 3 MW and higher rated capacities.

Harmonic analysis was performed by using Digsilent PowerFactory software taking into account the same elements as ones used in modelling by PSS/E.

Time of exploitation of transmission infrastructre projects represents the end of relevant year.

2.4 Differences compared with the previous 2016-2026 version of ten-year plan

As it has been already mentioned, the transmission network is experiencing continuous development as well as projects of transmission network development are being changed and modified. Such changes are depended on several factors – forecasts of generation and consumption, dates of commissioning of new power plants and decommissioning of aged power plants etc. In addition, calculations for ten-year plan and/or analysis methods are being improved annually. Therefore, below are the changes, which was carried out in comparison with 2017-2017 version of the ten-year plan.

1. **The changes in commissioning dates and list of perspective power plants.** As far as construction of transmission network infrastructure is significantly intended for provision of reliable evacuation of generated power of power plants, therefore, the updating of data of power plants results in changes in transmission network projects. It is noteworthy new cascade in Svaneti region, river Enguri, possibly in 2029, with total capacity of 550 MW.
2. **Change in forecasted characteristics of consumption growth.** Pessimistic, moderate and optimistic forecasted characteristics 3%, 5% and 7% have been changed to 1%, 3.5% and 5% respectively.
3. **The changes in projects and the new ones.**
   3.1. "North Ring – Tskaltubo". In this project, the 500/220/110 kV substation was replaced by 500/220/110 kV substation "Nenskra". Therefore, OHL "Khudoni-Mestia" was replaced by OHL "Nenskra-Mestia", within 220 kV range, but will initially operate on 110 kV. Double-circuit 220 kV transmission line "Khudoni-Jvari" was replaced by single-circuit 500 kV OHL "Nenskra-Jvari". OHL "Kavkasioni" will be tie-lined to "Nenskra-500", and the new OHL "Jvari-Nenskra" will be tie-lined to "Khudoni" HPP. New 500/220/110 kV substation will be constructed in Lajanuri to replace SS "Tsageri-500", where Kheledula HPP, Tskhenistskali Cascade and Oni Cascade will be connected. "Lajanuri-500" will be connected two SS "Tskaltubo" through 500kV OHL. "Sadmeli-220" and double-circuit OHL "Sadmeli-Zestaponi" where removed from the project; "Kheledula" HPP will be connected to SS "Lajanuri", instead of SS "Jakhunderi". Thus, double-circuit OHL "Kheledula-Jakhunderi" will be replaced with double-circuit OHL "Kheledula-Lajanuri",

which will be constructed within 220 kV range, since "Tskhenistskali" cascade HPPs shall be tie-lined to this line;

3.2. "Jvari-Tskaltubo-Akhaltsikhe". Considering scope of works, estimated date of exploitation of this project was postponed to 2021. Length of double-circuit OHL "Tskaltubo-Akhaltsikhe" (160km) was changed to 110 km;

3.3. "Marneuli". Construction of 500 kV OHL "Marneuli-Airum" was postponed till end of 2020;

3.4. "Akhaltsikhe-Tortumi". Date of exploitation of third block of HVDC back-to-back station was postponed to 2023;

3.5. New 220/110 kV SS "Teleti" and tie-line of 220kV OHL "Algeta" to this substation where added to substation development project. Besides, this project includes addition of 2 new autotransformers to SS "Gldani 220;

3.6. Reinforcement of SS "Telavi" with 220 kV wing, as well as new 110/35 kV substation in Napareuli and 110 kV OHL Telavi-Napareuli were added to Kakheti Infrastructural Development Project;

4. **Possible types of conductors are replaced by transfer capacity.** Transfer capacity is given on 25^{0}C temperature.
5. **Strategic Environmental Assessment is provided for all projects**.
6. **New challenges and relevant solutions are discussed.**

2.5 Structure

This Ten-Year Network Development Plan of Georgia has the following structure:

Chapter 1 – Executive Resume, provides brief overview of major purpose, content, outputs, projects, development scenarios, conclusions and recommendations applicable to the entire Ten-Year Plan.

Chapter 2 – Introduction, reviews legal compliance, planning criteria, process of preparation of the Ten-Year Plan, data management and engineering simulation softwares used for estimations.

Chapter 3 – Existing Situation, presents characteristics of Georgian transmission network and entire electric power system, capacities of OHLs and transformers, data about generation, capacities of cross-border lines, possible extremal power flows, network operation strategy, security level and network bottlenecks.

Chapter 4 – Inputs for Network Development Planning, provides information on capacities, outputs, categories and commissioning years of the planned power plants; information about decommissioning of aged power plants; forecasted annual demand growth percentages, estimated prices of substations of different voltage levels and costs of 1 km lines for different voltage level; Agreements with transmission system operators of neighboring countries and their network development close to Georgia border. Minimal technical requirements to power plants and units and special requirements to the back-to-back stations. Changes in projects based on assignments of ministry of energy and signed memorandums between government and power plants.

Chapter 5 – Georgian Transmission Network Development Drivers, Network security, transmission of existing generation, integration of new power plants and consumers, decommissioning of aged power plants, power system adequacy etc.

Chapter 6 – Strategy and Methodology for Development of Georgian Transmission Network, discusses the major principles and visions with respect to Georgian transmission network development, as well as describes its feasible development scenarios.

Chapter 7 – Forecasted Capacity and Energy Balances, annual energy balances (generation, consumption, export and import) and power balances (Summer and Winter Maximum and Minimum) for 2017-2027 time span, peak load forecasts for individual substations, generation adequacy.

Chapter 8 – Identified Projects and Required Investments, discusses and briefly describes transmission grid development projects envisaged for 2017-2027 time span, as well as their purpose, estimated costs and single line diagrams, their CBA (cost-benefit analysis) and assessment of individual projects. Summary investment needs by years.

Chapter 9 – Sequence of Georgian Transmission Network Developments, specifies commissioning years of the generation facilities and matching development of the transmission network.

Chapter 10 – Load Flow Analysis, deals with normal established modes for 2017-2027, and results of transmission loses and single contingency (N-1) analysis. Analysis of voltage, reactive power and substation reinforcement needs.

Chapter 11 – Short Circuit Analysis, specifies maximum and minimum short circuit currents in 500/400/330/220 kV bus bars.

Chapter 12 – Dynamic Stability Analysis, describes behaviour of the power system under single contingencies (N-1).

Chapter 13 – Harmonic Analysis, presents results of power quality study in normal (N) and single contingency (N-1) modes for 2017-2027 period.

Chapter 14 – Analysis of Georgian Transmission Network Development Indicators, provides information on length and capacities of the planned OHLs and substations needed for evacuation of the power output of generation facilities to the network.

Chapter 15 – Power Exchange Capabilities (NTC) and opportunities of integration of generation and consumption into the grid, specifies maximum feasible power flows to be transferred via cross-border lines, while ensuring stability and reliability of the power system. Except the power already considered in ten-year plan, which additional amount of generation and consumption is possible to connect in 500/220 kV nodes.

Chapter 16 – State-of-the-Art Technologies, describes SCADA, HVDC stations and emergency control system.

Chapter 17 – Ten Year Plan of SCADA and Information Technologies (IT) Development, development of optical connection and dispatch control of power system operation.

Chapter 18 – Opportunities of integration renewable energy sources into the Georgian power system. Challenges in case of integration of Wind and Solar energy as well as opportunities of their integration according to the conducted analysis are presented in this chapter.

Chapter 19 – Vision for 2028-2050 Horizon

Chapter 20 – Conclusions and Recommendations.

Abbreviations and Terminology

Reference

Annexes

3 Present Situation

According to Grid Code, transmission network development plan, besides other information must include information about operational characteristics:

a. General characteristics of transmission network including cross-border connections with neighboring countries;
b. Current situation of transmission network and analysis about locations not satisfying planning criteria;
c. … capacity of high voltage overhead lines;
d. Power flow analysis of transmission network in case of maximum loads;

3.1 Transmission System Operator

Joint Stock Company "Georgian State Electrosystem" (GSE) – Dispatch Licensee became Transmission System Operator according to amendments (12 December 2014) to the "Georgian Law on Electricity and Natural Gas". The parent company of GSE holding 100% of its shares is the state-owned JSC Georgian Partnership Fund. GSE was founded in 2002 in result of merger of former state-owned electricity transmission and dispatch companies (JSC Electrogadatsema and Electrodispatch Ltd.). Based on the Licenses and tariffs charged for transmission and dispatch services approved by Georgian National Energy and Water Regulatory Commission (GNERC), GSE implements technical control of the power system for ensuring stable supply/consumption regimes, and transmission of locally generated and imported power to distribution companies, eligible customers and neighbouring states' power systems. GSE holds power transmission and dispatch licenses approved by GNERC on 20 December 2002.

3.1.1 System Dispatch

The National Dispatch Centre (NDC) located in GSE's headquarters undertakes operating control of Georgian power system, and is responsible for sound operation of 500/400/330/220/110/35 kV transmission facilities and overall stability of the system as in the steady state, so under contingencies. This facility is equipped with state-of-the-art technologies allowing collection of the system information in on-line regime, remote control of the system and effective response to disturbances. For this, NDC receives comprehensive data from dispatched substations and power plants, maintains continuously updated database and promptly reacts to emergencies.

3.1.2 Power Transmission

The balance sheet assets owned by GSE and its daughter company Energotrans consist of 500/400/330/220/110/35 kV overhead lines with total length of 4,380 km and 93 substations with aggregated installed capacity of 12,114 MVA, including strategically important seven 500 kV and twenty-four 220 kV substations.

3.1.3 Mission

Gaining leading position in the regional energy sector, increasing the transit potential of the country and provision of domestic and foreign customers with high quality, reliable power transmission services.

3.2 2015 Statistics

Peak Load (MW)	1 869
Generation of Seasonal HPPs (mln kWh)	3 335.23
Generation of Regulated HPPs (mln kWh)	5 118.53
Generation of Thermal Power Plants (mln kWh)	2 378.75
Export (mln kWh)	701.01
Import (mln kWh)	699.9
Total Consumption (mln kWh)	10 730.1
Total Generation (mln kWh)	10 832.5

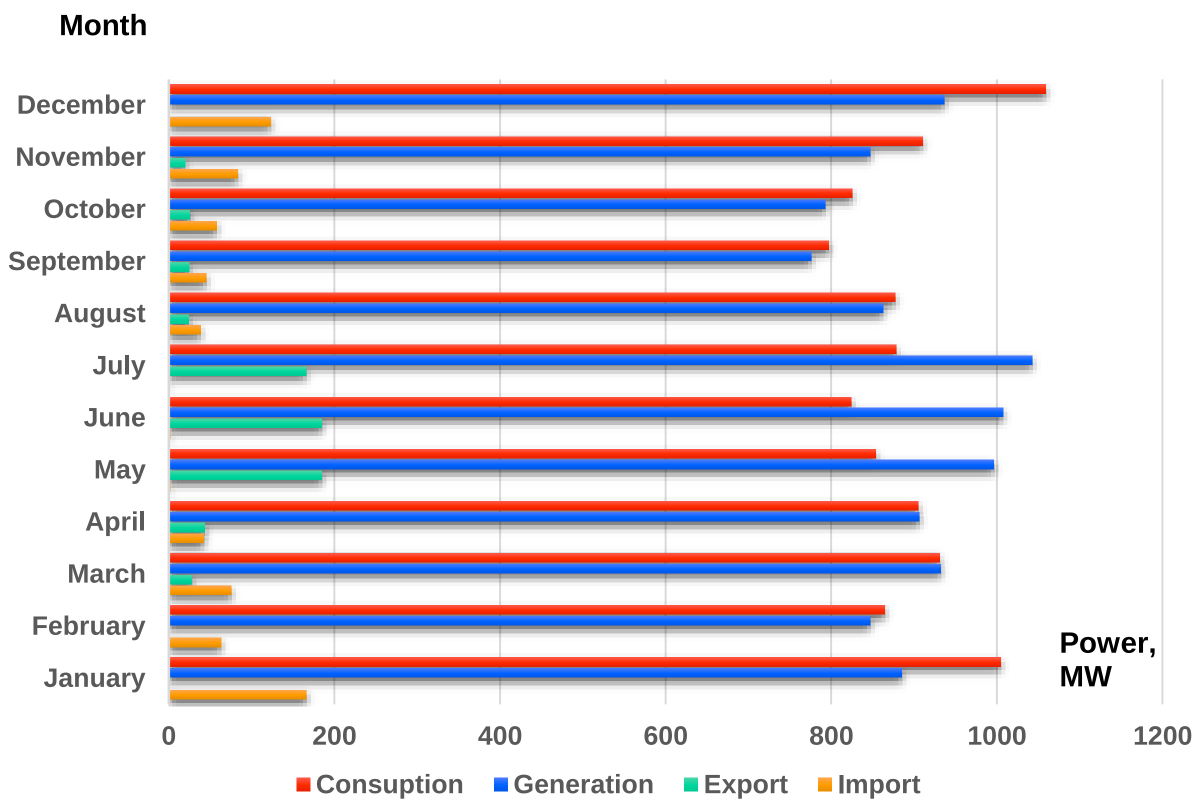


Fig. 3.1

The total annual power output of seasonal power plants amounted to 3335.23 mln kWh, i.e. 9.14 mln kWh in average daily. The peak demand (1869 MW) was experienced on 31 December 2015. During the whole year, the frequency was maximally closed to the standard value (50 Hz) fluctuating in the range of 49.8-50.2 Hz. First in practise Energy export from Georgia to Turkey through Back-to-Back station has been implemented in 2014, resulting increase of loading of Georgian transmission network. However, level of technical losses was near 2% as well as outage statistic was the same as in previous years.

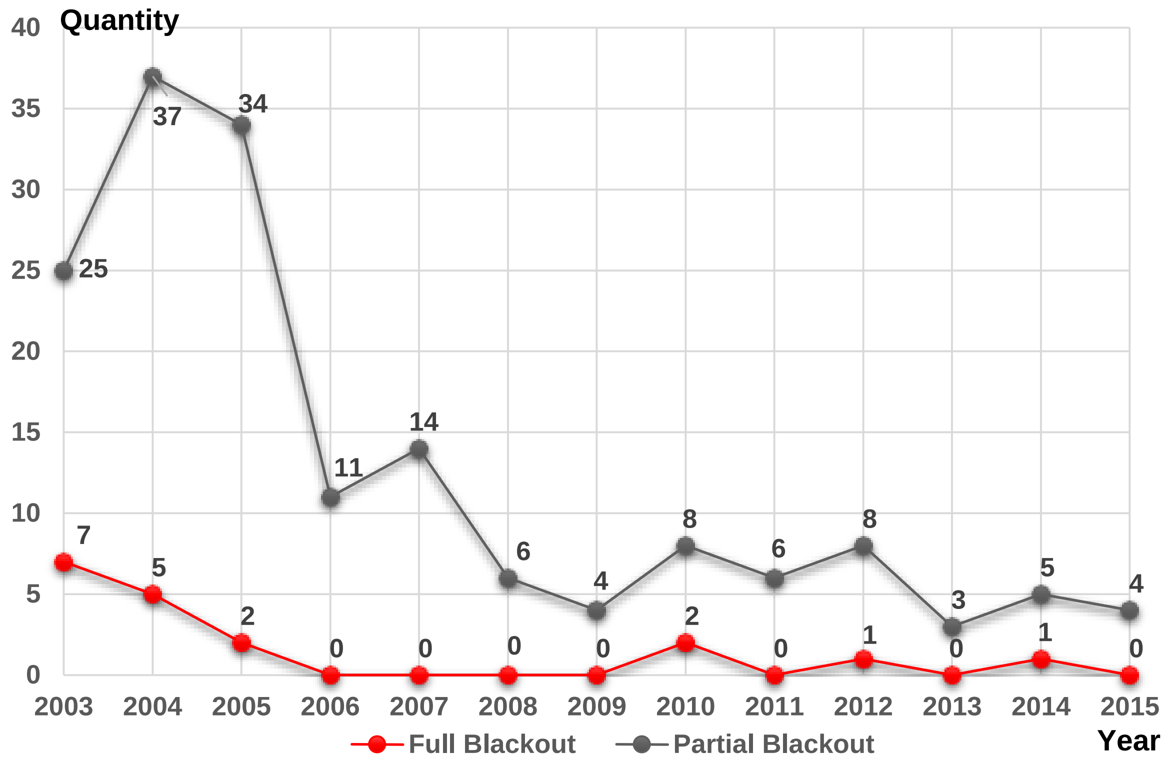


Fig. 3.2 Outages, 2003-2015

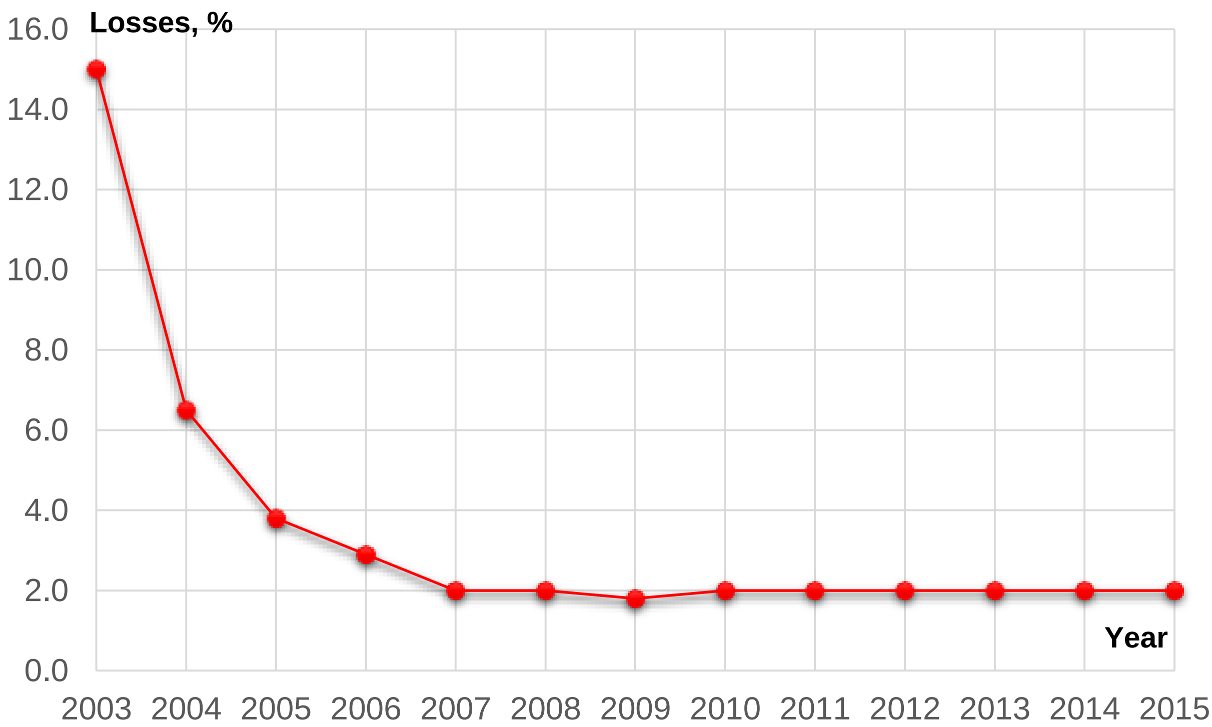


Fig. 3.3 Technical Losses in Transmission System (%), 2003-2015

3.3 Generation Data

Georgian power system is characterized by asymmetric generation/consumption pattern due to law demand and high generation in summer and high demand and low generation in winter allowing

Georgia to export the power during summer period. During winter, when less water is available for HPPs, thermal power's share in total generation increases to 28% from the less than 1% in summer.

The third of aggregated energy produced in the country comes from the largest Enguri HPP having installed and operating capacities of 1,300 MW and 1,200 MW respectively. This plant in tandem with Vardnili Cascade HPPs (second larges hydropower facility in Georgia) and other relatively lower capacity HPPs compose the pool of regulated hydro power plants with total installed capacity of about 1,990 MW.

By the end of 2017, total installed capacity will equal to 4059 MW, which includes installed capacity of HPPs 3113 MW and installed capacity of thermal power plants of 925 MW. It is anticipated that in 2018-2028, additional capacity of new HPPs wll be added, which will provide the increase of total installed capacity from the existing 4059 MW to 4734 MW by 2020, 6093 MW by 2022 and 7590 MW by 2028.
In line with growth of hydropower generation, Georgia's dependence on imported and thermal power gradually decreased. In 2007, the total power output generated by HPPs amounted to 6.8 bln kWh, i.e. 82% of full national demand. In 2010, total hydropower generation grew to 9.4 bln kWh covering 93%of the demand. In 2013, domestic hydropower generation decreased to 8.3 bln kWh, as for 2016 – 9.3 bln kWh. Such variations in hydropower generation is explained by varying hydrology conditions, as well as rehabilitation of the existing plants.

Georgian power system is connected to the Russia, Turkey, Azerbaijan and Armenia and biggest part of electricity trade comes from first two countries. Energy import from mentioned power systems is implemented in order to satisfy demand increased in winter period, as for energy export – due to the surplus of electricity generated during natural fluid period in summer. Energy exchange between Georgia and Armenia is carried out be smaller volumes, relatively.

During 2006-2010, energy expory volumes were continuously increasing year-by-year. In 2011-2013, due to the increased internal consumption, volume of electricity export was decreased, during 2014 – implemented energy export was equal to 0.6 bln kWh, which was 25% increase compared to the same indicator for 2013. It is noteworthy that in 2014, due to the increased consumption, 0.85 bln kWh energy import was implemented – an increase of 75% from the same data of 2013. In 2015-2016, export / import volumes are slightly different.

Tab. 3.1 Existing Power Plants in Georgian Power System for the end of 2017

№	Power Plant	Installed capacity (MW)	Number of units	Type	Commissioning years
1	Enguri HPP	1300.0	5x260	Regulating	1978
2	Vardnili 1 HPP	220.0	3x73.33	Regulating	1971
3	Khrami 1 HPP	113.5	3x37.6 + 1x0.65	Regulating	1947
4	Khrami 2 HPP	110.0	2x55	Regulating	1963
5	Shaori HPP	38.4	4x9.6	Regulating	1955
6	Dzevrula HPP	80.0	4x20	Regulating	1956
7	Jinvali HPP	130.0	4x32.5	Regulating	1984
8	Rioni HPP	48.0	4x12	Run-of-River	1933
9	Gumati HPP cascade	66.7	4x11 + 3x7.6	Run-of-River	1958-1956
10	Vartsikhe HPP cascade	184.0	8x23	Run-of-River	1976-1977
11	Lajanuri HPP	111.8	3x37.28	Run-of-River	1960

12	Zahesi HPP	36.8	4x3.2 + 2x12	Run-of-River	1927
13	Ortachala HPP	18.0	3x6	Run-of-River	1954
14	Chitakhevi HPP	21.0	3x7	Run-of-River	1949
15	Atshesi HPP	16.0	2x8	Run-of-River	1937
16	Satskhene HPP	14.0	2x7	Run-of-River	1992
17	Khadori HPP	26.0	2x13	Run-of-River	2004
18	Larsi HPP	19.5	2x6.5	Run-of-River	2014
19	Paravani HPP	87.0	2x45	Run-of-River	2014
20	Bjuja HPP	12.2		Small HPP	1956
21	Tetrikhevi HPP	13.6		Small HPP	1952
22	Alazani HPP	4.8		Small HPP	1942
23	Abhesi HPP	2.0		Small HPP	1928
24	Sioni HPP	9.1		Small HPP	1964
25	Ritseula HPP	6.3		Small HPP	1967
26	Chala HPP	1.5		Small HPP	1941
27	Chkhori HPP	5.4		Small HPP	1967
28	Dashbashi HPP	1.3		Small HPP	1935
29	Mashavera HPP	1.0		Small HPP	1949
30	Kabala HPP	1.5		Small HPP	1953
31	Kakhareti HPP	2.1		Small HPP	1957
32	Martkopi HPP	3.9		Small HPP	1952
33	Intsoba HPP	1.5		Small HPP	1998
34	Stepantsminda 2 HPP	3.8		Small HPP	1951
35	Energetiki HPP	0.5		Small HPP	2006
36	Algeta HPP	1.3		Small HPP	2006
37	Matchakhela HPP	1.6		Small HPP	1957
38	Misaktsieli HPP	3.0		Small HPP	1964
39	Skuri HPP	1.0		Small HPP	1958
40	Tiriponi HPP	3.2		Small HPP	1951
41	Khertvisi HPP	0.3		Small HPP	1950
42	Kinkisha HPP	0.9		Small HPP	1954
43	Atchi HPP	1.0		Small HPP	1958
44	Rustavi HPP	0.5		Small HPP	2009
45	Sulori HPP	0.8		Small HPP	2009
46	Okami 2007 HPP	1.6		Small HPP	2009
47	Boldoda HPP	2.5		Small HPP	2009
48	Zvareti HPP	0.2		Small HPP	2010
49	Pshavela HPP	1.0		Small HPP	2010
50	Igoeti HPP	2.0		Small HPP	1953
51	Sanalia HPP	3.0		Small HPP	2007
52	Mini khadori 1 HPP	0.0		Small HPP	2011
53	Khadori 2 HPP	6.0		Small HPP	2012
54	Khani HPP	0.3		Small HPP	2012
55	Racha HPP	11.0		Small HPP	2013
56	Dagva HPP	0.1		Small HPP	2013
57	Alazani 2 HPP	6.0		Small HPP	2013
58	Shilda HPP	5.0		Small HPP	2013
59	Stepantsminda HPP	6.0		Small HPP	2014
60	Bakhvi-3 HPP	10.0		Small HPP	2013

61	Pantiani HPP	0.4		Small HPP	2012
62	Aragvi HPP	8.5		Small HPP	2014
63	Akhmeta HPP	9.1		Small HPP	2014
64	Pshavela HPP	2.0		Small HPP	2015
65	Kazreti HPP	2.5		Small HPP	2014
66	Dariali HPP	108.0		Run-of-River	2016
67	Saguramo HPP	4.2		Run-of-River	2016
68	Kintrisha HPP	6.0		Run-of-River	2016
69	Shuakhevi HPP	187.0		Daily Reg	2016
70	Skhalta HPP	6.0		Run-of-River	2016
71	Khelvachauri-1 HPP	47.5		Daily Reg	2016
72	Unit №9	300.0	1x300	Thermal Power Plant	1991
73	Units №3, №4	272.0	130+142	Thermal Power Plant	1963
74	Gas turbine	110.0	2x55	Thermal Power Plant	2006
75	Tkibuli Coal TPP	13.0	2x6.5	Thermal Power Plant	2011
76	Gardabani CCGT	230.0	2x75+80	Thermal Power Plant	2015*
77	Wind Farm	20.7		Wind farm	2016
I	**Sum of Regulating HPPs**	**2226.4**			
II	**Sum of RoR HPPs**	**934.3**			
III	**HPPs in total**	**3160.7**			
IV	**TPPs in total**	**925.0**			
V	**System**	**4106.4**			

3.4 Current Opportunities for Power Exchange with Neighbouring Countries

In result of its geographical location, Georgia can gain an important function in course of the planned regional integration of the power systems of the Caucasian (and Black Sea) countries assuming promotion of energy trading between these states and development and use of Georgian hydropower resources.

At present, power exchange between Georgian power system and its neighbouring systems is carried out by 500/400/330/220 kV overhead lines.

Energy exchange is implemented: From Georgia to Russia, Turkey, Azerbaijan, Armenia and vise-versa as well as From Russia to Turkey, from Azerbaijan to Turkey. Cross-border overhead lines serve for realization this task, however, such “international” power flows are restricted due to both limitations stemmed from the acceptable operating modes of national power system (tab. 3.2, fig 3.4) and transmission capacities of above mentioned cross-border OHLs.

Table 3.2 Present power exchange capabilities with neighbouring power systems

Country	Cross-border line, conductor	Nom. Voltage (kV)	Exchange	TTC (MW)	Mode
Russia	„Kavkasioni“ AC-3x300	500	Export	700	≈
			Import	700	≈
	„Salkhino“	220	Export	50	isl

	AC-400		Import	150	isl
Azerbaijan	,,Mukhranis Veli“ AC-3x300	500	Export	700	≈
			Import	700	≈
	,,Gardabani“ AC-480	330	Export	320	≈
			Import	320	≈
Armenia	,,Alaverdi“ AC-300	220	Export	150/100	≈/isl
			Import	150/100	≈/isl
Turkey	,,Meskheti“ AC-3x300	400	Export	700	B2B *
			Import	700	B2B
	,,Adjara“ AC-400	220	Export	150	isl (res)
			Import	150	isl (res)

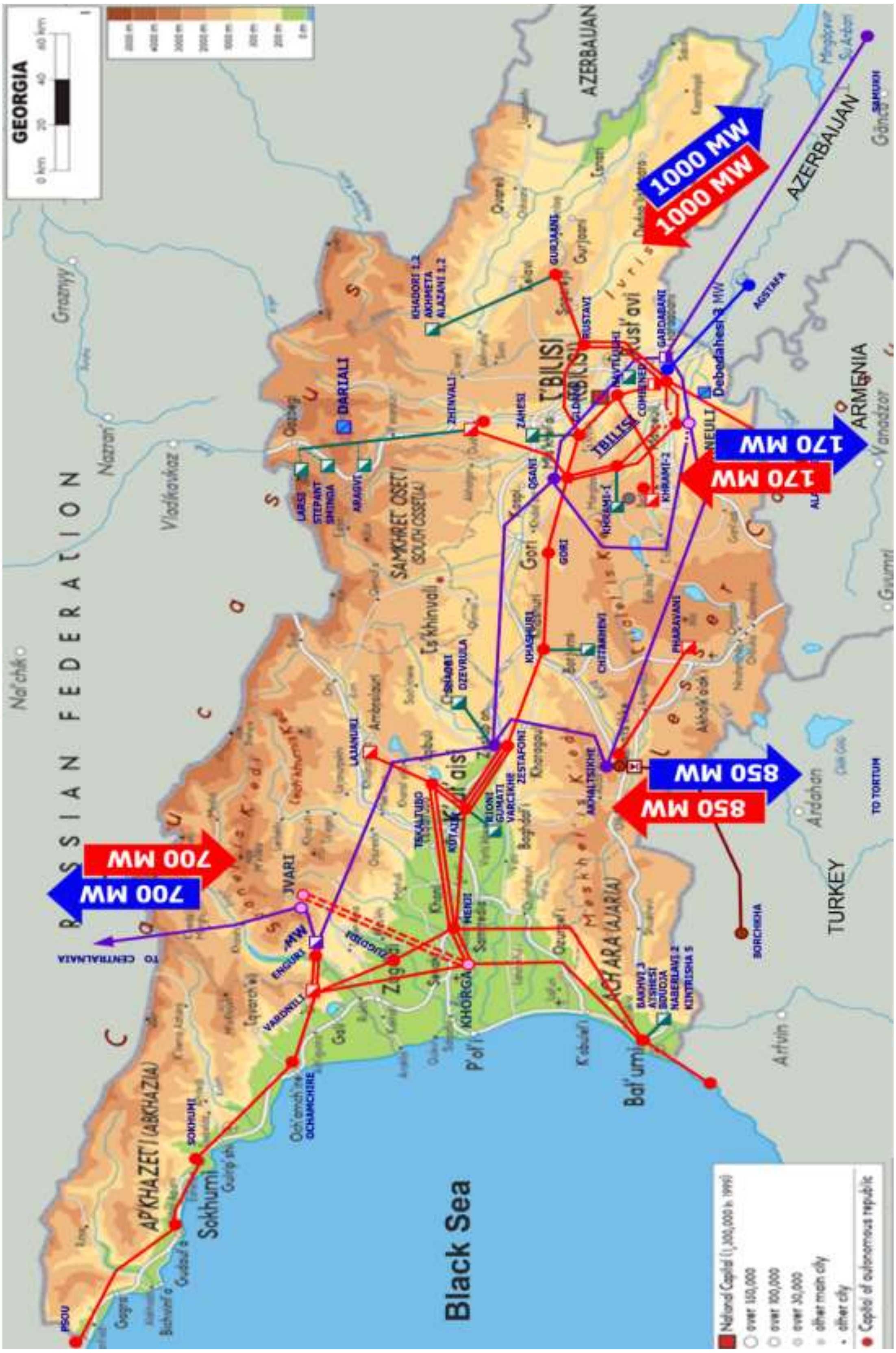


Fig. 3.4 Cross-border transfer capacities between power systems of Georgia and its neighbouring countries

3.5 Main Present Power Exchange Flows

As noted above, the major Georgian generation sources are concentrated in Enguri River basin, and include Enguri HPP and Vardnili HPP. During summer flood period (May-June-July), the total power generated by these plants amounts to 1250 MW. From this, one part (250 MW) is transmitted to Abkhazia by OHL Kolkhida-3 (Vardnili HPP – Ochamchire), other part (100 MW) is used for feeding

Zugdidi, Menji and Batumi substations (110 kV double circuit OHL Sesheleti-1,2 (Vardnili-Gali). Remaining almost 900 MW is transported to the east by 500 kV OHL Imereti, and distributed between export to Turkey through SS Akhaltsikhe (350 MW) and power supply of Tbilisi-Rustavi load centre. Meantime, demand of the bulk load centres of Tskaltubo-Kutaisi (100 MW) and Zestaponi (250 MW) is mainly balanced by several local hydro power plants located in Kutaisi-Tskaltubo (320 MW) and Zestaponi (30 MW) regions. Thus, roughly 900 MW power is available for transfer through OHL Imereti to the east. From this, about 550 MW is required for feeding Tbilisi-Rustavi and Khashuri-Gori load centres, and remaining 350 MW may be transferred to Turkey. Since OHL Imereti is unable to transport more than 900 MW, during summer months, possibilities for power transit from Russia to Turkey are limited, even Georgian and Russian power systems operate in parallel regime. In result of such load flow pattern, 350 MW conversion/transmission capacity of the HVDC back-to-back station located in SS Akhaltsikhe remains “vacant” that may be dedicated to transferring power inflows from Azerbaijan and/or Armenia under the island layout.

It should be noted that, assuming such loading of OHL Imereti, its loss should lead to overloading and tripping of 220 kV transmission mains connecting Enguri HPP and SS Zestaponi that is avoided by operation of Emergency Control System (ECS), which initiates generation reduction in Enguri basin and load/export shedding in Tbilisi-Rustavi/Akhaltsikhe, such as to keep the power flow within acceptable limits.

Therefore, the eastward transmission capacity must be increased by means of constructing parallel branch to 500 kV Imereti that will allow avoidance of generation/load shedding by ECS, i.e. development of the transmission network should ensure fulfilment of single contingency (N-1) criterion under any operating mode.

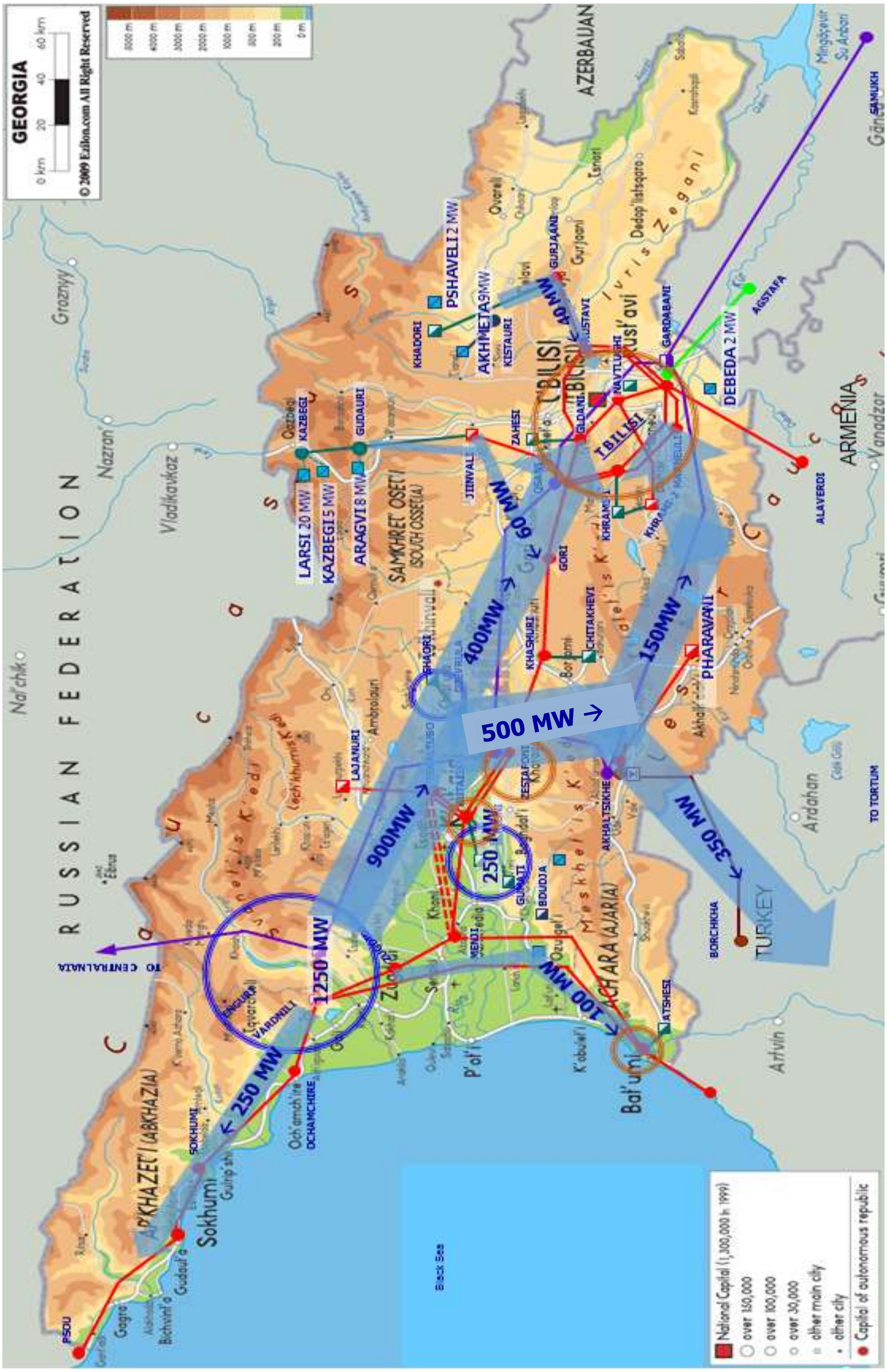


Fig. 3.5 Bulk power flows during flood period

3.6 Operating strategy, security of supply and adequacy level of Power system

Operation strategy. For purposes of analyzing power system security and designing appropriate control systems, it is helpful to conceptually classify the system-operating conditions into five states: normal, alert, emergency, in extremis and restorative.

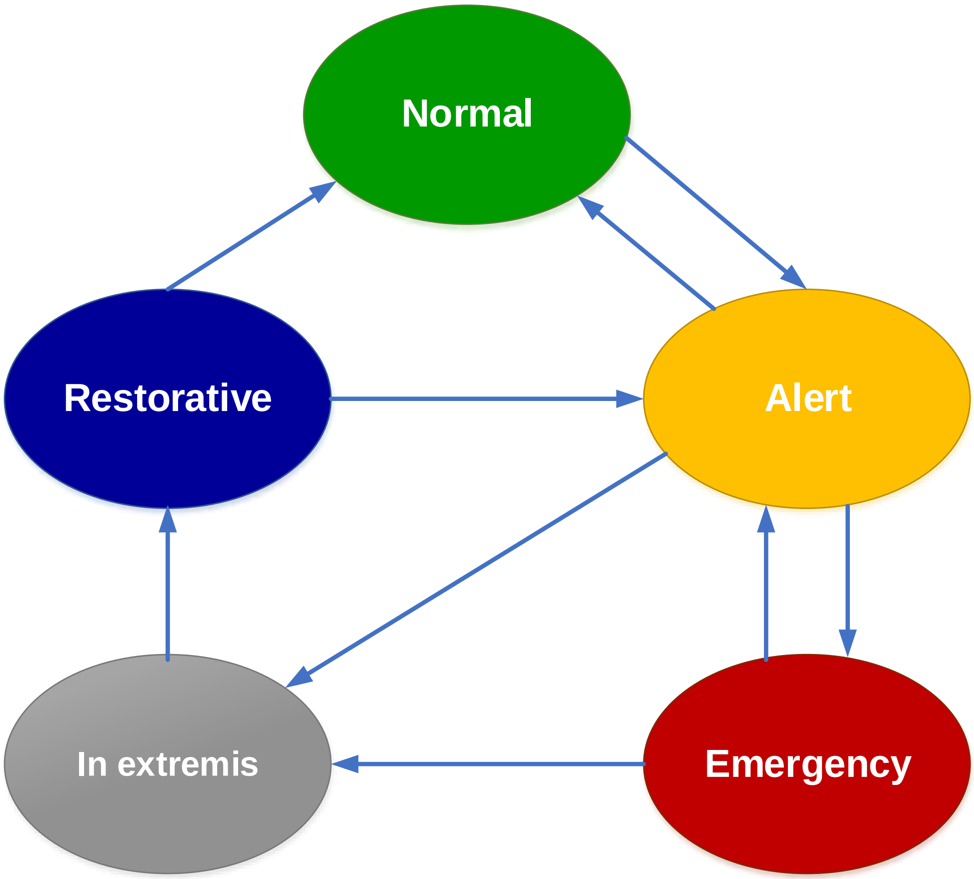


Fig. 3.6 Power system operating states

In the normal state, all system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand a contingency without violating any of the constraints. This means there are enough reserves of generation in power system as well as enough reserves of transmission system capacity. System meets N-1, G-1 and N-G-1 conditions.

The system enters the alert state if the security level falls below a certain limit of adequacy, or if the possibility of a disturbance increases because of adverse weather conditions such as the approach of severe storms. In this state, all system variables are still within the acceptable range and all constraints are met. However, the system has been weakened to a level where a contingency may cause an overloading of equipment that places the system in an emergency state. If the disturbance is very severe, the in extremis (or extreme emergency) state may result directly from the alert state.

Preventive action, such as generation shifting (security dispatch) or increased reserve, can be taken to restore the system to the normal state. If the restorative steps do not succeed, the system remains in the alert state.

The system enters the emergency state if a sufficiently severe disturbance occurs when the system is in the alert state. In this state, voltages at many buses are low and/or equipment loadings exceed short-term emergency ratings. The system is still intact and may be restored to the alert state by the initiating of emergency control actions: fault clearing, excitation control, fast-valving, generation tripping, generation run-back, HVDC modulation, and load curtailment. If the above measures are not applied or are ineffective, the system is in extremis; the result is cascading outages of possibly a shut-down of a major portion of the system. Control actions, such as load shedding and controlled system separation, are aimed at saving as much of the system as possible from a widespread blackout.

The restorative state represents a condition in which control action is being taken to reconnect all the facilities and to restore system load. The system transits from this state to either the alert state or the normal state, depending on the system conditions.

Present transmission grid of Georgia. Georgian Power system had been designed for parallel operation with big united power system and as well as for case of simultaneous operation of all interconnection line with Russia, Armenia and Azerbaijan. Hence 500 kV grid which had radial topology in territory of Georgia, was backed up by three neighbor countries simultaneously. Moreover, 500 kV grid was acting as one of the branch of big power system. Hence, emergency outage of any network element (500 kV OHL or big generation unit) in Georgian system didn't lead to limit consumers. Starting from 90's, due to the independent reasons, there was no possibility of parallel synchronous operation with more than one neighbor country, which caused leaving internal radial network of Georgia as well as any operating interconnection line without backup. Specific emergency situation was in case of island operation of Georgian power system. In such case, outage of any 500 kV OHL as well as any dead end 220 kV OHL (see below) and 100 MW or bigger generation unit (#3, #4, #9 unit in Gardabani and units in Enguri HPP) causes severe condition in emergency point of view. One of the reason of this situation is that there are no speed governors and excitation system in some part of generation units or, at least they are aged enough and decommissioned because they do not meet requirements of "technical operation rules" and "Grid Code", which leads to more difficult condition of voltage control as well as more difficult situation for frequency control in isolated mode.

At the end of 2016 the following projects in terms of transmission network reinforcement have been commissioned: 220/110 kV SS Khorga, 500/220 kV SS Jvari, double circuit 220 kV OHL Khorga-Menji (Khorga 1,2). At the beginning of 2017, construction of double circuit 220 kV OHL Jvari-Khorga (Odishi 1,2) will be completed, also SS Jvari will be tied to 500 kV OHL Kavkasioni. Network bottlenecks such as 500/220 kV AT Enguri, Double circuit 220 kV OHL Egrisi 1,2, 220 kV OHL Kolkhida-2a, 220 kV OHL Kolkhida-2 still stay unreserved despite implementation of above mentioned infrastructure. Reserving of these bottlenecks will be realized after commissioning of double circuit 220 kV OHL Jvari-Khorga. At the end of 2016, 220 kV OHL Sataplia 2 has been commissioned, as for 220 kV OHL Ajameti 3, it will be completed for the beginning of 2017. These two 220 kV OHLs will increase safe evacuation of the generation from Kutaisi-Tskaltubo node, also together with new infrastructure of JvarI-Khorga will increase reliability of 220 kV grid in West part of Georgia. Construction of double-circuit 220 kV OHL Batumi-Shuakhevi was completed in 2017, which, at first stage will ensure integration of Shuakhevi HPP into the grid. In addition, starting from 2018, in case of outage of 500 kV OHL Imereti, disconnected capacity of consumers will decrease significantly, since OHL Imereti will be reserved by at least three 220 kV OHLs. 220 kV line Surami – Urbnisi – Liakhvi is not effectively reserved and in case of overload of 500 kV OHLS Kartli-2 and Vardzia, and in case of outage of either of them, there is a threat of overloading 220 kV route and splitting Georgia's power supply system. In case of outage of 220 kV lines connecting to SS Gldani, 220 kV OHL Aragvi might overload because of Gldani's increased consumption. Besides, 500/220 kV SS Marneuli was put into operation, and 500 kV OHL Asureti (Mukhrani) was tie-lined to it. As a result, the 500 kV network reliability was enhanced and Gardabani 500/220 kV transformer was fully reserved. Based on the above, several weaknesses in the network were eliminated.

Bottlenecks of tranismission network of Georgia are:

- Interconnetion lines
  - Kavkasioni, 500 kV
  - Gardabani, 330 kV
  - Alaverdi, 220 kV
  - Meskheti, 400 kV
  - Adjara, 220 kV
- Radial / Inefficiently reserved network of West Georgia
  - Imereti, 500 kV
  - Zekari, 500 kV
  - Autotransformer at Enguri, 500/220 kV
  - Egrisi 1,2
  - Kolkhida 2a
  - Kolkhida 2
- Batumi supply grid
  - Paliastomi 1,2
- 220 kV grid of Shida Kartli, reserved inadequately:
  - Surami
  - Urbnisi
  - Liakhvi
  - Aragvi
- 220 kV dead end transmission lines
  - Kolkhida 3
  - Derchi
  - Lomisi
  - Manavi
  - Paravani
  - Sno (Ksania-Dariali HPP)

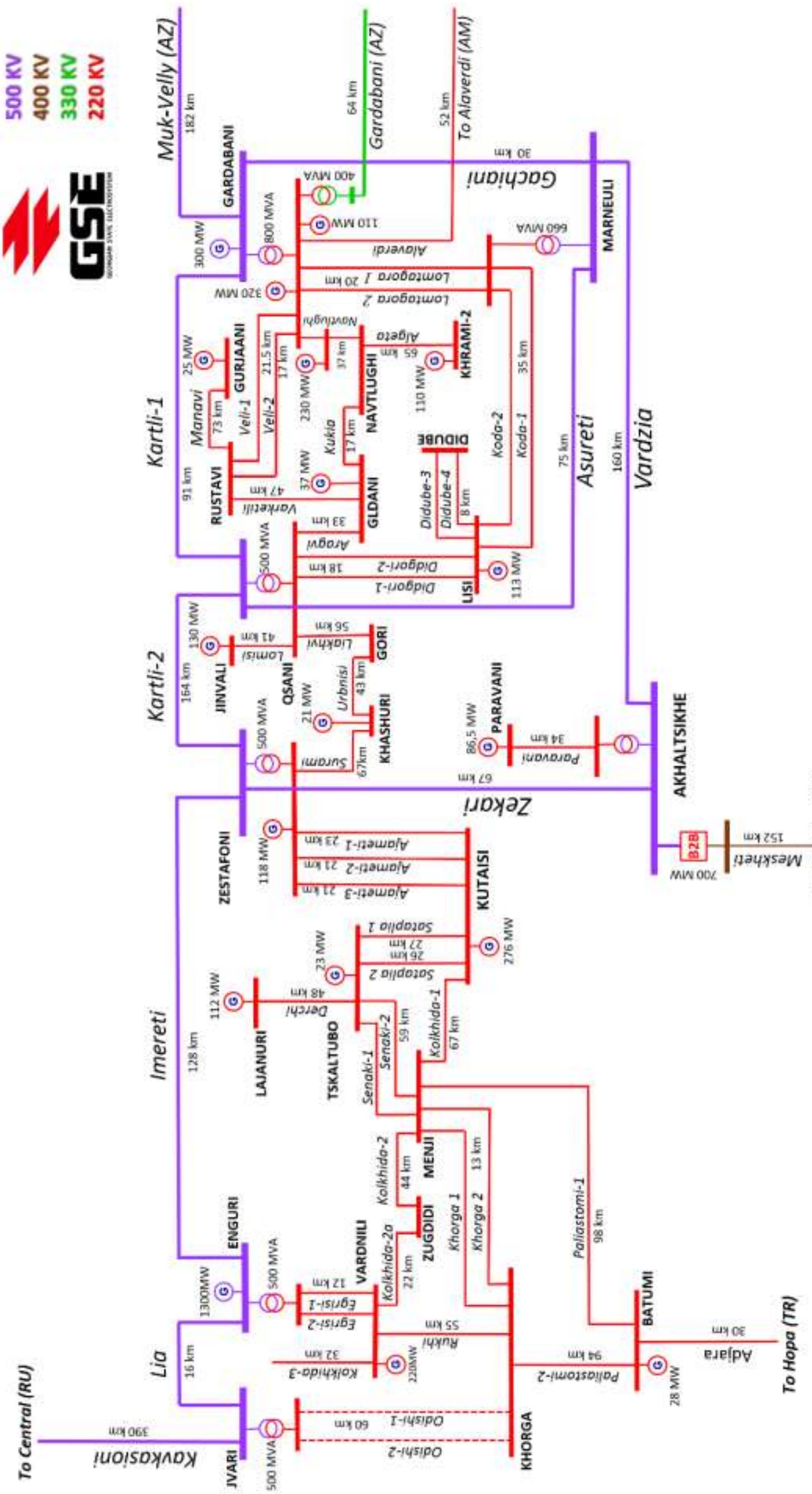


Fig 3.7 Single line diagram of Georgian transmission network

As a conclusion from above mentioned, in case of outage of OHLs Kavkasioni, Alaverdi, Meskheti, Adjara, Imereti, Paliastomi 1,2, Kolkhida 3, Derchi, Lomisi and Manavi there is a risk of tripping of consumers/generation units, in addition there is risk of load shedding in case of outage of #3, #4 and #9 units in Gardabani and units of Enguri HPP. Hence, there is a huge risk to violation of N-1 criteria which will be shown in the table of statistic of emergency outage of network elements (Tab. 3.3), where we can find that the biggest challenge for system stability is the outage of 500 kV OHL Imereti which supplies the most part of East Georgia from Enguri bus bar during summer period. Hence, despite of existence of very high reliable emergency automatic in Georgia system, average level of energy not supplied caused by outage of OHL Imereti is about 1.20 ml. kWh/year. After Imereti, the most problematic elements of network in terms of emergency outage are 220 kV OHL Paliastomi 2 (because simultaneous outage of these two 220 kV OHLs led to complete blackout of Adjara region), then 220 kV OHL Kolkhida 3 (Abkhazia region), 9th unit of Gardabani, 2nd and 3rd units of Enguri and 500 kV OHL Kavkasioni (cross-border line with Russia). In this point of view, 400 kV OHL “Meskheti” connecting Georgian system to Turkish one worth to be separately noted because its outage led to 7.27 mln kWh nonrealized energy export, which is not energy not supplied to Georgian consumers, but it is energy had to be transferred as export to Turkey what would be significant revenue for Georgia and participants of its power system.

As a conclusion, operation mode of Georgian transmission network corresponds “alert mode” even if there are all the elements at normal operating condition and all the parameters are at their normal ranges. Therefore, **security of supply is the most critical problem of Georgian transmission network** and **increase of security of supply/system reliability is the main scope of transmission network development during nearest ten years**.

Hence, maintain of security criteria:

- N-1, G-1;
- Maintaining voltage level in permissible range;
- Maintaining frequency in permissible range.

will be goal of Georgian transmission network and whole power system, reaching of which requires reinforcement of transmission network and adding new element to the grid.

Tab 3.3

Reliability indicators and averaged statistic for 2012-2016 of emergency outage of 500, 400, 330, 220 kV OHLs and 100MW or more powerful generation units

Element		Voltage	N	T	U	DE
Type	Name	kV	(Numb/year)	(Hour/year)	%	(kWh/year)
OHL	Kavkasioni	500	21.8	124.39	1.42%	206 103
OHL	Imereti	500	5.2	9.54	0.11%	1 067 258
OHL	Kartli 2	500	1.2	0.2	0.00%	0
OHL	Kartli 1	500	3.2	1.33	0.02%	0
OHL	Zekari	500	9.8	115.15	1.32%	0
OHL	Vardzia	500	37.6	51.31	0.59%	0
OHL	Gachiani	500	0	0	0.00%	0
OHL	Asureti (Mukhrani)	500	6.8	8.48	0.10%	0
OHL	Mukhranis Veli	500	0	0	0.00%	0

OHL	Meskheti	400	17	66.31	1.90%	0(7 276 827)*
OHL	Gardabani	330	13.5	11.6	0.19%	24 061
OHL	Egrisi 1	220	4	8.07	0.09%	93 432
OHL	Egrisi 2	220	2.4	4.51	0.06%	0
OHL	Paliastomi 1	220	5.2	34.51	0.40%	45 726
OHL	Paliastomi 2	220	11	40.18	0.46%	804586
OHL	Kolkhida 1	220	5	10.31	0.12%	33 804
OHL	Kolkhida 2	220	2.4	3.48	0.04%	3733.4
OHL	Kolkhida 2a	220	4.8	7.05	0.08%	1 920
OHL	Sataflia	220	2	7.23	0.08%	0
OHL	Derchi	220	3	19.14	0.22%	7 810
OHL	Ajameti 1	220	1.4	3	0.03%	4 535
OHL	Ajameti 2	220	1.6	2.09	0.03%	0
OHL	Surami	220	1.2	4.24	0.05%	0
OHL	Urbnisi	220	3.2	0	0.00%	0
OHL	Liakhvi	220	3.8	0.18	0.00%	0
OHL	Lomisi	220	1.2	0.3	0.01%	1 034
OHL	Aragvi	220	2.6	4.46	0.05%	13 419
OHL	Didgori 1	220	1.8	11.22	0.13%	0
OHL	Didgori 2	220	1.8	13.34	0.16%	0
OHL	Koda 1	220	2.8	0.01	0.00%	0
OHL	Koda 2	220	2.6	1.26	0.02%	0
OHL	Lomtagora	220	0	0	0.00%	0
OHL	Lomtagora 2	220	0.8	0.002	0.00%	0
OHL	Varketili	220	1	4.49	0.06%	0
OHL	Kukia	220	2.4	3.16	0.04%	0
OHL	Navtlugi 1	220	0.2	1.32	0.02%	0
OHL	Navtlugi 2	220	0.2	0	0.00%	0
OHL	Veli 1	220	0.4	0	0.00%	0
OHL	Veli 2	220	1	0.01	0.00%	0
OHL	Algeta	220	1.2	0.09	0.00%	0
OHL	Manavi	220	4.6	31.1	0.36%	17 097
OHL	Didube 3	220	0.6	1.42	0.02%	0
OHL	Didube 4	220	0.8	0.47	0.01%	0
OHL	Pero 3	220	8.4	5.31	0.06%	43 914
OHL	Salxino	220	3.2	6.5	0.08%	13 583
OHL	Adjara	220	0.8	0.13	0.00%	3 933
OHL	Kolkhida 3	220	14.6	15.22	0.18%	695 727
OHL	Alaverdi	220	8.6	15.28	0.18%	12 549
OHL	Senaki 1	220	1.4	0.43	0.01%	0
OHL	Senaki 2	220	0.8	0	0.01%	0
OHL	Rukhi	220	1	0.06	0	0
OHL	Khorga 1	220	0.2	0	0	0
OHL	Khorga 2	220	0.2	0	0	0
Gen	Enguri HPP g1	500	1	124.319	_	32 116

Gen	Enguri HPP g2	500	1.4	12.016	_	155 812
Gen	Enguri HPP g3	500	0.4	0.368	_	30 658
Gen	Enguri HPP g4	500	1.6	6.577	_	63 279
Gen	Enguri HPP g5	500	0	0	_	0
Gen	Gardabani unit N3	220	0	0	_	0
Gen	Gardabani unit N4	220	0.2	8.799	_	662
Gen	Gardabani unit N9	500	0.4	31.913	_	251 529
				Total		3 628 280

In Tab. 3.2: N – number of outages of element per year; T – Recovery time after emergency outage. U – Number of emergency outages (T/8760). DE – Amount of Energy not supplied during year. It should be noted that only parts of T and N correspond to DE because in most cases outage of element does not lead to interrupt energy transmission on appropriate OHL. Flow with little amount was in specific regime and N-1 criteria has been reached in case of outage of loading of its parallel branches.

* - Approximately 7.27 mln kWh nonrealized energy export caused by outages of 400 kV OHL “Meskheti”.

Low inertia phenomenon. Frequency shall be near nominal value to ensure reliable operation of the system.

Frequency is a system parameter, which is same at any given time (and changes similarly), at any point of the power supply system.

Frequesncy depends on the balance of actual capacity. Change of consumption of actual capacity or generation at one particular point of the system will result in the change of frequency in the whole supply sustem. Disconnection of power line of generator or system, results in capacity deficit and frequency reduction, and vice versa - higher load or line outage will cause increase of frequency.

Generator movement equation shall be written approximately in the following manner:

$$\frac{df}{dt} = \frac{1}{T_M}(P_m - P_e) \qquad (1)$$

Where:

f = network frequency at instant;

T_M = constant of the total innertion of power system generators;

P_m= total generated mechanical capacity of generators (i.e. generated by their turmines);

P_e= total electric load capacity on generator shafts.

Equation shows that the frequency will be permanent, if total generated and total consumption capacities are equal. In addition, in case of excess generated (mechanical) capacity (occures during load outage) frequency derivative will be positive; In case (electric) capacity of total system load is higher than generated capacity, frequency derivative will be negative, i.e. frequency will start to decrease. Besides, the more innertive the system is, the slower will change of frequency occure (i.e. more generators are connected in the system).

During capacity imbalance, in order to avoid unaccepable increase or decrease of frequency, system generators shall be equipped with capacity regulating equipment – speed regulators, which will ensure primary speed regulation according to their statism coefficients.

It should be noted that speed regulators, as representing complex of electric-hydraulic-mechanical equipment, are characterized by long delay from receiving signal till its operation (1-2 seconds). Therefore, during this period, active capacity of turbines is unchanged, as well as deficite.

Therefore, frequency reduction depends on total system inertia only. Thus, as the movement equation shows, the higher system inertia is, the lower system deviation and vice versa, the lower system inertia, the more sensitive system frequency is towards small disturbances. Inertii constant depends on the mass of connected units, geometric dimensions, number of rotations and nominal capacity, although can be shown as value proportionate to nominal value of units.

$$T_M \approx \frac{P_n}{18}$$

Thus, (1) the equation may be formulated in the following manner, at $t = 1$ end of second:

$$\Delta f = \frac{18}{P_n}(P_m - P_e)\, t \qquad (2)$$

Thus, the higher total nominal capacity of the system (connected units), the lower frequency deviation.

As summaration of above mentioned, frequency deviation for the end of first second, when there is 100 MW deficit in power system, for the system with 1200 MW installed capacity is 1.5 Hz (48.5 Hz), as for 2250 MW system – 0.8 Hz (49.2 Hz – activation setpoint for load shedding relays). Hence, nominal capacity of the system, in case of which loss of the biggest generation unit does not lead to the decrement of frequency below to 49.2 Hz is calculated as follows:

$$P_n = \frac{18}{\Delta f}(P_m - P_e)\, t = \frac{18}{\Delta f}(P_m - P_e)\, t = \frac{18}{0.8}(250)\; 1.0 = 5625 \text{ MW}$$

Taking into account that even in case of the most loaded scenario, ratio between summary installed capacity of operating generation units and total installed capacity of the system equals to 0.7, total installed capacity of Georgian power system in case of which loss of 250 MW generation unit does not lead to the activation of load shedding will be 5625/0.7 = 8035 MW. This amount will be achieved during 2028-2030, before this period there will be deficit of inertia (installed capacity of power system).

3.7 Main Network Bottlenecks of the Georgian transmission network and projects to eliminate them

Transmission network of Georgia has predominantly axial arrangement i.e. it is oriented from west to east. The main 500 kV substations are “Enguri”, “Zestaponi”, “Akhaltsikhe”, “Ksani” and “Gardabani”. Transmission grid of Georgia may be theoriticaly divided into East and West districts, dividing bus bar of which is ss „Zestaponi”.

Power capacity of 500 kV OHL is about 5 times more than power capacity of 220 kV OHL, hence main part of power flows is implemented by 500 kV OHLs of Georgian Transmission network. Enguri HPP is connected to Zestaponi bus bar by 500 kV OHL Imereti. There is no paralel branch of this line in east part of Georgia and therefore, emergency outage of Imereti causes overload of 220 kV energy corridor Vardnili-Zugdidi-Menji-Kutaisi-Zestaponi. Hence, non-existance of 500 kV parallel connection of Imereti is the main bottleneck of West part and entire Georgian transmission network. Therefore, in order to meet N-1 criteria, system automatic should trip part of consumers in East Georgia and part of Generation in Enguri HPP in such manner that after fault in steady-state power flow on 220 kV OHLs in West part of Georgia will not exceed pertimatable ranges. In addition, emergency outage of 500 kV OHL Zekari (Zestaponi-Akhaltsikhe) may be the result of impossibility of power transit from Russia to Turkey in summer flooding period.

Despite 67 km 500 KV OHL line “Zekari” is backed up by OHLs “Qartli 2”, “Vardzia”, the sum of length of these two lines is near 325 km what makes impossible to backup OHL “Zekari” in case of bulk power flow on this line.

Supply of substation Batumi is carried out by long overhead lines – Paliastomi-1 (Menji-Batumi) and Paliastomi-2 (Vardnili-Batumi) 97 km and 150 km respectively. This lines represents the parallel branch of 220 kV energy corridor Vardnili-Zugdidi-Menji. Due to their legths there are voltage problems in 220 kV ss Batumi. This issue is actual in case of power export from Batumi to Khopa (Turkey). In addition, outage of either Paliastomi-1 or Paliastomi-2 may result overload of 220 kV OHLs Kolkhida-2a and Kolkhida-2.

One of the weekest point of Georgian transmission network is 500/220 kV autotransformer in Enguri, power capacity of which is 450 MW (500 MVA). This restricts power flow in Vardnili direction by 220 kV double-circuit lines Egrisi-1,2. Outage of above mentioned AT causes voltage problems in Ajara-Abkhazia-Guria-Samegrelo districts.

Another one of the most problematic element of East part of Georgian transmission grid is 220 kV OHL Kolkhida-3 which serves power transit from Vardnili HPP to Abkhazia (250 MW). This is due to non-existance of parallel line of Kolkhida-3. Hence, outage of this line results abundance in system which is equal to power flow on Kolkhida-3 in pre-fault mode.

500 kV OHL Kavkasioni which is main connector of Georgian and Russian power systems is weak point of Georgian system as well due to its legth (405.5 km) and difficult relief of highway (main ridge of Kavkasioni). Outage of above mentioned line has negative effect on stability of Georgian system and Power Quality (frequency control is mainly implemented by Russian system).

400 kV OHL Meskheti – connecting Georgia to Turkey. However legth of this line is not critically huge (less than 150 km), it will serve in 700 MW transit and its emergency outage will cause huge abundance of power in Georgian power system.

220 kV OHL Alaverdi (Gardabani-Alaverdi) connects Georgia to Armenia and is weak point by which is possible to implement only 150 MW power exchange between this countries in synchronous mode and 100 MW in Island mode.

Disbalance of Active as well as reactive power may be the result of outage of 500 kV lines in Georgian system and action of system automatic. Hence, fast-acting, regulated reactive power compensator SVS or FACTS Device may be required in both East and West part of Georgian power system.

Thus, weak and problematic points of Georgian transmission networks are:

- 500 kV OHL Imereti;
- 500 kV OHL Zekari;
- 500 kV OHL Kavkasioni; 400 kV OHL Meskheti; 220 kV OHL Alaverdi;
- Security of Supply of Ajara-Abkhazia-Guria-Samegrelo districts;
- 220 kV OHL Kolkhida 3;
- 220 kV OHLs Ajameti-1,2; 220 kV OHL Sataplia;
- Enguri units;
- 9th thermal unit of Gardabani.

Several projects are considered in 10-year network development plan of Georgia which will resolve above mentioned problems, integrate new HPPs into the grid and reinforce transit ability of Georgian system.

Toghether Jvari-Khorga and Tskaltubo-Zestaponi (already in operation) projects:

1. Backs up the following present weak points:
   - 500/220 kV Autotransformer Enguri;
   - 220 kV double-circuit line Egrisi-1,2;
   - 220 kV OHL Kolkhida 2a;
   - 220 kV OHL Kolkhida 2;
   - 220 kV OHLs Ajameti-1,2;
2. Reinforces Security of Supply of ss Batumi;
3. Partly backs up 500 kV OHL Imereti and reduces value of consumers to be tripped by system automatic in case of emergeny outage of above mentioned line.

Jvari-Tskaltubo-Akhaltsikhe Project (in parallel of integration of Enguri HPP, Namakhvani HPP and other HPPs) will resolve the most problematic issue in Georgian transmission network – complete backup of 500 kV OHL Imereti, after outage of which system automatic will not trip consumers in Georgia.

Ksani-Stepantsminda-Mozdok Project, which is parallel line of 500 kV OHL Kavkasioni, will reserve it and reinforce stability of Georgian system. Outage of 500 kV OHL Kavkasioni will not result power abundance or deficit and therefore trip of consumers or generation by system automatic. This project will partly backup 500 kV OHL Imereti by North Kavkasian network.

400 kV OHL Akhaltsikhe-Tortum will fully backup 400 kV OHL Meskheti (Akhaltsikhe-Borchkha) and power disbalance will not arise after outage of 400 kV OHL Akhaltsikhe-Tortum.

Marneuli Project (500 kV OHL Marneuli-Airum) will fully replace 220 kV OHL Alaverdi and ensure reinforcement of power transit ability among Russia-Georgia-Armenia-Iran.

This projects, besides of above mentioned goals may have some other designations, for example, integration of HPPs and increase of cross-border capacity (see chapter “Identified Projects and Investment Needs“).

Project “Akhaltsikhe – Batumi” will increase reliability of supply of “Adjara” region (besides integration of “Shuakhevi”, “Koromkheti” and other HPPs of Upper Adjara region) and will help to backup 500 kV OHL “Imereti” with projects “Jvari – Khorga” and “Tskaltubo – Zestaponi”.

Power plants “Khudoni HPP”, “Nenskra HPP” and “Namakhvani Cascade HPPs” are increase on one hand flexibility of the system and on the other hand inertia constant and with this respect they increase the sustainability of the Energysystem. Therefore after commissioning of these HPPs will not be problematic swiching of Enguri units and N9 block.

To ensure reliability of Kakheti region power supply, construction of 110 kV route Akhmeta-Telavi-Gurjaani is planned (within 220 kV range), as well as addition of 220 kV wing to SS Telavi, reinforcement of SS Telavi with 220 kV wing and 125 MW autotrasformer, addition of new 220/110 kV 125 MW autotransformer at SS Gurjaani“.

Shida Kartli network reliability plan is under elaboration.

3.8 Specifications of 500/400/330/220 kV overhead lines of Georgian transmission system

Table 3.4 Parameters of Overhead lines of 500/400/330/220 kV transmission network of Georgia

№	Name of OHL	From (SS)	To (SS)	Rated Voltage (kV)	Circuit	Conductors (Type, number, cross-section)	Length (km)	Capacity (MW)	
								Winter	Summer
1	**Kartli-1**	Ksani	Gardabani	500	∑	AC-3x400/51	91	870	765
2	**Kartli-2**	Zestaponi	Ksani	500	∑	AC-3x400/51	164	870	765
3	**Imereti**	Enguri	Zestaponi	500	∑	AC-3x400/51	127.5	870	765
4	**Lia**	Enguri	Jvari	500	∑	AC-3x300/66	16	650	572
5	**Mukhrani**	Ksani	Marneuli	500	∑	AC-3x330/43	75	650	572
6	**Vardzia**	Akhaltsikhe	Gardabani	500	1	AC-3x330/43	77.72	1588	1397
					2	AC-3x300/67	53.36		
					3	AC-3x400/93	29.63		
					∑		160.7		
7	**Zekari**	Zestaponi	Akhaltsikhe	500	1	AC-3x330/43	3.72	1588	1397
					2	AC-3x300/67	29.46		
					3	AC-3x300/204	34.19		
					∑		67.31		
8	**Kavkasioni**	Jvari	Tsentralnaya	500	∑	AC-3x300/66	89.5 [390.5]	650	572
9	**Gachiani**	Gardabani	Marneuli	500	∑	AC-3x400/93	30	1926	1695
10	**Mukhranis Veli**	Gardabani	Samukh	500	∑	AC-3x330/43	19.5 [182]	715	629
11	**Meskheti**	Akhaltsikhe	Borchka	400	∑	AC-3x500/64	32.6 [152.2]	1794	1578
12	**Gardabani**	Gardabani	Agstapa	330	∑	ACO-480	21.1 [64]	237	209
13	**Koda-1**	Marneuli	Lisi	220	∑	AC 400/51	35.5	226	212
14	**Koda-2**	Gardabani	Lisi	220	∑	AC 400/51	35.5	226	212
15	**Didgori-1**	Ksani	Lisi	220	∑	AC 300/39	18.7	206	188
16	**Didgori-2**	Ksani	Lisi	220	∑	AC 300/39	18.7	206	188
17	**Didube-3**	Didube	Lisi	220	∑	AC 300/48	8.12	206	188
18	**Didube-4**	Didube	Lisi	220	∑	AC 300/48	8.12	206	188
19	**Lomtagora-1**	Gardabani	Marneuli	220	∑	AC 400/51	20.25	226	212
20	**Lomtagora-2**	Gardabani	Marneuli	220	∑	AC 400/51	20.25	226	212
21	**Veli-1**	Rustavi	Gardabani	220	∑	AC 500/64	21.5	226	212
22	**Veli-2**	Rustavi	Gardabani	220	∑	AC 500/64	16.8	226	212
23	**Senaki-1**	Menji	Tskaltubo	220	∑	AC 300/39	58.7	223	211
24	**Senaki-2**	Menji	Tskaltubo	220	∑	AC 300/39	58.7	223	211
25	**Navtlugi-1**	Gard.Akhali	Gardabani	220	∑	ACO-500	3.67	274	257
26	**Navtlugi-2**	Navtlugi	Gard.Akhali	220	∑	ACO-480	34.2	257	240
27	**Manavi**	Rustavi	Gurjaani	220	1	AC 500/64	8	195	185
					2	AC 300/48	65.72		
					∑		73.72		
28	**Algeti**	Navtlugi	Khrami-2 HPP	220	∑	AC 400/93	65.51	233	225
29	**Varketili**	Gldani	Rustavi	220	∑	AC 500/64	46.8	274	257

30	**Kukia**	Gldani	Navtlugi	220	1	AC 400/51	16.42	223	206
					2	AC 500/204	1		
					∑		17.42		
31	**Aragvi**	Ksani	Gldani	220	1	ACO-480	28.2	223	206
					2	AC 400/51	5.2		
					∑		33.4		
32	**Liakhvi**	Gori	Ksani	220	1	AC 400/93	51.4	205	171
					2	AC 480/51	4.57		
					∑		55.83		
33	**Urbnisi**	Khashuri	Gori	220	1	AC 400/93	3.564	206	188
					2	ACO-480	39.67		
					∑		43.23		
34	**Lomisi**	Zhinvali HPP	Ksani	220	1	AC-300/39	40.71	171	171
					2	AC-480	0.499		
					∑		41.2		
35	**Surami**	Zestaponi	Khashuri	220	1	AC 400/93	24.6	206	188
					2	ACO-480	42.65		
					∑		67.24		
36	**Pero-3**	Zestaponi	Pero	220	∑	AC 400/51	6	137	130
37	**Ajameti-1**	Kutaisi	Zestaponi	220	∑	AC 400/93	23.6	233	225
38	**Ajameti-2**	Kutaisi	Zestaponi	220	∑	AC 400/93	21.6	206	195
39	**Ajameti-3**	Kutaisi	Zestaponi	220	∑	AC 400/93	21.1	233	225
40	**Sataplia-1**	Tskaltubo	Kutaisi	220	1	AC 400/93	13.82	137	130
					2	ACO-480	13.4		
					∑		27.2		
41	**Sataplia-2**	Tskaltubo	Kutaisi	220	∑	AC 400/93	26.2	233	225
42	**Derchi**	Lajanuri HPP	Tskaltubo	220	1	ACO-480	34.63	147	143
					2	AC 400/93	13.82		
					∑		48.5		
43	**Kolkhida-1**	Menji	Kutaisi	220	∑	AC 300/66	67.2	139	131
44	**Kolkhida-2**	Zugdidi	Menji	220	1	AC 300/66	29.7	202	192
					2	AC 400/64	13.9		
					∑		43.6		
45	**Kolkhida-2a**	Vardnili HPP	Zugdidi	220	1	AC 400/39	9	151	140
					2	AC 300/48	13		
					∑		22		
46	**Egrisi-1**	Enguri HPP	Vardnili HPP	220	∑	AC 500/64	11.5	226	212
47	**Egrisi-2**	Enguri HPP	Vardnili HPP	220	∑	AC 500/64	11.5	226	212
48	**Paliastomi-1**	Menji	Batumi	220	∑	AC 400/51	97.76	185	175
49	**Paliastomi-2**	Khorga	Batumi	220	∑	AC 400/51	93.87	185	175
50	**Rukhi**	Vardnili HPP	Khorga	220	∑	AC 400/51	55.21	185	175
51	**Kolkhida-3**	Vardnili HPP	Sokhumi	220	∑	AC 300/66	31.5	245	216
52	**Iveria-1**	Tkvarcheli	Sokhumi	220	∑	AC 400/51	61.7	297	261
53	**Iveria-2**	Sokhumi	Bzipi	220	∑	AC 400/51	78.2	297	261
54	**Alaverdi**	Gardabani	Alaverdi	220	∑	AC 300/66	28.5 [51.9]	195	185
55	**Adjara**	Batumi	Khopa	220	∑	ACK 400/51	12.3 [30]	127	112
56	**Salkhino**	Bzipi	Psou	220	∑	ACK 400/51	38 [43]	297	261
57	**Faravani**	Faravani HPP	Akhaltsikhe	220	∑	AC 300/39	33.6	255	224
58	**Khorga-1**	Khorga	Menji	220	∑	AC 400/51	12.74	212	200
59	**Khorga 2**	Khorga	Menji	220	∑	AC 400/51	12.73	212	200

Summarized data:

Total length of 500 kV OHLs: 841 km

Total length of 400 kV OHLs: 32.6 km

Total length of 330 kV OHLs: 21.1 km

Total length of 220 kV OHLs: 1689.2 km

As a result of temperature fluctuation, operational characteristics of OHLs are being changed. Hence, thermal capacity of the overhead lines are given for winter (25⁰C) and summer (35⁰C) temperatures, as for different conditions they can be calculated by use of following ratios (K_t):

T_{amb}	20 ⁰C	25 ⁰C	30 ⁰C	35 ⁰C	40 ⁰C	45 ⁰C	50 ⁰C
K_T	1.05	1.00	0.94	0.88	0.81	0.74	0.67

3.9 Installed Capacities of Autotransformers Installed in 500/400/330/220 kV Substation of Georgian Transmission Network

Table 3.5

Substation	Voltage (kV)	Capacities of ATs (MVA)	
Gardabani	500/220	800	3x267
Ksani	500/220	500	3x167
Zestaponi	500/200	500	3x167
Akhaltsikhe	500/220	500	3x167
Enguri	500/220	500	3x167
Gardabani	330/220	400	3x133
Gurjaani	220/110	125	1x125
Gardabani	220/110	250	2x125
Rustavi	220/110	400	2x200
Marneuli	220/110	125	1x125
Navtlugi	220/110	250	2x125
Gldani	220/110	250	2x125
Didube	220/110	250	2x125
Lisi	220/110	250	2x125
Ksani	220/110	250	2x125
Gori	220/110	125	1x125
Khashuri	220/110	250	2x125
Zestaponi	220/110	400	2x200
Pero	220/110	400	2x200
Kutaisi	220/110	250	2x125
Tskaltubo	220/110	125	1x125
Menji	220/110	125	2x63
Zugdidi	220/110	125	2x63
Batumi	220/110	250	2x125
Tkvarcheli	220/110	120	3x40
Sokhumi	220/110	250	2x125
Bzipi	220/110	125	1x125
Vardnili	220/110	200	1x200
Khrami-2	220/110	250	2x125
Akhaltsikhe B2B	500/400	875	2x437.5
Gardabani	500/220	800	3x267
Ksani	500/220	500	3x167
Zestaponi	500/200	500	3x167

Summarized data:

500/220 kV	3960 MVA
220/110 kV	5733 MVA
330/220 kV	400 MVA
500/400 kV	875 MVA
Total:	**10968 MVA**

4 Inputs for Network Development Planning

According to paragraph 2 of article 3[2] (Network Development Plan of Georgia) of Georgian law on "Electricity and Natural Gas":

2) Georgian Ten Year Network Development Plan should contain:

a) Information about existing and predicted demand supply;
b) Reasonable forecast about generation, supply, load and transmission to other countries.

According to network rules, article 39, paragraph 6:

transmission network development plan, along with other information should include information about the operational characteristics of the transmission network, which includes:

...

g) transmission network development, which is based on forecast of consumption growth;

h) transmission network development, which is based on plans of construction of new power plants.

i) offers about construction of new interconnection lines and substatntions.

j) planned interflows with neighbouring countries.

The initial information for transmission grid development are following: 1. Load and Generation data, specifically, type of new object, installed capacity, annual output, commissioning date, category; Decommissioning dates of old power plants, load growth scenarios. 2. Approximate prices of new transmission elements. 3. Agreements about construction of trans boundary infrastructure, between Georgia and neighboring countries and Development of surrounding grid. 4. Special requirements for generators and dc links. 5. Assignments about changes to be made in TYNDP, coming from Ministry of energy/Government.

Data about load and generation (4.1 .. 4.4) was received from Ministry of energy by letter #03/3376 dated 13/08/2015.

Information about forecasted prices (4.5) has been defined based on current projects.

Development of surrounding grid of Georgia (4.6) is one the most important factor for TYNDP, which represents technical basis about development of trans boundary infrastructure. This information has been provided by TSOs of neighboring networks and/or was found in internet. As for legal basis, it is based on agreements, memorandums and protocols between governments, TSOs and other companies.

Minimal technical requirements for power plants, generating units and dc links (4.7 and 4.8) has been developed by GSE engineers. This is because GSE, as a transmission system operator, provides real time operation and maintains dynamic stability of the power system, which is mainly implemented by dispatching power plants (active/reactive power increase/decrease, switch on/off of units. Therefore, it is very important new plants, units, dc links not to have worse dynamic parameters and possibilities than is allowed from the system point of view considering dynamic stability.

4.1 Time Span 2017-2031

4.2 Forecasted balance scenarios/growth of consumption

4.2.1 Growth of consumption of country

Scenario	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Pessimistic	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Normal	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%
Optimistic	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

4.2.2 Consumed energy, bln. kwh (gross domestic consumption)[1]

Scenario	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Pessimistic	11.36	11.48	11.59	11.71	11.82	11.94	12.06	12.18	12.30	12.43	12.55	12.68	12.80	12.93	13.06
Normal	11.64	12.05	12.47	12.91	13.36	13.83	14.31	14.81	15.33	15.87	16.42	17.00	17.59	18.21	18.85
Optimistic	11.81	12.40	13.02	13.67	14.36	15.08	15.83	16.62	17.45	18.33	19.24	20.20	21.21	22.27	23.39

[1] population growth in unknown

4.3 Forcasted installed capacity (MW)

Energy source	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
hydro	3229	3374	3874	4044	4438	4706	4927	5717	6419	6419	6419	6419	6419	6419	6419
thermal	925	925	655	1205	905	905	905	905	905	1155	1155	1155	1155	1155	1155
wind	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
solar					*	*	*	*	*	*	*	*	*	*	*
biomass				*	*	*	*	*	*	*	*	*	*	*	*
Other*															
sum	4175	4320	4550	5270	5364	5632	5853	6643	7345	7595	7595	7595	7595	7595	7595

* On studying stage

[2] Integration of Wind farms with total installed capacity of 100 MW and more is related to: 1) Construction of second 500 kV cross-border line between Georgia and Russia, 2) Construction of Khudoni, Namakvani HPPs and Tskhenistskali cascade HPPs, 3) Rehabilitaion of speed governors and excitation systems in existing power plants, 4) Integration into united energy market.

** on studying stage but total capacity coming from Wind and Solar power plants must not exceed 400 MW.*

4.4 Generation data

4.4.1 HPPs (According to signed MoUs)

№	Name	Installed Capacity (MW	Generation (Gwh)	Type	Commissioning date	Category[3]
1	Rachkha HPP	10.3	31.5	Run-of-River	09.09.2017	1
2	Jonouli HPP 1	1.1	5.1	Run-of-River	11.09.2017	2
3	Nabeglavi HPP	2	13	Run-of-River	2017	1
4	Squridіdi HPP	1.3	6.8	Run-of-River	16.09.2017	1
5	Shilda HPP 1	1.9	11.4	Run-of-River	15.10.2017	1
6	Kirnati HPP	51.3	219	Daily Reg	31.12.2017	1
7	Ifari HPP	3.2	14.2	Run-of-River	12.01.2018	3
8	Khelra HPP	3.1	12.1	Run-of-River	12.01.2018	3
9	Avani HPP	4.6	18.6	Run-of-River	29.01.2018	2

10	Kasleti HPP 1	8.1	45.8	Run-of-River	01.02.2018	2
11	Kobi HPP 1	60	320	Run-of-River	20.08.2018	3
12	Kobi HPP 2	41.6	191.4	Run-of-River	20.08.2018	1
13	Lukhuni HPP 2	12	73.6	Run-of-River	30.09.2018	1
14	Goginauri HPP	1.8	9.3	Run-of-River	01.10.2018	1
15	Oqropilauri HPP	1.8	9.4	Run-of-River	01.10.2018	1
16	Kasleti HPP 1	8.1	46.4	Run-of-River	31.12.2018	3
17	Kheori HPP	1	6.7	Run-of-River	31.12.2018	3
18	Aragvi HPP 2	2	11	Run-of-River	01.01.2019	3
19	Bochorma HPP	7.5	32.2	Run-of-River	01.01.2019	3
20	Nakra HPP	13.8	73.3	Run-of-River	12.01.2019	3
21	Natanebi HPP 2	7.5	52.5	Run-of-River	23.01.2019	3
22	Natanebi HPP 3	11.5	78	Run-of-River	08.02.2019	3
23	Mtkvari HPP	53	230	Run-of-River	16.02.2019	1
24	Mestiachala HPP 2	27	115	Run-of-River	28.02.2019	2
25	Kheledula HPP 3	60.4	255	Seasonal reg	29.03.2019	2
26	Stori HPP 1	14	69.4	Run-of-River	13.06.2019	2
27	Sashuala HPP 1	5.1	35.5	Run-of-River	01.10.2019	2
28	Sashuala HPP 2	5	34.3	Run-of-River	01.10.2019	2
29	Samkuristskali HPP	13.1	68.3	Run-of-River	2019	3
30	Chapala HPP	0.5	3	Irrigation	2019	3
31	Nenskra HPP	280	1200	Seasonal reg	2019	1
32	Khokhnistskali HPP 3	3.1	18	Run-of-River	01.01.2020	3
33	Vedi HPP	19.4	96.8	Run-of-River	01.01.2020	3
34	Tsirmindi HPP	13.4	65.8	Run-of-River	01.01.2020	3
35	Zekari HPP	1.6	8.2	Run-of-River	01.01.2020	3
36	Mleta HPP	5.5	36.2	Daily Reg	01.01.2020	3
37	Qvesheti HPP	10.1	67.4	Daily Reg	01.01.2020	3
38	Narovani HPP	4.1	18.6	Run-of-River	01.01.2020	3
39	Qvedi HPP	1.7	9.9	Run-of-River	01.01.2020	3
40	Tsablari HPP 2	14.6	63.2	Run-of-River	01.01.2020	3
41	Baramidze HPP	8.4	42	Run-of-River	31.01.2020	2
42	Buja HPP 1	1.6	8.7	Run-of-River	31.01.2020	3
43	Buja HPP 2	1	5.2	Run-of-River	31.01.2020	3
44	Buja HPP 3	2.3	12.3	Run-of-River	31.01.2020	3
45	Lajanuri HPP 1	4.3	23.6	Run-of-River	22.03.2020	3
46	Lajanuri HPP 2	5.8	31.2	Run-of-River	22.03.2020	3
47	Lajanuri HPP 3	4.3	23.6	Run-of-River	22.03.2020	3
48	Lakhami HPP	8.8	50	Run-of-River	17.04.2020	2
49	Darchi HPP	16.9	93.6	Run-of-River	31.12.2020	3
50	Ubisa HPP	7.6	35	Run-of-River	2020	3
51	Artana HPP	2.5	13.5	Run-of-River	2020	3
52	Lopota HPP 1	8	46	Run-of-River	2020	3
53	Paldo HPP	6.8	48.9	Run-of-River	2020	3
54	Khadori HPP 3	5.4	38.8	Run-of-River	2020	3
55	Samkuristskali HPP 2	13.1	68.3	Run-of-River	30.11.2020	3
56	Akavreta HPP	19	82	Run-of-River	01.01.2021	3
57	Metekhi HPP 1	23.8	131	Daily Reg	01.01.2021	3
58	Metekhi HPP 2	21.2	116	Daily Reg	01.01.2021	3
59	Kvirila HPP	6.6	40	Run-of-River	01.01.2021	3
60	Khokhnistskali HPP 1	1.3	7.9	Run-of-River	01.01.2021	3
61	Khokhnistskali HPP 2	1.3	7.5	Run-of-River	01.01.2021	3
62	Machakhela HPP 1	23	127	Run-of-River	01.01.2021	3
63	Machakhela HPP	19	115	Daily Reg	01.01.2021	3
64	Udzilaurta HPP	7.7	38.3	Daily Reg	01.01.2021	3
65	Barisakho HPP	15.3	77	Seasonal reg	01.01.2021	3
66	Laskadura HPP	6.6	33	Run-of-River	01.01.2021	3

67	Dolra HPP 3	30	124	Run-of-River	11.02.2021	3
68	Koromkheti HPP	150	463	Run-of-River	28.10.2021	2
69	Magana and leqarde HPPs	40.6	213.4	Run-of-River	11.12.2021	2
70	Mestiachala HPP 1	23.7	103.5	Run-of-River	25.12.2021	2
71	Samkuristskali HPP 1	4.8	24	Run-of-River	2021	3
72	Majieti HPP	12.3	56.4	Daily Reg	01.01.2022	3
73	Gebi HPP	14	72.8	Daily Reg	01.01.2022	3
74	Gere HPP	8.3	44.7	Run-of-River	01.01.2022	3
75	Chiora HPP	14.9	68.8	Run-of-River	01.01.2022	3
76	Sakaura HPP	12	56.7	Run-of-River	01.01.2022	3
77	akhaldabaHPP	93	494	Run-of-River	01.01.2022	3
78	Zoti HPP	48	225.1	Run-of-River	25.04.2022	2
79	Khertvisi HPP	65	239	Run-of-River	28.10.2022	3
80	Tskhvandiri HPP	9.8	44.1	Run-of-River	01.01.2023	3
81	Okrili HPP	7	30.5	Run-of-River	01.01.2023	3
82	Surebi HPP	6.9	40.8	Run-of-River	01.01.2023	3
83	Vani HPP	7.6	44.5	Run-of-River	01.01.2023	3
84	Bukistsikhe HPP	7.4	40.7	Run-of-River	01.01.2023	3
85	Sufsa small HPP	1.1	6.3	Run-of-River	01.01.2023	3
86	Larsi HPP 2	4.2	21.8	Run-of-River	15.11.2023	3
87	Oni cascade	177.2	789	Run-of-River	16.10.2023	3
88	Tskhenistskali cascade	357.1	1576.9	Seasonal reg	12.02.2024	3
89	Namakhvani cascade	433	1500	Seasonal reg	2024	2
90	Khudoni HPP	702	1500	Seasonal reg	2025	2
91	ENGURI 7 HPP	173.6	831.7	Run-of-River	Studying stage	3
92	ENGURI 8 HPP	173.6	821.7	Run-of-River	Studying stage	3
93	ENGURI 6 HPP	150.3	734	Run-of-River	Studying stage	3
94	ENGURI 5 HPP	50.6	255.2	Seasonal reg	Studying stage	3
95	ANDEZITI HPP	129.2	291.6		Studying stage	3
96	KHRAMI 3 HPP	1.1	4.3		Studying stage	3
97	KHRAMI 4 HPP	16.1	112.4		Studying stage	3
98	KHRAMI 5 HPP	15	102		Studying stage	3
	TOTAL	**3814**	**15222**			

4.4.2 TPPs

№	NAME	Instaled capacity (MW)	Efficiency (%)	Type	Commissioning date	Category[3]
1	1-Thermal	250	55	CCGT	01.01.2020	3
2	2-Thermal	250	55	CCGT	01.01.2026	3
3	3-Thermal	150	40	Coal	01.01.2020	3

[3] *Feasibility and environmental impact study has been done. Negotiations about tariffs are being held.*

4.4.3 Solar[4], wind[5], geothermal[6] or other[7] renewables

№	NAME	Type	Commissioning date	Category *
1	Chorokhi, Poti, Kutaisi, Mountain Sabueti 1+2, Gori, Kaspi, Samgori, Rustavi, Paravani, Akhalkalaki	Wind	Unknown	3
2	Imereti	Wind	Studying stage	3
3	Rikoti	Wind	Studying stage	3

4	Power plants of Pona	Wind	Studying stage	3
5	Central power plants	Wind	Studying stage	3
6	Nigoza	Wind	Studying stage	3
7	Kartli 2	Wind	Studying stage	3
8	Gardabani	Solar	Studying stage	3
9	Desert power plants	Solar	Studying stage	3
10	Gardabani	Biogas	Studying stage	3

Category 1 - *projects at construction stage*
Category 2 - *projects at license stage*
Category 3 – *Projects at feasibility study stage*

4,5,6,7 *- 400 MW is the total capacity coming from Wind power plants that can be integrated into the Georgian transmission network for 2025. In addition, it's not allowed to integrate more than 45 MW renewables in total in each of wind regions. Working on permissible amounts of power coming from Solar power plants is in progress (Chapter 18).*

4.4.4 Power plants to be decommissioned

№	Name	Instaled capacity (MW)	Type	Decommissioning date
1	Thermal Unit №3	130.0	Steam PP	01.01.2019
2	Thermal Unit №4	140.0	Steam PP	01.01.2019
3	Thermal Unit №9	300.0	Steam PP	01.01.2021

4.5 Forecasted prices of transmission system elements

1 km sin-circuit 110 kv. ohl – 0.136 mln euros[1] 1 km doub-circuit 110 kv. ohl – 0.210 mln euros 1 km sin-circuit 220 kv. ohl – 0.210 mln euros 1 km sin-circuit 220 kv. ohl - 0.310 mln euros 1 km sin-circuit 400 kv. ohl – 0.372 mln euros 1 km doub-circuit 400 kv. ohl – 0.558 mln euros 1 km sin-circuit 500 kv. ohl – 0.372 mln euros 1 km doub-circuit 500 kv. ohl – 0.620 mln euros 350 MW Converter - 60 mln euros[2] Extension of converter SS – 31-37 mln euros[2]	500 MVA 500/220 kv SS - 25 mln euros[2] 500/220 or 500/110 kv SS – 17 mln euros 250 MVA 220/110 kv SS - 14 mln euros 125 MVA 110/35 kv SS - 8 mln euros Consulting services 5% (of construction cost) Land redemption10% Environmental work 5% Unforeseen expenses 5%

1 – Cost of OHL, *may be changed in ±25% range according to the route relief.*
2 – Cost of construction/extension of substation / HVDC back-to-back link, *may be changed in ±20% range according to the route relief.*
Costs are including VAT.

4.6 Agreements with neighboring TSOs and their TYNDPs

According to the paragraph 2 of article 29 of grid code, dispatch licensee provides information exchange with neighboring TSOs.

Information about development of bordering networks is one of the important input for TYNDP. Information about trans boundary given in this document is based on different agreement between countries and they may be shown in the relevant TYNDP (if it exists).

Georgia has trans-boundary infrastructure with all four countries. Possibility of power transfer to Azerbaijan exceeds 1000 MW. Reinforcement and increasing of reliability is planed in directions to Turkey, Armenia and Russia.

4.6.1 To Turkey

Drivers. Main drivers for Projects to Turkey are the increase of export capabilities in Georgia due to construction of new HPPs and electricity Transmit from neighboring countries. Also intense increase in Consumption of electricity of Turkey. Besides, it is planned to build new transmission lines from Tortum's neighboring areas to rest of Turkey.

Basis.

Agreements. According to the agreement about reinforcesment of trans boundary infrastructure between ministries of energy of Georgia and Turkey, signed in september 29, 2010 between these to countries was reached an agreement about construction of OHL Batumi – Muratli and technical study of Akhlatsikhe–Tortum project. According the mentioned Mou the grouping of the technical team is being processed. In September 7, 2015, at the meeting between TEIAS and GSE, in Ankara, parties agreed that at the end of 2016 will be signed agreement about construction of 400 kV Akhaltsikhe–Tortum OHL, construction of which will be completed for the end of 2019 or 2020.

Development of neighboring network. During 2015-2017, transit grid of Turkey bordering of Georgia will be developed in the directions of Borchka as well as Tortum, Keban and other its neighbor bulk power consumption centers (fig. 4.1). In particular:

400 kV ohl Bagistash-Keban was constructed in 2016.
400 kV ohl Ispir-Arkun was constructed in 2016.

Here are completion dates for planned projects of transmission network reinforcement in Turkey which are bordering Georgian system for near future:

400 kV ohls Borchka-Ispir-Erzrum - till the end of 2016;
400 kVohl Ispir-Bagistash - till the end of 2016;
400 kV ohl Ordu-Resadie - till the end of 2016;
400 kV ohl Ispir-Koze-Resadie – till the end of 2018;
400 kV ohl Kalkandere-Koze – till end of 2019;
400 kV ohl Resadie-Iozgat-Ich Anadolu power plant (Ankara) – end of 2020;
400 kV ohl Erzurum-Alpaslan HPP-Kalekoi HPP – end of 2020.
400 kV ohl Koze-Decheko-Iozgat-Ich Anadolu power plant (Ankara)– end of 2021.

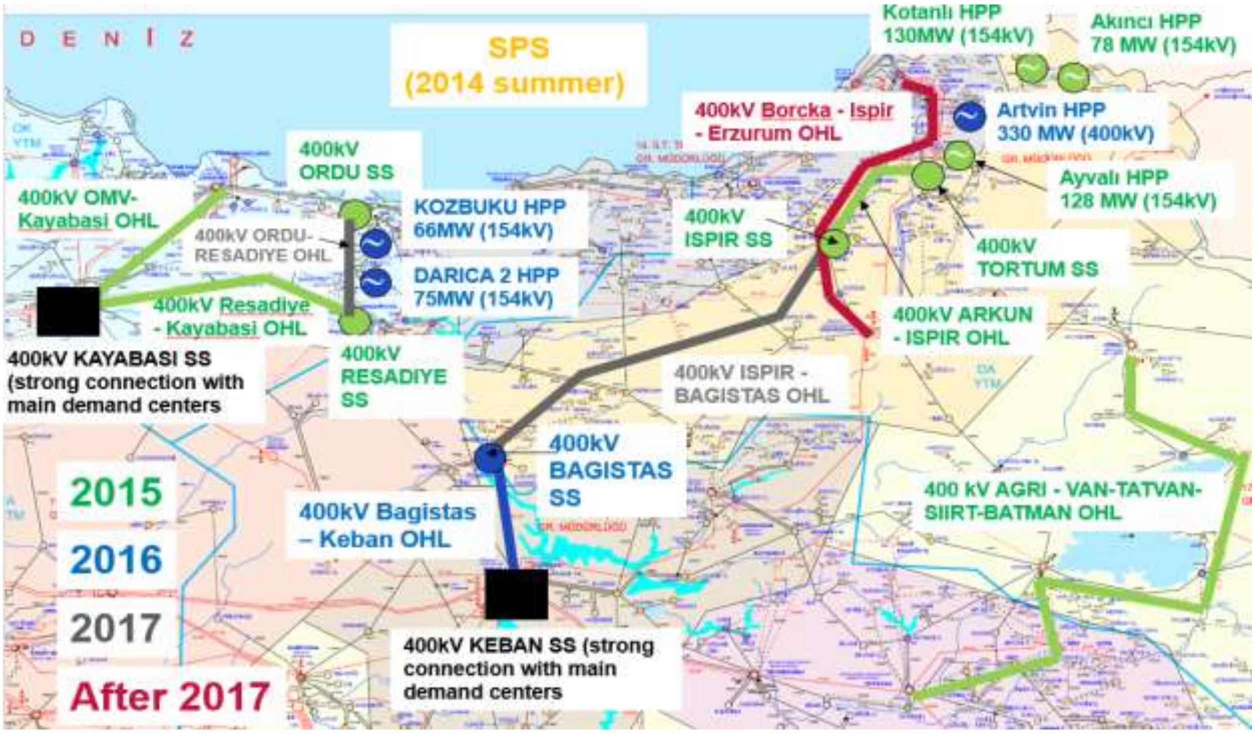


Diagram 4.1 Power system enhancement projects in Turkey

Also, will be enhanced the ability of capacity transit from the black sea directions, which provides reliable transfer of electricity to huge consumption centers located in west part of Turkey. Therefore, since 2019-2020 years, 1400 MW power transfer from Georgian power system to Turkish consumption centers most likely will be possible in a safe and reliable manner. Based on the above, starting from 2020. 1400 MW power export from Georgia to Turkey is considered.

4.6.2 To Armenia

Drivers. Main drivers to that direction are: increasing of reliability of Georgian and Armenian power systems and digestion of electricity trade potential between Russia-Armenia-Iran trough Georgia.

Basis

Agreements. According the agreement about construction of interconnection line between Armenia and Georgia signed on 26 January 2010, and changes in this agreement made on 6 July 2011 and 16 April 2014 between GSE, Armenian high voltage grid operator and Armenian power system operator, Georgia will construct the part of that 500 kv line till border, Armenia – the rest part of this line from border to Airum and 700 MW DC B2B station in Airum. Construction of these elements will be completed for 2018.

Development of neighboring network. In 2018-2019 it is planned important reinforcement of Armenian network constructing following elements: 500kv ohl from Georgian border to Airum, 500/400 kv 350 MW DC back to back station in Airum (with probability of adding additional 350MW block in 2021), SS Noravan, SS Damashen, Gas turbine station and 400 kv SS Hiusisian, 400 kv ohl Airum-Damashen, 400 kv ohl Damashen-Hiusinian, 400 kv ohl Damashen-Noravan, double-circuit 400 kv Noravan-Iran (Diagram 4.2)

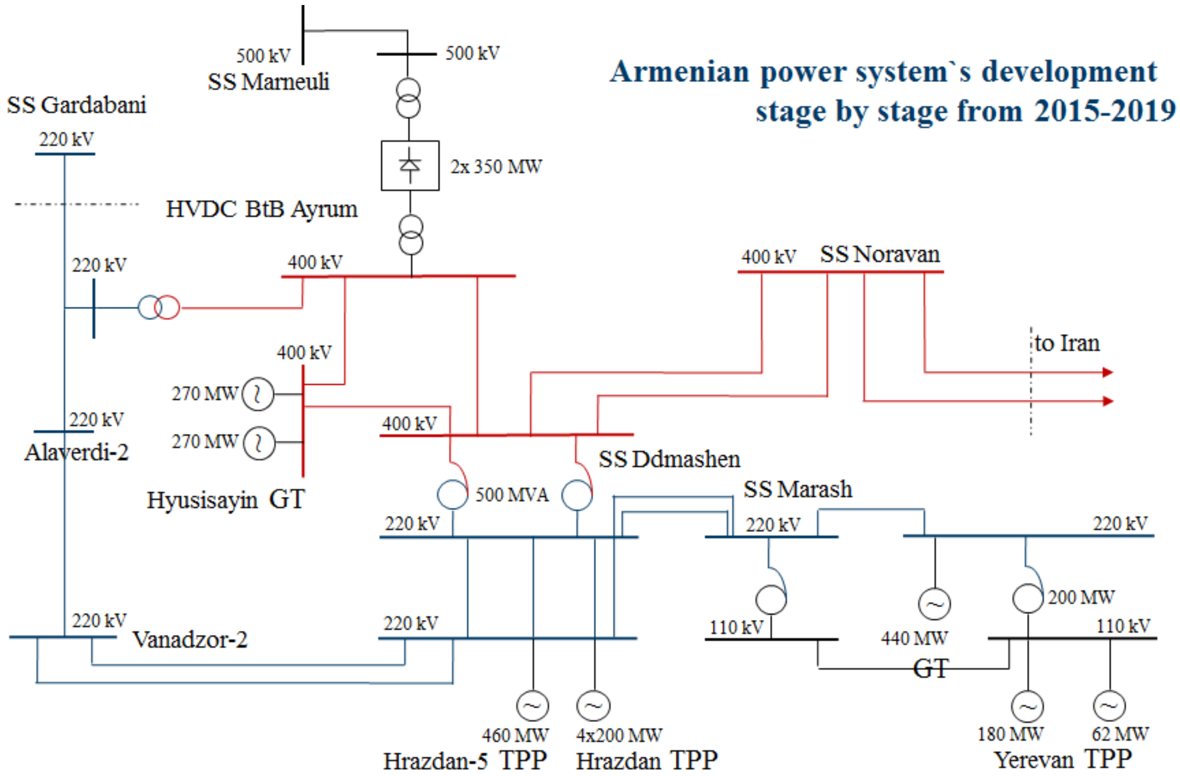


Fig. 4.2 Power system enhancement projects in Armenia

4.6.3 To Russia

Drivers. Main drivers to that direction are: increasing of reliability of Georgian and Russian power systems and digestion of electricity trade potential between Russia-Armenia-Iran trough Georgia and improvement of stability of north Caucasus and east Georgian system.

Basis

Agreements.

At the meetings between GSE and Russian system operator held in 2013 has been launched and in 2015 march 31, proceeding of technical feasibility study of 500 kv ohl Ksani-Stephantsminda-Mozdok has been agreed.

Development of surrounding grid of Georgia. According to 2013-2019 years development plan of Russian power system (fig. 4.3), in surrounding grid of Georgia implement the following projects are planned: 330 kv substation “Ilenko” and tie line from this SS to 330 kv ohl “Cherkesk-Baskan” till 2017. 330 kv ohl “Nalchik-Sverokavkaskaia” , 500 kv ohl “Stavropolskaia-Nevinominsk”, 500 kv substation “Mozdok” and 500 kv ohl “Nevinominsk-Mozdok”. Till 2020, 500 kv substations “Chernomorskaia” and “Novosvobdnaia”, 500 kv ohl “Chernomorskaia-Novosvobodnaia” and 500 kv ohl “Novosvobodnaia-Nevonominsk” will be constructed, also, 500 kv ohl “Kavkasioni” (Enguri-Centralnaia) will be cut into substation “Novosvobnaia”, which will reduce the length of “Kavkasioni” by 100 km and thus improve its reliability. Also substations “Sunja”, “Alagir” will be constructed along with HPP “Zaramag” in which ohl “Nalchik-Severokavkasia” will be entered.

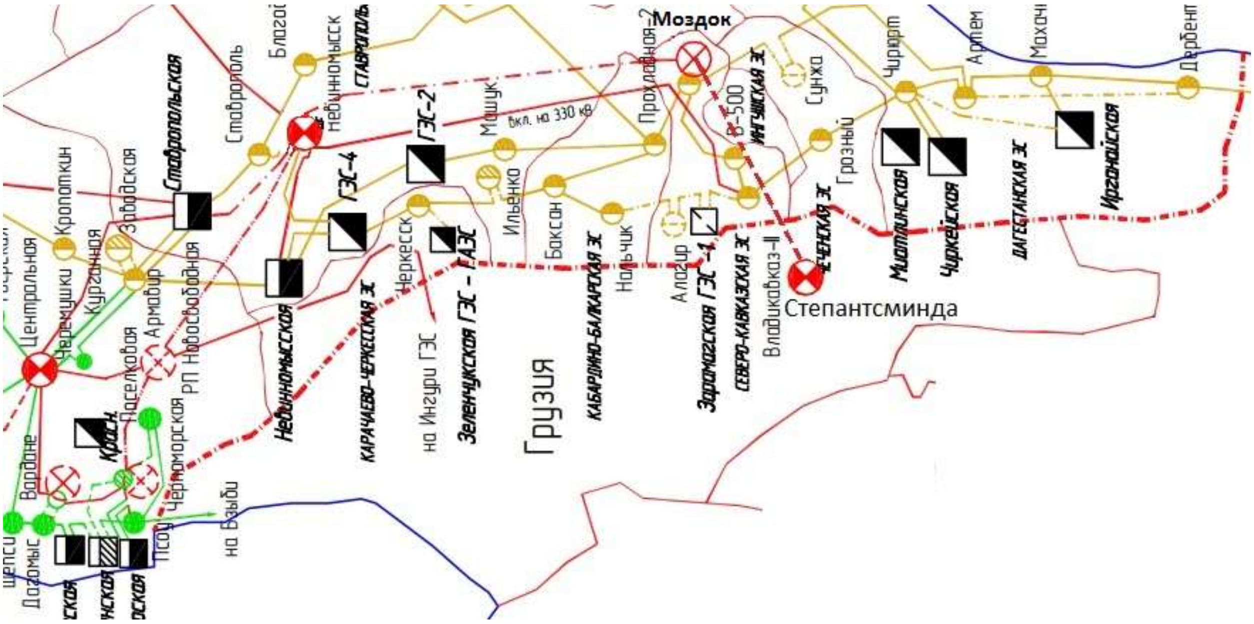


Fig 4.3 Reinforcement projects of part of Russian power system neighboring of Georgia

Thus, till 2020 north Caucasus network is significantly developed and in case of connection of 500 kv ohl “ Stepantsminda-Mozdok” to it, on one hand the stability of that grid will be improved (will be reserved through Georgian transmission network) and on the other hand this network will backup Georgian network.

4.6.4 To Azerbaijan

There is already strong enough cross border infrastructure between Georgia and Azerbaijan (500 kV OHL Gardabani-Samukh). However, this line has not been in operation yet, in presense, testing works and analysis of necessity of reactor installation in SS Samukh are in progress. After full readiness of above mentioned OHL, transit potential between Georgia and Azerbaijan will be increased up to 1000 MW. In addition, Azerbaijan side is considering to construct second circuit of 330 kV OHL “Gardabani” (Gardabani-Agstafa) which will increase power exchange capabilities between Georgia and Azerbaijan up to 1000 MW in N-1 mode.

4.6.5 Project “North-South” AGIR (Armenia-Georgia-Iran-Russia)

As a result of meeting held in Batumi city (Georgia) on 16 September 2016, agreement among Armenia, Georgia, islamic republic of Iran and Russia about analysis of reasonableness of infrastructure connecting power systems of above mentioned countries has been signed. Countries were presented by the following companies – JSC “Georgian state electrosystem” (Georgia); “Power system operator” and “High voltage grids” (Armenia); “Company of management of power generation, transmission and distribution of Iran” [TAVANIR] and “Management company of network of Iran” [IGMC] (Iran); “SO UPS” [System operator], “Rosseti” [Network company] and “Inter RAO” [Energy trade company] (Russia).

This project is very important for electricity trading between two large power systems like Russia and Iran which will use corridors of Georgian and Armenian power systems in order to realize above mentioned task. United systems of Georgia-Russia and Armenia-Iran will be connected to each other asynchronouslu – by planned 500/400 kV HVDC back-to-back station in “Airum” SS (Armenia).

The most important element of above mentioned project is perspective 500 kV cross-border OHL Stepantsminda-Mozdok. It has been mentioned by parties that all rest highway ensuring realization of Project “North-South” are completed or on construction stage.

- In Georgia:
  - Constructed
    - New 500/220 kV SS „Marneuli“
    - Rehabilitated 500/220 kV SS „Ksani“
    - 500 kV OHL „Asureti“ (Ksani-Marneuli) connected with SS „Marneuli“
  - On construction stage
    - 500 kV OHL „Sno“ (Ksani-Dariali HPP [Stepantsminda])
- Georgia-Armenia section
  - Working
    - 220 kV OHL „Alaverdi“ (Gardabani-Alaverdi)
  - On construction stage
    - 500 kV OHL „Debeda“ (Marneuli-Airumi)
- In Armenia
  - On construction stage
    - 500/400 kV B2B SS „Airumi“
    - 400 kV OHL „Marneuli“-„Ddmasheni“
    - 400 kV OHL doub-circuit OHL „Ddmasheni“-„Noravani“
- In Armenia-Iran section
  - Working
    - 220 kV OHL Cottage-Ahari
    - 220 kV OHL Cottage-Sunguni
  - On construction stage
    - 400 kV OHL Norovani-Jilpa (Completed territory of Iran)
    - 400 kV OHL Norovani-Herisi (Completed territory of Iran)
- In Russia
  - On construction stage
    - 500 kV OHL Nevinomisski-Mozdok
- In Georgia-Russia section
  - Working
    - 500 kV OHL „Kavkasioni“ (Enguri-Tsentralnaya)
  - Be considered
    - 500 kV OHL **„Gergeti“ (Stepantsminda-Mozdok)** – main part of the project AGIR is reasonableness analysis of this line construction.

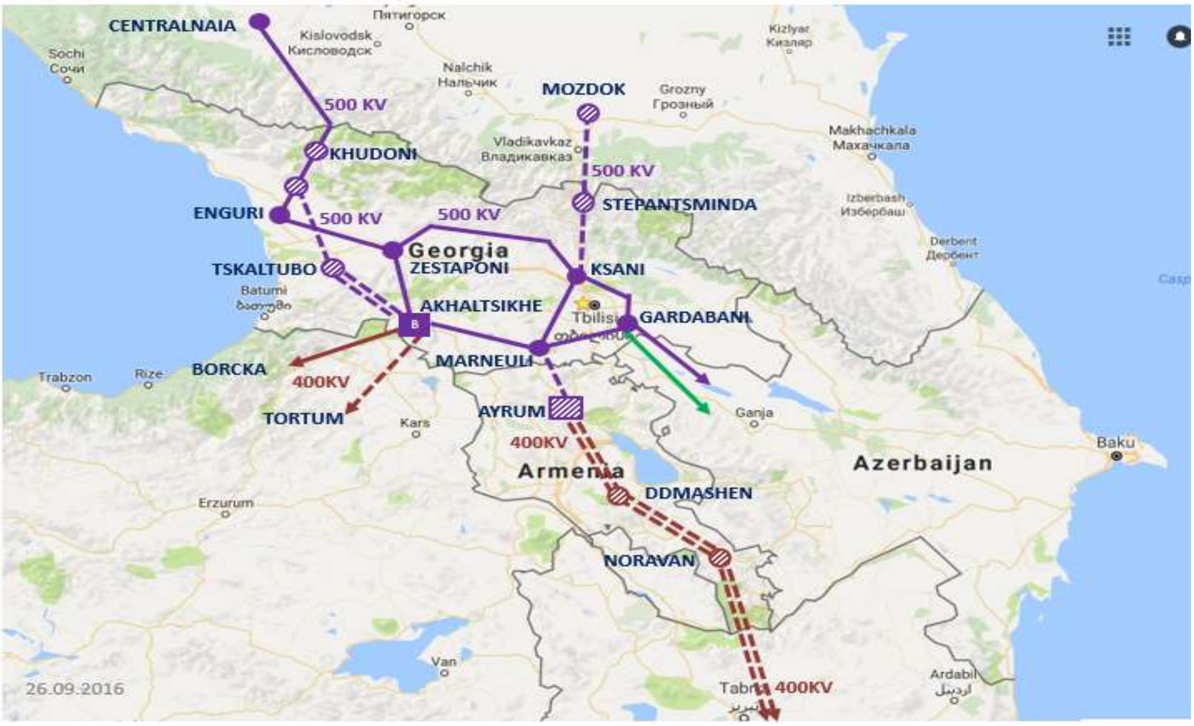


Fig. 4.4 Basic elements of AGIR project

4.7 The minimum technical requirements for power stations and generators.

Transmission network provides power delivery from generations to users. Sustaining high quality of Electricity transmission network provides the transport energy from the sources to consumers. And even electricity transmission network itself is reliable, parameters required to ensure the quality of electricity and is carried out in by the sources - power plants and the relevant units / blocks. The NCC of transmission system operator JSC "Georgian State Electric System" national control center in real time compensates the change of power balance caused by consumption through a change of generation. Therefore, in order to ensure acceptable quality of supply of electricity, maintaining the reliability of the power system, its operational parameters, the power sources must to meet the minimum technical requirements. The requirements in the following regulations

1. Network Code (Approved by the GNERC, 17.04.2015)
2. Technical Operational Rules of Power Plants and Networks. (N 434 Resolution of Goverment, 31.12.2013)
3. Concept of System Services (GSE, 01.07.2015)

It must be noted that the units of power plants have to satisfy the requirements for system services, such are primary, secondary and terchiary reserves, voltage control, black start (except the situation when there is different clarification in their projects and this is agreed with transmission system operator (dispatch licensee) – JSC “Georgia State Electrosystem”.

In addition especial capabilities, particular capability of compensation must implemented on the power plants witch will be connected with 500 kV and 220 kV nodes, remote from consumption centers, particularly HPPs of Racha and Svaneti regions.

In addition, GSE is intensively working with European power energy community, with the support of Ministry of Eenergy and Energy and Water Supply Regulatory Commission, to adopt Entso-e network codes (European united power transmission system operator). RfGs are elaborated and ready for discussion, as well as consumer requirements and HVDC codes. After these codes are adopted, minimal technical requirements for these equipment will become more flexible, simple and understandable, that will provide system reliability and efficiency.

4.8 Special requirements for Back to Back stations

4.8.1 Adding of third 350MW HVDC back-to-back unit in Akhalstikhe SS is planned for 2021 which will have to met the same requirements existing for already installed ones.

4.8.2 As for HVDC back-to-back stations in Batumi and Airum (Armenia) subsations, they should be charged with following requirements:

1. **Type.** “HVDC light”
2. **Reactive power support, voltage control.** B2Bs should have possibilities to control reactive power in full permissible range according to pattern required from dispatchers. This means that despite the direction of active power flow, back-to-back units must vary reactive power by its amount and direction according to the requirements of specific regime in order to achieve desired voltage level.
3. **Black start**. In case of blackout in one of the system, back to back station should provide voltage for system black start according to the dispetcher requirement.
4. **Frequency control.** Based on preliminary agreement HVDC units should have readiness to activate control function of active power by frequency or frequency derivative in any time.
5. **Participation in RAS system.** Back to backs should be able to receive or transmit signals nesessery for Ras or other system protection systems.

4.9 The changes made into the projects according to instruction made by Ministry of Energy and The MoUs signed between the Government of Georgia and Power plants

1. For the purpose of integration of Svaneti’s new 560 MW HPP cascade (Dizi-250 MW, Kvanchianari-230 MW, Ieli-80 MW) into the network (presumably in 2029), double-circuit 110 kV OHL Nenskra-Mestia will be constructed within 220 kV range.
2. Based on the Decree N 1557 dated July 24, 2017 of the Government of Georgia on Additional Measures for Supply of Electricity to the City of Tbilisi“, GSE was tasked to a) plan and construct new 220/110 kV substation in Teleti, b) integrate this substation to 220/110 kV network and c) tie-line 220 kV OHL “Algeta” to it.

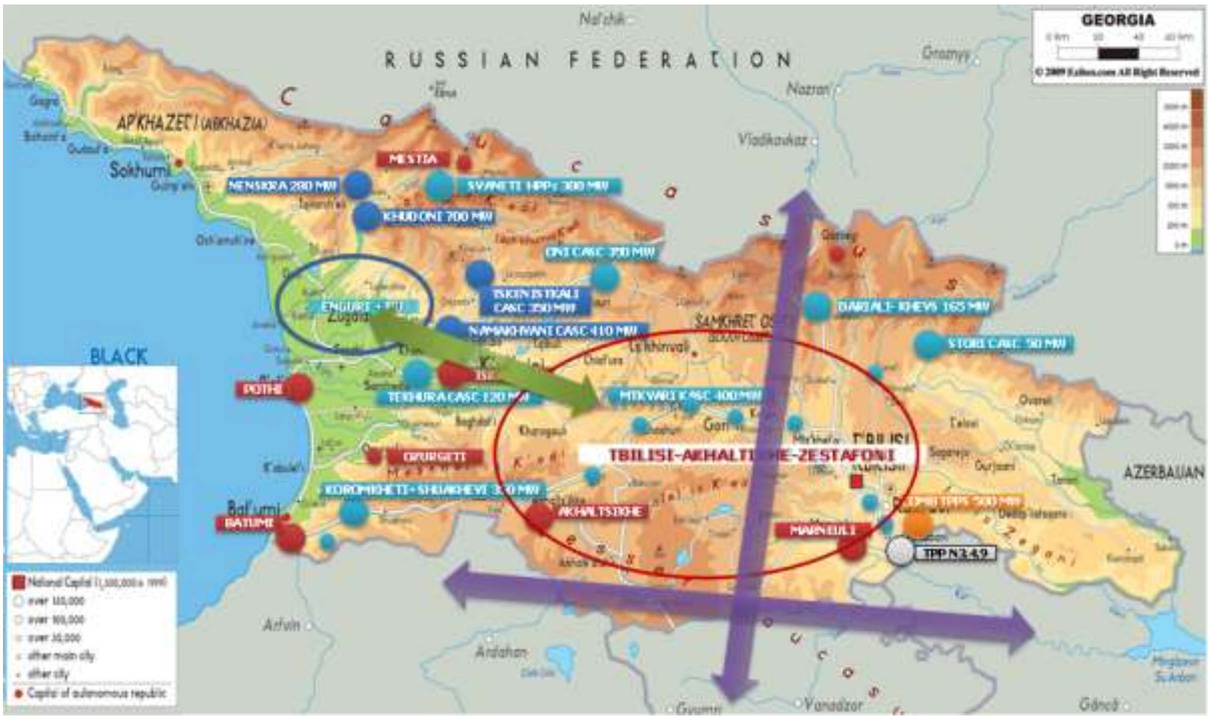
4.10 Information for the request of the postponement of existent projects by transmission licensees

As an annex for letter N 5466/09 dated 08/12/2015, technical condition with the requirements presented in 4.8.2 paragraph for Energo-Pro Georgia's prospective HVDC back-to-back station to be connected to 220 kV SS Batumi has been issued by JSC GSE.

Respective to the request received by letter N 2216960 dated 02/08/2016 from Energo-Pro Georgia, GSE agreed on postponemet of construction of above mentioned HVDC station and respective 154 kV OHL Batumi-Muratli till 31 December 2020 with the condition of fulfilling above mentioned requirements.

5 Drivers of Georgian Transmission System Development

Development of the transmission network is influenced by various factors that are specific to individual electric power systems. For Georgia, these are: Network Security, connection of new power plants and consumers, usage of transit potential etc which are underpinned with Georgian legislation. Currently Georgian electric power system is in transition – transformation of transmission network developed for operation with big power system in order to create reliable transmission network ready for presence and future challenges; Replace of aged Soviet Union equipment with modern one of European standards.



- Prospective regulated HPPs
- Prospective seasonal HPPs
- Prospective demand growth
- Thermal power plants scheduled for decommissioning
- New combined cycle thermal power plants
- ⇔ Necessary upgrades of cross-border (inter-system) links
- ⇔ Necessary upgrades of internal network links
- O Existing bulk generation region
- O Existing bulk demand region

Fig. 5.1 Map illustrating development drivers of Georgian electric power network

Some of the foregoing development drivers are reviewed in detail in the following sections.

5.1 Primary Development Drivers of Georgian Transmission Network

Georgian Legislation According to 3[2] article (Ten-Year Network Development Plan of Georgia) of Georgian Law about "Electricity and Natural Gas": The purpose of working out the Ten-year Transmission Network of Georgia Development Plan shall be the reliability, safety, and sustainable development of the transition network, provision of electricity of adequate quality, and raising the transit capacity of the electricity network of the country. *According to Article 33 of Georgian Grid Code* The Dispatch Licensee is obliged to conduct necessary studies for transmission network planning periodically or upon necessity four providing economical, safe, reliable and stable functioning.

So development drivers, given below, are implications of Georgian Legislation.

Improvment of security of supply/system reliability. According to the grid code article 30, paragraph 2, *for estimation of network reliability two criteria : a)adequacy – ability of the system to uninteruptely meet the demand for electricity, in both plaaned outages and emergency cases. b) stability – ability of the system to withstand disturbances such as short circuit or unexpected outages of system elements.*

During power transfer from generation facilities to the loads, the loss of any single line may cause load shedding or even full blackout. From such lines the major one is 500 kV OHL Imereti connecting Enguri HPP to the load centres located east of Zestaponi, and at Akhaltsikhe substation providing power export to Turkey. The Emergency Control System (ECS) provides certain reliability level, however its activation causes short-term disconnection of the customers and, in addition, even ECS can not provide 100% guarantee of network survival. Therefore, for ensuring required reliability level, it is necessary to design the system in conformity with single contingency (N-1) condition, such as when any single line is lost, other lines should be capable to undertake the load without disconnecting the customers, subject to maintaining power quality within prescribed limits.

Transmission of the existing generation. Under certain operating regimes, topology of the transmission system may limit transportation of the existing generation to the load centres. The major power supply source of Georgia is Enguri HPP, which during summer months covers more than a half of total country consumption, as well as participates in electricity export to Turkey. Despite construction of SS “Jvari”, SS “Khorga” and double-circuit 220 kV OHL “Khorga-Menji”, during summer excessive water period, the only 500 kV OHL “Imereti” from Enguri HPP into the Georgian network as well as 220 kV route “Enguri HPP – Vardnili HPP – Zugdidi – Menji” still restricts power transit from Russian Federation and from Enguri-Vardnili nod towards eastern Georgia,Turkey and Armenia.

Reclamation of the new energy resources. No transmission network of any country, despite its scale, can guarantee integration and reliable transfer of the new generation without appropriate pre-arrangements. Georgia is among the richest countries around the globe by its hydropower recourses. Hydro power plants generate the cheapest and ecologically clean electric power. Meanwhile, demand on electric power steadily grows as in Georgia, so in Turkey and European countries interconnected with Turkish power system.

The major power potential of Georgia is associated with water (hydro), wind, solar and geothermal energy resources. Also, Georgia has some fossil deposits (natural gas, oil, peat, coal), however they are available in insufficient quantities to allow economical use. Assuming instability of wind and solar radiation patterns, solar and wind energy, despite consistent development and cost reduction of relevant technologies, call for availability of the additional reserve capacities in the power system, and hence, in general, provoke negative effects in terms of system stability. Georgian power system is small scale, with radial topology of its western part and only 500 kV synchronous link with Russia provided by OHL Kavkasioni. Therefore, for the sake of stability and reliability, bulk integration of wind and solar power facilities into Georgian network prior to 2021 is unreasonable. Meantime, the opposite is true regarding hydropower potential.

The hydropower resources have the largest share in the entire Georgian natural wealth. There are 26,060 rivers with aggregated length of about 60,000 km recorded on the territory of Georgia. The total volume of Georgia’s fresh waters stored in glaciers, lakes and man-made reservoirs amounts to 96.5 km^3. The major hydropower potential is concentrated in 300 rivers with total feasible power potential of 15,000 MW that is equivalent to average annual generation of 50 billion kWh.

The hydro power plants are characterized by high flexibility allowing adjustment of their outputs in line with load changes, and even several start-ups and shutdowns during a day. Such type power plants are distinguished by high stability and reliability ensuring the same of the entire power system. Besides these, hydropower still provides the cheapest technological opportunity for electricity production. All above makes reclamation of hydropower resources the major direction in course of developing Georgian electric power system.

Therefore, integration of hydro power plants into the network is the essential driver for development of Georgian transmission grid.

Dully considering such importance, the following 10-15 years will be devoted to construction of the new hydro power plants, mostly in the West Georgia, and evacuation of their output will require considerable enforcement of the transmission system from the west to the east, towards the major load centres and cross-border lines.

Increasing network transit potential. Shortage or surplus of domestic power in the interconnected national systems, as well as considerable differences in electricity prices may necessitate bulk cross-border electricity trade. This is particularly true about Georgian power system characterized by clearly distinguished seasonality, expressed as power excess and shortage during flood and low water periods respectively. Therefore, assuming integration of significant hydropower capacity into the network during the next ten years, increasing the power exchange capabilities with neighbouring states via new cross-border line obviously comes to agenda. In addition, due to its geographical position, Georgia may provide the transit route for power trade among its neighbouring countries, which do not border each other. At present, such trade between Russia and Iran is limited by transmission capacity of 220 kV OHL Alavardi interconnecting Georgian and Armenian transmission systems. In similar, energy transits between Russia and Turkey are limited by transmission capacity of OHL Kavkasioni. Meanwhile, considering growing demand on electricity in Turkey, its market should be attractive not only for Georgia, but also for other countries having links with Georgian power system, provided that sufficient power transfer capabilities from Caucasian states to Turkey are available. Therefore, this Ten-Year Plan assumes construction of 500 kV SS Stepantsminda which will be connected with Russian power system by 500 kV OHL. 350 MW HVDC back-to-back link near 220 kV SS Batumi, additional (third) 350 MW HVDC back-to-back link will be installed at SS Akhaltsikhe and 400 kV OHL Akhaltsikhe-Tortum will be constructed leading to increase net transfer capacity between Georgia and Turkey by 700 MW. 500 kV OHL Marneuli-Alaverdi will be constructed and connected to the 700 MW HVDC back-to-back link in SS Airum (Armenia). For 2022, Georgia's total cross-border power transfer capacities with Turkey will be 1400 MW, 1000-1200 MW with Azerbaijan, 700 MW with Armenia and 1400 MW with Russia. This will allow both evacuation of the bulk power from Georgia, and increase of electricity trade volumes among its neighbouring states through Georgia's territory.

Construction of the reliable power supply centres for supporting potential developments in production and tourist industries. Generally, development of the national economy entails creation of the bulk power supply centres responding to the demands of factories, ports, tourist centres and construction of the new cities. In this course, development of Georgian transmission network will serve as one of the supporting factors to development of production industry. This assumes construction of the powerful 500/220 kV and 220/110 kV substations planned for power supply of the specific bulk load centres developed around certain large cities such as **500/220 kV SS Tskaltubo**, **500/220 kV SS Jvari** and **500/220 kV SS Khudoni** as well as **500/220 kV SS Marneuli** serving as alternative to SS Gardabani for interconnection of the new large production facilities, possibly including chemical or metallurgical plants, or refinery, **220/110 kV Khorga** supplying power to the existing and future ports in Poti and

Anaklia respectively, and supporting to development of the new production facilities in this cities, **220/110 kV SS Ozurgeti** facilitating realization of the regional agricultural potential including processing of tea, citruses, hazelnut, etc., and **500/110 kV SS Stepantsminda** backing development of the tourist infrastructure in Stepantsmnda region.

Replacement of the aged thermal units with flexible and cost-effective combined cycle thermal power plants. In Georgian power system, the base load power is generated by thermal power units Nos. 3, 4 and 9 installed in Gardabani Thermal Power Plant (TBILSRESI). These unites are overaged both physically and morally, and their efficiency does not exceed 30%. Neither of these units participates in system frequency regulation. Moreover, units nos. 3 and 4 are also not involved in system voltage control. Therefore, for the nearest futures, it has been envisaged to replace all these units by the new combined cycle thermal power plants, with efficiencies around 55% (i.e. the new plants will generate 90% more energy from the same fuel), and capable to participate in both frequency and voltage regulation. The new plants will also serve as secondary and tertiary operating control reserves. However, even the reserve capacity supplied by them may currently be received at their interconnection points (mainly at SS Gardabani), undertaking of such function still requires modification of the transmission network (adding 500 kV or 220 kV bay in SS Gardabani and/or tying any 500 kV or 220 kV lines outgoing from this substation into the prospective plants, for example, cut of 220 kV ohl "Navtlugi" into 230 MW Gardabani CCGT).

Responding to the growing demand on electricity. The changes in electricity consumption depend on dynamics of the national economical parameters. During preparation of this plan, 1.0%, 3.5%, and 5% growth rates were applied during simulation for internal power demand in Georgia, and 8-10 % for demand in Turkey. Generally, any increase in demand shall be compensated by growth of generation or import (the latter conventionally considered as a generation source). Both cases entail increase of power flows from generation to customer, and hence new substations and transmission lines shall be added to the network to allow continuous reliable and stable operation of entire power system.

Improvement of power quality. Provision of sufficient operating reserves will allow to address the problem related with frequency that is one of the power quality parameters.

As regards to the second power quality parameter – voltage, it shall be regulated by automatic regulators installed on the generators and tap changers of transformers and autotransformers that are approximately in the similar state as the speed governors, i.e. their one part is inoperable and other damaged. Therefore, the following is necessary for dealing with voltage instability problems:

- Rehabilitation of the voltage regulators installed in the existing power plants;
- Obligation of all power plants to participate in voltage regulation;
- Periodic testing/checking of voltage regulators at each power plant;
- Installation/upgrading of automatic tap changers of power transformers and autotransformers installed in the substations.

Flexibility of the power system was significantly improved during recent years, mainly due to projects implemented in Georgian State Electrosystem, which are still ongoing, specifically:

- Installation of the generators' grouped regulation system in the national dispatch centre and gradual (staged) integration of the regulated plants into the network;

- Improvement of Emergency Control System, which allows to maintain system stability during loss of any critical OHLs or autotransformers;
- Automation of the substations allowing their full remote control from dispatch centre;
- Rehabilitation of OLTC (on-load tap changer) of transformers;
- Installation of regulating reactors;
- The need for the automatic phase-shifting transformers is under study, and if found necessary such equipment may be installed:
  - between 500 kV parallel OHLs connecting Georgian and Russian power systems for regulating power flows, specifically between OHL Kavkasioni and OHL Stepantsminda (Stepantsminda-Mozdok), from SS Ksani or SS Stepantsminda;
  - In SS Batumi, for regulating power flows between 220 kV mains Tskaltubo-Kutaisi-Zestaponi and Batumi-Akhaltsikhe.

6 Strategy, Scenarios and Methodology for Planning Ten-Year Development of Georgian Transmission Network

6.1 Development Strategy

Electric power sector is an important part of economy with high influence on social status of Georgian people, and as such, development of the power infrastructure is among the most important national tasks.

The emerged cross-border electricity trade opportunities, high electricity demand growth and need for evacuation of the energy generated by the planned power plants, call for investments in the transmission infrastructure for ensuring adequate development of the network. Such objective targets availability of the transmission network capable ensuring of the consistent response to generation and demand growth by reliable and safe transportation of electricity, without any interruptions caused by outage of any single network element.

In general, development of the transmission system is a long-term process targeting reinforcement, expansion and upgrading of the network in line with generation and demand growth.

This document covers all components relevant to evolution of Georgian power system. However, other projects that are not included in this Ten-Year Plan may also be reviewed in current and/or subsequent years. In addition, some projects described herein may be modified, implemented in shorter timeframes or delayed. All such changes will be accounted for in 2018 revision of the plan.

Generation adequacy constitutes one of the major conditions for reliable power supply. Sufficient generation shall be always available to cover national demand without any negative influence on the power quality parameters. Such adequacy shall provide for availability of the system services including primary, secondary and tertiary frequency controls and voltage regulation as stipulated in the Grid Code that should obviously require centralized control of the generation facilities. GSE aims improving current technical environment in cooperation with power plants, and integrating into the network only such prospective generators, which are capable to provide the system services (provided that their capacities and outputs are sufficient to allow desired effect on Georgian power system).

The goal of GSE is to develop stable, reliable, cost-effective and efficient transmission system ensuring at any development stage:

- Network security;
- Power quality;
- Sufficient transfer capacity for
  - integration of renewable energy sources into the network; and
  - power exchange with neighbouring countries;
- Preparedness for integration into ENTSO-E's Ten-Year Network Development Plan

The reason of long-term development planning is explained by the need for the future transmission network satisfying all applicable design requirements, the most important from which is single contingency (N-1) criteria.

This Ten-Year Plan has been prepared based on the following principles:

- At any network development stage, power supply from generating facilities to the customers shall be carried out in compliance with N-1 criterion;
- The most cost-efficient network development option satisfying N-1 criterion shall be selected for implementation;
- Reliable operation of the power system shall be ensured;
- Power shall be supplied to the customers with high level of reliability;
- The network shall be developed in consistent and sustainable manner;
- Efficient operation of the power system shall be ensured.

This plan covers 500/400/330/220/154/110 kV overhead lines and substations that are important for the network, i.e. which existence or operation affects stability of the entire power system. Comparing to 220 kV lines, transmission capacities of 500 kV OHLs are about 5-times higher, while the losses are significantly less, although such lines entail higher construction and operation costs. Therefore, 500 kV OHLs are used for bulk power transit.

The eastern part of Georgian transmission network where the bulk loads are concentrated is well-developed at both 500 kV and 220 kV voltage levels, while the western part of the network has weak points despite the most portion of the domestic generation facilities (both existing and prospective) are accumulated therein. Therefore, the underlying trend in the development of Georgian transmission system will be reinforcement of the western network and its interconnection with the eastern part of the grid (Akhaltsikhe node).

Since cross-border power exchange is one of the key drivers of Georgian transmission network development, this Ten-Year Plan envisages reinforcement of the lines connecting Georgia with Turkey, Armenia, Azerbaijan and Russia. The parallel synchronous operation with the power systems of neighbouring states provides the optimal regime for Georgian power system reflected in increased reliability and reduced need for operating reserves. However, possibility of contingent outages of cross-border lines should not be excluded, and therefore developments included in the Ten-Year Plan are intended for allowing continuous operation of Georgian power system under the island mode while providing its customers (and export to Turkey) with reliable and secure power supply.

Considering above, this Ten-Year Plan has been prepared assuming stability and reliability of the national power system at each development stage, with **specific focus on fulfilment of N-1 criterion that is essential design condition of Georgian transmission network**. For this purpose, GSE's specialists have performed number of calculations (power flow modelling, short circuit, stability and harmonic analyses, assessing capabilities for network integration of HPPs and determining system transfer capacities) allowing identification of the bottlenecks (weak points) of both existing and prospective network considering several alternative development options. From these, the best option as in terms of compliance with design (N-1) criterion so from the economical point of view was adopted for detail planning.

To achieve satisfaction of N-1 criterion without the need for shedding customer loads, that is an essential goal of Georgian transmission network development, requires mobilization of technical resources, as well as provision of sufficient finance (investments) that obviously may not occur immediately. However, within its available capabilities, GSE strives to compliance with single contingency criterion that, assuming the current network topology will be achieved during 2015-2019, subject to short-term demand limitations initiated by emergency control system.. Meanwhile, beginning from 2020, after commissioning of 500 kV transmission main Jvari-Tskaltubo-Akhaltsikhe fully backing up the existing 500 kV OHL Imereti, this criterion will be unconditionally satisfied without any impact on demand.

The major development drivers of Georgian transmission network include:

1. Increased reliability of power transmission from the existing generation sources to the loads;
2. Safe evacuation of the generation from prospective power plants;
3. Realization of power transfer potential with neighbouring states.

Reliability of the power transmission from the existing power plants to the customers is limited by geographical layout of Georgian power system with the largest plants, such as Enguri HPP and Vardnili HPPs located at the west of Georgia, and major loads distributed in the central (Kutaisi, Zestaponi), south (Akhaltsikhe export line) and east (Tbilisi, Rustavi) parts of the country. Originally, when developing hydropower resources of Enguri River basin, essential intention was supplying of peak power to the south part of Russian power system. Therefore, 500 kV OHL Kavkasioni was considered as the major transmission line outgoing from Enguri HPP, while 500 kV Imereti transported only smaller power flows from Enguri River basin towards the bulk loads located at the east, since the latter were mainly supplied from the thermal plants located near Tbilisi-Rustavi node. Rocketed increase of fuel prices experienced during previous two decades, necessitated power supply of the eastern demand from Enguri basin reducing loads on OHL Kavkasioni and increasing burden on OHL Imereti. Such situation was further aggravated after construction of 700 MW HVDC back-to-back station in Akhalstikhe and 400 kV OHL Meskheti resulting in additional loads on OHL Imereti. Meantime, any outage of this line causes overloading of paralleling 220 kV mains posing risk to reliability of the entire power system. Therefore, reinforcement of 500/220 kV transmission system in the West Georgia is of high necessity that will be achieved in the first phase, by OHLs of Jvari-Khorga Interconnection Project, followed by the second phase envisaging construction of 500 kV **OHL Jvari-Tskaltubo Akhaltsikhe that is the most necessary and strategic project for development of Georgian transmission network**.

The projects to be implemented in the transmission network have been divided into the following three groups:

1. ***Internal Projects,*** including the projects affecting power transit and reliability;
2. ***Cross-Border Projects***, i.e. the projects affecting capacity and reliability of the transit flows among the power systems of Georgia and its neighbouring states;
3. ***Local Projects,*** comprising 220 kV and 110 kV dead-end feeder lines.

Transit and system importance projects are considered in detail in this development plan. Meanwhile, Cross-Border and Internal projects are further classified by their specific functions. Such division is reasonable considering that part of the network development projects target construction of cross-border lines intended for increasing power trade between Georgia and its neighbouring countries, and hence their implementation depends on special agreements and arrangements between participating states. Other part of such projects aims integration of HPPs into the network, and their implementation timing will be directly dictated by availability of relevant generation facilities. Third part of the projects included in the Ten-Year Plan are intended for increasing transfer capacity and reliability of the internal transmission network to satisfy N-1 design criterion, and therefore their implementation shall not depend either on integration of HPPs or on demand growth rates.

1. **Projects aiming at integration of HPPs into the network.** Construction deadlines and necessity of these projects will depend on construction of matching new HPPs, and include:

- **Double-circuit 220 kV OHL Batumi-Akhaltsikhe**, intended for evacuation of the generation of Shuakhevi HPP, Koromkheti HPP and other hydro power plants to be constructed in Adjara, increasing reliability of power supply in Adjara and Guria regions, and improving reliability of the power export from SS Batumi to Turkey via HVDC back-to-back station.

- **North Ring (500/220/110 kV SS "Nenskra", 500/220 kV SS "Lajanuri" and 500 kV OHL "Lajanuri – Tskaltubo", single-circuit 500 kV OHL "Kvari – Nenskra". Double-circuit 110 kV OHL "Nenskra – Mestia" (within 220 kV range), 220 kV OHL "Lentekhi – Tsageri – Lajanuri", 220 kV OHL "Oni cascade–Lajanuri)**
designed for integration of the HPPs of Khudoni, Nenskra, Tskenistskali Cascade as well as HPPs in Mestia region and Oni-Sadmeli HPPs into the grid.

- **Double-circuit 220 kV OHL Tvishi-Namakhvani-Tskalbuto**, intended for network integration and reliable evacuation of the power generated by Namakhvani Cascade HPPs (410 MW).

- **220/110 kV SS Guria,** which will integrate HPPs from Guria district into the grid and increase reliability of evacuation capacities of Kutaisi HPPs.

- **Reinforcement of Kakheti infrastructure** main purpose of which is integration of HPPs from Kakheti region into the network and improving of reliability of evacuating power generated by HPPs in Kutaisi.

- **Zestaponi**, new 500/220 kV, 500 MVA Autotransformer and 250 MVAR reactor in SS Zestaponi, designed to implement reliable evacuation of power generated by Oni cascade HPPs into the 500 kV network.

2. **Strategic projects of system wide importance intended for upgrading reliability and capacity, as well as integration of prospective HPPs and/or for increasing internal network transmission capacity.** Implementation of these projects are of highest necessity both from technical and economical perspectives, and therefore shall be affected notwithstanding actual progress of matching planned hydropower projects.

    - **Jvari-Khorga Interconnection Project**, including construction of 500/220 kV SS Jvari, 220/110 kV SS Khorga and double-circuit 220 kV OHL Jvari-Khorga (Odishi-1,2). This project aims to respond on growing demand in Black Sea region (Abkhazia, Poti Industrial Zone, Guria, Adjara), increasing capacity of 220 kV transmission main Enguri-Zestaponi, upgrading reliability level of the West Georgia's transmission network and integration of the Khobi cascade HPPs into the network. *Constuction of all components is complete, except for 220 kV OHL "Jvari – Khorga" and tie-line of 500 kV OHL "Kavkasioni" to SS "Jvari" (project to be fully completed in 2018).*

    - **Tskaltubo-Zestaponi Interconnection Project.** This project envisages construction of 220 kV OHLs from SS Tskaltubo to Kutaisi (forming parallel link to OHL Sataplia) and from SS Kutaisi to SS Zestaponi (in parallel to OHL Ajameti-1,2). It's purpose is improvement of reliability of the West Georgia's network and reduction of the load/generation shedding effects in result of operation of the Emergency Control System. When implemented, this project will allow safe transfer of 700-750 MW power eastwards under emergency tripping of above mentioned 500 kV lines. Moreover, this project will implement integration of Tekhura cascade HPPs into the grid. *Completed.*

    - **Rehabilitation of Kolkhida-1**. After commissioning the projects "Tskaltubo-Zestaponi" and "Jvari-Khorga" this overhead line is the most loaded one in case of "Imereti" outage. Hence, in order to avoid contingency severing, it is necessary to reinforce "Kolkhida-1" which will be the important part of reliability improvement of west part of transmission network.

- **500 kV OHL Jvari-Tskaltubo-Akhaltsikhe and 500 kV switchyard with 220 kV linkage in SS Tskaltubo**. This project is intended for improving security and reliability of the power evacuation from Khudoni-Enguri node to Turkey and East Georgian regions (to Armenia); from Russia to Turkey and Armenia – increase of power transit ability and reliability; supporting to opportunities related with development of production and tourist facilities in Kutaisi-Tskaltubo region, and evacuation of power generated by Khudoni, Nenskra HPPs as well as HPPs of Mestia district, Tskhenistskali and Oni-Sadmeli Cascade HPPs (through SS Jvari and SS Tskaltubo respectively) along with transmission of their generation to Akhaltsikhe (for export to Turkey) and East part of Georgia (for supply of Tbilisi-Rustavi bus bars and for export to Armenia).

- **Rehabilitation of 500 kV OHL Imereti**. Jvari-Tskaltubo-Akhaltsikhe project will not have any effect unless its parallel 500 kV branch is not rehabilitated, present transfer capacity of which does not exceed 750-87 MW.

3. **Cross-border projects**, purposed for increasing power exchange and using the energy trade opportunities with neighbouring countries. Implementation timing of these projects are less dependant on dynamics of the national generation/demand, but instead are mainly linked to special bilateral arrangements supporting cross-border electricity trade. Such projects include:

- **400 kV OHL Akhaltsikhe-Tortum and 350 MW HVDC back-to-back link at SS Akhaltsikhe**, intended for increasing power exchange potential between Georgia and Turkey, providing redundancy for 400 kV OHL Meskheti and upgrading security of the power export to Turkey.

- **500 kV OHL Ksani-Stepantsminda-Mozdok and 500/110 kV SS Stepantsminda**, designed for increasing potential and security of power exchange between Russia and Georgia (along with Armenia and Iran), and integration of Tergi River HPPs into the network.

- **500 kV OHL Marneuli-Airum, 500 kV switchyard with linkage to 220 kV switchyard in SS Marneuli, and connection of existing 500 kV OHL Asureti (Mukhrani) to SS Marneuli**. This project aims at increasing power transfer potential between Georgia and Armenia (as well as Russia and Iran), and improving reliability of Tbilisi power supply (provided by resulting new 500 kV link between SS Ksani and SS Marneuli and backing up 500/220 kV AT at Gardabani). *All the elements are already commissioned except 500 kV OHL Marneuli-Airum.*

- **154 kV OHL Batumi-Muratli and 350 MW HVDC back-to-back link at SS Batumi**, intended for partly evacuating generation of new Shuakhevi and Koromkheti HPPs and increasing power exchange potential between Georgia and Turkey.

6.2 Planning Methodology

Development of transmission system is a long-term process for upgrading the network in line with growth of generation and demand. This document describes the planning process encompassing all stages of transmission network development along with applicable planning criteria.

The planning process is divided into two phases, as Technical Planning and Cost Benefit Analysis (CBA).

6.2.1 Technical Planning

The first phase of the planning involves identification of development scenarios that should provide consistent, complete and realistic description of the future. Analysis of the scenarios shall target identification of the generation/load-related uncertainties in course of power network development. For dully considering such uncertainties in the planning process, each scenario shall be broken down into several planning cases, each of them accounting for specific demand/generation growth and relevant geographical locations, dispatchability (start-up/shutdown features, operation at pre-defined capacity level), potential power exchange flows with other countries and economical opportunities for development of the grid.

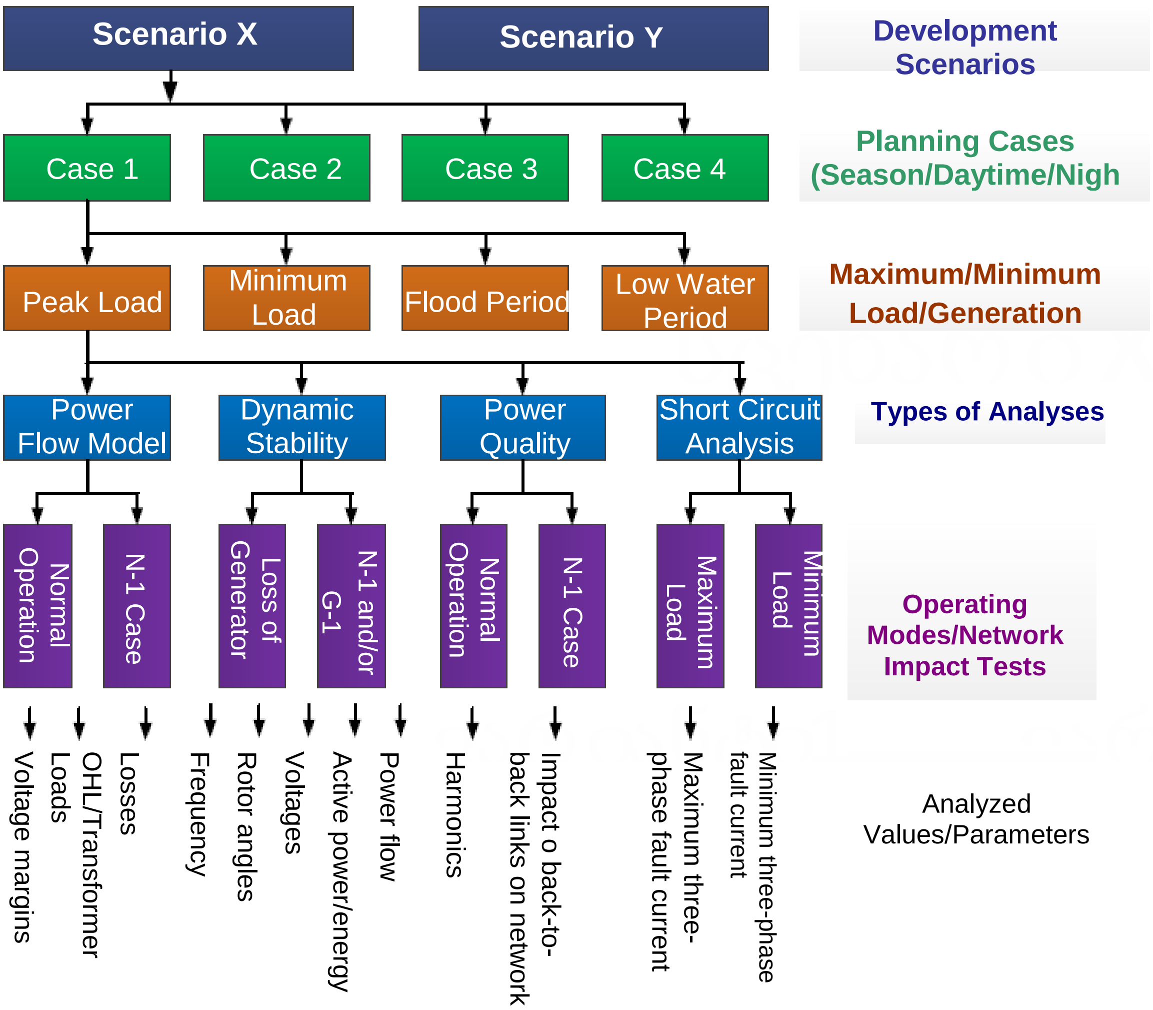


Fig. 6.1. Process of technical analysis of the scenarios

Analysis and network impact tests shall be performed for each design case to identify adequate technical requirements for network reinforcements in the long-term horizon according to the planning criteria. Based on a long-term experience of Georgian engineers, such criteria shall include checking of the system behaviour during contingencies, i.e. when any system element is lost. The applied criteria assume selection of such contingency “indicators” that allow modelling of the system behaviour during any possible contingencies. The simulated behaviour of the power system shall be characterized by “health” and soundness. In case the system “fails” such test, it shall be deemed as “unhealthy” requiring adequate response measures for its “curing” and ensuring successful performance of the test. Hence, several design options shall be reviewed for checking adequacy off the system reinforcement level during development process.

Finally, the last planning stage involves identification of the projects ensuring restoration of the system “health”.

Impact assessment described in this document shall be applicable to all projects.

Planning Scenarios and Cases

Planning scenarios are defined to represent the future environment. Scenario analysis is necessary to obtain realistic picture of a future. Scenarios are means to approach the uncertainties and acknowledge interaction between these uncertainties.

In other words, planning scenarios shall provide coherent, comprehensive and internally consistent description of a plausible future (in general composed of several time horizons) built on the imagined interaction of key economic parameters (including economic growth, variation of losses, reduction of outages etc.).Planning scenarios are characterized by generation portfolio (generation integration forecast, types of generation, etc.), demand forecasts (demand growth rate, shape of demand curve, etc.), and estimated patterns of the power exchange between different systems. Such scenarios may be based on local specifics (bottom-up scenarios) or targets of energy policy (top-down scenarios). Then each scenario shall be represented by several planning cases.

The planning shall adequately consider relevant input data and number of specific assumptions. The scenarios take into account technical and economical state of the network, along with forecasts of demand/generation growth and cross-border power flows.

Each scenario encompasses several planning cases, i.e. particular situations that may occur within the framework of the specific planning scenario, taking into account the following issues:

- Projected generation and power exchange for various time horizons, and specific number of network facilities to be commissioned during planning period;
- Daily, seasonal and annual variations of demand and generation (e.g. peak/off-peak, winter/summer, and annual);
- Detail locations of generation and demand;
- Cross-border power exchange forecasts; and
- Grid development assumptions.

Representative Planning Scenario(s) and Cases

The planning is intended to address the challenges faced by Georgian power network with due consideration of network peculiarities and need for approaching European network standards. Therefore, only scenarios considering above issues will be presented herein.

Representative planning scenarios shall cover representative planning cases in order to assess the need for grid reinforcement and/or optimization. Planning cases are defined based on criticality and/or frequency of occurrence.

Each selected scenario shall be assessed by analyzing its representative cases that are defined by TSO taking into account regional and national particularities

Time Horizons:

At least the following three time horizons shall be considered:

- Short-term horizon (typically 1-3 years);

- Mid-term horizon (typically 4-5 years);
- Long-term horizon (typically 6-10 years).

The following issues may have been taken into account during development of the representative planning cases:

- Estimated power exchange values with neighbouring state's transmission systems;
- Seasonal variation (e.g. winter/summer);
- Demand variation (e.g. peak/valley);
- Weather variation (e.g. temperature, wind, sun, precipitation etc.) [if necessary].

Planned Transmission System

Investments in new transmission assets envisaged for reinforcement of the network that are considered in this plan shall include all representative cases and take into account the forecasted commissioning dates of new network elements.

1. 500 kV substation is being built with the 3/2 (1.5) scheme, 220 kV substation – with double system with bypass bus bars.
2. In order to improve network reliability and stability, construction of tie-lines from 220 kV OHLs to power plants below 100 MW is maximally avoided due to two reasons:
   2.1 Substation of power plant will be constructed on transmission route which will complicate harmonization of modern relay protection and automatic and the rest systems.
   2.2 Both ends of overhead lines are being switched off in case of short circuit in power plant.
3. Connecting is wind farms to the network is permissible by 110 kV and lower voltage with maximum 45 MW capacity for one point – wind zone (opportunities of connection of these marginal capacities are presented in chapter 18).

6.2.2 Technical Criteria for Planning

Technical methods and criteria shall be defined and used when assessing the planning scenarios in order to identify future problems and determine required network reinforcements. **The lines that are of critical importance for the country shall be identified considering fulfilment of N-1 criterion without limiting customer demand.**

The general methodology includes:

- **Network analysis**
  - Investigation of base case topology (all network elements are available)
  - Different type contingencies (failures of network elements, loss of generation, etc.) to be considered depending on their probability of occurrence.
- **Evaluation of consequencies**
  - Evaluation of consequences by checking the main technical indicators, such as:
    - thermal limits,
    - voltages,
    - loss of demand,
    - loss of generation,
    - short circuit levels,
    - stability conditions,
    - angular difference,

- cascade tripping
- Acceptable consequences can depend on the probability of occurrence of a contingency.

Deterministic criteria are currently used in network planning.

6.2.3 Grid Analysis

Data used for network analysis are mainly determined by the planning cases. For any relevant point of time, the expected state of the entire system "with all network elements available", forms the basis for the analysis (Base case analysis).

Contingencies

Contingency is a loss of one (or several) elements of transmission system. A determination is made between high, medium and low probability contingencies.

- **High probability (ordinary) contingencies** include loss of one of the following elements:
  - generator;
  - transmission line (underground or overhead);
  - single transformer/autotransformer or several transformers connected to the same busbar;
  - shunt equipment (e.g. reactor, capacitor, etc.);
  - single DC link;
  - network equipment for load flow control (phase-shifting transformer, FACTS devices, etc.)

- **Medium probability (exceptional) contingencies** are defined as loss of the following elements:
  - OHL with two or more circuits on the same towers;
  - single busbar system;
  - loss of two or more generators or entire power plant;
  - loss of two DC links.

- **Low probability (out-of-range) contingencies** include loss of the following elemetns:
  - two OHLs simultaneously;
  - substation with more than one busbar system;
  - loss of two or more generation units in different power plants.

Due to general small scale of Georgian power system, occurrence of only ordinary contingencies may be occured, since exceptional and out-or-range contingencies may occur only in different geographical areas of very large interconnected systems. Therefore, in this plan, only ordinary contingencies are taken into account.

N-1 Criterion for Grid Planning

Single contingency (N-1) criterion shall be fulfilled, i.e. system shall remain within acceptable limits following outage of one of the elements from the list of high probability (ordinary) contingencies given above.

Required Studies

Power flow analysis assumes normal condition of the network, i.e. when all elements are in the operable condition and operating parameters are in the acceptable ranges, defined as the "base case" (N) and deals with N-1 case, i.e. failure of any single network element.

Short circuit analysis involves evaluation of maximum and minimum three-phase short-circuit currents for any node of the transmission network according to IEC 60 909. This analysis aims at estimating maximum short-circuit current values to ensure that power equipment selected for designed power plants and substations are capable to withstand thermal and electrodynamic loads.

Voltage collapse study. The analysis of the planning cases assumes certain growth of both average and peak loads that will affect reactive power demand and voltage level.

Stability analysis includes transient simulations and other detailed analysis only in cases where the problems with stability significantly affecting the power system are expected.

Harmonic analysis assumes study of the power quality in critical points of the power system with respect to susceptibility to harmonic distortion. Performance of such analysis if of particular importance for Georgian power system, since HVDC back-to-back links integrated into the network are acting as sources of harmonics. The total capacity of these back-to-back links amount to almost a half of the total demand on power in Georgia, and is expected to triple in future accounting to the HVDC links to be installed in Armenia, near Georgian border.

6.2.4 Criteria for Assessment of Consequences

Steady State Criteria

- **Cascade tripping.** A single contingency must not result in any cascade tripping that may lead to a serious interruption of supply within any region (this may occur when additional trappings are initiated by system protection schemes after tripping of the primarily failed element).
- **Maximum permissible thermal load.** Permitted thermal rating of the network equipment shall not be exceeded neither in base nor in contingency cases. Taking into account duration, short-term overload capability can be considered, but only assuming that the overloads can be eliminated by operational countermeasures within the defined time interval, and do not cause a threat to safe operation.
- **Maximum and minimum voltage levels.** Neither in normal nor in contingency cases shall any voltage collapse occur, as well as shall not result in unacceptably long-lasting shortfall/excess of minimum/maximum voltage levels beyond prescribed limits necessary for maintaining integrity of the transmission network.

Loss of maximum load or generation

Maximum amount of load / generation to be lost should not exceed primary operating reserve available in the system.

Short circuit criteria

The rating of installed equipment shall be adequate for withstanding thermal and mechanical loads of maximum single-phase and three-phase circuit currents. The breakers of these equipment shall be capable to withstand multiple commutation of such currents without any damage. Minimum short-circuit currents must be assessed in busbars where HVDC installations are connected.

Voltage collapse criteria

The reactive power output of generators and compensation equipment should not exceed their continuous rating, taking into account transformer tap ranges.

Stability Criteria

Taking into account definitions and classifications of system stability phenomena, and depending on specific task, the objective of stability analysis in case of ordinary contingencies includes rotor angle stability, frequency stability and voltage stability. Stability analysis allows identification of the bottlenecks of the transmission network along with appropriate reinforcement measures, as well as determining maximum permitted short circuit clearance time.

- **Dynamic stability analysis** studies power system behaviour and ability of maintaining synchronous operation of the generators during limited contingencies, for ensuring that:
    - System can maintain stability during tripping of internal lines in 500 kV and 220 kV networks by major protection devices (0.12 sec);
        - Wind power plants should not cause any significant impact on system stability, particularly they should continue operation during short circuit failures without consuming reactive current, and be provide for voltage and frequency regulation.

- **Static stability analysis** simulates system behaviour under minor contingencies that may occur during start-up/shutdown operations. Stability shall be deemed maintained if after such operations resulting swings in the transmission network are damped in the desired pattern.

- **Voltage security level**. In steady state situation, voltage deviation from nominal value shall not exceed -5% +10% in 110 kV, -5% +7% in 220 kV and +5% in higher voltage networks. During emergencies, similar limits shall be ±10% for 220 kV and higher voltage grids.

Possible Counter Measures

Inability to fulfil above criteria will require reinforcement of the planned network. Such reinforcement measures may include (without any limitation):

- Construction of the new overhead lines and underground cables;
- Expansion and/or construction of substations;
- Reinforcement of transmission lines for increasing their capacities (e.g. increasing the clearance to ground, replacement of conductors, etc.);
- Duplication of cables to increase rating;
- Replacement of the network equipment and/or reinforcement of the substations (e.g. based on short-circuit rating);
- Installation of reactive power compensation equipment (e.g. capacitor banks, synchronous condensers);
- Adding active power flow equipments (phase-shifting transformer) in the network;
- Changing of voltage levels of existing transmission infrastructure.

6.3 Cost Benefit Analysis

Economical appraisal of technically feasible projects has been performed applying the cost-benefit analysis (CBA) methodology. Using this method, expected benefits and relevant estimated investment costs and environmental impacts were individually assessed for each planned project.

The analysed factors included:

- **Increase of Network Transfer Capacity,** providing estimate of the incremental power transfer capacity between two cross-border points of transmission system (MW);
- **Project Cost,** specifying estimated total project value (mln Euros);
- **Social and Environmental Impacts,** reflecting level of certainty with respect to the planned commissioning time of the project and its impacts on the environment;
- **Security of Power Supply,** evaluating project impact on reliability status of the connected part of the network;
- **Socio-Economic Welfare**, specifying annual income generated by operation of the project (mln Euros/year);
- **Integration of Renewable Energy Sources (RES)**, estimating installed capacity of the renewable power plants (major Georgian HPPs) integrated into the network (MW) via the planned project;
- **Effect on Transmission Losses (Energy Efficiency)**, comparing losses (in MWs) relevant to the scenarios with and without project (or its specific components);
- **Effect on CO_2 Emissions**, specifying changes in carbon emissions in result of project implementation as proportional coefficient determined for RES;
- **Technical resilience / system safety margin**, evaluating project influence on entire system reliability;
- **Reliability / Flexibility,** specifying dependence of the specific project on various factors (RES integration, load growth, etc); Project is assessed as flexible if its implementation remains necessary for any alternative development scenarios.

Each project was assessed in terms of compliance with above criteria applying the scores from 0 to 3.

6.4 Scenarios of Georgian Transmission Network Development

Applying the methodology described above, several scenarios of Georgian transmission network development were reviewed. Information about prospective generation facilities to be integrated into the network was used as the input data for planning. Such facilities were divided into the following categories:

Category 1 Power plants under construction, which are provided with relevant executed Memorandums;

Category 2 Power plants that are objects of interests formally expressed by reputable investor companies, which feasibility studies have been commenced;

Category 3 Large strategic power plants of country wide importance, which feasibility studies will commence in the nearest future.

Table 6.1 Scenarios of transmission grid development of Georgia

GROWTH OF LOAD | GENERATION	"G1" 100% K1, 50% K2	"G2" 100% K1, 50% K2, 25% K3	"G3" 100% K1, 100% K2, 100% K3
1 % growth "L1"	L1G1	**L1G2**	L1G3
3.5 % growth "L2"	L2G1	L2G2	**L2G3**
5 % growth "L3"	L3G1	L3G2	L3G3

The estimated annual demand growth rate of 7% approved by the Ministry of Energy was applied for the base scenario, along with 3% and 5% growth rates for "optimistic" and "pessimistic" cases respectively.

The table 6.1 shows various cases with different growth rates regarding demand (load) and generation, while actual development of the transmission network will depend on progress of real integration of the loads/generation into the network.

In overall, the following scenarios were analysed:

L1G1 - Annual 3% increase of consumption and commissioning of (100%) category-1 power stations and 50% of category-2 power stations; delay of commissioning of the rest of power stations by 3 years.

L1G2 - Annual 3% increase of consumption and commissioning of (100%) category-1 power stations, 50% of category-2 power stations and 25% of category-3 power stations; delay of commissioning of the remaining power stations by 3 years.

L1G3 - Annual 3% increase of consumption and commissioning of (100%) all category power stations; delay of commissioning of the remaining power stations by 3 years.

L2G1 - Annual 5% increase of consumption and commissioning of (100%) category-1 power stations only, and 50% of category-2 power stations; delay of commissioning of the remaining power stations by 3 years.

L2G2 - Annual 5% increase of consumption and commissioning of (100%) category-1 power stations, 50% of category-2 power stations and 25% of category-3 power stations; delay of commissioning of the remaining power stations by 3 years.

L2G3 - Annual 5% increase of consumption and commissioning of (100%) all category power stations; delay of commissioning of the remaining power stations by 3 years.

L3G1 - Annual 7% increase of consumption and commissioning of (100%) category-1 power stations only, and 50% of category-2 power stations; delay of commissioning of the remaining power stations by 3 years.

L3G2 - Annual 7% increase of consumption and commissioning of (100%) category-1 power stations, 50% of category-2 power stations and 25% of category-3 power stations; delay of commissioning of the remaining power stations by 3 years.

L3G3 - Annual 7% increase of consumption and commissioning of (100%) of all three category power stations; delay of commissioning of the remaining power stations by 3 years.

After consultations held with the Ministry of Energy, L3G3 was selected as the most realistic scenario that assumes annual demand growth of 7% and integration of 100% of HPPs included in all three categories. Therefore, this development plan is based on the calculations performed for this scenario, although all other scenarios were also analyzed.

7 Forecasted Energy and Capacity Balances

According to law on "electricity and natural gas", Article 3[2], paragraph 2: *Ten Year Network Development Plan of Georgia contains:*

a) Information about existing and predicted demand supply;
b) Reasonable forecast about generation, supply, load and transmission to other countries.

According to "Grid Code" Article 29*, dispatch license is obligated to make ten year balance forecast of demand-supply.*

7.1 Hydropower Booming by 2027

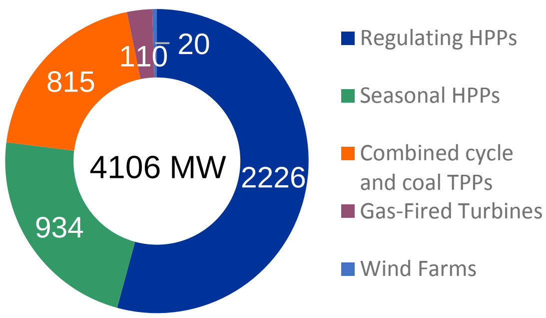


Fig. 7.1 Installed capacities of the existing power plants

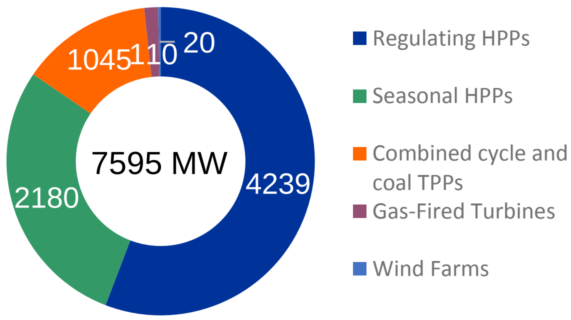


Fig. 7.2 Installed capacities of power plants as for 2027

At present, total installed capacity of electric power plants operated in Georgia amounts to 4106 MW. From this, 2226 MW is generated by the so called "regulated" HPPs (with water storage), 934 MW by "seasonal" (run-of-river) HPPs, 110 MW by Gas Turbines and 815 MW by thermal power plants (Fig. 7.1). Roughly 77% of the total in-country installed capacity is provided by HPPs, including 54% generated by regulated hydro power plants.
For 2027, the total installed capacity available in Georgian power system will grow to 7595 MW (Fig. 7.2). From this, 4239 MW will be attributed to regulated HPPs, 2180 MW to seasonal HPPs, 20 MW to Wind Power Plants, 110 MW to Gas turbines and 1045 MW to high efficiency combined cycle as well as coal thermal power plants, which will replace the older Gardabani TPP's Units Nos. 3, 4 and 9. For 2027, percentage share of hydropower in total national installed capacity will grow to 85%, including 56% regulated hydro power plants. This will ensure use of the water stored during flood season for low flow periods, thus reducing dependence on import of electricity and fossil fuels necessary for operation of thermal power plants.

7.2 Annual Energy Balances

The annual electric energy balances have been developed based on forecasted growth of generation and demand (Table 7.1, Fig. 7.3) for base L2G3 scenarion.

Table 7.1. Forecasted annual energy balances of Georgian electric power system (bln kWh) for L2G3 scenario

Year	Generation	HPPs	TPPs	Wind Farms	Consumption	Export
2016	11.37	9.08	2.29	-	11.25	0.12
2017	12.9	10.23	2.58	0.093	11.64	1.26
2018	12.97	10.76	2.12	0.093	12.05	0.92
2019	14.61	11.99	2.53	0.093	12.47	2.14
2020	17.61	14.12	3.4	0.093	12.9	4.71
2021	18.3	15.37	2.84	0.093	13.35	4.95
2022	19.51	17.08	2.34	0.093	13.82	5.69
2023	20.15	17.63	2.43	0.093	14.3	5.85
2024	23.84	21.2	2.55	0.093	14.8	9.04
2025	25.66	22.96	2.61	0.093	15.32	10.34
2026	26.15	22.96	3.09	0.093	15.86	10.29
2027	26.3	22.96	3.24	0.093	16.4	9.9

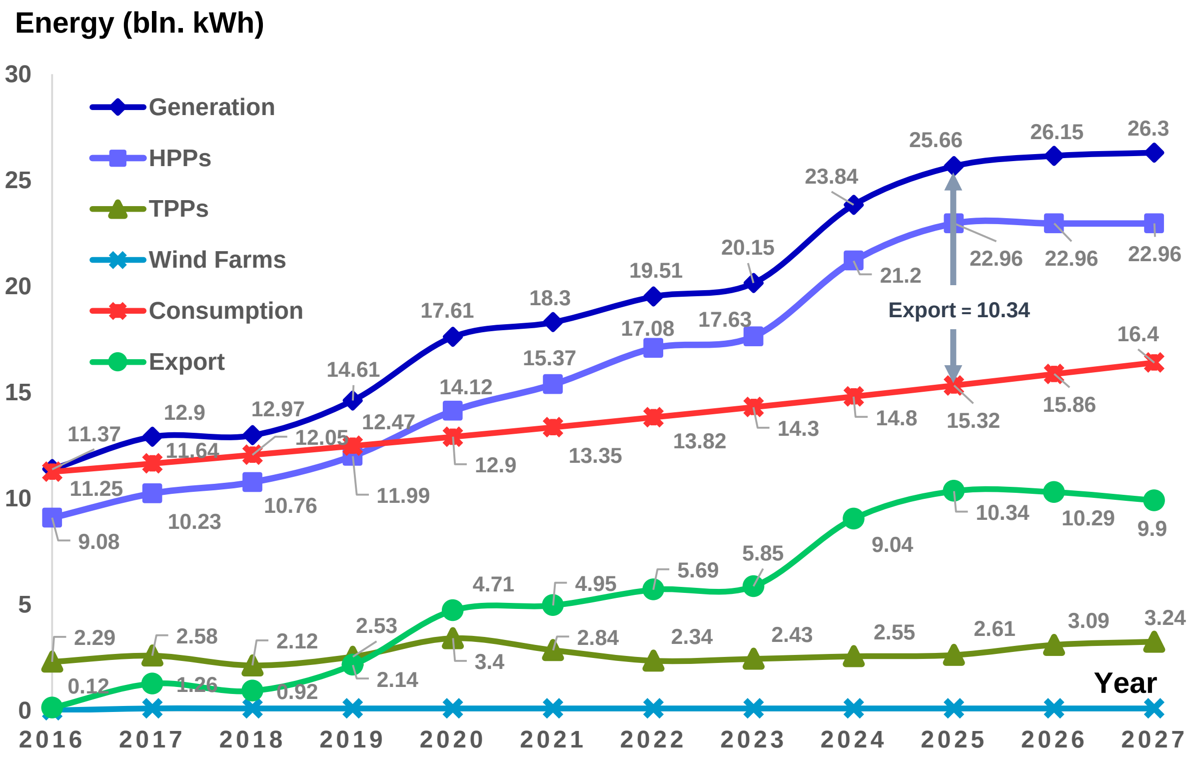


Fig. 7.3 Georgian generation, consumption and export graphs corresponding to table 7.1

In case commissioning of generation and demand growth during a long period is less optimistic, then energy balance will be different, in particular, the annual output of HPPs will be less. However, less intensity of load increment will lead to increase export and during a long period, considering L2G2 scenario, compared to L2G3 one, there will be more electricity export in neighbor countries.

Table 7.2. Forecasted annual energy balances of Georgian electric power system (bln kWh) for L2G2 scenario

Year	Generation	HPPs	TPPs	Wind Farms	Consumption	Export
2016	11.37	9.08	2.29	-	10.98	0.39
2017	12.9	10.23	2.58	0.093	11.09	1.81
2018	12.97	10.76	2.12	0.093	11.2	1.77
2019	14.61	11.99	2.53	0.093	11.31	3.3
2020	17.61	14.12	3.4	0.093	11.42	6.19
2021	18.3	15.37	2.84	0.093	11.53	6.77
2022	19.51	17.08	2.34	0.093	11.64	7.87
2023	20.15	17.63	2.43	0.093	11.76	8.39
2024	23.84	21.20	2.55	0.093	11.88	11.96
2025	25.66	22.96	2.61	0.093	12.0	13.66
2026	26.15	22.96	3.09	0.093	12.12	14.03
2027	26.3	22.96	3.24	0.093	12.24	14.06

The relation between hydro power genation and consumption growth shows that:

1. In case of timely commissioning of HPPs (optimistic scenario), for any scenario of consumption growth, Georgia'spower supply system will not be depended on imported power or fuel required for its generation, after 2020-2022. Moreover, in cease of slow or moderate consumption growth scenario, electricity export might amount to 6-11 billion kV annually.
2. In case of moderate sceario of construction of HPPs, based on the consumption growth scenario, Georgia's power supply system will maintain existing level of power independence, or will increase this level.
3. In case of pessimistic scenario of HPP construction, in case moderate or high consumption growth maintains, Georgia's power supply system's reliance on imported electricity and/or fuel will increase significantly and the deficite might amount to 5-9 billion kVh a year.

7.3 Specific regimes of Georgian Electrical System (Power Balances)

According to "Grid Code" article 39 [2] : "In transmission network development plan, must be included forecasted regimes according to years…"

Power system consumption and peak load growth forecast. Although there exists load increasing indicator, one of the hardest task is peak demand forecasting. Determine this values are the most important because at the peak loads network elements take the most of the stress, in particular overhead lines and autotransformers. Hence, in case of peak load growth forecast, there will be timely releaved necessity of reinforcement of network elements and by such way their overload and damage will be avoided.

On the other hand it is noteworthy that peak consumption growth is less dependened on the total load of consumers in service.

Projection of peak increases in 2018-2028 regimes of Georgia's power transmission network has been discussed in the following manner:

Table 7.3 The Georgian power system consumption, summer and winter loads ten years Statistics

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	Y-10	Y-9	Y-8	Y-7	Y-6	Y-5	Y-4	Y-3	Y-2	Y-1	Y
L_{SUM}	1074	1075	1167	1106	1200	1347	1374	1422	1540	1574	1631
L_{WIN}	1679	1712	1651	1538	1620	1682	1681	1811	1851	1869	2100
E	8303	8146	8411	7908	8746	9647	10194	10093	10619	10872	11327
KL_{SUM}	1.0009	1.0856	0.9477	1.0850	1.1225	1.0200	1.0349	1.0830	1.0221	1.0241	
KL_{WIN}	1.0197	0.9644	0.9316	1.0533	1.0383	0.9994	1.0773	1.0221	1.0097	1.0112	
K_E	0.9811	1.0325	0.9402	1.1059	1.1030	1.0568	0.9901	1.0522	1.0238	1.0419	

On the basis of this 10-year statistic data, relation between 2006-2017 relative peak growths and relative consumption growths has been determined.

$$\frac{KL_{SUM}}{K_E} = \frac{1}{N}\sum \frac{L_{SUM(Y)}/L_{SUM(Y-1)}}{E_{(Y)}/E_{(Y-1)}} = 1.0136$$

$$\frac{KL_{WIN}}{K_E} = \frac{1}{N}\sum \frac{L_{WIN(Y)}/L_{WIN(Y-1)}}{E_{(Y)}/E_{(Y-1)}} = 0.9920$$

Relatively, in case of 3, 5 and 7% growth, following scenarios of winter and summer peak load growth will occur:

K_E	1.03	1.05	1.07
L_{SUM}	1.044	1.0643	1.0846
L_{WIN}	1.0218	1.0416	1.0615

Table 7.4

Georgian power system consumption of the summer and winter loads ten years forecast for the annual consumption growth of 3.51%

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11
L_{SUM}	1731	1815	1904	1997	2095	2197	2304	2417	2535	2659	2789
L_{WIN}	1915	1940	1966	1992	2018	2045	2072	2100	2128	2156	2184
(L_{WIN})	*(2153)*	*(2207)*	*(2263)*	*(2320)*	*(2378)*	*(2438)*	*(2500)*	*(2563)*	*(2627)*	*(2693)*	*(2761)*
E	11725	12136	12562	13004	13460	13933	14422	14929	15453	15995	16557
KL_{SUM}	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489	1.0489
KL_{WIN}	1.0132	1.0132	1.0132	1.0132	1.0132	1.0132	1.0132	1.0132	1.0132	1.0132	1.0132
(KL_{WIN})	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*	*(1.0252)*
K_E	1.0351	1.0351	1.0351	1.0351	1.0351	1.0351	1.0351	1.0351	1.0351	1.0351	1.0351

Considering that the proportion between the growths of consumption and load is constant, ie:

$$\frac{1-KL_{SUM}}{1-KE} = \frac{1-1.0489}{1-1.0351} = 1.314 = const$$

$$\frac{1-KL_{WIN}}{1-KE} = \frac{1-1.0252}{1-1.0351} = 0.7179 = const$$

Then for the case of 1% growth we will have the following (Table 7.5):

Table 7.5

Georgian power system consumption of the summer and winter loads ten years forecast for the annual consumption growth of 1%

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11
L_{SUM}	1633	1655	1676	1698	1721	1743	1766	1790	1813	1837	1861
L_{WIN}	1897	1904	1911	1919	1926	1933	1940	1948	1955	1962	1970
(L_{WIN})	*(2115)*	*(2130)*	*(2146)*	*(2161)*	*(2177)*	*(2192)*	*(2208)*	*(2224)*	*(2240)*	*(2256)*	*(2272)*
E	11440	11554	11670	11787	11905	12024	12144	12265	12388	12512	12637
KL_{SUM}	1.0131	1.0131	1.0131	1.0131	1.0131	1.0131	1.0131	1.0131	1.0131	1.0131	1.0131
KL_{WIN}	1.0037	1.0037	1.0037	1.0037	1.0037	1.0037	1.0037	1.0037	1.0037	1.0037	1.0037
(KL_{WIN})	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*	*(1.0072)*
K_E	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01

And 5% growth (Table 7.6):

Table 7.6

Georgian power system consumption of the summer and winter loads ten years forecast for the annual consumption growth of 1%

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
	Y+1	Y+2	Y+3	Y+4	Y+5	Y+6	Y+7	Y+8	Y+9	Y+10	Y+11
L_{SUM}	1718	1831	1951	2079	2216	2362	2517	2682	2859	3046	3247
L_{WIN}	1926	1962	1999	2037	2075	2114	2154	2195	2236	2278	2321
(L_{WIN})	*(2175)*	*(2253)*	*(2334)*	*(2418)*	*(2505)*	*(2595)*	*(2688)*	*(2785)*	*(2885)*	*(2988)*	*(3095)*
E	11893	12488	13112	13768	14456	15179	15938	16735	17572	18450	19373
KL_{SUM}	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657	1.0657
KL_{WIN}	1.0189	1.0189	1.0189	1.0189	1.0189	1.0189	1.0189	1.0189	1.0189	1.0189	1.0189
(KL_{WIN})	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)	(1.0359)
K_E	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05

In accordance with above tables, statistics consumption evolution and ten-yaer forecasts are given on figures 7.4-7.6.

() – Corrected data based on the information obtained in January 2017

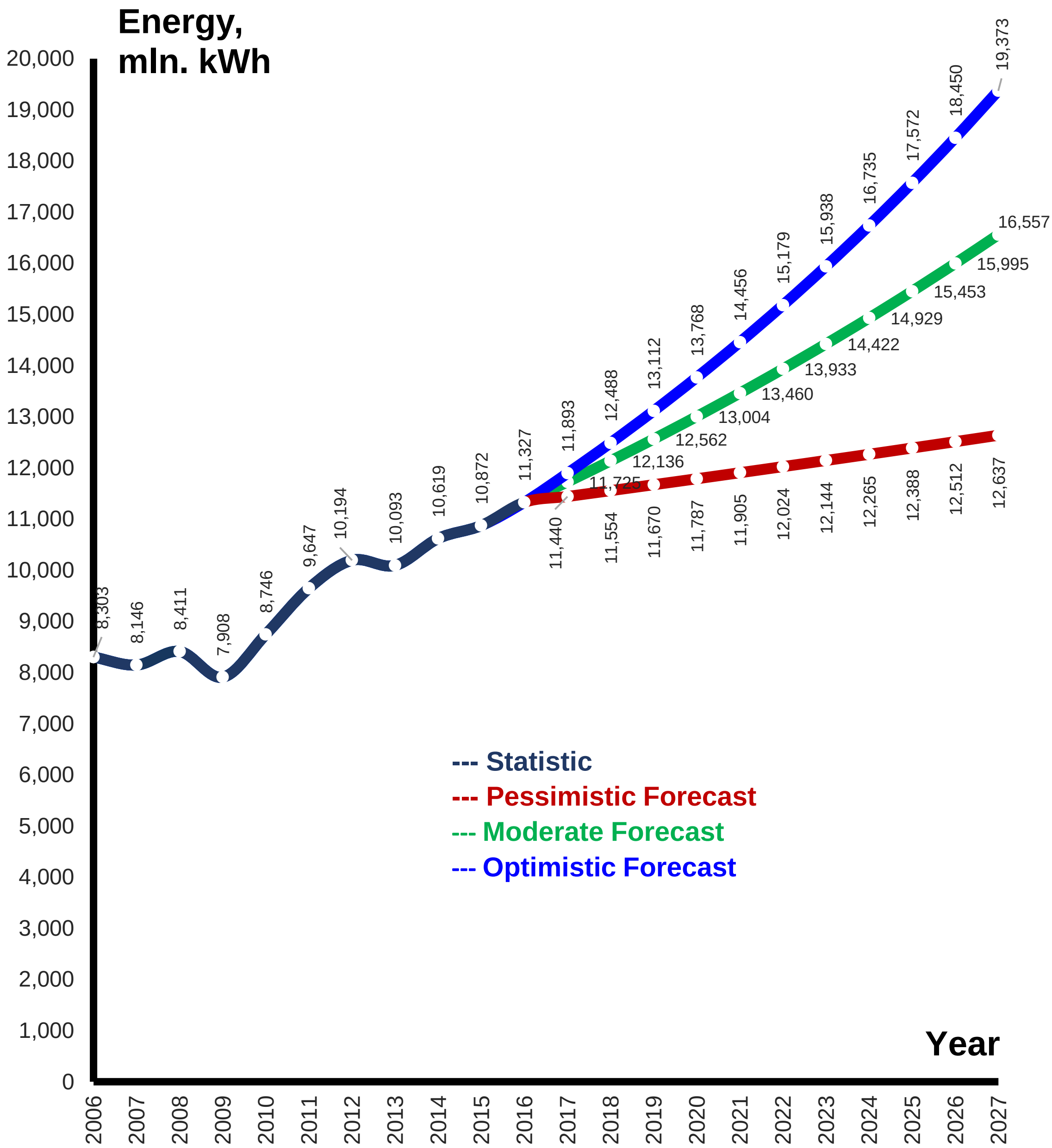


Figure 7.4
Statistic and forecast of consumption growth

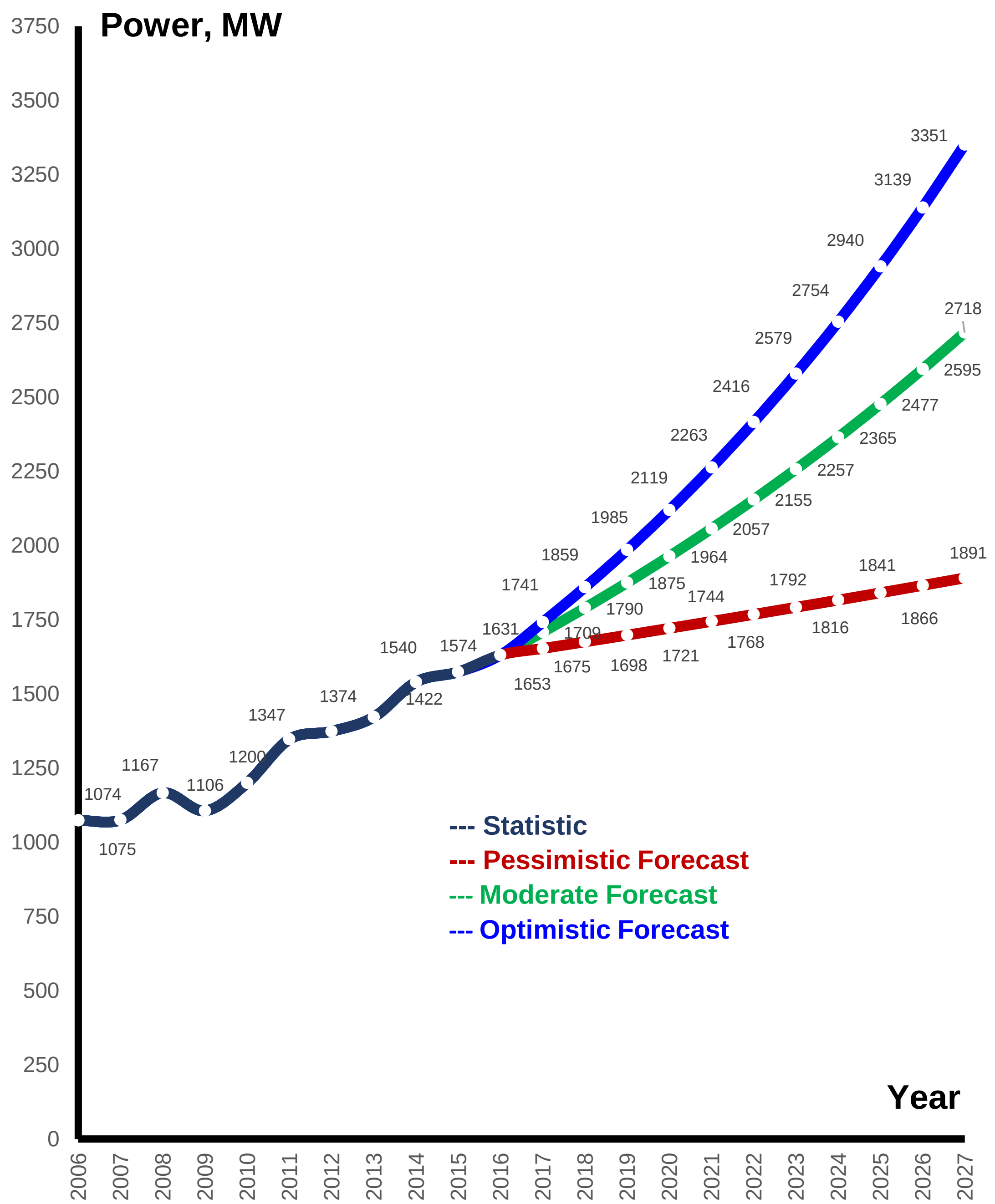


Figure 7.5
Statistic and growth forecast of summer peak load

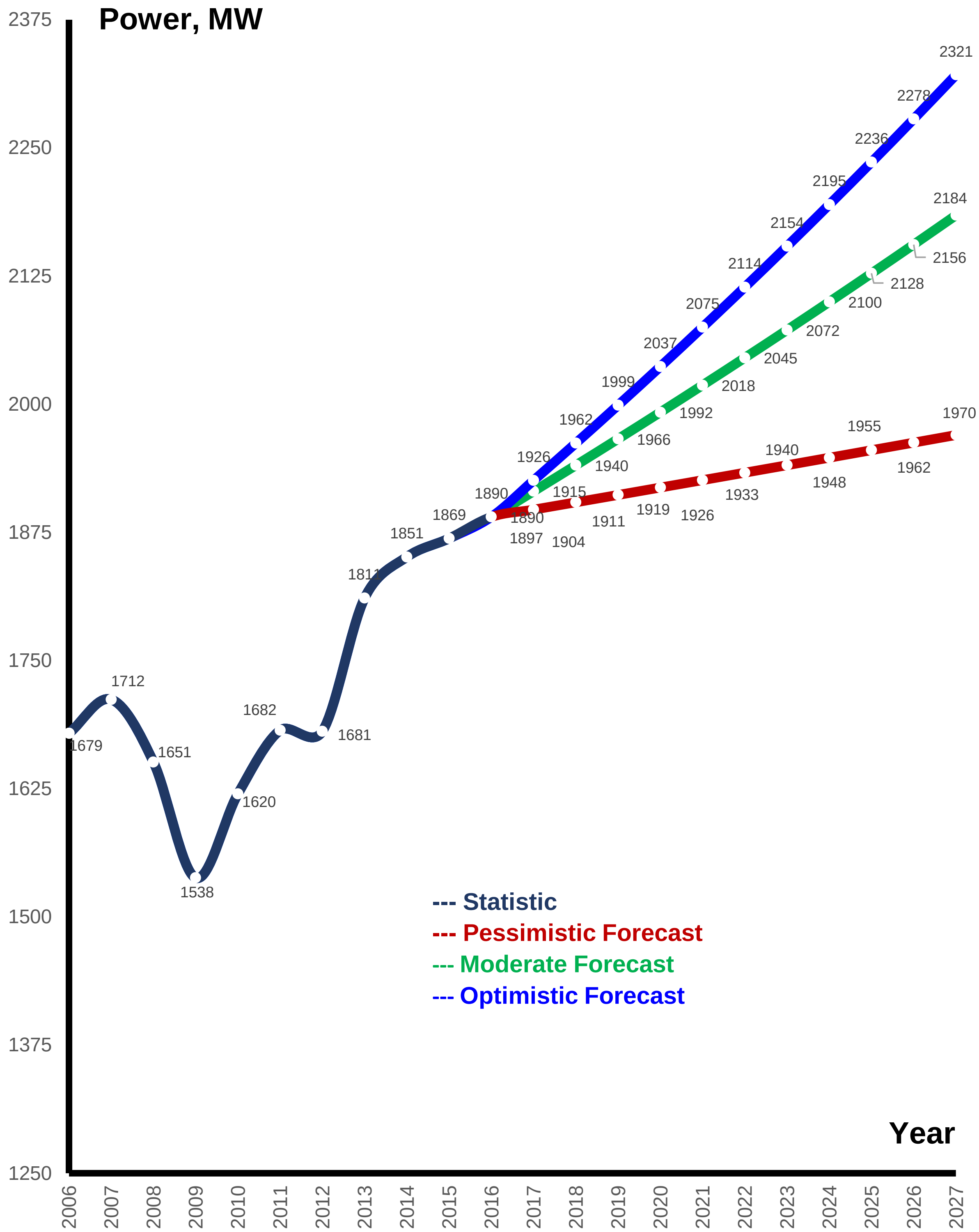


Figure 7.6-a
Statistic and growth forecast of winter peak load

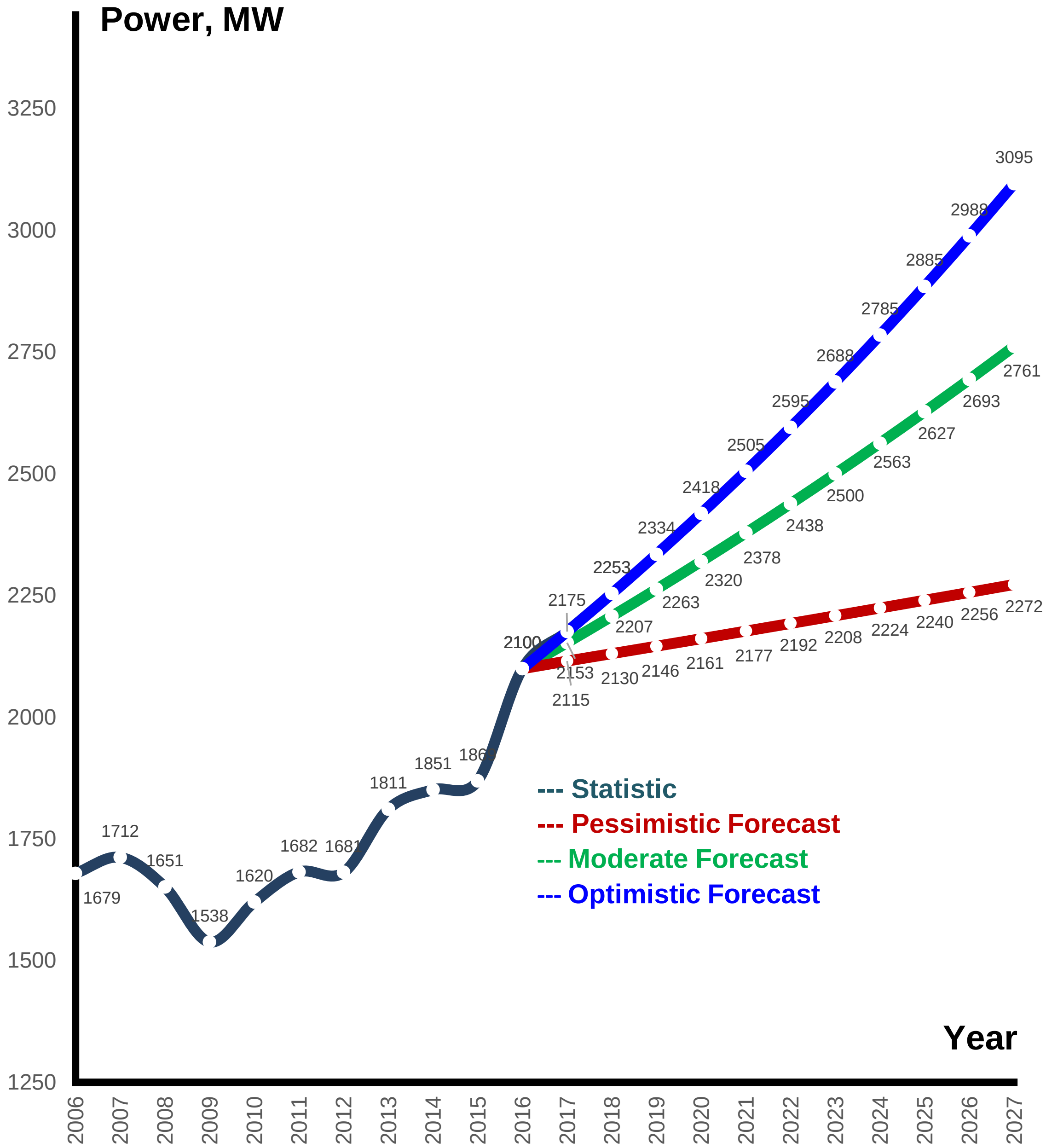


Figure 7.6-b
Statistic and growth forecast of winter peak load (corrected)

Peak load forecast for Individual substations by the analysis of statistical trends. Based on the statistical variation of peak consumption in past ten-year and by the use of method of "Least Squares" various pollinomial charts are being plotted base on which it is possible to determine peak values for future years. Plotting of first-order (linear) graph is the simpliest and relatively reliable method:

$$P_{N\,X} = aX + b$$

where

a,b = coefficients are defined by least squares method
X = *Y*, *Y*+1, *Y*+2... is any year to be planned

Peak load analysis was conducted on the basis of 2006-2017 statistic data, for winter and summer regimes.

Table 7.7 Peak load statistics, summer peak

BUS	YEAR										
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ENGURI	10	10	11	11	12	9	11	11	13	10	11
KOLKHIDA-3	113	124	143	127	105	119	125	123	139	162	143
VARDNILI	29	32	37	33	27	31	32	31	36	42	37
ZUGDIDI	22	24	24	25	26	30	30	25	25	32	30
MENJI	24	26	27	28	32	40	42	48	46	48	53
KHORGA	-	-	-	-	-	-	-	-	-	0	5
BATUMI	60	62	67	68	68	79	92	85	97	102	104
KUTAISI	58	61	65	75	72	83	82	82	82	100	104
TSKALTUBO	20	21	22	25	24	28	28	28	28	34	33
LAJANURI	5	4	5	5	5	5	5	5	5	7	6
ZESTAFONI	111	86	122	69	108	150	184	177	196	119	182
FERO	37	29	41	23	36	50	61	59	65	40	61
KHASHURI	24	22	24	26	24	35	27	36	42	47	45
GORI	34	26	32	27	28	27	35	36	51	63	52
KSANI	30	33	34	37	36	34	35	34	43	45	43
ZHINVALI	12	13	14	15	15	14	14	13	17	19	17
GARDABANI	42	50	48	49	52	51	53	62	61	61	64
RUSTAVI	70	83	80	81	86	85	88	103	101	101	106
GURJAANI	31	32	34	35	36	40	38	39	39	53	47
MARNEULI	21	20	23	24	23	25	28	34	37	32	36
KHRAMI-2	5	5	5	5	5	6	6	8	9	7	8
NAVTLUGI	84	85	85	88	104	119	105	121	120	117	129
GLDANI	76	76	77	80	94	107	95	110	109	106	117
DIDUBE	83	82	79	80	97	96	84	81	95	120	105
LISI	73	72	69	70	85	84	74	72	84	106	93
SYSTEM	**1074**	**1075**	**1167**	**1106**	**1200**	**1347**	**1374**	**1422**	**1540**	**1574**	**1632**

* - 2017 summer and winter peak load data is live data

Table 7.8 Peak load statistics, winter peak

BUS	YEAR									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ENGURI	15	16	17	18	18	28	21	34	23	17
KOLKHIDA-3	230	233	233	211	172	205	218	230	242	273
VARDNILI	98	99	99	89	73	87	92	98	102	115
ZUGDIDI	35	36	34	32	35	30	35	34	21	49
MENJI	42	40	32	34	39	49	50	53	49	52
KHORGA	-	-	-	-	-	-	-	-	-	-
BATUMI	88	102	89	77	92	94	86	77	104	109
KUTAISI	86	88	89	78	92	96	100	102	113	112
TSKALTUBO	22	22	23	20	23	24	25	26	28	28
LAJANURI	5	6	5	6	5	5	4	6	7	9
ZESTAFONI	121	105	108	106	109	158	141	162	177	107
FERO	41	35	36	36	37	53	47	55	59	36
KHASHURI	32	34	32	32	34	31	29	34	46	50
GORI	52	53	48	50	52	58	65	59	65	72

KSANI	33	34	33	34	44	29	33	30	34	36
ZHINVALI	20	20	20	20	27	18	20	18	20	21
GARDABANI	75	88	78	76	81	66	68	80	68	72
RUSTAVI	97	114	102	99	105	87	89	105	88	93
GURJAANI	37	37	36	38	38	32	37	42	52	54
MARNEULI	37	37	34	34	34	23	37	39	37	38
KHRAMI-2	13	13	12	12	12	9	14	15	14	14
NAVTLUGI	136	132	131	116	130	136	136	142	149	140
GLDANI	126	122	121	108	120	126	126	132	139	130
DIDUBE	132	137	133	118	138	132	116	132	119	134
LISI	106	109	107	94	110	106	92	106	95	108
SYSTEM	**1679**	**1712**	**1651**	**1538**	**1620**	**1682**	**1681**	**1811**	**1851**	**1869**

* - 2017 winter peak load data is the estimated data and will be determined in 2018

Power system peak load regimes.

Scenarios of power systems' peak load usually do not match to the sum of the loads of individual substations meaning that load of some substation is less than peak one. However, to the extent that transmission network has to be checked on marginal level of load, it is assumed that loadings for all substations are being increased in a linear way, according to the statistic trend. Gldani and Khorga substations are exceptions where there are applications about adding significant amounts received.

Summer peak loads are shown below, in case of 3 and 7% annual consumption growth.

Table 7.9

Peak load growth forecast for substations in summer. 3.5% growth of consumption

BUS	YEAR									
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ENGURI	12	12	12	12	12	12	12	12	12	13	13
KOLKHIDA-3	146	149	151	154	157	160	162	165	168	171	173
VARDNILI	38	38	39	40	40	41	42	42	43	44	45
ZUGDIDI	31	32	32	33	34	35	35	36	37	38	38
MENJI	56	59	62	66	69	72	75	78	81	84	87
KHORGA	35	65	95	125	155	185	215	245	275	305	335
BATUMI	109	114	119	124	129	133	138	143	148	153	158
KUTAISI	109	114	119	124	129	133	138	143	148	153	158
TSKALTUBO	34	36	37	38	40	41	42	44	45	46	48
LAJANURI	6	6	6	7	7	7	7	7	7	7	8
ZESTAFONI	191	200	210	219	228	237	246	255	264	273	283
FERO	64	67	70	73	76	79	82	85	88	91	94
KHASHURI	47	50	52	55	57	60	63	65	68	70	73
GORI	55	58	61	63	66	69	72	75	78	81	84
KSANI	44	45	46	47	49	50	51	52	53	55	56
ZHINVALI	18	18	19	19	20	20	21	21	22	22	23
GARDABANI	66	68	70	72	74	76	78	80	82	84	86
RUSTAVI	109	112	116	119	122	125	129	132	135	138	142
GURJAANI	49	51	52	54	56	58	59	61	63	65	67
MARNEULI	38	40	41	43	45	47	48	50	52	54	55
KHRAMI-2	9	9	9	10	10	11	11	11	12	12	13

NAVTLUGI	134	139	143	148	153	158	163	167	172	177	182
GLDANI	125	134	144	154	164	176	188	201	215	231	247
DIDUBE	107	110	113	115	118	121	123	126	129	132	134
LISI	95	98	100	102	105	107	110	112	115	117	120
SYSTEM	**1727**	**1822**	**1919**	**2016**	**2113**	**2212**	**2311**	**2411**	**2512**	**2614**	**2717**

Table 7.10

Peak load growth forecast for substations in summer. 5% growth of consumption

BUS	YEAR										
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ENGURI	12	13	14	15	16	17	18	19	21	22	24
KOLKHIDA-3	153	163	174	186	199	212	227	242	259	276	295
VARDNILI	39	42	45	48	51	55	58	62	67	71	76
ZUGDIDI	32	34	37	39	42	45	48	51	55	58	62
MENJI	57	61	65	69	74	79	84	90	96	103	110
KHORGA	5	6	6	7	7	7	8	8	9	10	10
BATUMI	112	119	127	136	145	155	166	177	189	202	215
KUTAISI	112	119	127	136	145	155	166	177	189	202	215
TSKALTUBO	35	38	40	43	46	49	52	56	60	64	68
LAJANURI	6	7	7	8	8	9	9	10	11	11	12
ZESTAFONI	195	208	222	237	253	270	289	308	329	352	376
FERO	65	69	74	79	84	90	96	103	110	117	125
KHASHURI	48	51	54	58	62	66	71	76	81	86	92
GORI	55	59	63	67	72	77	82	88	94	100	107
KSANI	45	49	52	55	59	63	68	72	77	82	88
ZHINVALI	19	20	21	23	24	26	28	29	31	34	36
GARDABANI	68	73	78	83	89	95	101	108	115	123	132
RUSTAVI	113	121	129	138	147	157	168	179	191	204	218
GURJAANI	50	54	58	61	66	70	75	80	85	91	97
MARNEULI	39	41	44	47	50	54	57	61	65	70	75
KHRAMI-2	9	9	10	11	11	12	13	14	15	16	17
NAVTLUGI	138	147	157	168	179	192	205	219	233	249	266
GLDANI	125	134	143	152	163	174	186	198	212	226	242
DIDUBE	112	119	127	136	145	155	166	177	189	202	216
LISI	99	106	113	120	129	137	147	157	167	179	191
SYSTEM	**1743**	**1861**	**1988**	**2123**	**2267**	**2421**	**2586**	**2762**	**2950**	**3150**	**3365**

* - Ferro-alloy plant consumption was added.

Table 7.11-a

Peak load growth forecast for substations in winter. 3.5-5.0% growth of consumption

BUS	YEAR										
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ENGURI	28	29	30	31	32	33	34	35	36	37	38

KOLKHIDA-3	244	247	250	253	256	259	262	265	268	271	274
VARDNILI	103	104	105	106	107	108	110	111	112	113	114
ZUGDIDI	35	35	35	36	36	36	36	36	36	36	37
MENJI	57	58	60	62	64	66	68	70	72	74	76
KHORGA	45	75	105	135	165	195	225	255	285	315	345
BATUMI	103	104	105	106	107	108	110	111	112	113	114
KUTAISI	117	120	124	127	130	134	137	140	143	147	150
TSKALTUBO	29	30	31	31	32	33	34	34	35	36	37
LAJANURI	7	8	8	8	8	9	9	9	9	10	10
ZESTAFONI	161	166	171	176	180	185	190	195	200	205	210
FERO	54	56	57	59	60	62	64	65	67	69	70
KHASHURI	45	47	48	49	51	52	54	55	57	58	60
GORI	72	74	76	79	81	83	85	88	90	92	94
KSANI	36	37	37	37	37	37	37	38	38	38	38
ZHINVALI	21	21	21	22	22	22	22	22	22	22	22
GARDABANI	73	73	73	74	74	75	75	75	76	76	76
RUSTAVI	94	94	95	95	96	96	97	97	98	98	99
GURJAANI	52	53	55	56	58	60	61	63	65	66	68
MARNEULI	36	36	37	37	37	37	37	38	38	38	38
KHRAMI-2	14	14	15	15	15	15	15	16	16	16	16
NAVTLUGI	146	147	149	151	152	154	156	157	159	161	162
GLDANI	152	153	155	156	158	159	161	162	164	166	167
DIDUBE	135	136	137	137	138	139	139	140	141	142	142
LISI	109	110	110	111	111	112	112	113	114	114	115
SYSTEM	**1967**	**2027**	**2087**	**2148**	**2209**	**2269**	**2330**	**2391**	**2451**	**2512**	**2573**

Besides above presented winter peak growth forecast based on 2006-2015 data, second option of this forecast has been elaborated base year in which is 2016 instead of 2015. Peak load 2024 MW has been recorded on 9th December. Considering this, 2100 MW is expected as winter peak load. Forecast of peak load growth for 2017-2027 has been developed according to the peak load data of 2016. Peak load for each substation has been analyzed by trend method and corrections have been submitted in tab. 7.11-a (7-11-b).

Table 7.11-b

Peak load growth forecast for substations in winter (corrected). 3.5-5.0% growth of consumption

BUS	YEAR											
	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
ENGURI	26	27	28	29	30	31	32	33	34	35	36	37
KOLKHIDA-3	308	268	274	280	286	292	298	304	310	316	322	328
VARDNILI	110	106	107	109	110	112	114	115	117	118	120	121
ZUGDIDI	44	38	39	40	40	41	41	42	42	43	43	44
MENJI	52	56	57	59	61	63	65	66	68	70	72	74
KHORGA	6	40	70	100	130	160	190	220	250	280	310	340
BATUMI	104	110	114	119	123	127	131	135	139	144	148	152
KUTAISI	126	128	133	139	145	150	156	162	167	173	179	184

TSKALTUBO	40	41	45	49	54	58	62	66	70	75	79	83
LAJANURI	9	9	9	10	10	10	10	10	11	11	11	11
ZESTAFONI	160	161	162	163	164	165	166	167	168	169	170	171
FERO	58	59	59	60	60	61	61	62	62	63	63	64
KHASHURI	42	50	53	56	58	61	64	67	70	72	75	78
GORI	82	78	81	85	88	91	94	97	101	104	107	110
KSANI	36	39	41	43	45	47	49	51	53	55	57	59
ZHINVALI	22	22	22	22	22	22	22	22	22	22	22	22
GARDABANI	83	79	80	82	83	84	86	87	88	89	91	92
RUSTAVI	100	100	102	103	105	107	109	111	112	114	116	118
GURJAANI	58	59	63	66	69	73	76	80	83	86	90	93
MARNEULI	42	42	43	44	45	46	47	48	49	50	51	52
KHRAMI-2	16	15	15	15	16	16	16	16	16	17	17	17
NAVTLUGI	145	149	152	154	156	159	161	163	166	168	170	173
GLDANI	165	230	235	237	241	245	248	252	255	259	262	265
DIDUBE	158	144	146	149	152	155	158	161	163	166	169	172
LISI	107	108	110	111	113	114	116	118	119	121	122	124
SYSTEM	**2100**	**2158**	**2242**	**2323**	**2406**	**2489**	**2571**	**2654**	**2736**	**2819**	**2902**	**2984**

7.4 Specific working regimes for Georgian Grid (Power Balances)

Winter Maximum corespondes the peak demand at the end of December that is 1950 (2100) mw for 2016. At this period flow on seasonal HPPs is low, and therefore those HPPs generate less power. Also power demand is higher at this time span, therefore Georgian power system has deficit. Regulating HPPs (ENGURI, KHRAMI 1,2, VARDNILI, DZEVRULA, SHAORI, LAJANURI), thermal power plants (№3, 4, 9 Blocks and Gas Turbine) and import from neighbor countries take by themselves this lack of generation. In 2020-2026 №3, 4 and 9 blocks will be replaced by more effective combined thermal power plants.

As it is seen from table 7.12 and on diagram 7.7, in winter months till 2025 power demand is smoothly increased. Significant export and import growth is anticipated till 2023. Export-import volumes from 2023 till 2026 is sated, caused by the fact that generation growth in the system balances the consumption growth. Import increases from 2026 till 2028. This occurs because no new source of generation enters the system, thus the consumption increases, which is covered through the electric power imported into the country.

Table 7.12-a Forecasted balance (MW)

YEAR	WINTER MAXIMUM			
	GENERATION	LOAD	EXPORT	IMPORT
2016	2009	1950	50	0
2017	2359	1966	700	350
2018	2373	2027	700	400
2019	2533	2087	1045	650
2020	3130	2148	1045	100
2021	3136	2209	2085	1250
2022	3241	2269	2085	1200
2023	3255	2330	2085	1250
2024	3858	2391	2085	700
2025	4377	2451	2235	400
2026	4433	2512	2235	400
2027	4496	2573	2235	400

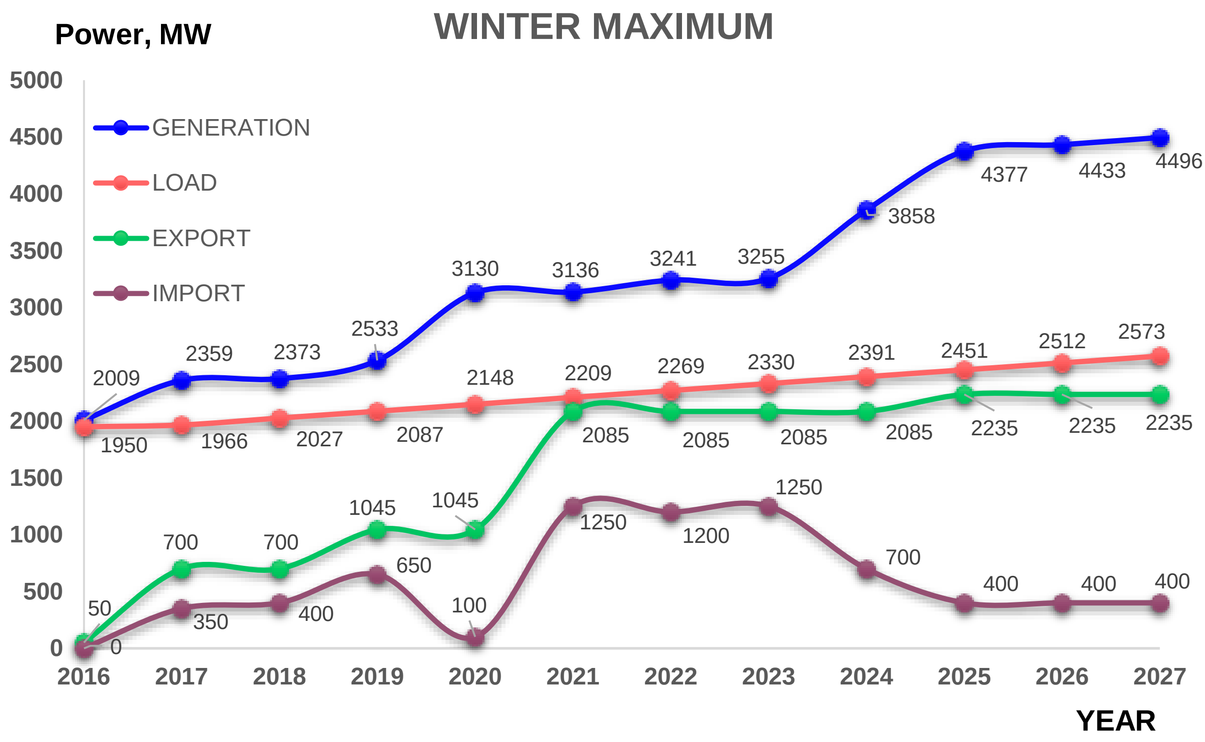


Fig 7.7-a Winter maximum

Table 7.12-b Forecasted balance (MW)

YEAR	WINTER MAXIMUM (CORRECTED)			
	GENERATION	LOAD	EXPORT	IMPORT
2016	2070	2100	0	50
2017	2421	2158	700	480
2018	2507	2242	700	480
2019	2624	2323	1045	800
2020	3199	2407	1045	300
2021	3227	2490	2085	1445
2022	3351	2571	2085	1400
2023	3438	2655	2085	1400
2024	3960	2735	2085	950
2025	4466	2819	2235	700
2026	4640	2903	2235	600
2027	4724	2984	2235	600

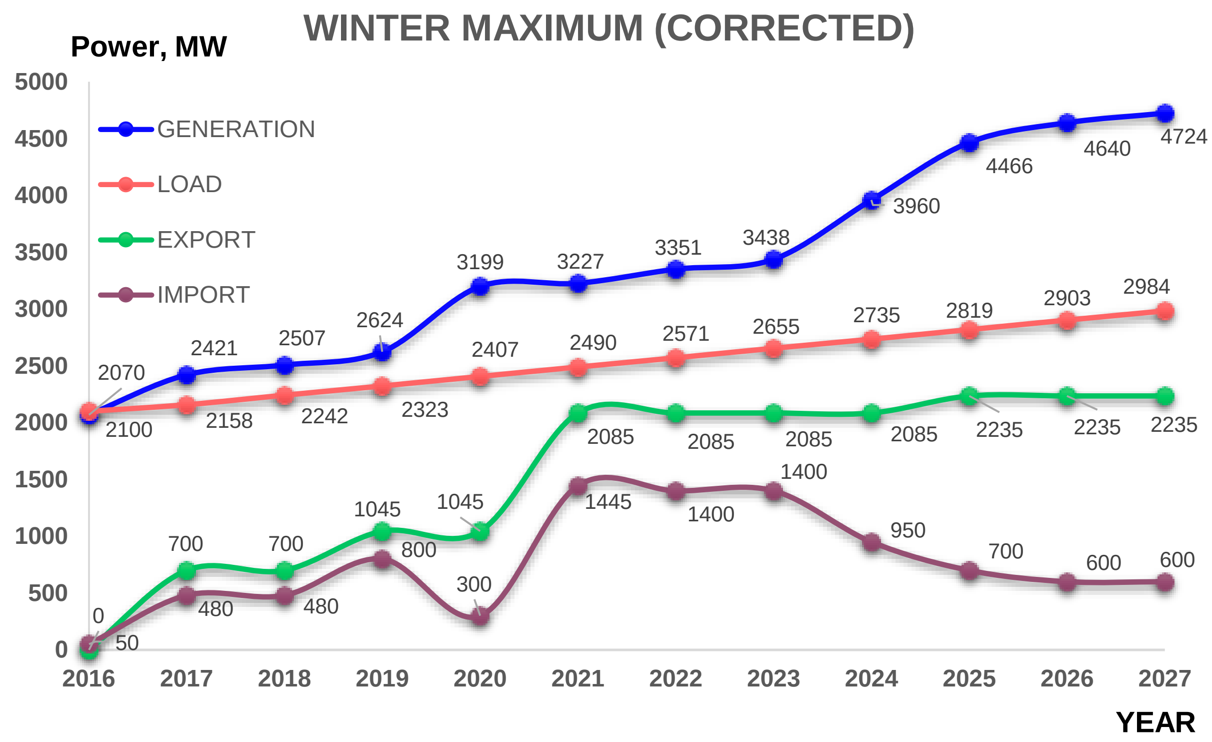


Fig 7.7-b Winter maximum (corrected)

Winter Minimum coresponds load at night minimum regime, that for 2016 is approximatelly 1002 mw. At this period thermal blocks work at their base power and their load is the same as in winter maximum regimes. Power generation of seasonal HPPs is same. Power generation of regulating HPPs is decreased. In 2017-2027 the cause of power balance change is the same as in winter maximum regimes.

Table 7.8 Forecasted power balance (MW)

YEAR	WINTER MINIMUM			
	GENERATION	LOAD	EXPORT	IMPORT
2016	1042	1002	0	50
2017	1460	1032	694	300
2018	1488	1061	694	300
2019	1720	1090	1045	450
2020	2250	1120	1295	200
2021	2255	1144	2085	1050
2022	2335	1179	2085	1050
2023	2365	1205	2085	996
2024	2686	1237	2085	700
2025	2879	1267	2385	850
2026	3059	1296	2535	850
2027	3090	1326	2535	850

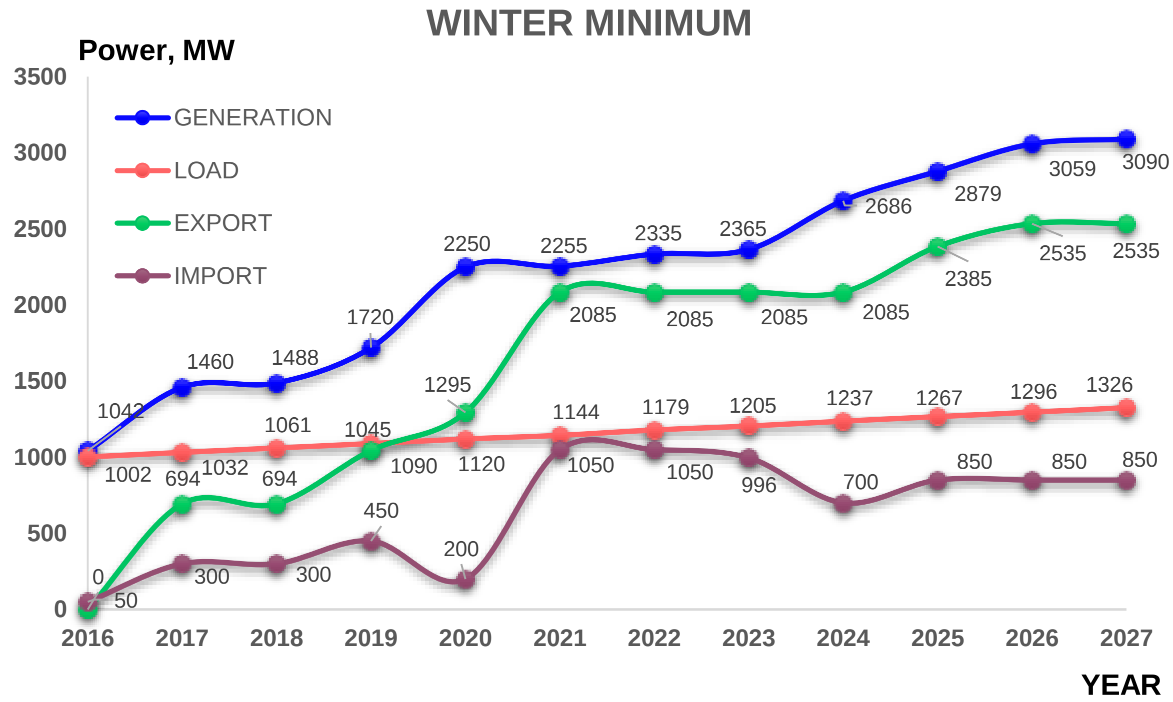


Fig 7.7 Winter Minimum

Summer maximum corresponds the period when water flow is highest in rivers. In this period export potential is being increased. Forecasted load of Georgian electrical network for 2016 is 1612 mw. Because this HPPs are located in Enguri basin and TPPs are shut off because of increased water flow in rivers, electricity transmission is increased for the direction from west to east from Enguri-Vardnili generation nod to Akhaltsikhe and Lisi-Rustavi consumtion nods. HPPs in Enguri basin provide energy export in Turkey that increases power flow on OHL “Imereti” to 700-800 mw.

Despite of surplus amount of generation, during 2018-2020 years, power will be imported (for transit) from Armenia, Russia and Turkey. Starting from 2021, due to the commissioning of powerful HPPs import will totally be eliminated by their generation. From 2017 to 2027, generation significantly increases and this happens along with increase of consumption by only 3.5% annually, and hence there is a significant increase in export.

Table 7.9 Forecasted power balance (MW)

YEAR	SUMMER MAXIMUM			
	GENERATION	LOAD	EXPORT	IMPORT
2016	1985	1612	448	53
2017	2270	1727	700	200
2018	2415	1822	700	150
2019	2726	1919	1300	550
2020	3194	2016	1394	300
2021	3398	2113	2085	900
2022	3788	2212	2085	600
2023	3887	2311	2085	600
2024	4905	2411	2685	300
2025	5535	2512	2885	0
2026	5643	2614	2885	0
2027	5647	2717	2785	0

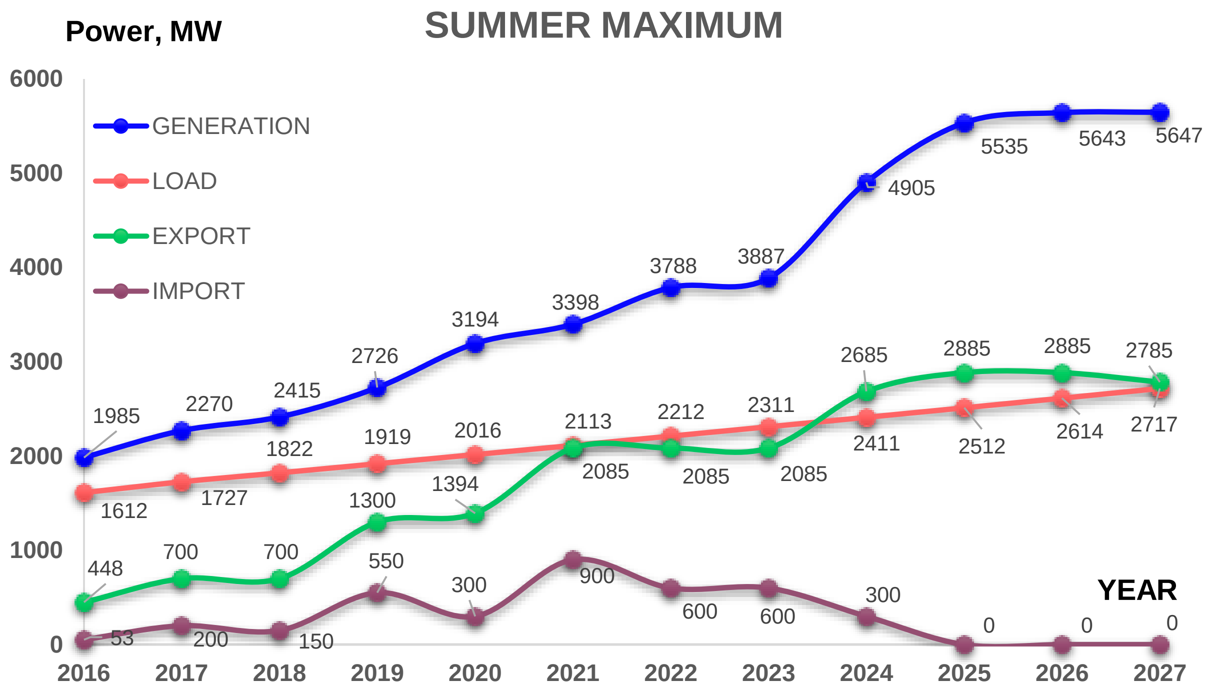


Fig 7.8 Summer maximum

Summer Minimum Summer Minimum corrresponds to high water flood period. Total consumption of Georgian electrical system is 900 MW. Because main HPPs are located in Enguri basin and Gardabani TPP is switched off, power flow from west to east is increased. During 2017-2017, power flow balance change is derived from the same factor as in summer maximum regimes.

Table 7.10 Forecasted power balance (MW)

YEAR	SUMMER MINIMUM			
	GENERATION	LOAD	EXPORT	IMPORT
2016	1075	908	189	22
2017	1470	928	804	300
2018	1584	986	804	250
2019	2157	1014	1300	200
2020	2202	1060	1300	200
2021	2399	1098	2085	850
2022	2901	1142	2485	800
2023	3047	1188	2485	700
2024	3444	1232	2685	550
2025	3791	1275	2685	250
2026	3835	1318	2685	250
2027	3880	1362	2685	250

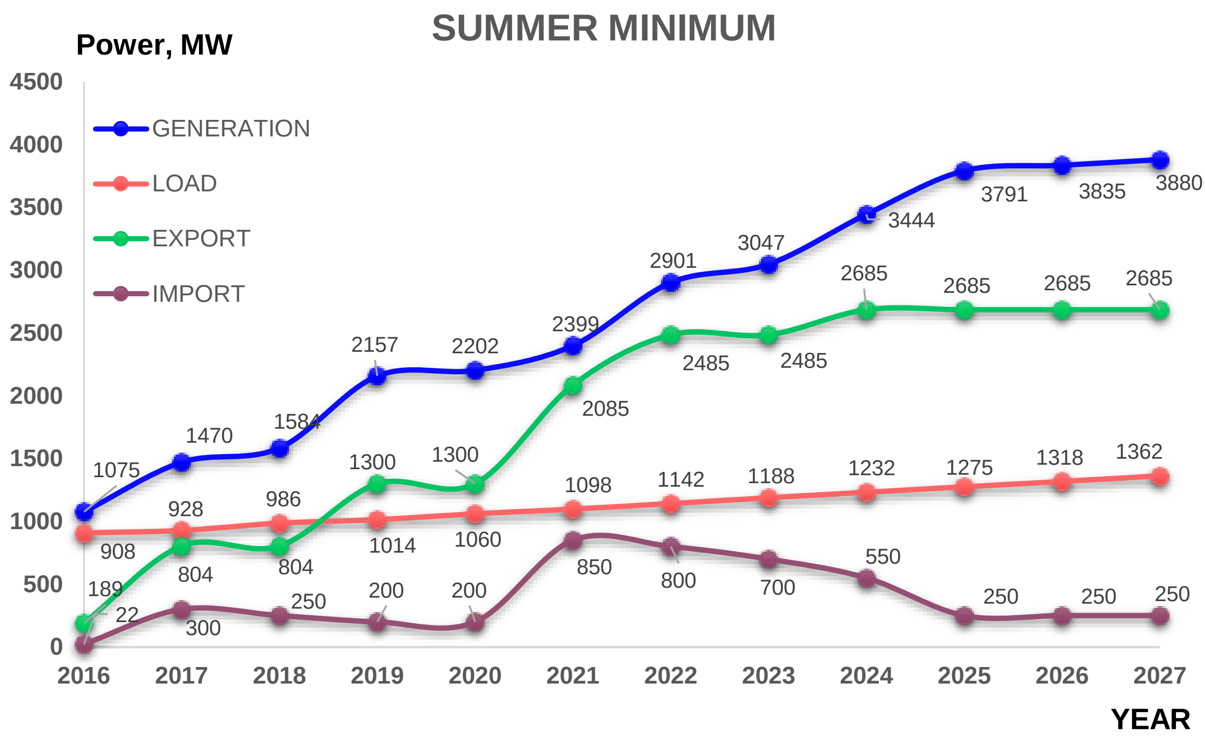


Fig 7.9 Summer minimum

7.5 Generation Adequacy

According of of Network Code (point 3 of Article 30) "… criteria ..used in this Code for assessing reliability of the transmission network:

a) Adequacy – ability of the electricity system to uninterruptedly satisfy the consumers' requirements on electricity, taking into account the both scheduled and unscheduled outages of system elements".

Adequacy of power generation is determined by 2 methds:

1. Deterministic – minimizes time required for calculations, but is based on just a few scenarios. This requires deep knowledge of the system and may not cover all accidents;
2. Probabilistic – requires software with strong mathematical equipment, requires more time for calculations (a second, or tenths of seconds), although reflects the influence of reliability of each element of the system on the adequacy of power generation.

Hence the adequacy may be expressed as the ability of Power System's generation to satisfy 100% of peak load with 95% probability. If less than 100% of peak load is satisfied, than the system treated as inadequate and installation of new generation sources and reinforcement of cross border transmission is required.

Thereto, by adding generation, 10% of total NTCs of cross border lines can be used as well.

The assessment of Generation adequacy conducted with simplified approach for estimated peak loads of Winter and Summer (Table 7.9, 7.11) by taking in account of following assumptions:

It was established that

1. Operation of HPP with reservoir
   a) At summer peak, without one unit (reserved unit) with installed capacity will occur with high probability

$$P_{HPP} = P_i \cdot (k-1)$$
$$A_{HPP} = 1.0$$

b) At winter peak, withut one unit (reserved unit) with 80% of installed capacity, occurs with the same probability as in summer peak

$$P_{HPP} = 0.8\, P_i \cdot (k-1)$$
$$A_{HPP} = 1.0$$

c) In addition, this probability for Enguri HPP and Vardnili HPP will be limited till 2022 (until additional 500 kV OHL is constructed to the east of Enguri basin) with the reliability of 500 kV OHL "Imereti" (Table 3.2) 1-0.002=0.998 and result in:

2. Reliability of combined power plants (Gardabani 2, Gardabani 3), air turbines and new thermal station included at 0.995; №4 unit reliability at 0.995; №3 and №9 unit reliability at 0.98.
3. Small HPP generation with probability equalt to 1.0 is 50% of the plants install capacity in summer mode, and 30% of installed capacity during winter peak.

LSI (Load Supply Index) shows the ratio between generation capacity (with respective availability) and peak load of country.

If LSI>1.0 then the generation and interconnection capacity of power system is treated as adequate otherwise system is inadequate and new generation sources and the reinforcement of transmission capacity is required.

For Georgian power system the analysis was conducted for 95% of generation availability (standard for central European countries) for Summer and Winter peak loads and for scenarios made by combination of generation and consumption growth (see the table 6.1). Generation and NTC information are given in table 7.16, Peak loads are given in table 7.17 where L1 corresponds to 1%, L2 – 3.5% and L3 – 5.0% annual load growth. LSI results are presented in table 7.18.

Table 7.16

With 95% of probability generation readiness, according to regimes and scenarios.

G SCEN	REGIME	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
G1	SUMMAX	2764	2766	2771	2814	2961	2966	2981	2999	3090	3162	3215
	WINMAX	2258	2260	2263	2393	2444	2459	2455	2473	2492	2585	2585
G2	SUMMAX	2764	2767	2777	2864	3157	3167	3198	3235	3415	3560	3665
	WINMAX	2258	2263	2268	2527	2631	2661	2653	2687	2727	2913	2913
G3	SUMMAX	2764	2771	2791	2965	3550	3570	3632	3705	4067	4356	4567
	WINMAX	2258	2268	2278	2797	3004	3064	3048	3117	3196	3568	3568

Table 7.17

Peak load, according to regimes and scenarios

L SCEN	REGIME	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
L1	SUMMAX	1633	1655	1676	1698	1721	1743	1766	1790	1813	1837	1861
	WINMAX	1897	1904	1911	1919	1926	1933	1940	1948	1955	1962	1970
	(WINMAX)	*(2115)*	*(2130)*	*(2146)*	*(2161)*	*(2177)*	*(2192)*	*(2208)*	*(2224)*	*(2240)*	*(2256)*	*(2272)*
L2	SUMMAX	1731	1815	1904	1997	2095	2197	2304	2417	2535	2659	2789
	WINMAX	1915	1940	1966	1992	2018	2045	2072	2100	2128	2156	2184

	(WINMAX)	*(2153)*	*(2207)*	*(2263)*	*(2320)*	*(2378)*	*(2438)*	*(2500)*	*(2563)*	*(2627)*	*(2693)*	*(2761)*
L3	SUMMAX	1718	1831	1951	2079	2216	2362	2517	2682	2859	3046	3247
	WINMAX	1926	1962	1999	2037	2075	2114	2154	2195	2236	2278	2321
	(WINMAX)	*(2175)*	*(2253)*	*(2334)*	*(2418)*	*(2505)*	*(2595)*	*(2688)*	*(2785)*	*(2885)*	*(2988)*	*(3095)*

Table 7.18

LSI (Load Supply Index) according to regimes and scenarios

SYS SCEN	REGIME	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
G1L1	SUMMAX	1.69	1.67	1.65	1.66	1.72	1.7	1.69	1.68	1.7	1.72	1.73
	WINMAX	1.19	1.19	1.18	1.25	1.27	1.27	1.27	1.27	1.27	1.32	1.31
	(WINMAX)	1.07	1.06	1.05	1.11	1.12	1.12	1.11	1.11	1.11	1.15	1.14
G1L2	SUMMAX	1.6	1.52	1.46	1.41	1.41	1.35	1.29	1.24	1.22	1.19	1.15
	WINMAX	1.18	1.17	1.15	1.2	1.21	1.2	1.19	1.18	1.17	1.2	1.18
	(WINMAX)	1.05	1.02	1.00	1.03	1.03	1.01	**0.98**	**0.97**	**0.95**	**0.96**	**0.94**
G1L3	SUMMAX	1.61	1.51	1.42	1.35	1.34	1.26	1.18	1.12	1.08	1.04	1
	WINMAX	1.17	1.15	1.13	1.17	1.18	1.16	1.14	1.13	1.11	1.13	1.11
	(WINMAX)	1.04	1.00	**0.97**	**0.99**	**0.98**	**0.95**	**0.91**	**0.89**	**0.86**	**0.87**	**0.84**
G2L1	SUMMAX	1.69	1.67	1.66	1.69	1.83	1.82	1.81	1.81	1.88	1.94	1.97
	WINMAX	1.19	1.19	1.19	1.32	1.37	1.38	1.37	1.38	1.39	1.48	1.48
	(WINMAX)	1.07	1.06	1.06	1.17	1.21	1.21	1.20	1.21	1.22	1.29	1.28
G2L2	SUMMAX	1.6	1.52	1.46	1.43	1.51	1.44	1.39	1.34	1.35	1.34	1.31
	WINMAX	1.18	1.17	1.15	1.27	1.3	1.3	1.28	1.28	1.28	1.35	1.33
	(WINMAX)	1.05	1.03	1.00	1.09	1.11	1.09	1.06	1.05	1.04	1.08	1.06
G2L3	SUMMAX	1.61	1.51	1.42	1.38	1.42	1.34	1.27	1.21	1.19	1.17	1.13
	WINMAX	1.17	1.15	1.13	1.24	1.27	1.26	1.23	1.22	1.22	1.28	1.26
	(WINMAX)	1.04	1.00	**0.97**	1.05	1.05	1.03	**0.99**	**0.97**	**0.95**	**0.98**	**0.94**
G3L1	SUMMAX	1.69	1.67	1.67	1.75	2.06	2.05	2.06	2.07	2.24	2.37	2.45
	WINMAX	1.19	1.19	1.19	1.46	1.56	1.59	1.57	1.6	1.63	1.82	1.81
	(WINMAX)	1.07	1.06	1.06	1.29	1.38	1.40	1.38	1.40	1.43	1.58	1.57
G3L2	SUMMAX	1.6	1.53	1.47	1.48	1.69	1.63	1.58	1.53	1.6	1.64	1.64
	WINMAX	1.18	1.17	1.16	1.4	1.49	1.5	1.47	1.48	1.5	1.66	1.63
	(WINMAX)	1.05	1.03	1.01	1.21	1.26	1.26	1.22	1.22	1.22	1.33	1.29
G3L3	SUMMAX	1.61	1.51	1.43	1.43	1.6	1.51	1.44	1.38	1.42	1.43	1.41
	WINMAX	1.17	1.16	1.14	1.37	1.45	1.45	1.42	1.42	1.43	1.57	1.54
	(WINMAX)	1.04	1.01	0.98	1.16	1.20	1.18	1.13	1.12	1.11	1.19	1.15

Based on tab 7.18, LSI diagrams have been plotted for Winter and Summer periods, for all scenarios of system development (fig 7.11, 7.12-a, 7.12-b). It seems that in summer the system is adequate for 95% availability of generation. As for winter period, in case of pesimistic scenario of generation and optimistic and moderate scenarios of consumption growth (G2L3, G1L3), it is anticipated that LSI will be reduced below 1.0. If generation objects are connected to the network by more pessimistic scenarios than G1, LSI may drop below 1.0 not only in winter, but in summer as well. Thus, in case of pessimistic generation scenarios, generation adequacy risk will be created. that in order to avoid reduction of SoS (security of supply), timely implementation of projects of generation and transmission infrastructure are necessary.

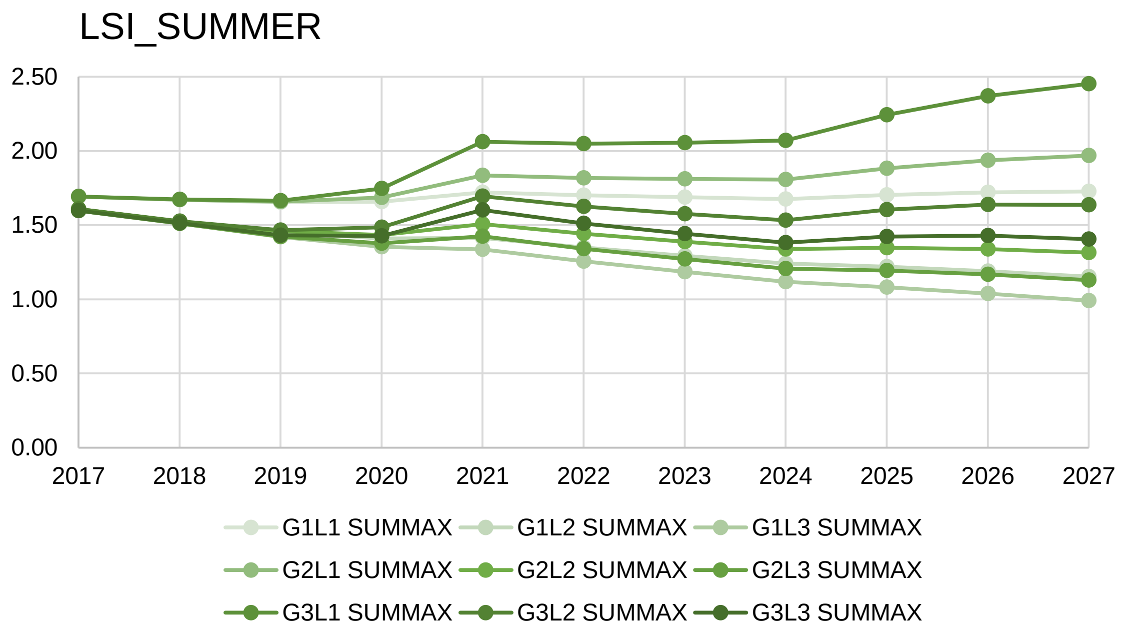


Fig. 7.11 LSI during summer

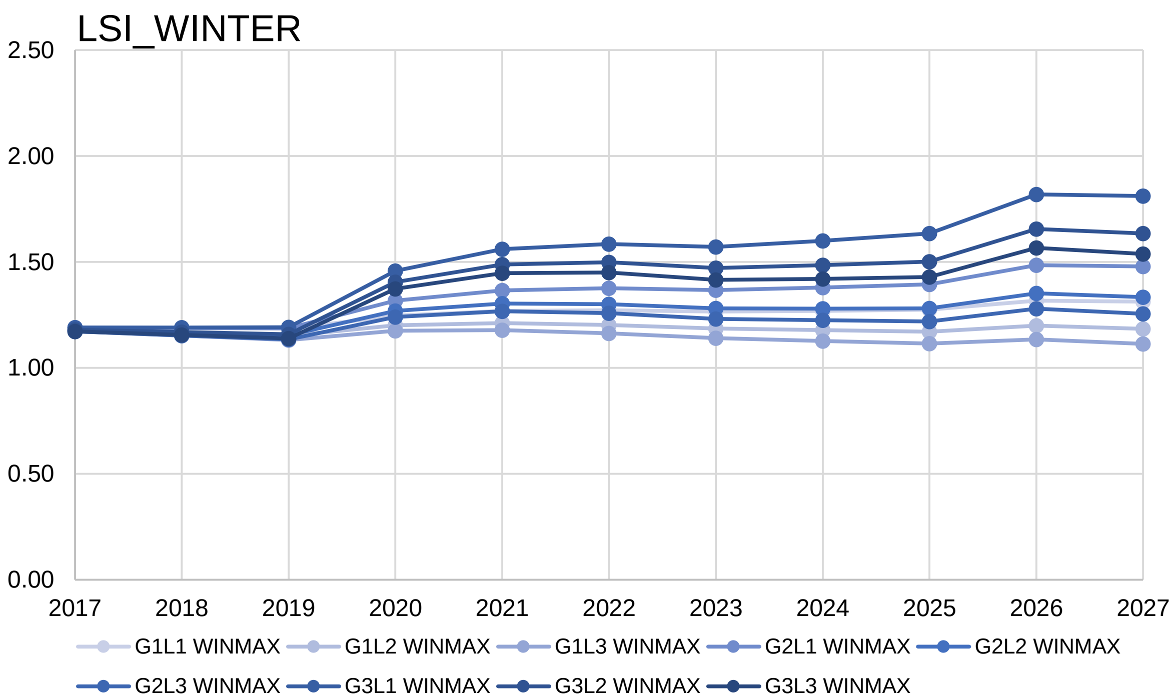


Fig. 7.12-a LSI during winter

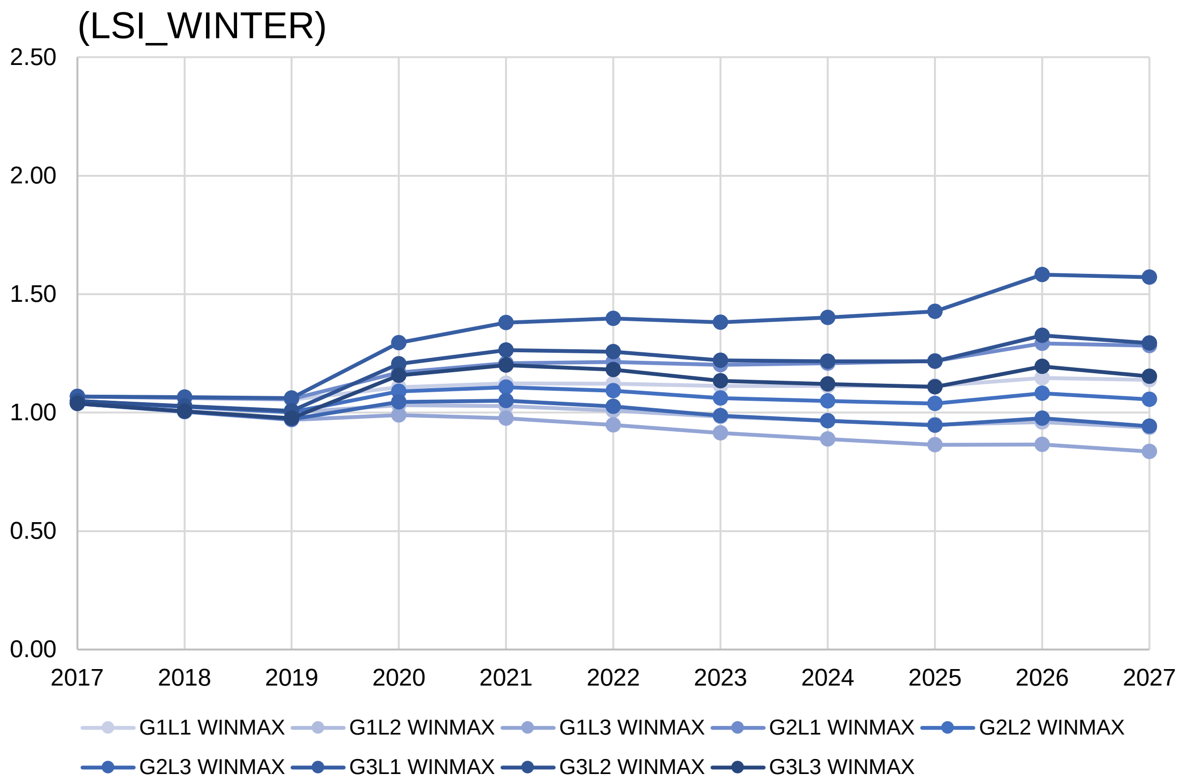


Fig. 7.12-b LSI during winter (corrected)

() - Corrected data based on information obtained in January 2017

According on above mentioned, in order to avoid the reduction of security of supply and the adequacy of power system, following recommendations have to be take in account:

1. Construction of 500 kV parallel line of 500 kV OHL "Imereti" in order to increase reliability of power evacuation from Enguri node;
2. Timely construction of cross border transmission infrastructure;
3. Future Generation objects have to be in operation at least according the schedule;
4. Existing generation objects must (!) improve their technical situation, according the "Grid Code" and "Technical Operation Rules";
5. HPPs with Reservoirs (Khudoni and Nenskra HPPs, Tskhenistskali, Mtkvari and Namakhvani cascasdes) have to be commissioned on time in order to "save energy" for winder period;
6. It is recommended to construct pymped-storage HPPs which will lead to improve generation adequacy, power system stability and flexibility and to make opportunity to integrate additional capacities coming from sources of variable generation (solar and wind) to the network.
7. Conduct measures to ensure increased power efficiency and mitigation of consumption growth.

8 Identified Projects and Investment Needs for Infrastructure strengthening

According to Georgian law on "electricity and natural gas" Article 3[2] (Network Development Plan of Georgia) paragraph 2: *Georgian Ten Year Network Development Plan should contain:*

…

C) Information about transmission system infrastructure that should be built or strengthen during the next 10 years according to investment dates.

According to grid code Article 39, paragraph 3: *In network development plan… Should be indicated locations where new electrical installations or rehabilitation of old ones are needed.*

8.1 Identified Projects

As noted above (ref. to Sections 2 and 6), the projects to be implemented in the transmission network has been divided into the following three groups:

1. ***Internal Projects,*** including the projects affecting power transit and reliability;
2. ***Cross-Border Projects***, i.e. the projects affecting capacity and reliability of the transit flows among the power systems of Georgia and its neighbouring states;
3. ***Local Projects,*** comprising 220 kV and 110 kV dead-end feeder lines.

The direct affect on development of the transmission network is provided only by Cross-Border and Internal Projects.

The estimated costs, as well as lengths and commissioning dates of these projects are of a forecasted nature, and GSE shall in no event be liable for their inaccuracy. These data shall be subject of review and specification during implementation of the projects by consultants and/or project developers.

Fifteen projects described below are of the system wide importance, and when implemented, will address current and future challenges. Each of these projects will provide individual infrastructural elements of the transmission network, although consisting of several sub-projects and/or power lines and substations operated at one or several rated voltages.

Thirteen from described projects assume construction of overhead line or substation, and the remaining two – construction of HVDC link along with AC transmission line.