# 10 Power Flow Analysis

## 10.1 Steady Mode Analysis

*According to 2nd paragraph of article 33 of Grid Code (Studying of transmission network for planning purpose), Studying of transmission network for planning purpose may include: a) Power flow studying of load in transmission network… d) Analysis of steady-state regimes;*

**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.

Similar to dynamic and static stability analyses, power flow analysis (power flow modelling) was performed using PSS/E software (v. 33.5) developed by Siemens, which is one of the most popular power system simulator software in the world.

This software is being used in GSE since 2005.

The power flow analysis and all other calculations were performed by GSE's system analysis specialists who have . They have delivered trainings in application of PSS/E software to the specialists from Russia, Ukraine, Azerbaijan, Armenia, Moldova and Kyrgystan.

The following was taken into account in course of analysis performed using PSS/E:

- 500/400/330/220/154/110 kV voltage elements of Georgian network, as well as part of the lower voltage transmission facilities used for interconnection of the power plants with 110 kV and higher voltage grid.
- Models and/or equivalent instruments covering Azeri, Armenian, Turkish and part of South Russian electric power systems.
- Synchronous generators with 3 MW and higher rated capacities.

One or several power stations are presented as one unit but detailed model of transmission network has been used for power flow analysis.

Power flow analysis was performed for each typical operating regimes relevant to 2017-2027 period, including Summer Maximum, Summer Minimum, Winter Maximum and Winter Minimum. These regimes were analysed according to forecasted power balances specified in Chapter 7 herein.

According to the results of power flow modelling, 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.

Finally, in both base case and after single contingency, the nodal voltages are within the limits set forth in the Grid Code without violation of thermal ratings of OHLs, subject to operation of ECS.

The maps given below (Figs. 10.2-10.5) illustrate normal (steady state) operating modes under maximum summer demand and generation (flood season) for 2017, 2020, 2023 and 2027 denoted as “Summer Maximum”. Such modes were selected for illustration since the larges loading of the transmission system occurs during summer flooding period, when the largest HPPs located in the West Georgia are operating near their installed capacities, and transmission network has to transfer such bulk generation to the east, where the bulk load centres and cross-border lines (existing 400 kV OHL Aklatsikhe-Borchka along with the planned 400 kV OHLs Akhaltsikhe-Tortum and Marneuli-Airum) are. In addition, thermal power plants located in east part of Georgia are not in operation in summer scenarios.

The maps given on the Figs 10.2-10.5 show only active power flows, generations and nodal demands, without indicating Mvar flows and voltage levels.

The detail modes typical to individual seasons during 2017-2027 are described in Annex D-1.

Power losses in Georgian transmission network per individual voltage level are given in Table 10.1 evidencing that total transmission losses at 500/400/330/220 kV voltage levels very in the range of 2.27 %-4.76 %. In addition, losses are relatively increased in 2020 due to the planned construction of 700 MW cross-border infrastructure in total in this period. This capacity will be mainly used by power transit. Losses are decreased again during 2021-2024 because of commissioning of following power plants: Khudoni HPP, Tskhenistskali cascade which replace transit.

## 10.2 Losses by operating modes

**Table 10.1**

| YEAR | REGIME | TOTAL GENERATION of GEORGIA (MW) | LOSSES | | | |
|---|---|---|---|---|---|---|
| | | | 220-330-154-110 kV (MW) | 500-400 kV (MW) | Total (MW) | Total (%) |
| 2017 | SUMMER MAX | 2370 | 24.8 | 44.9 | 69.7 | 2.94% |
| | SUMMER MIN | 1471 | 17.2 | 35.2 | 52.4 | 3.56% |
| | WINTER MAX | 2433 | 16.9 | 48.2 | 65.1 | 2.68% |
| | WINTER MIN | 1459 | 6.7 | 39.6 | 46.3 | 3.17% |
| 2018 | SUMMER MAX | 2498 | 22.1 | 43.6 | 65.7 | 2.63% |
| | SUMMER MIN | 1569 | 17.6 | 39.4 | 57.0 | 3.63% |
| | WINTER MAX | 2473 | 16.4 | 50.6 | 67.0 | 2.71% |
| | WINTER MIN | 1988 | 11.0 | 39.0 | 50.0 | 2.52% |
| 2019 | SUMMER MAX | 2804 | 24.8 | 47.2 | 72.0 | 2.57% |
| | SUMMER MIN | 1963 | 22.0 | 44.5 | 66.5 | 3.39% |
| | WINTER MAX | 2520 | 17.5 | 57.6 | 75.1 | 2.98% |
| | WINTER MIN | 1637 | 9.2 | 55.1 | 64.3 | 3.93% |
| 2020 | SUMMER MAX | 3061 | 26.5 | 61.8 | 88.3 | 2.88% |
| | SUMMER MIN | 2112 | 22.1 | 49.0 | 71.1 | 3.37% |
| | WINTER MAX | 2950 | 15.7 | 51.2 | 66.9 | 2.27% |
| | WINTER MIN | 1951 | 8.7 | 39.3 | 48.0 | 2.46% |
| 2021 | SUMMER MAX | 3247 | 29.4 | 63.7 | 93.1 | 2.87% |
| | SUMMER MIN | 2364 | 25.5 | 66.4 | 91.9 | 3.89% |
| | WINTER MAX | 2967 | 33.9 | 78.2 | 112.1 | 3.78% |
| | WINTER MIN | 2017 | 22.2 | 73.9 | 96.1 | 4.76% |
| 2022 | SUMMER MAX | 3942 | 35.5 | 56.1 | 91.6 | 2.32% |
| | SUMMER MIN | 3150 | 28.4 | 55.5 | 83.9 | 2.66% |

| | | | | | | |
|---|---|---|---|---|---|---|
| | WINTER MAX | 3412 | 34.7 | 86.2 | 120.9 | 3.54% |
| | WINTER MIN | 2359 | 22.1 | 86.8 | 108.9 | 4.62% |
| 2023 | SUMMER MAX | 5064 | 41.6 | 91.9 | 133.5 | 2.64% |
| | SUMMER MIN | 3497 | 29.9 | 58.7 | 88.6 | 2.53% |
| | WINTER MAX | 3755 | 36.8 | 91.7 | 128.5 | 3.42% |
| | WINTER MIN | 2531 | 22.5 | 79.8 | 102.3 | 4.04% |
| 2024 | SUMMER MAX | 5575 | 52.9 | 101.4 | 154.3 | 2.77% |
| | SUMMER MIN | 3694 | 33.1 | 57.8 | 90.9 | 2.46% |
| | WINTER MAX | 4044 | 42.8 | 91.5 | 134.3 | 3.32% |
| | WINTER MIN | 2607 | 22.9 | 76.1 | 99.0 | 3.80% |
| 2025 | SUMMER MAX | 5665 | 53.7 | 103.8 | 157.5 | 2.78% |
| | SUMMER MIN | 3737 | 33.3 | 58.4 | 91.7 | 2.45% |
| | WINTER MAX | 4135 | 43.4 | 93.1 | 136.5 | 3.30% |
| | WINTER MIN | 2638 | 23.1 | 76.8 | 99.9 | 3.79% |
| 2026 | SUMMER MAX | 5765 | 55.4 | 106.6 | 162.0 | 2.81% |
| | SUMMER MIN | 3781 | 33.4 | 58.9 | 92.3 | 2.44% |
| | WINTER MAX | 4316 | 44.5 | 86.8 | 131.3 | 3.04% |
| | WINTER MIN | 2861 | 23.9 | 69.7 | 93.6 | 3.27% |
| 2027 | SUMMER MAX | 5822 | 55.9 | 106.6 | 162.5 | 2.79% |
| | SUMMER MIN | 3826 | 33.6 | 59.5 | 93.1 | 2.43% |
| | WINTER MAX | 4406 | 46.2 | 88.8 | 135.0 | 3.06% |
| | WINTER MIN | 2891 | 24.1 | 70.0 | 94.1 | 3.25% |

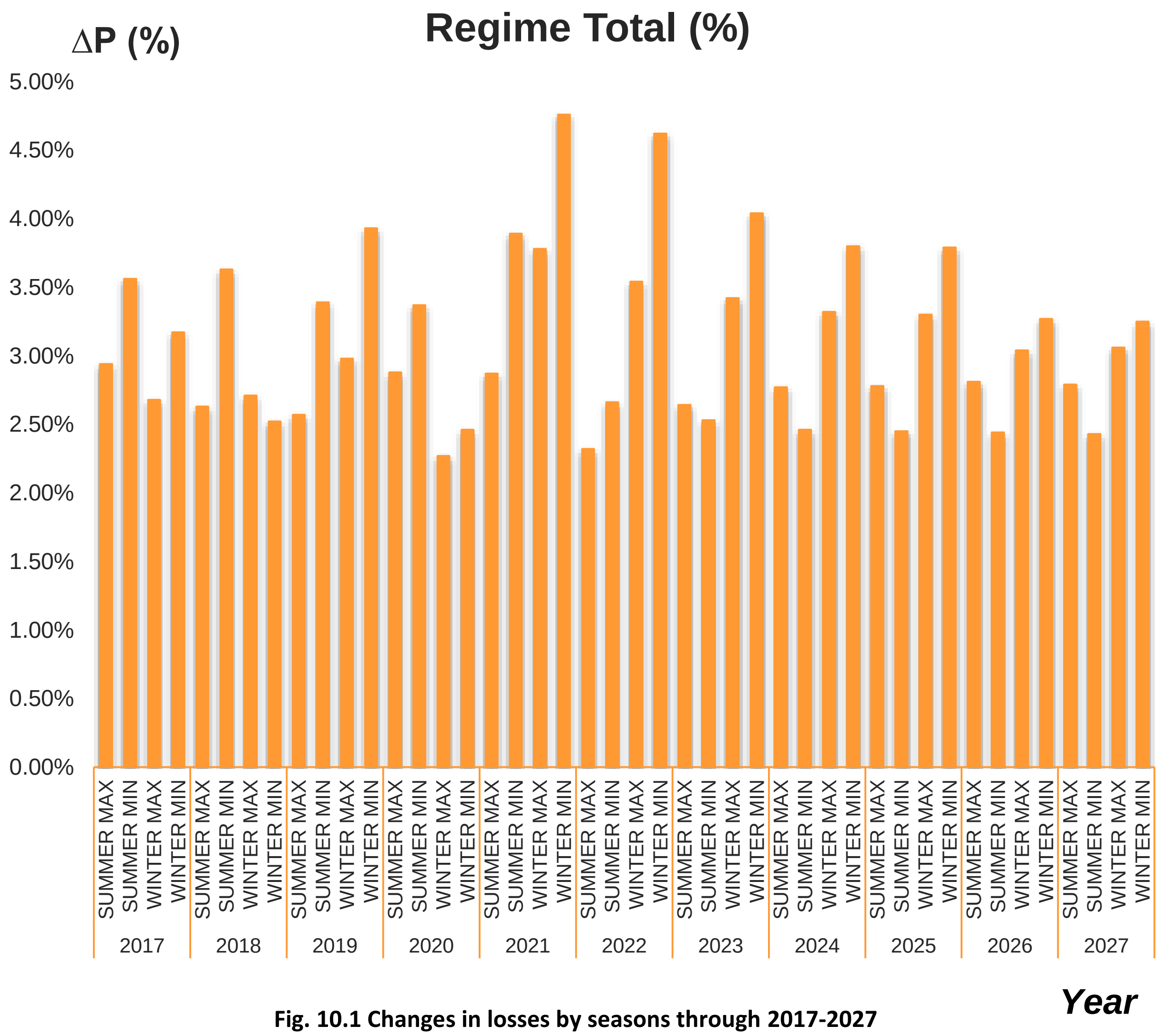



**Fig. 10.1 Changes in losses by seasons through 2017-2027**

Optimistic load flows (with the consideration of possible speed-up of commissioning of generation and transmission infrastructure) are presented on figures 10.2-10.5 which differ from diagrams shown in Annex-1.

Load frow regimes from Annex-1 are fully compatible with consequence of network development (chapter 9, table 9.2).

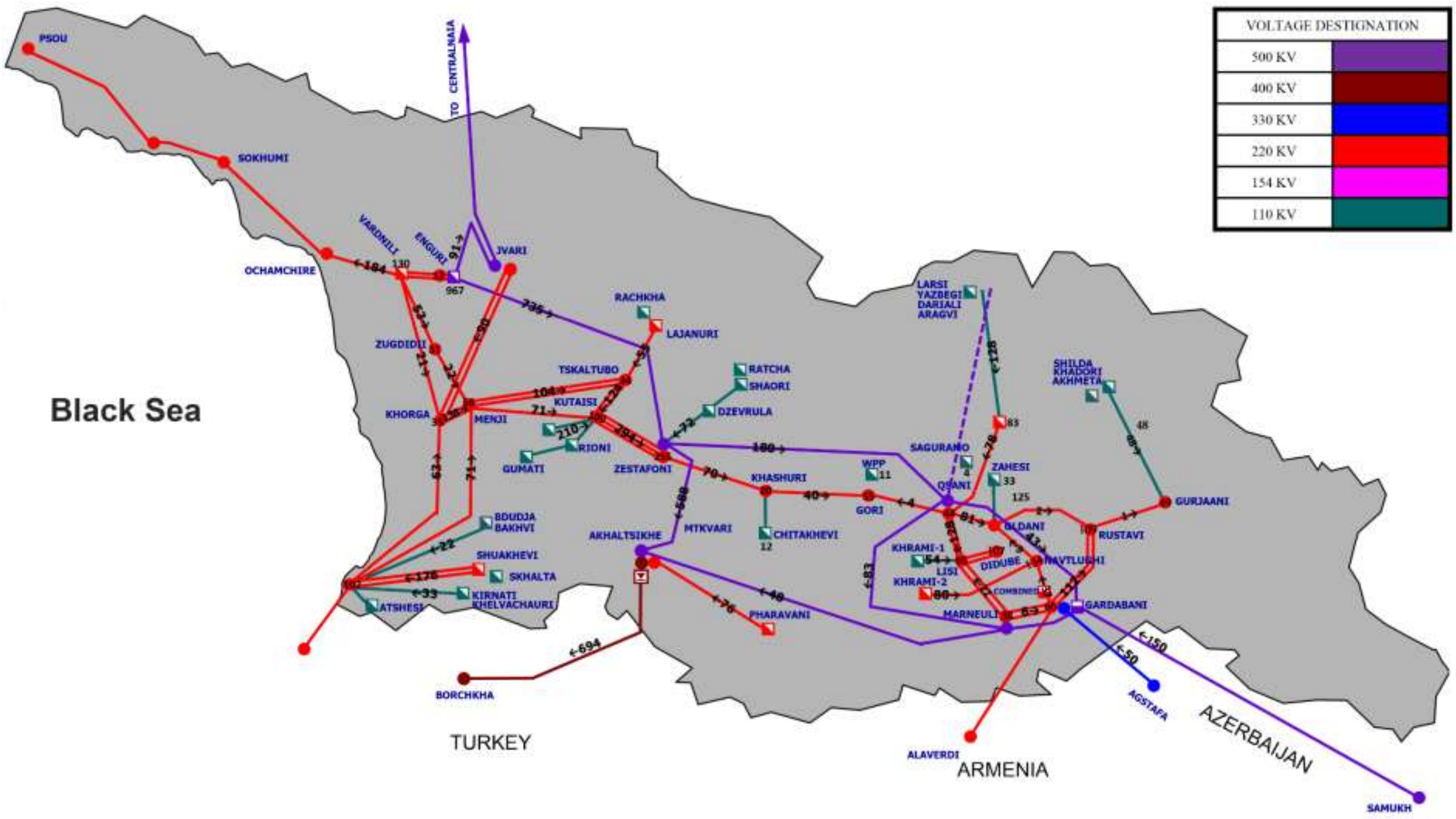



Fig. 10.2 Summer Maximum - 2017

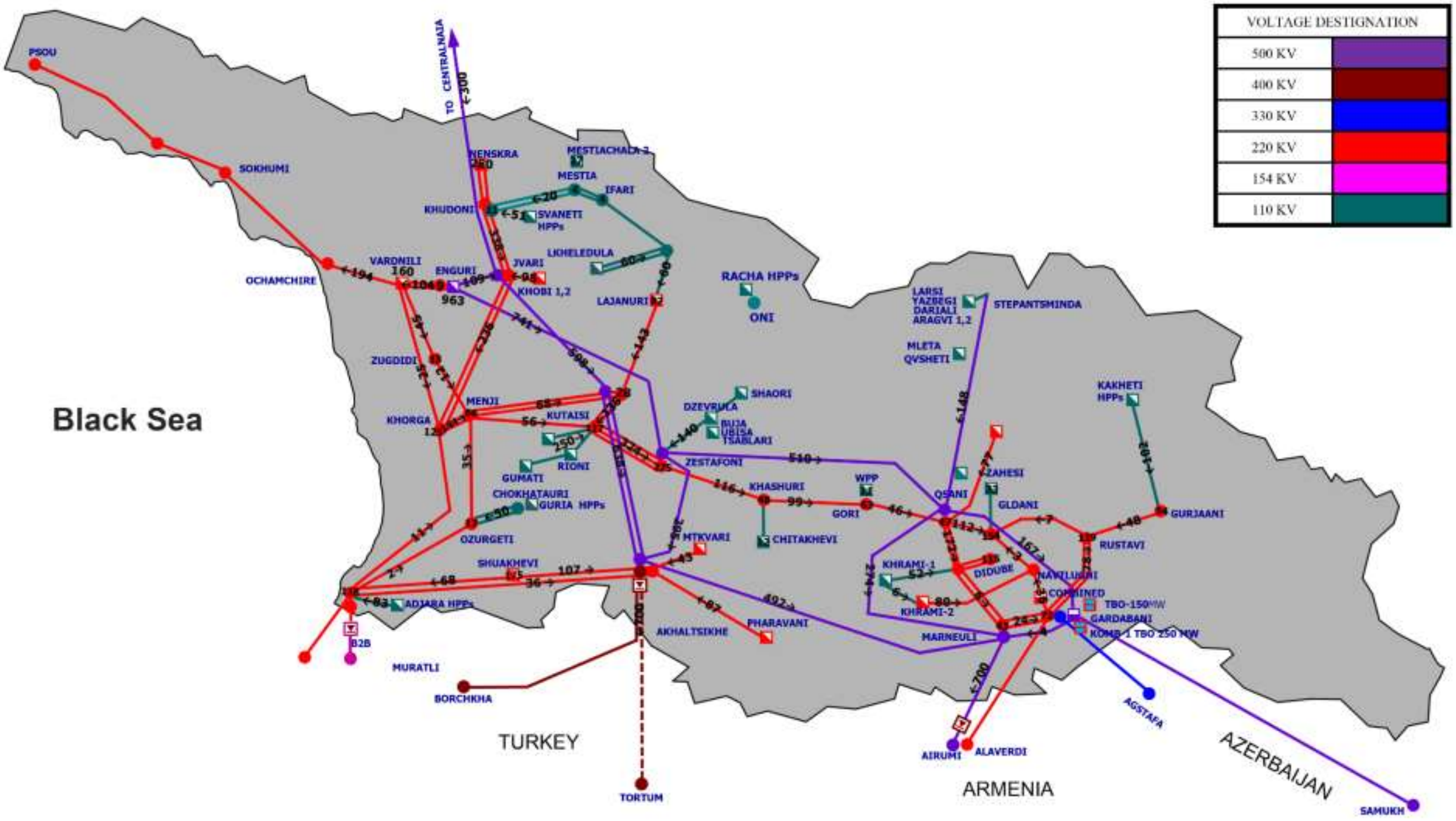



Fig. 10.3 Summer Maximum – 2020

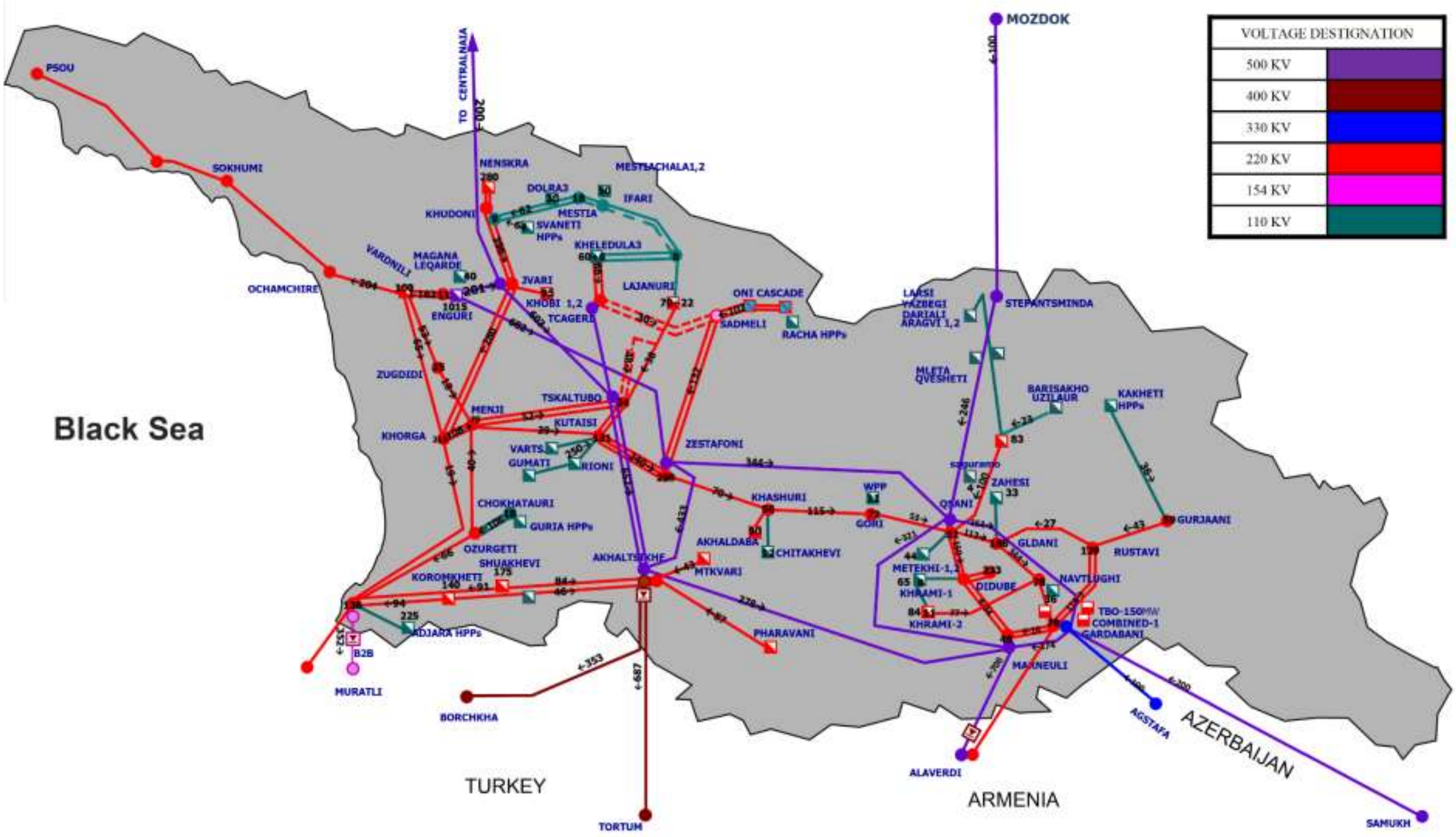



Fig. 10.4 Summer Maximum - 2023

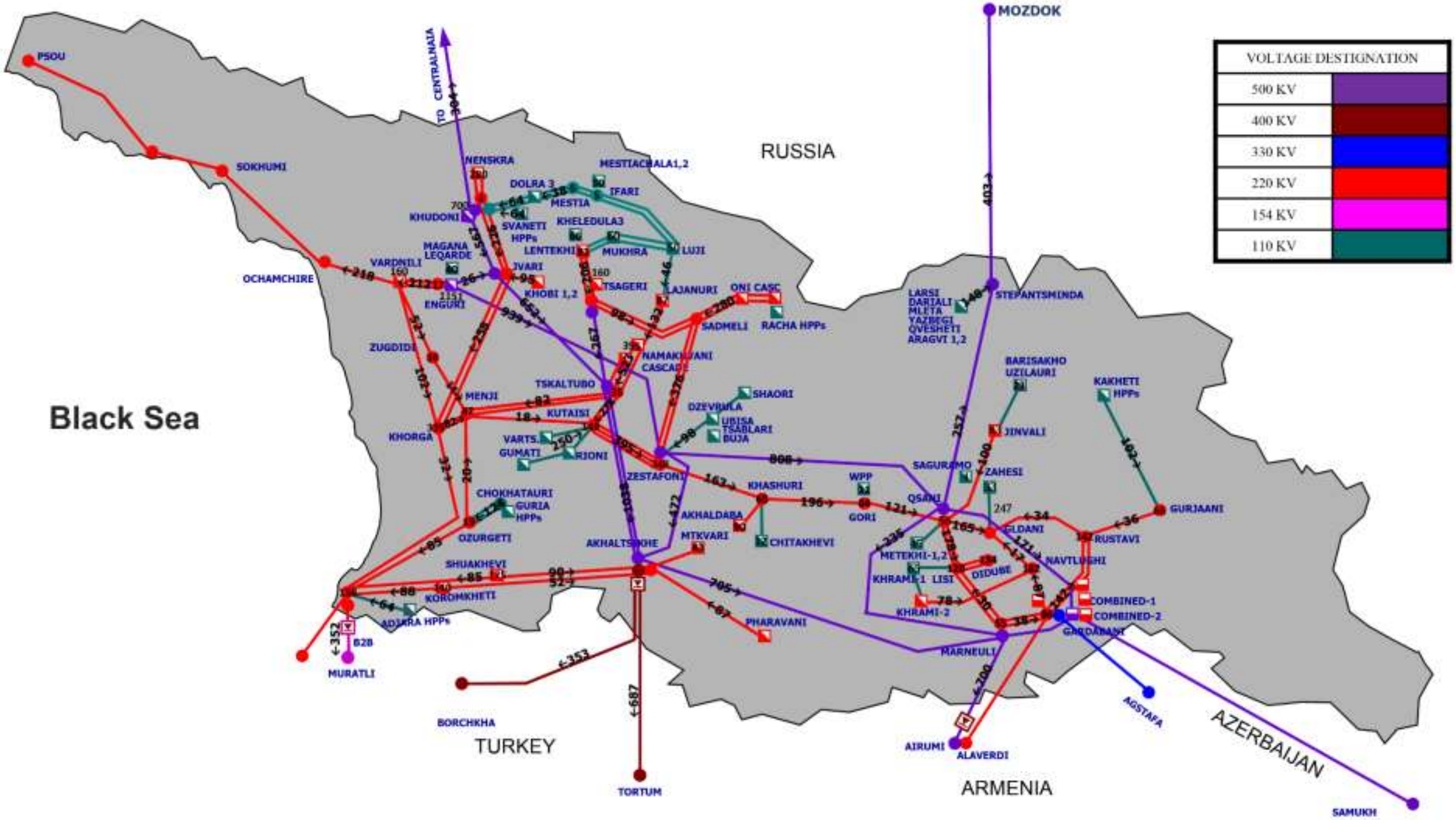



Fig. 10.5 Summer Maximum - 2027

## 10.3 Voltage Analysis

**Necessity for Voltage Analysis and Methods for Addressing Voltage Related Problems**

The voltage is an important power quality parameter affecting reliability and operating conditions of power plants, transmission network and customer facilities. When reactive power flow in the node is excessive, voltage increases, and vice versa. During normal operating regime of the power system in general, and customer facilities in specific, nodal voltages shall always remain within the limits prescribed in the Grid Code. Specifically, under the normal conditions, in 110 kV and lower rated networks the voltages shall not deviate more that ±10% from the nominal values that is reduced to ±5% for the networks operated at 220 kV and higher. After contingency is cleared, acceptable voltage deviation limits shall not exceed ±15% of nominal (rated) values for 110 kV and lower voltage systems, and ±10% for the ones operated under 220 kV and higher voltages.

In line with development of the network, the reactive power balances in the nodes change. This may be caused by increased nodal consumption on the one hand, and generation growth on the other hand. The Mvar generation sources are composed of synchronous generators, as well as the OHLs and reactive power compensation equipment installed in the network.

In course of the network development, new transmission lines act as additional inductance and capacitance elements of the network. The voltage losses occur in result of series inductive reactance, while reactive power is produced due to shunt capacitive conductance. This has positive effect when system operates at the lower voltages, however in certain cases (under minimum load modes) such capacitance effect is negative and causes excessive voltage increase.

In addition, the generated reactive power is higher in the transmission lines with higher rating. Therefore, during network development, excessive voltages may occur in the nodes where the OHLs are interconnected.

While adding 220 kV OHLs to the network, it may be assumed that the effects of their series and shunt parameters compensate each other, and thus in such cases reactive power balances in the nodes do not change much. The opposite is true when adding 500 kV OHLs. Specifically, under no load operation, reactive power generated in the line is calculated by the following formula:

$$Q_c = BU^2 = U^2 \omega C \qquad (10.1)$$

where U is a voltage (kV), $\omega -$ is an angular frequency (rad/s), C is a capacitance (F), $Q_c$ is a reactive power generated due to line's shunt capacitance effects (Mvar).

Taking into account that the capacitance per unit length of 500 kV OHL is about 1.4 times higher than the same of 220 kV line, then according to (10.1), 500 kV OHL generates approximately 7 times more reactive power than 220 kV OHL of the same length.

As noted above, nodal voltage depends on reactive power balance. In turn, such balance is depended on operating condition, i.e. nodal load. The less the nodal node is, the higher is a voltage in the appropriate node. Therefore, under the minimum demand regimes, when the loads in nodes and in interconnected lines are small, the nodal voltage increases, with opposite effect under the maximum flow regimes. When the nodal voltages are out of the limits established for normal operation, use of reactive power compensation devices is required to maintain the voltage within acceptable range (0.95-1.05 p.u.). The inductive (shunt) reactors are used to limit voltage rise in the high voltage transmission line, while the capacitance elements (capacitors) are applied for avoiding voltage drop. Here it should be noted that switching (on/off) of the compensation equipment installed in the network, which has fixed Var outputs causes rapid voltage changes (flickers). Therefore, availability of the stepped Var outputs generated by var compensating equipment is desired to reduce network voltage swings during reactive power compensation.  More modern and probably the most advanced voltage regulation method is provided by SVC (Static Var Compensation) or STATCOM (Static Synchronous Compensation) equipment. Even such equipment is relatively expensive, they are very efficient that almost always justifies their costs.

**Calculations and Assumptions**

Using PSS/E software, the network voltages were analysed for each estimated power flow scenario relevant to 2017-2027 time span, including maximum/minimum winter/summer load regimes for each ear.

Prior to power flow modelling, the following assumptions were made for analysing the voltage/reactive power balance:

1. Power factors of active loads at each node equal to 0.85;
2. Demand is composed of symmetrical 3-phase loads;
3. Reactive power produced by generators fluctuate to maintain the voltage at interconnection point close to 1.0 p.u., while remaining between maximum and minimum allowable limits.

The following measures were assumed to be implemented for keeping the voltages in Georgian electric power network within allowable limits:

1) Switching (on/off) of the reactors installed in the 500 kV network;
2) Selection of AC filters in SS Akhaltsikhe according to power value converted by/transmitted through the back-to-back links;
3) Regulation of the transformation ratios of 500/200 kV and 220/110 kV transformers.

**Reactive Power Compensation Equipment for Present and Planned Schemes**

At present, the backbone 500 kV OHLs operating in Georgia include Enguri-Zestaponi (OHL Imereti, 128 km), Zestaponi-Ksani (OHL Kartli-2, 164 km), Ksani-Gardabani (OHL Kartli-1, 91 km), Gardabani-Marneuli ("Gachiani, 30 km), Marneuli-Akhaltsikhe (OHL Vardzia, 160 km), Zestaponi-Akhaltsikhe (OHL Zekari, 67 km), Ksani-Marneuli ("Asureti", 55 km), Enguri-Tsentralnaya (OHL Kavkasioni, 405 km), Gardabani-Samukh (OHL Mukhranis Veli, 155 km).

Under the no load operation, 500 kV OHLs transmit reactive power towards their both ends, which aggregated numerical value approximately equals to the line length, i.e. 100 km long OHL delievers about 50 Mvar reactive power at its each end. Therefore, all in-country 500 kV lines transfers to the system the reactive power with total value of their approximate aggregated length, while the cross-border lines transfer towards Georgian network the reactive power, which total numerical value is about half of their total length (in Mvar). It should be noted that, in general, the reactors shall be selected with assumption that even the minimum loading modes 500 kV OHLs still transmit the active power resulting in reactive power losses occur in the inductive elements of such lines that are partially compensated by the reactive energy generated therein.

Considering above, the capacity of the reactor $Q_i$ (in Mvar) installed at any *i*-th node of 500 kV system should equal:

$$Q_i = \frac{l_{\max}}{2} + 0.7\frac{l_{\Sigma}}{2} \tag{10.2}$$

Where:

$\boldsymbol{l_{max}}$ is length of the longest OHL connected to this node

$\boldsymbol{l_{\Sigma}}$ – total length of all other OHLs connected to the same node.

In Georgian network, the reactors with capacities of 180 Mvar each, have been installed in the following 500 kV substations: Enguri, Zestaponi, Ksani and Gardabani. Therefore, the total reactive power consumed by these reactors amounts to 720 Mvar. Taking into consideration that the aggregated length of 500 kV OHLs connected to Georgian network's nodes is 966 km, then resulted reactive power generated in these lines is $966 \times 0.7 = 676$ Mvar that is well approximated with the total capacity of the reactors installed in Georgian network. The capacities of the reactors necessary for the prospective (developed) network may also be calculated using the same approach.

The layout of prospective 500 kV transmission network of Georgia is shown on Fig. 10.13. The present reactors' capacities were used as input data, and the capacities of needed supplemental reactors to be installed at 500 kV nodes were calculated applying formula (10.2).

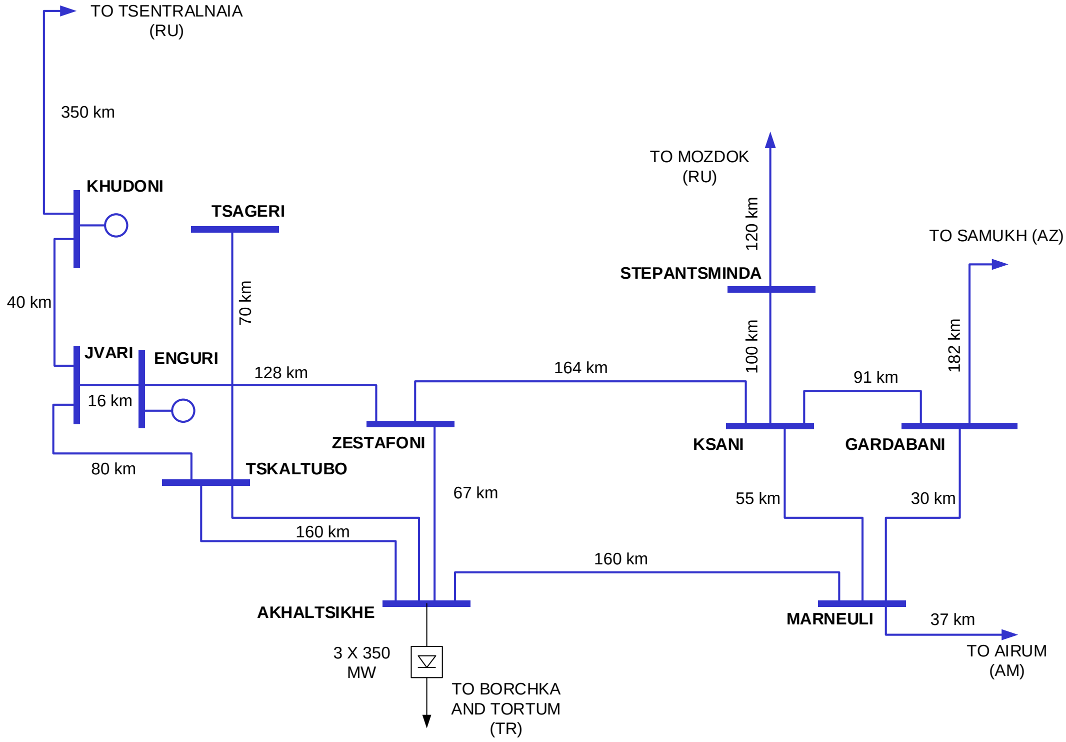



**Fig. 10.6 Georgian 500 kV transmission network as for 2027**

The derived results are given in table 10.2. The middle column shows capacities of the needed reactors. Since installation of the reactors at each 500 kV node is both technically and economically unreasonable, installation of single shared reactor for several nodes located in proximity to each other have been envisaged.

Assuming possibility for changes of the active loads under the minimum demand regimes, separate calculations were performed by PSS/E software for different minimum winter operating modes (such winter modes assume operation of the thermal power plants located in the Eastern Georgia allowing unloading of the OHLs connecting Enguri basin with the eastern load centres). Namely, Mode 1 – all synchronous interconnection lines are energized but transmit near-zero power flows, and back-to-back links are off; Mode 2 – Batumi and Akhaltsikhe back-to-back links (including their filters) are operated that causes loading of the OHLs routed from the power plants located in the West Georgia to the east. Such simulations were purposed to determine regulation limits for appropriate reactors. For the sake of system reliability, installation of the controllable (adjastable) reactors was considered at 500 kV substations Tskaltubo, Zestaponi and Marneuli. No reactor was considered directly at Akhalsikhe substation to avoid creation of the resonance circuits at the filters, hence, Switch off one circuit of 2-circuit 500 kV OHL Tskaltubo-Akhaltsikhe will be possible in order to avoid overvoltage in minimum load modes. Hence, length of only one circuit of this line has been considered in voltage analysis, in table below.

As shown in the following table, no reactors were envisaged at 500 kV substations Jvari, Akhaltsikhe, Tsageri and Stepantsminda. The needed reactor capacities calculated for these substations have been reallocated among the reactors to be installed at their neighbouring nodes. In particular, according to calculation, reactive power for Khudoni bus bar is near standard capacity. Bus bars of Jvari, Enguri, Tsageri, Tskaltubo and partially Akhaltsikhe are compensated only by reactors of Enguri and Tskaltubo. Reacotr at Zestaponi compensates Zestaponi itself and remaining part of Akhaltsikhe. Gardabani, Marneuli, Stepantsminda and Ksani are compensated by reactors of Gardabani, Marneuli and Ksani.

**Table 10.2**

| 500 kV SS | Required Capacity, MVAR | | Standard Capacity, MVAR | |
|---|---|---|---|---|
| Name | Bus bar | “Neighbor bus bars” | Name | “Neighbor bus bars” |
| Khudoni | 189 | 318 | 180 | 360 |
| Jvari | 60 | | 0 | |
| Enguri | 69 | | 180 | |
| Tsageri | 35 | 614 (478[1]) | 0 | 500 |
| Tskaltubo | 213 (133[1]) | | 250 | |
| Akhaltsikhe | 216 (160[1]) | | 0 | |
| Zestaponi | 150 | | 250 | |
| Gardabani | 133 | 534 | 180 | 540 |
| Stepantsminda | 95 | | 0 | |
| Marneuli | 130 | | 180 | |
| Ksani | 175 | | 180 | |
| Total | **1465 (1329[1])** | | **1400** | |

**1 – amount of reactive powers are given in case of operation only with single circuit of 500 kV OHL Tskaltubo-Akhaltsikhe.**

**2 – This reactor will be moved from SS “Jvari” to SS “Nenskra”, when the later is commissioned. Ksani reactor might be moved to SS “Stepantsminda”. Installation of SVC or FACTS devices in Ksani might be considered.**

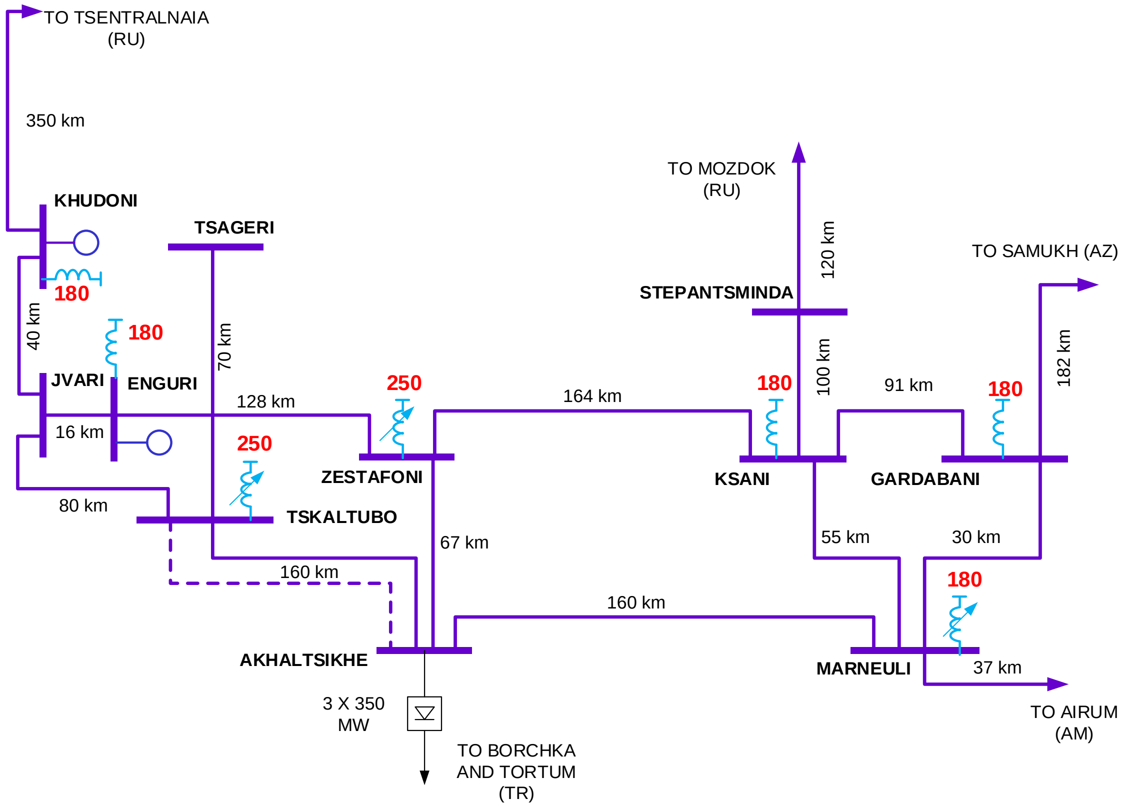



**Fig. 10.7. Georgian 500 kV transmission network as for 2027**

Results of R-1 analysis for reactors are presented below in tab. 10.3. 2027 winter minimum scenario has been selected, while Georgia imports 300 MW from Russia, power flows on cross-border lines between Georgia and Azerbaijan, Armenia are less than 100 MW.

Step-by-step switching off reactors in existing and perspective 500 kV substations has been performed during analysis.

**Table 10.3 R-1 analysis results, voltage in kV**

| Substation | R | R-1 Khudoni | R-1 Enguri | R-1 Tskaltubo | R-1 Zestaponi | R-1 Ksani | R-1 Gardabani | R-1 Marneuli |
|---|---|---|---|---|---|---|---|---|
| Khudoni | 503 | 515 | 513 | 519 | 515 | 504 | 504 | 505 |
| Jvari | 501 | 510 | 511 | 517 | 514 | 502 | 501 | 503 |
| Enguri | 500 | 509 | 511 | 516 | 513 | 501 | 501 | 502 |
| Tsageri | 510 | 518 | 519 | 531 | 525 | 512 | 512 | 513 |
| Tskaltubo | 500 | 509 | 510 | 523 | 515 | 503 | 502 | 504 |
| Akhaltsikhe | 503 | 510 | 511 | 519 | 519 | 507 | 506 | 508 |
| Zestaponi | 499 | 506 | 508 | 515 | 518 | 503 | 502 | 504 |
| Gardabani | 494 | 497 | 498 | 502 | 503 | 499 | 501 | 501 |
| Stepantsminda | 502 | 505 | 505 | 508 | 508 | 506 | 506 | 506 |
| Marneuli | 494 | 498 | 499 | 504 | 504 | 500 | 500 | 503 |
| Ksani | 496 | 500 | 501 | 506 | 507 | 504 | 502 | 503 |

Voltages (kV) at 500 kV nodes of transmission network of Georgia in normal mode are given in **R** column, as for **R-1** column – voltages (kV) after switching off reactors in respective SS.

Analysis has been performed in case of operation by only single circuit of 500 kV Tskaltubo-Akhaltsikhe. Results show that voltage voumes are maintained within accepted limits when reactors are switched off.

## 10.4 Analysis of needs of the strengthening of substations

The Georgian transmission network is the transmission network infrastructure that connects the generation objects to distribution one. Besides OHLs it consists of transformers and autotransformers reliable operation of which has huge influence of security of supply of consumers. Hence, analysis of 220/110 kV transformers' reinforcement has been conducted with the consideration of following principles:

Usually, part of the 110 kV transmission network operates impasse mode. In other words, this is because the 220 kV network with the parallel work on the one hand there would be 110 kV network overloading risk, while on the other hand dramatically increase the size of the short circuits.

220/110 kV substations consist of one or more transformers of these voltage levels. Their 110 kV splints (sections) are usually glued to each other or sequestered. Thus, normally 220/110 kV transformer (autotransformer) feeds several consecutively connected 110 kV substations of distribution network.

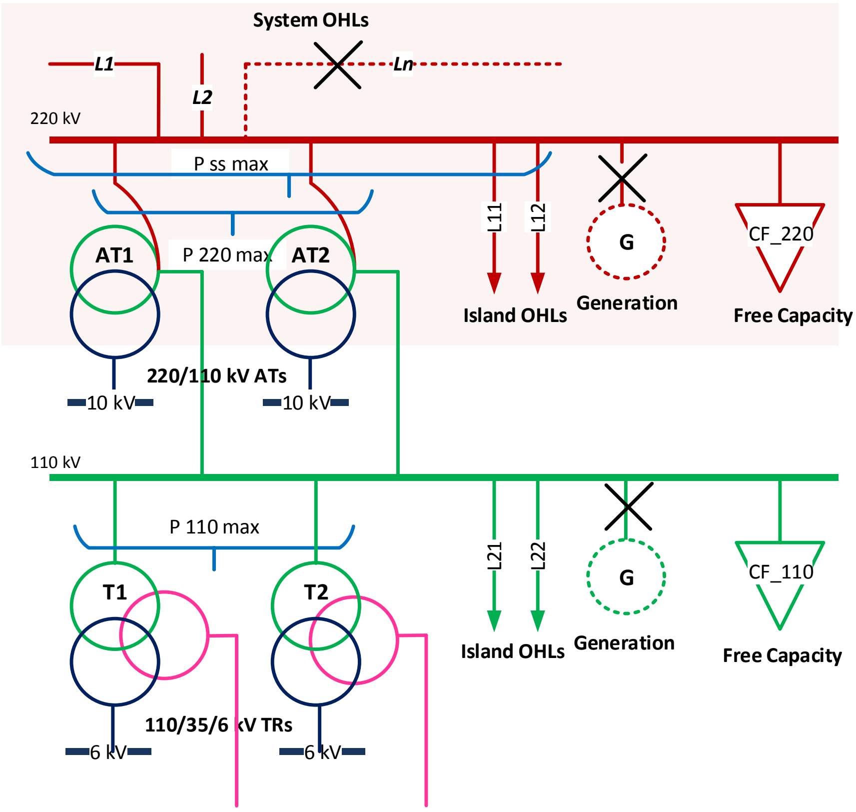



**Fig 10.8 Principal Diagram of 220 kV Substation**

**The principle of calculation of the free capacities**

1.The free capacities are calculating independently at 220 and 110 kV levels of SS (Fig. 10.8);

2. for certain voltage rate the free capacity is determined by taking in account the real capacities of feeding elements and regime loadings;

3. Generation is neglected due their forced and planned outages

4. the loading factor for the 220 kV OHLs, ATs and Ts is treated as η=0.9 (with the consideration of operational conditions and avoiding of overloads);

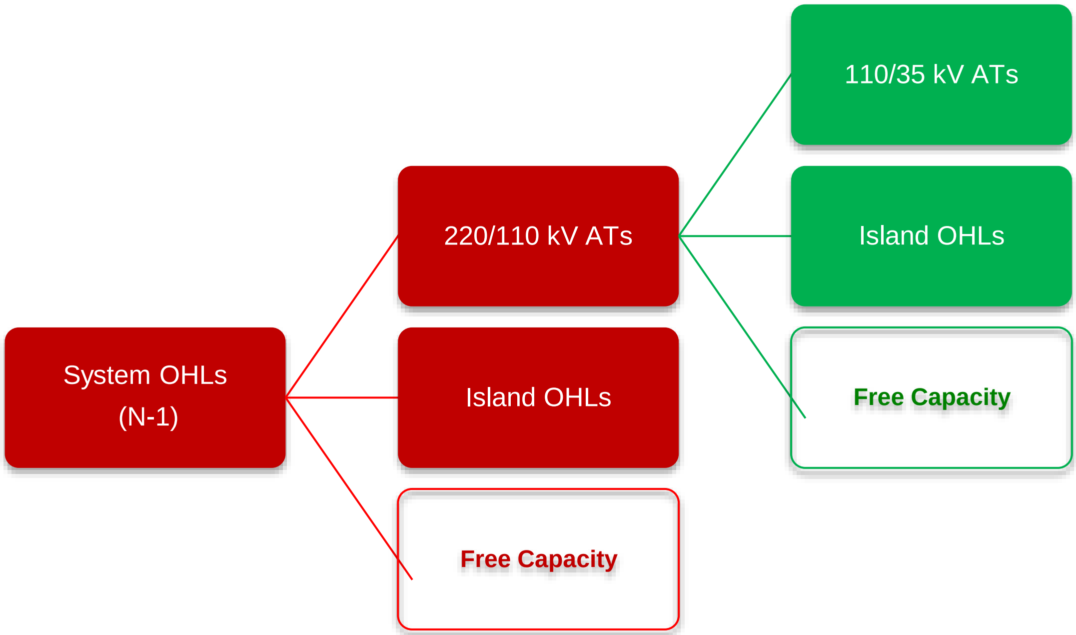



**Fig. 10.9 The Block Diagram of 220 kV Substation**

**5. For the determination of the Free Capacity at 220 kV level**, as seems from the fig 10.9, the 220 kV busbars of the SS are feed from the 220 kV system OHLs and for the calculation the N-1 criteria is considered – when the OHL with maximal capacity is out of service. 220/110 kV ATs/Ts and island 220 kV OHLs are considered as a Loads. Hence, the free capacity at 220 kV level might be determined as the sum of transfer capacities of system OHLs feeding Substation (in N-1 condition, with considering the loading factor), minus the maximal loads of 220/110 kV ATs and island 220 kV OHLs of last two years, with neglecting of generation.

**6. For the determination of the "Free Capacity" at 110 kV level** shall be taken in account that the feeding of the consumers is providing by 220/110 kV ATs. Therefore the "Free Capacity" at 110 kV level will be the sum of the nominal capacities of Autotransformers (with taking in account of loading factor) minus minus the maximal loads of 110/35 kV ATs and isolated 110 kV OHLs and 10-6 kV consumers (in case of existing) of last two years, with neglecting of generation.

7. The capacity of perspective 220 kV OHLs are treated as 200-225 MW (beside some of them, for instance Khresili can carry 2x400 MW), in order to avoid obtaining more "Free Capacity" when it is actually.

The calculations are made for 2017, 2019, 2023 and 2027 years, where the load increasing is considered, so particularly the permissions are not take in account.

### Calculation of the free Capacity of substations

**At 220 kV Busbars,** The additional marginal value of the Load, when the loading of all connected system OHLs are below their capacities, is represented the Free capacity on this voltage level and is calculated as:

$$C_{F\ 220} = \Sigma P_{(N-1)} \cdot \eta_{220} - \Sigma P_{\max ss} \qquad (10.3)$$

where:

$\Sigma P_{(N-1)}$ - the total capacity of 220 kV system OHLs connected with the SS (in N-1 condition)

$\eta_{220}$ – loading factor of OHLs, $\eta_{220}$=0.9;

$\Sigma P_{\max ss}$ – Maximal load of SS, which is representing the sum of maximal loading of 220 kV windings of 220/110 kV ATS and 220 kV consumer feeding OHLs.

**At 110 kV Busbars,** There is taken in account the nominal capacity with (loading factor) of 220/110 kV ATs and the maximal loading of 220 kV windings, because these windings are feeding the 110 kV busbars of SS and in excusive cases 10 and 6 kV consumers of the same ATs:

$$C_{F\ 110} = \Sigma S_{nom\ 220} \cdot \eta_{220} \cdot \cos\varphi - \Sigma P_{\max 220} \qquad (10.4)$$

where:

$S_{nom\ 220}$ – the sum of nominal capacities of ATs

$\eta_{220}$ - loading factor of ATs

$\cos\varphi$ – power factor, $\cos\varphi = 0.9$;

$\Sigma P_{\max 220}$ - maximal loading of 220 windings of 220/110 kV ATs

**Table 10.4 result of analysis of available capacities to be connected to the substations**

| S/S Name | KV | Name of element | Ci | 2017 | | 2020 | | 2023 | | 2027 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pmax | CF | Pmax | CF | Pmax | CF | Pmax | CF |
| Navtlugi | 220 | OHL Kukia | 206 | 0 | 388 | 0 | 388 | 0 | 388 | 0 | 388 |
| | | OHL Navtlugi | 240 | | | | | | | | |
| | | Algeta | 225 | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | 146 | 56 | 149 | 53 | 156 | 46 | 182 | 20 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| Gldani | 220 | OHL Aragvi | 206 | 0 | 371 | 0 | 371 | 0 | 371 | 0 | 371 |
| | | OHL Kukia | 206 | | | | | | | | |
| | | OHL Varketili | 257 | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | 152 | 50 | 155 | 47 | 161 | 41 | 247 | 0 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| Didube | 220 | OHL Didube 3 | 188 | 0 | 169 | 0 | 169 | 0 | 169 | 0 | 169 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | OHL Didube 4 | 188 | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | 135 | 67 | 137 | 65 | 139 | 63 | 134 | 68 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| **Lisi** | 220 | OHL Didube 3 | 188 | 0 | 677 | 0 | 677 | 0 | 677 | 0 | 677 |
| | | OHL Didube 4 | 188 | | | | | | | | |
| | | OHL Didgori 1 | 188 | | | | | | | | |
| | | OHL Didgori 2 | 188 | | | | | | | | |
| | | OHL Koda 1 | 212 | | | | | | | | |
| | | OHL Koda 2 | 212 | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | 109 | 93 | 110 | 92 | 112 | 90 | 120 | 82 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| **Rustavi** | 220 | OHL Veli 1 | 212 | 0 | 548 | 0 | 548 | 0 | 548 | 0 | 548 |
| | | OHL Veli 2 | 212 | | | | | | | | |
| | | OHL Manavi | 185 | | | | | | | | |
| | | OHL Varketili | 257 | | | | | | | | |
| | 110 | AT1+AT2 | 2X200x0.9 | 94 | 230 | 95 | 229 | 97 | 227 | 142 | 182 |
| | | N-1 | 200x0.9 | | 68 | | 67 | | 65 | | 20 |
| **Gardabani** | 220 | AT 500/220 | 800 x0.9 | 0 | 979 | 0 | 979 | 0 | 979 | 0 | 979 |
| | | OHL Veli 1 | 212 | | | | | | | | |
| | | OHL veli 2 | 212 | | | | | | | | |
| | | OHL Navtlugi 1 | 240 | | | | | | | | |
| | | OHL Lomtagora 1 | 212 | | | | | | | | |
| | | OHL Lomtagora 2 | 212 | | | | | | | | |
| | 110 | AT1 AT2 | 2X125x0.9 | 73 | 129 | 73 | 129 | 75 | 127 | 86 | 116 |
| | | N-1 | 125x0.9 | | 28 | | 28 | | 29 | | 15 |
| **Gurjaani** | 220 | OHL Manavi | 185 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 110 | AT1+AT2 2019 Y | 125x0.9 | 51 | 50 | 55 | 147 | 61 | 141 | 66 | 136 |
| | | N-1 | 125x0.9 | | 0 | | 46 | | 40 | | 35 |
| **Marneuli** | 220 | AT 500/220 | 660x0.9 | 0 | 763 | 0 | 763 | 0 | 763 | 0 | 763 |
| | | OHL Lomtagora 1 | 212 | | | | | | | | |
| | | OHL Lomtagora 2 | 212 | | | | | | | | |
| | | OHL Koda 1 | 212 | | | | | | | | |
| | | OHL Koda 2 | 212 | | | | | | | | |
| | 110 | AT1+AT2 2017 Y | 2x125x0.9 | 36 | 166 | 37 | 165 | 37 | 166 | 55 | 148 |
| | | N-1 | 125x0.9 | | 65 | | 64 | | 64 | | 46 |
| **Qsani** | 220 | AT 500/220 | 500x0.9 | 0 | 604 | 0 | 604 | 0 | 604 | 0 | 604 |
| | | OHL Liakhvi | 171 | | | | | | | | |
| | | OHL Aragvi | 206 | | | | | | | | |
| | | OHL Didgori 1 | 188 | | | | | | | | |
| | | OHL Didgori 2 | 188 | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | 36 | 166 | 37 | 165 | 37 | 165 | 56 | 146 |
| | | N-1 | 125x0.9 | | 65 | | 64 | | 64 | | 45 |
| **Gori** | 220 | OHL Liakhvi | 171 | 0 | 154 | 0 | 154 | 0 | 154 | 0 | 154 |
| | | Ohl Urbnisi | 188 | | | | | | | | |
| | 110 | AT1+AT2 2023 Y | 2x125x0.9 | 72 | 29 | 76 | 25 | 85 | 118 | 85 | 118 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 16 | | 16 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Khashuri** | 220 | OHL Liakhvi | 171 | 0 | 154 | 0 | 154 | 0 | 154 | 0 | 154 |
| | | OHL Surami | 188 | | | | | | | | |
| | 110 | AT1 | 2X125x0.9 | 45 | 157 | 48 | 154 | 54 | 148 | 73 | 129 |
| | | N-1 | 125x0.9 | | 56 | | 53 | | 47 | | 28 |
| **Zestaponi** | 220 | AT 500/220 | 500x0.9 | 0 | 750 | 0 | 750 | 0 | 1155 | 0 | 1155 |
| | | OHL Surami | 188 | | | | | | | | |
| | | OHL Ajameti 1 | 225 | | | | | | | | |
| | | OHL Ajameti 2 | 195 | | | | | | | | |
| | | OHL Ajameti 3 | 225 | | | | | | | | |
| | | OHL Khresili 1 | 225 (400) | | | | | | | | |
| | | OHL Khresili 2 | 225 (400) | | | | | | | | |
| | 110 | AT1, AT2 | 2X200x0.9 | 161 | 163 | 171 | 153 | 190 | 134 | 283 | 41 |
| | | N-1 | 200x0.9 | | 1 | | 0 | | 0 | | 0 |
| **Fero** | 220 | OHL Fero 3 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 110 | AT1, AT2 | 2X200x0.9 | 54 | 108 | 57 | 105 | 64 | 98 | 70 | 92 |
| | | N-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Qutaisi** | 220 | OHL Ajameti 1 | 225 | 0 | 986 | 0 | 986 | 0 | 986 | 0 | 986 |
| | | OHL Ajameti 2 | 195 | | | | | | | | |
| | | OHL Ajameti 3 | 225 | | | | | | | | |
| | | OHL KOLKHIDA 1 | 300 | | | | | | | | |
| | | OHL Sataflia 1 | 225 | | | | | | | | |
| | | OHL Sataflia 2 | 225 | | | | | | | | |
| | 110 | AT1, AT2 | 2X125x0.9 | 117 | 85 | 124 | 78 | 137 | 65 | 158 | 44 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| **Tskaltubo** | 220 | AT 500/220 | 500x0.9 | 0 | 711 | 0 | 711 | 0 | 1274 | 0 | 1274 |
| | | OHL Sataflia 1 | 225 | | | | | | | | |
| | | OHL Sataflia 2 | 225 | | | | | | | | |
| | | OHL Derchi | 143 | | | | | | | | |
| | | OHL Senaki 1 | 211 | | | | | | | | |
| | | OHL Senaki 2 | 211 | | | | | | | | |
| | | OHL Zarati 1 | 200 | | | | | | | | |
| | | OHL Zarati 2 | 200 | | | | | | | | |
| | 110 | AT1+AT2 [2023 Y] | 125x0.9 | 29 | 72 | 31 | 70 | 34 | 169 | 48 | 154 |
| | | N-1 | 125x0.9 | 0 | 0 | 0 | 0 | | 67 | | 53 |
| **Zugdidi** | 220 | OHL Kolkhida 2a | 140 | 0 | 126 | 0 | 126 | 0 | 126 | 0 | 126 |
| | | OHL Kolkhida 2 | 192 | | | | | | | | |
| | 110 | AT1, AT2 | 2X63x0.9 | 35 | 67 | 35 | 67 | 36 | 66 | 38 | 64 |
| | | N-1 | 63x0.9 | | 16 | | 16 | | 15 | | 13 |
| **Menji** | 220 | OHL Kolkhida 1 | 300 | 0 | 1070 | 0 | 1070 | 0 | 1070 | 0 | 1070 |
| | | OHL Senaki 1 | 211 | | | | | | | | |
| | | OHL Senaki 2 | 211 | | | | | | | | |
| | | OHL Khorga 1 | 200 | | | | | | | | |
| | | OHL Khorga 2 | 200 | | | | | | | | |
| | | OHL Kolkhida 2 | 192 | | | | | | | | |
| | | OHL Paliastomi 1 | 175 | | | | | | | | |
| | 110 | AT1, AT2 | (125+63) | 57 | 94 | 60 | 91 | 68 | 83 | 87 | 64 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | x0.9 | | | | | | | | |
| | | N-1 | 63x0.9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Khorga** | 220 | OHL Khorga 1 | 200 | 0 | 855 | 0 | 855 | 0 | 855 | 0 | 855 |
| | | OHL Khorga 2 | 200 | | | | | | | | |
| | | OHL Rukhi | 175 | | | | | | | | |
| | | OHL Paliastomi 2 | 175 | | | | | | | | |
| | | OHL Odishi 1 | 200 | | | | | | | | |
| | | OHL Odishi 2 | 200 | | | | | | | | |
| | 110 | AT1+AT2 | 2X200x0.9 | 45 | 279 | 105 | 219 | 225 | 99 | 335 | 0 |
| | | N-1 | 200x0.9 | | 114 | | 57 | | 0 | | 0 |
| **Batumi** | 220 | OHL Paliastomi 1 | 175 | 0 | 495 | 0 | 495 | 0 | 495 | 0 | 495 |
| | | OHL Paliastomi 2 | 175 | | | | | | | | |
| | | OHL Feria 1 | 200 | | | | | | | | |
| | | OHL Feria 2 | 200 | | | | | | | | |
| | 110 | AT1, AT2 | 2X125x0.9 | 103 | 99 | 105 | 97 | 110 | 92 | 158 | 44 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| **Jvari** | 220 | AT 500/220 | 500x0.9 | 0 | 360 | 0 | 900 | 0 | 900 | 0 | 900 |
| | | OHL Odishi 1 | 200 | | | | | | | | |
| | | OHL Odishi 2 | 200 | | | | | | | | |
| | | Khobi 1 | 200 | | | | | | | | |
| | | Leqarde 1 | 200 | | | | | | | | |
| | | Leqarde 2 | 200 | | | | | | | | |
| **Ozurgeti** | 220 | OHL Paliastomi 1 | 175 | | | 0 | 157 | 0 | 157 | 0 | 157 |
| | | OHL Guria | 175 | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | | | | | 26 | 176 | 26 | 176 |
| | | N-1 | 125x0.9 | | | | | | 75 | | 75 |
| **Sokhumi** | 220 | OHL Kolkhida 3 | 216 | 0 | 194 | 0 | 194 | 0 | 194 | 0 | 194 |
| | | OHL Iveria 1 | 261 | | | | | | | | |
| | 110 | AT1, AT2 | 2X125x0.9 | 130 | 72 | 136 | 66 | 145 | 57 | 175 | 27 |
| | | N-1 | 125x0.9 | | 0 | | 0 | | 0 | | 0 |
| **Bzifi** | 220 | OHL Salkhino | 261 | 0 | 235 | 0 | 235 | 0 | 235 | 0 | 235 |
| | | OHL Iveria 2 | 261 | | | | | | | | |
| | 110 | AT1, | 1X125x0.9 | 80 | 21 | 80 | 21 | 82 | 19 | 82 | 19 |
| | | N-1 | - | | 0 | | 0 | | 0 | | 0 |
| **Tkvarcheli** | 220 | OHL Iveria 1 | 261 | 0 | 235 | 0 | 235 | 0 | 235 | 0 | 235 |
| | | OHL Kolkhida 3 | 261 | | | | | | | | |
| | 110 | T1 | 3x40x0.9 | 34 | 63 | 34 | 63 | 35 | 62 | 38 | 59 |
| | | N-1 | 2x40x0.9 | | 30 | | 30 | | 29 | | 26 |
| **Enguri HPP** | 220 | AT 500/220 | 500x0.9 | 0 | 378 | 0 | 378 | 0 | 378 | 0 | 378 |
| | | OHL Egrisi 1 | 212 | | | | | | | | |
| | | OHL Egrisi 2 | 212 | | | | | | | | |
| | 110 | AT1 | 1X32x0.9 | 10 | 18 | 10 | 18 | 12 | 16 | 12 | 16 |
| | | N-1 | - | | 0 | | 0 | | 0 | | 0 |
| **Khrami 2HPP** | 220 | OHL Algeta | 225 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 110 | AT1,AT2 | 2X125x0.9 | 14 | 188 | 15 | 187 | 15 | 187 | 16 | 186 |
| | | N-1 | 1X125x0.9 | | 87 | | 86 | | 86 | | 85 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jinvali HPP** | 220 | OHL Lomisi | 171 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 110 | T1, | 1X63x0.9 | 21 | 30 | 21 | 30 | 22 | 29 | 22 | 29 |
| | | N-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Lajanuri HPP** | 220 | OHL Derchi | 143 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 110 | AT1 | 1X125x0.9 | 0 | 0 | 8 | 93 | 9 | 92 | 10 | 91 |
| | | N-1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Shuakhevi HPP** | 220 | OHL Feria2 | 200 | 0 | 180 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | OHL Feria 1 | 200 | | | 0 | 180 | 0 | 180 | 0 | 180 |
| | | OHL Feria 1a | 200 | 0 | 0 | | | | | | |
| | 110 | AT1 | 1X125x0.9 | _ | _ | _ | _ | 0 | 0 | 0 | 0 |
| | | N-1 | 0 | _ | _ | _ | _ | 0 | 0 | 0 | 0 |
| **Khudoni** | 220 | AT 500/220 KV [2024Y] | 500x0.9 | 0 | 0 | 0 | 540 | 0 | 540 | 0 | 720 |
| | | OHL Neskra 1 | 200 | | | | | | | | |
| | | OHL Neskra 2 | 200 | | | | | | | | |
| | | OHL Leqarde 1 | 200 (400) | | | | | | | | |
| | | OHL Leqarde 2 | 200 (400) | | | | | | | | |
| | 110 | AT1+AT2 | 2X125x0.9 | _ | _ | 15 | 187 | 23 | 179 | 27 | 175 |
| | | N-1 | 0 | _ | _ | | 86 | | 78 | | 74 |

*** - ree capacities for the given N modes. N-1 modes for these substations are not met.**
**table 10.4 shows data for the year 2017 regarding free capacities. This data might be correced during 2018.**

**Summary:**

1. In case of annual 5% or more increase of cinsumption, it is necessary to add (auto)transformer at “Gldani” substation in order to ensure uninterrupted power supply to Tbilisi population.
2. It may be necessary to strengthen 220/110 kV transformer in SS Navtlugi.
3. Alternatives of measures from 1, 2 topic can be construction of a new 220/110 kV 250 MVA SS "Varketili”.
4. It will be necessary to add new 220/110 kV autotransformer in SS Khorga in case of planned demand growth.
5. Adding of 200 MVA 220/110 kV transformer to SS Khorga will be necessary in order to fulfill N-1 criteria in case of load growth according to plan;
6. In case of load growth by 100 MW or more, it will be necessary to strengthen 220/110 kV transformers in several substation;
7. It’s preferable to reflect strengthen of 220/110 kV transformers in ten-year plan for the 2018-2028 when the data about adding 100 MW of load to the Gldani SS as well as load data for Khorga SS is clariffiied.

# 11 Short Circuit Analysis

*According to $3^2$ article (Ten-Year Network Development Plan of Georgia) of Georgian Law about*

*"Electricity and Natural Gas": The Ten-year Transmission Network of Georgia Development Plan implies:*

*g) Calculation of short circuit current for purpose of selecting of power equipment of elements planned to be built.*

*According to $33^2$ article (Studying of transmission network for planning purpose) of Grid Code: The studies to be performed for transmission Network planning may imply:*

*b) short circuit analysis*

Short circuit fault is the most common and dangerous contingency occurring in the electric power system. This event occurs when insulation of electrical circuit fails that may be caused by the lightning strike on power lines, aged or disintegrated insulators, conductor's earth fault, occurrence of animals and birds into insulation gaps, etc. The short circuit currents, which values are much higher comparing to the normal mode ones, result in overheating of electrical equipment and excessive forces between conductive parts. The proper specification of short circuit currents is necessary during designing power plants and/or substations to allow correct selection of the needed equipment. In summary, the short circuit faults may cause damages to circuit breakers, disconnect switches, current transformers and busbars due to overheating or mechanical disintegration. All such equipment is designed against certain rated short circuit currents indicated in their technical specifications. In addition, it should be noted that whenever short circuit fault occurs, the voltage rapidly drops at adjacent sections of the network badly affecting operation of synchronous and asynchronous drives operated for station service system, and if short circuiting continuous, may even cause their shutdowns. Therefore, selected electrical equipment should be capable to withstand maximum short circuit currents, together with limiting duration of any short circuit fault. The latter condition shall be provided by relay protection systems installed at power plants and substations. To summarize, it is obvious that proper estimation of short circuit currents is of particular importance for sound designing of power plants and substations.

The most dangerous is three-phase short circuit fault. As a rule, contingent currents created during such event are of the highest values and thus may cause the most severe damages to the elements of electric power system. Exactly this is a reason why electric equipment is commonly selected based on the rated three-phase short circuit current.

The values of short circuit currents change in line with system development. At each specific point of the network, the rated short circuit current increases in line with interconnecting generation and reduction of the resistance between such generation and specific point.

Therefore, introduction of the new generation facilities to the power system along with interconnection of the new linkage lines and transformers (that reduces resistance between equivalent generator and specific node) causes rise of short circuit currents. Hence, proper acknowledgement of short circuit current values is of high importance at each development stage of the power system in general and transmission network in specific. This is necessary to ensure both accurate selection of equipment for prospective/planned power stations, substations and transmission lines, and replacing appropriate power equipment if their short circuit rating fails to comply with standard requirements.

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 all cross-border OHLs are switched off was considered when calculating the minimum short circuit current values.

Short circuit currents were analysed using PSS/E software, which has integrated detail model of Georgian and neighbouring electric power systems.

The results of the analysis covering 500/400/330/220 kV transmission network of Georgia is presented in a form of appropriate tables.

Maximum and minimum values of short circuit currents and capacities are given in the following Tables 11.1 and 11.2.

**Table 11.1 Maximum ($I_{MAX}$) and minimum ($I_{MIN}$) values of symmetrical three-phase short circuit current**

| NAME | KV | $I_{MAX}$ (A) | | | | $I_{MIN}$ (A) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2019 | 2023 | 2027 | 2017 | 2019 | 2023 | 2027 |
| ENGURI | 500 | 10679 | 14280 | 17463 | 17968 | 6320 | 10011 | 9903 | 11210 |
| ZESTAPONI | 500 | 9879 | 12112 | 14161 | 14446 | 5459 | 8734 | 9099 | 9257 |
| KSANI | 500 | 9559 | 11389 | 14553 | 14448 | 4308 | 6670 | 7080 | 6943 |
| GARDABANI | 500 | 10744 | 10928 | 15387 | 15273 | 4137 | 6373 | 6816 | 6630 |
| AKHALTSIKHE | 500 | 8133 | 11897 | 14082 | 14379 | 4624 | 8679 | 9108 | 8700 |
| MARNEULI | 500 | 10222 | 11150 | 14910 | 14818 | 4260 | 6670 | 7123 | 6931 |
| JVARI | 500 | 9968 | 13576 | 17429 | 17938 | 6073 | 9919 | 9786 | 11133 |
| STEPANTSMINDA | 500 | *** | *** | 7987 | 8234 | *** | *** | 3983 | 4022 |
| TSAGERI | 500 | *** | *** | 7354 | 7570 | *** | *** | 6035 | 3442 |
| KHUDONI | 500 | *** | *** | *** | 14477 | *** | *** | *** | 9008 |
| TSKHALTUBO | 500 | *** | *** | 14114 | 14498 | *** | *** | 8921 | 10038 |
| AKHALTS-INV | 400 | 9966 | 10118 | 10063 | 10063 | 9822 | 9950 | 9924 | 9945 |
| GARDABANI | 330 | 7520 | 4697 | 8440 | 8322 | 3148 | 3873 | 4058 | 3994 |
| ENGURI | 220 | 13178 | 16095 | 16099 | 15929 | 9748 | 11961 | 12781 | 13961 |
| VARDNILI | 220 | 13210 | 16677 | 17778 | 17770 | 9778 | 11659 | 12549 | 14026 |
| TKVARCHELI | 220 | 5663 | 6276 | 6196 | 6203 | 4891 | 5436 | 5762 | 5945 |
| SOKHUMI | 220 | 2692 | 2856 | 2849 | 2850 | 2495 | 2687 | 2645 | 2821 |
| BZIFI | 220 | 1587 | 1661 | 1646 | 1637 | 1513 | 1609 | 1581 | 1655 |
| KHORGA | 220 | 14389 | 18368 | 19288 | 19951 | 10784 | 14564 | 14982 | 16626 |
| BATUMI | 220 | 10050 | 11226 | 12489 | 12249 | 7761 | 10129 | 10187 | 10523 |
| ZUGDIDI | 220 | 9854 | 10983 | 11522 | 11567 | 7877 | 9367 | 9342 | 10562 |
| MENJI | 220 | 13664 | 17083 | 18404 | 19367 | 10449 | 14227 | 14868 | 16231 |
| TSKALTUBO | 220 | 11041 | 16526 | 23375 | 29692 | 9031 | 17167 | 20720 | 21835 |
| QUTAISI | 220 | 13644 | 17506 | 20437 | 21696 | 10368 | 15858 | 16671 | 17571 |
| ZESTAPONI | 220 | 14691 | 20452 | 22585 | 23780 | 10531 | 16896 | 17759 | 18568 |
| LAJANURI | 220 | 5387 | 18752 | 20569 | 25596 | 4975 | 14812 | 19004 | 18361 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| KHASHURI | 220 | 5811 | 6339 | 7046 | 7040 | 4754 | 6203 | 6387 | 6426 |
| GORI | 220 | 6107 | 6442 | 7801 | 7708 | 4805 | 6658 | 6764 | 6598 |
| KSANI | 220 | 15716 | 16718 | 20748 | 20489 | 8524 | 12302 | 13079 | 13104 |
| JINVALI | 220 | 6220 | 6534 | 7068 | 6961 | 4735 | 5513 | 5603 | 6239 |
| GLDANI | 220 | 12131 | 12322 | 14804 | 14550 | 6935 | 9521 | 10074 | 9955 |
| GURJAANI | 220 | 3652 | 3837 | 4051 | 3953 | 2951 | 3513 | 3480 | 3480 |
| NAGTLUGHI | 220 | 11118 | 11189 | 13517 | 13285 | 6434 | 8796 | 9294 | 9201 |
| GARDABANI | 220 | 20903 | 20021 | 29823 | 29519 | 8432 | 12228 | 13582 | 12722 |
| MARNEULI | 220 | 17071 | 17274 | 22419 | 22128 | 8167 | 11682 | 12614 | 12210 |
| LISI | 220 | 14626 | 15182 | 18541 | 18276 | 7938 | 11152 | 11854 | 11775 |
| DIDUBE | 220 | 12459 | 12847 | 15233 | 14980 | 7243 | 9856 | 10394 | 10365 |
| KHRAMI-2 | 220 | 5006 | 4975 | 5352 | 5232 | 3360 | 4188 | 4258 | 4546 |
| RUSTAVI | 220 | 13526 | 13588 | 17244 | 16967 | 7071 | 9848 | 10579 | 10102 |
| AKHALTSIKHE | 220 | 10760 | 12243 | 14948 | 14506 | 7754 | 11665 | 11744 | 11826 |
| MTKVARI-HESI | 220 | *** | 9619 | 5813 | 5679 | *** | 5017 | 5257 | 5360 |
| FARAVANI | 220 | 4593 | 4757 | 5970 | 5836 | 3449 | 4820 | 4979 | 5182 |
| JVARI | 220 | 12025 | 17501 | 22993 | 23328 | 9215 | 15844 | 15884 | 17832 |
| KHOBI-2 | 220 | *** | 11624 | 13070 | 13190 | *** | 10474 | 10550 | 11302 |
| OZURGETI | 220 | *** | 7088 | 7020 | 7020 | *** | 6406 | 6421 | 6637 |
| KOROMKHETI | 220 | *** | *** | 11988 | 11197 | *** | *** | 11025 | 12237 |
| SHUAKHEVI | 220 | 6955 | 7225 | 7551 | 7398 | 6043 | 6093 | 6854 | 6200 |
| MESTIA | 220 | *** | 10265 | 13701 | 14125 | *** | 11148 | 11465 | 12330 |
| KHUDONI | 220 | *** | 10343 | 23179 | 23260 | *** | 15271 | 16742 | 17325 |
| SADMELI | 220 | *** | *** | 17786 | 21306 | *** | *** | 15835 | 15912 |
| TSAGERI | 220 | *** | *** | 21879 | 25509 | *** | *** | 19316 | 17226 |
| LENTEKHI | 220 | *** | *** | 18453 | 20028 | *** | *** | 16233 | 15005 |
| TVISHI | 220 | *** | *** | 20933 | 21580 | *** | *** | 16435 | 16514 |
| NAMAKHVANI | 220 | *** | *** | 21334 | 21994 | *** | *** | 16313 | 16532 |
| JONETI | 220 | *** | *** | 9759 | 10061 | *** | *** | 8401 | 8538 |
| ONI | 220 | *** | *** | 15112 | 15261 | *** | *** | 11788 | 11899 |
| NENSKRA | 220 | *** | 20378 | 20378 | 20352 | *** | 13546 | 13546 | 15486 |

**Table 11.2 Maximum ($S_{MAX}$) and minimum ($S_{MIN}$) values of short-circuit capacity**

| NAME | KV | $S_{MAX}$ (MVA) | | | | $S_{MIN}$ (MVA) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2019 | 2023 | 2027 | 2017 | 2019 | 2023 | 2027 |
| ENGURI | 500 | 9248 | 12367 | 15123 | 15561 | 5473 | 8670 | 8576 | 9708 |
| ZESTAPONI | 500 | 8555 | 10489 | 12264 | 12511 | 4728 | 7564 | 7880 | 8017 |
| KSANI | 500 | 8278 | 9863 | 12603 | 12512 | 3731 | 5771 | 6131 | 6013 |
| GARDABANI | 500 | 9305 | 9464 | 13326 | 13227 | 3583 | 5519 | 5903 | 5742 |
| AKHALTSIKHE | 500 | 7043 | 10303 | 12195 | 12453 | 4005 | 7516 | 7888 | 7534 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| MARNEULI | 500 | 8853 | 9656 | 12912 | 12833 | 3689 | 5775 | 6169 | 6002 |
| JVARI | 500 | 8633 | 11757 | 15094 | 15535 | 5259 | 8590 | 8475 | 9641 |
| STEPANTSMINDA | 500 | *** | *** | 6917 | 7131 | *** | *** | 3449 | 3483 |
| TSAGERI | 500 | *** | *** | 6369 | 6556 | *** | *** | 5226 | 2981 |
| KHUDONI | 500 | *** | *** | *** | 12537 | *** | *** | *** | 7801 |
| TSKHALTUBO | 500 | *** | *** | 10751 | 11083 | *** | *** | 7379 | 7827 |
| AKHALTS-INV | 400 | 6905 | 7010 | 6972 | 6972 | 6805 | 6894 | 6876 | 6890 |
| GARDABANI | 330 | 4298 | 2685 | 4824 | 4757 | 1799 | 2214 | 2319 | 2283 |
| ENGURI | 220 | 5021 | 6133 | 6135 | 6070 | 3714 | 4558 | 4870 | 5320 |
| VARDNILI | 220 | 5034 | 6355 | 6774 | 6771 | 3726 | 4443 | 4782 | 5345 |
| TKVARCHELI | 220 | 2158 | 2391 | 2361 | 2364 | 1864 | 2071 | 2196 | 2265 |
| SOKHUMI | 220 | 1026 | 1088 | 1086 | 1086 | 951 | 1024 | 1008 | 1075 |
| BZIFI | 220 | 605 | 633 | 627 | 624 | 577 | 613 | 602 | 631 |
| KHORGA | 220 | 5483 | 6999 | 7350 | 7602 | 4109 | 5550 | 5709 | 6335 |
| BATUMI | 220 | 3830 | 4278 | 4759 | 4667 | 2957 | 3860 | 3882 | 4010 |
| ZUGDIDI | 220 | 3755 | 4185 | 4390 | 4408 | 3002 | 3569 | 3560 | 4025 |
| MENJI | 220 | 5207 | 6509 | 7013 | 7380 | 3982 | 5421 | 5665 | 6185 |
| TSKALTUBO | 220 | 4207 | 6297 | 8907 | 11314 | 3441 | 6542 | 7895 | 8320 |
| QUTAISI | 220 | 5199 | 6671 | 7788 | 8267 | 3951 | 6043 | 6349 | 6695 |
| ZESTAPONI | 220 | 5598 | 7793 | 8606 | 9061 | 4013 | 6438 | 6767 | 7075 |
| LAJANURI | 220 | 2053 | 7145 | 7838 | 9753 | 1896 | 5644 | 7241 | 6996 |
| KHASHURI | 220 | 2214 | 2415 | 2685 | 2683 | 1812 | 2364 | 2434 | 2449 |
| GORI | 220 | 2327 | 2455 | 2973 | 2937 | 1831 | 2537 | 2577 | 2514 |
| KSANI | 220 | 5989 | 6370 | 7906 | 7807 | 3248 | 4688 | 4984 | 4993 |
| JINVALI | 220 | 2370 | 2490 | 2693 | 2652 | 1804 | 2101 | 2135 | 2377 |
| GLDANI | 220 | 4623 | 4695 | 5641 | 5544 | 2643 | 3628 | 3839 | 3793 |
| GURJAANI | 220 | 1392 | 1462 | 1544 | 1506 | 1124 | 1339 | 1326 | 1326 |
| NAGTLUGHI | 220 | 4237 | 4264 | 5151 | 5062 | 2452 | 3352 | 3541 | 3506 |
| GARDABANI | 220 | 7965 | 7629 | 11364 | 11248 | 3213 | 4659 | 5175 | 4848 |
| MARNEULI | 220 | 6505 | 6582 | 8543 | 8432 | 3112 | 4451 | 4807 | 4653 |
| LISI | 220 | 5573 | 5785 | 7065 | 6964 | 3025 | 4249 | 4517 | 4487 |
| DIDUBE | 220 | 4748 | 4895 | 5805 | 5708 | 2760 | 3756 | 3961 | 3950 |
| KHRAMI-2 | 220 | 1908 | 1896 | 2039 | 1994 | 1280 | 1596 | 1623 | 1732 |
| RUSTAVI | 220 | 5154 | 5178 | 6571 | 6465 | 2694 | 3753 | 4031 | 3849 |
| AKHALTSIKHE | 220 | 4100 | 4665 | 5696 | 5528 | 2955 | 4445 | 4475 | 4506 |
| MTKVARI-HESI | 220 | *** | 3665 | 2215 | 2164 | *** | 1912 | 2003 | 2042 |
| FARAVANI | 220 | 1750 | 1813 | 2275 | 2224 | 1314 | 1837 | 1897 | 1975 |
| JVARI | 220 | 4582 | 6670 | 8762 | 8889 | 3511 | 6037 | 6053 | 6795 |
| KHOBI-2 | 220 | *** | 4429 | 4980 | 5026 | *** | 3991 | 4020 | 4307 |
| OZURGETI | 220 | *** | 2701 | 2675 | 2675 | *** | 2441 | 2446 | 2529 |
| KOROMKHETI | 220 | *** | *** | 4568 | 4267 | *** | *** | 4201 | 4663 |
| SHUAKHEVI | 220 | 2650 | 2753 | 2877 | 2819 | 2303 | 2322 | 2612 | 2363 |
| MESTIA | 220 | *** | 3911 | 5221 | 5382 | *** | 4248 | 4369 | 4698 |
| KHUDONI | 220 | *** | 3941 | 8832 | 8863 | *** | 5819 | 6380 | 6602 |
| SADMELI | 220 | *** | *** | 6777 | 8119 | *** | *** | 6034 | 6063 |
| TSAGERI | 220 | *** | *** | 8337 | 9720 | *** | *** | 7360 | 6564 |
| LENTEKHI | 220 | *** | *** | *** | 7632 | *** | *** | *** | 5718 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TVISHI | 220 | *** | *** | 7977 | 8223 | *** | *** | 6263 | 6293 |
| NAMAKHVANI | 220 | *** | *** | 8129 | 8381 | *** | *** | 6216 | 6300 |
| JONETI | 220 | *** | *** | 3719 | 3834 | *** | *** | 3201 | 3253 |
| ONI | 220 | *** | *** | 5758 | 5815 | *** | *** | 4492 | 4534 |
| NENSKRA | 220 | *** | 6765 | 7765 | 7755 | *** | 4162 | 5162 | 5901 |

# 12 Dynamic Stability Analysis

*According to 33[2] article (Studying of transmission network for planning purpose) of Grid Code: The studies to be performed for transmission Network planning may imply:*

*b) dynamic stability analysis*

**Dynamic stability** analysis deals with power system behaviour and capability of maintaining synchronous operation of the generators during limited disturbances, such as emergency shutdowns of OHLs and generators.

Such analysis is of high importance for Georgian electric power system since west to east transfer of electricity is conducted via a single 500 kV and several parallel 220 kV lines (the latters' transmission capacities are significantly lower than one of 500 kV OHL). In addition, it should be noted that Georgian power system was originally designed as a part of the unified power network and, therefore, its largest generators (as each of Enguri HPP units and thermal power unit no. 9) have capacities of 250-300 MW amounting to 20-30% of total in-country demand during minimum consumption modes. In result, any outage of such powerful units, as well as of 500 kV OHL may cause significant disturbances in entire the national power system. Assuming the foregoing, study of the impact of such disturbances over system stability is necessary during network planning to avoid aggravation of contingencies, loss of system integrity and even full blackouts.

Transmission system should maintain stability of 500 kV and 220 kV networks under emergency tripping of the internal lines in result of operation of major protections (0.12 s). However, assuming that in the steady mode, the total transmission capacity of 500 kV OHLs is 5-times higher than the same of paralleling 220 kV lines, with similar distribution of the power flows, only emergency tripping of 500 kV OHLs may affect stability of the entire electric power system.

Dynamic stability was studied using PSS/E software (Power System Simulator for Engineers), accounting for the following network elements:

- 500/400/330/220/154/110 kV voltage elements of Georgian network, as well as part of the lower voltage transmission facilities used for interconnection of the power plants with 110 kV and higher voltage grid.
- Models and/or equivalent instruments covering Azeri, Armenian, Turkish and South Russian electric power systems.
- Synchronous generators with 3 MW and higher rated capacities.

When conducting dynamic stability simulations, operation of ECS has been assumed that initiates the measures (generation or load shedding) necessary during tripping of the specific elements of Georgian power system to avoid overloading of transmission network elements and escalation of contingencies.

Comparing to other type estimations, dynamic stability analysis is the most time and effort consuming process involving modelling, adjustment of dynamic parameters of the power system and processing the obtained data, because the rated values relevant to dynamic stability study are not associated with any specific time moment, but instead are described by time dependence curves of relevant electrical (or mechanical) parameters. In addition, dynamic stability analysis of a system provides qualitative, but not quantitative description of the system. Considering all above, the calculations were performed only for typical years (exhibiting the major changes with respect to generation interconnection or network reinforcement).

Dynamic stability analysis was performed for maximum summer demand mode of Georgian electric power system for 2020, 2023 and 2027, considering the following disturbances:

- Emergency tripping of 500 kV OHLs;
- Tripping 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, 9$^{th}$ Thermal Unit and Khudoni HPP.

It should be noted that, assuming development of the transmission network in accordance with this plan, reliability state of Georgian electric power system will improve due to the following factors:

- First of all, such improvement will be supported by Tskaltubo-Zestaponi interconnection project that together with Jvari-Khorga project will allow creation of parallel loop to 500 kV OHL Imereti, which during contingencies will make possible reduction of the load shedding initiated from ECS by 300-350 MW; A bit later, double-circuit 220 kV OHL Batumi-Akhaltsikhe will additionally reduce total power of consumers to be tripped by 100 MW.
- Implementation of Jvari-Tskaltubo-Akhaltsikhe interconnection project will ensure full back up of 500 kV OHL Imereti, safe evacuation of electric power towards the east from the generation facilities located in Enguri River basin, and compliance with N-1 criterion without operation of emergency control automation (ECS).
- Implementation of Ksani-Stepantsminda-Mozdok interconnection project providing the second 500 kV link with Russia, as well as allowing full back up of 500 kV OHL Kavkasioni. This will provide for certain improvement of the reliability of the national network during trips of internal 500 kV OHLs along with parallel operation with Russian electric power system that considering the scale of the latter will serve as one of the major warranties for reliable operation of Georgian power system.
- Implementation of 400 kV OHL Akhaltsikhe-Tortum that besides increasing export capabilities will provide back up of OHL Akhaltsikhe-Borchka. In result, emergencies on the latter line will no more cause any power imbalances in Georgian electric power system.
- During analysis, improvement of speed governors and voltage regulators on the existing power units having high impact potential over reliability of Georgian electric power system has been assumed.
- Interconnection of prospective generation facilities into the network will cause increase of aggregated momentum of Georgia's electric power system, i.e. will improve its stability against contingencies. In addition, it has been assumed that such new facilities will be equipped with automatic speed and voltage control devices.

The results of simulated possible contingencies are briefly summarized in Table 12.1, where the following denotations have been used: OK - Power system maintains stability after disturbance; OK/RAS - System maintains stability after disturbance, subject to intervention of emergency control automation initiating remedial action schemes (ECS); OK/NK means system maintains stability after disturbance, provided that the North Caucasian network will allow transfer of the appropriate post-contingency power flows; in case such condition is not satisfied, the OK/RAS shall apply; SL - Loss of stability; N-1 - Trips of OHLs; G-1 - Loss of generation.

As indicated in Table 12.1, for 2020-2027, Georgian transmission network (power system) maintains stability in case of outage any internal OHL; When it comes to outage of cross border line, use of system automatic may be necessary which will restrict export in postemergency mode and respective amount of generation in Georgia in order to meet N-1 criteria for consumers of Georgia.

The diagrams presenting results of dynamic stability analysis are given in Annex D-2.

**Table 12.1 Results of dynamic stability modeling**

| | DISTURBANCE | 2020 | 2023 | 2027 |
|---|---|---|---|---|
| N-1 | ENGURI-ZESTAPONI | OK | OK | OK |
| | ENGURI-JVARI | OK | OK | OK |
| | KHUDONI-JVARI | *** | *** | OK |
| | ZESTAPONI-AKHALTSIKHE | OK | OK | OK |
| | ZESTAPONI-KSANI | OK | OK | OK |
| | KSANI-GARDABANI | OK | OK | OK |
| | KSANI-MARNEULI | OK | OK | OK |
| | GARDABANI-MARNEULI | OK | OK | OK |
| | JVARI/KHUDONI-NOVOASV. | OK/RAS | OK/NK | OK/NK |
| | MARNEULI-AIRUM | OK/NK | OK | OK |
| | GARDABANI-AGSTAFA | *** | OK | OK |
| | GARDABANI-SAMUKH | *** | OK | OK |
| | AKHALTSIKHE-BORCHKHA | OK/RAS | OK | OK |
| | AKHALTSIKHE-TORTUM | *** | OK | OK |
| | GARDABANI-ALAVERDI | *** | - | - |
| | ADJARA-HOPA | *** | *** | *** |
| | KSANI- STEPANTSMINDA | *** | OK/NK | OK/NK |
| | STEPANTSMINDA-MOZDOK | *** | OK/NK | OK/NK |
| | MARNEULI-AKHALTSIKHE | OK | OK | OK/NK |
| | JVARI-TSKALTUBO | OK | OK | OK |
| | TSKALTUBO-AKHALTSIKHE | OK | OK | OK |
| | BATUMI-MURATLI | *** | OK | OK |
| | AT-ENGURI 500/220 kV | OK | OK | OK |
| | AT-ZESTAPONI 500/220 kV | OK | OK | OK |
| | AT-KSANI 500/220 kV | OK | OK | OK |
| | AT-GARDABANI 500/220 kV | OK | OK | OK |
| | AT-AKHALTSIKHE 500/220 kV | OK | OK | OK |
| | AT-MARNEULI 500/220 kV | OK | OK | OK |
| | AT-JVARI 500/220 kV | OK | OK | OK |
| | AT-KHUDONI 500/220 kV | OK | OK | OK |
| | AT-STEPANTSMINDA 500/110 kV | *** | OK | OK |
| | UNIT B2B AKHALTSIKHE | OK/RAS | OK | OK |
| | **UNIT B2B BATUMI** | *** | OK | OK |
| G-1 | ENGURI-G1 | OK | OK | OK |
| | BLOCK N9 | *** | - | - |
| | KHUDONI-G1 | *** | OK | OK |

* - in 2023-2027, as a result of tripping above mentioned overhead lines, regimes are established after some fluctuation. This situation will be clarified after fine-tuning of electrical schemes, regimes, speed governors and excitation systems of North-Caucasus grid which is possible reason of this fluctuation in model. Otherwise, activation of system automatic and restriction of export may be necessary.

# 13 Harmonic Analysis

*According to 33[2] article (Studying of transmission network for planning purpose) of Grid Code: The studies to be performed for transmission Network planning may imply:… h) studies…*

In any electric power system, saturation of non-linear loads and electrical equipment causes generation of higher harmonics resulting in distortion of the sinusoidal voltage. The harmonics cause number of problems in electric power system. Specifically, they result in creation of undesired high frequency currents and increase of losses in customer's equipment, deterioration of production, severe interruptions in the telecommunication systems, intolerable inaccuracies in the measurement and metering circuits, and often provoke false operation of relay protection devices.

In summary, generation of harmonics deteriorates operating parameters of the system, as well as reduces its reliability level, worsens power quality, and even may lead to emergencies.

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 and concstruction of 700 MW HVDC back-to-back station in Armenia, near to Georgia border which will be connected to Georgian transmission network.

Considering that the minimum demand of Georgian power system is 1000 MW, and the maximum demand projected for 2027 does not exceed 2500 MW, it is obvious that total capacity of back-to-back links connected to Georgian network will be close, or even exceed the total internal demand. Operation of several HVDC back-to-back stations in the network leads to superimposition of their higher harmonics that in turn causes growth of the aggregated harmonic distortion calling for additional harmonics suppression measures. Due to such reasons, performance of harmonic analysis for all feasible operating modes of Georgian transmission network and identification of maximum individual and aggregated harmonic distortions is necessary.

Harmonic analysis has been performed using power system analysis software DIgSILENT PowerFactory. The model generated by this software fully covered electric power networks of Georgia and its neighbouring states.

The results of completed analysis are given in tabulated and chart formats. The tables provide the values of individual harmonics (h5, h7, h11, ...) and total harmonic distortion factors (THD-Total Harmonic Distortion) for all 500 kV substations and 220 kV SS Batumi which will be interconnected to 350 kV back-to-back link.

For the base case (N), the tables give both individual and total THDs, while for single contingency (N-1) mode assuming loss of 500 kV or 220 kV OHL, only the total distortion factors are shown.

Results of harmonic analysis have been taken from previous version of TYNDP document. Despite of partly decrease of accuracy, as far as main defining element of harmonic distortion in transmission grid of Georgia is power exported through Back to back stations as well as their technical data (powers, commissioning dates) remained unchanged, such approach by engineering point of view is enough.

## Results of harmonic analysis for normal operating mode (N)

**Table 13.1 Results of harmonic analysis for normal operating mode (N) 2017 y.**

| 2 0 1 7 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SS** | **h5** | **h7** | **h11** | **h13** | **h17** | **h19** | **h23** | **h25** | **h29** | **h31** | **h35** | **h37** | **THD** |
| Enguri | 0.099 | 0.129 | 0.201 | 0.228 | 0.008 | 0.015 | 0.03 | 0.03 | 0.004 | 0.008 | 0 | 0.01 | **0.348** |
| Zestaponi | 0.084 | 0.017 | 0.392 | 1.247 | 0.031 | 0.069 | 0.039 | 0.005 | 0.003 | 0.038 | 0.009 | 0.087 | **1.316** |
| Ksani | 0.093 | 0.255 | 0.142 | 0.529 | 0.035 | 0.063 | 0.051 | 0.007 | 0 | 0.022 | 0.009 | 0.052 | **0.620** |
| Gardabani | 0.082 | 0.252 | 0.244 | 1.023 | 0.02 | 0.013 | 0.033 | 0.039 | 0 | 0.014 | 0.025 | 0.076 | **1.089** |
| Marneuli | 0.085 | 0.238 | 0.139 | 0.774 | 0.007 | 0.031 | 0.064 | 0.05 | 0.007 | 0.019 | 0.043 | 0.013 | **0.832** |
| Akhaltsikhe | 0.047 | 0.112 | 0.568 | 0.883 | 0.022 | 0.044 | 0.204 | 0.148 | 0.009 | 0.005 | 0.051 | 0.017 | **1.089** |
| Jvari | 0.099 | 0.129 | 0.203 | 0.265 | 0.008 | 0.018 | 0.033 | 0.029 | 0 | 0.006 | 0 | 0.01 | **0.375** |

**Table 13.2 Results of harmonic analysis for normal operating mode (N) 2018 y.**

| 2 0 1 8 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SS** | **h5** | **h7** | **h11** | **h13** | **h17** | **h19** | **h23** | **h25** | **h29** | **h31** | **h35** | **h37** | **THD** |
| Enguri | 0.109 | 0.142 | 0.221 | 0.251 | 0.009 | 0.017 | 0.033 | 0.033 | 0.004 | 0.009 | 0.000 | 0.011 | **0.383** |
| Zestaponi | 0.092 | 0.019 | 0.431 | 1.372 | 0.034 | 0.076 | 0.043 | 0.006 | 0.003 | 0.042 | 0.010 | 0.096 | **1.448** |
| Ksani | 0.102 | 0.281 | 0.156 | 0.582 | 0.039 | 0.069 | 0.056 | 0.008 | 0.000 | 0.024 | 0.010 | 0.057 | **0.682** |
| Gardabani | 0.090 | 0.277 | 0.268 | 1.125 | 0.022 | 0.014 | 0.036 | 0.043 | 0.000 | 0.015 | 0.028 | 0.084 | **1.198** |
| Marneuli | 0.094 | 0.262 | 0.153 | 0.851 | 0.008 | 0.034 | 0.070 | 0.055 | 0.008 | 0.021 | 0.047 | 0.014 | **0.915** |
| Akhaltsikhe | 0.052 | 0.123 | 0.625 | 0.971 | 0.024 | 0.048 | 0.224 | 0.163 | 0.010 | 0.006 | 0.056 | 0.019 | **1.198** |
| Jvari | 0.109 | 0.142 | 0.223 | 0.292 | 0.009 | 0.020 | 0.036 | 0.032 | 0.000 | 0.007 | 0.000 | 0.011 | **0.412** |

**Table 13.3 Results of harmonic analysis for normal operating mode (N) 2019 y.**

| 2 0 1 9 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SS** | **h5** | **h7** | **h11** | **h13** | **h17** | **h19** | **h23** | **h25** | **h29** | **h31** | **h35** | **h37** | **THD** |
| Enguri | 0.125 | 0.163 | 0.254 | 0.288 | 0.010 | 0.019 | 0.038 | 0.038 | 0.005 | 0.010 | 0.000 | 0.013 | **0.440** |
| Zestaponi | 0.106 | 0.022 | 0.496 | 1.577 | 0.039 | 0.087 | 0.049 | 0.006 | 0.004 | 0.048 | 0.011 | 0.110 | **1.665** |
| Ksani | 0.118 | 0.323 | 0.180 | 0.669 | 0.044 | 0.080 | 0.065 | 0.009 | 0.000 | 0.028 | 0.011 | 0.066 | **0.785** |
| Gardabani | 0.104 | 0.319 | 0.309 | 1.294 | 0.025 | 0.016 | 0.042 | 0.049 | 0.000 | 0.018 | 0.032 | 0.096 | **1.378** |
| Marneuli | 0.108 | 0.301 | 0.176 | 0.979 | 0.009 | 0.039 | 0.081 | 0.063 | 0.009 | 0.024 | 0.054 | 0.016 | **1.053** |
| Akhaltsikhe | 0.059 | 0.142 | 0.719 | 1.117 | 0.028 | 0.056 | 0.258 | 0.187 | 0.011 | 0.006 | 0.065 | 0.022 | **1.378** |
| Jvari | 0.125 | 0.163 | 0.257 | 0.335 | 0.010 | 0.023 | 0.042 | 0.037 | 0.000 | 0.008 | 0.000 | 0.013 | **0.474** |

**Table 13.4 Results of harmonic analysis for normal operating mode (N) 2020 y.**

| 2 0 2 0 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SS** | **h5** | **h7** | **h11** | **h13** | **h17** | **h19** | **h23** | **h25** | **h29** | **h31** | **h35** | **h37** | **THD** |
| Enguri | 0.152 | 0.197 | 0.308 | 0.349 | 0.012 | 0.023 | 0.046 | 0.046 | 0.006 | 0.012 | 0.001 | 0.015 | **0.533** |
| Zestaponi | 0.129 | 0.026 | 0.600 | 1.909 | 0.047 | 0.106 | 0.060 | 0.008 | 0.005 | 0.058 | 0.014 | 0.133 | **2.015** |
| Ksani | 0.142 | 0.390 | 0.217 | 0.810 | 0.054 | 0.096 | 0.078 | 0.011 | 0.002 | 0.034 | 0.014 | 0.080 | **0.949** |
| Gardabani | 0.126 | 0.386 | 0.373 | 1.566 | 0.031 | 0.020 | 0.051 | 0.060 | 0.001 | 0.021 | 0.038 | 0.116 | **1.667** |
| Marneuli | 0.130 | 0.364 | 0.213 | 1.185 | 0.011 | 0.047 | 0.098 | 0.077 | 0.011 | 0.029 | 0.066 | 0.020 | **1.274** |
| Akhaltsikhe | 0.072 | 0.171 | 0.869 | 1.352 | 0.034 | 0.067 | 0.312 | 0.227 | 0.014 | 0.008 | 0.078 | 0.026 | **1.667** |
| Jvari | 0.152 | 0.197 | 0.311 | 0.406 | 0.012 | 0.028 | 0.051 | 0.044 | 0.001 | 0.009 | 0.001 | 0.015 | **0.573** |
| Tskaltubo | 0.215 | 0.252 | 0.410 | 0.535 | 0.016 | 0.036 | 0.067 | 0.059 | 0.002 | 0.012 | 0.002 | 0.020 | **0.757** |
| Batumi | 0.087 | 0.208 | 1.056 | 1.642 | 0.041 | 0.082 | 0.379 | 0.275 | 0.017 | 0.009 | 0.095 | 0.032 | **2.025** |

**Table 13.5 Results of harmonic analysis for normal operating mode (N) 2021 y.**

| 2 0 2 1 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | h5 | h7 | h11 | h13 | h17 | h19 | h23 | h25 | h29 | h31 | h35 | h37 | THD |
| Enguri | 0.182 | 0.237 | 0.369 | 0.419 | 0.015 | 0.028 | 0.055 | 0.055 | 0.007 | 0.015 | 0.001 | 0.018 | **0.639** |
| Zestaponi | 0.154 | 0.031 | 0.720 | 2.290 | 0.057 | 0.127 | 0.072 | 0.009 | 0.006 | 0.070 | 0.017 | 0.160 | **2.418** |
| Ksani | 0.171 | 0.468 | 0.261 | 0.972 | 0.064 | 0.116 | 0.094 | 0.013 | 0.002 | 0.040 | 0.017 | 0.096 | **1.139** |
| Gardabani | 0.151 | 0.463 | 0.448 | 1.879 | 0.037 | 0.024 | 0.061 | 0.072 | 0.002 | 0.026 | 0.046 | 0.140 | **2.000** |
| Marneuli | 0.156 | 0.437 | 0.255 | 1.422 | 0.013 | 0.057 | 0.118 | 0.092 | 0.013 | 0.035 | 0.079 | 0.024 | **1.528** |
| Akhaltsikhe | 0.086 | 0.206 | 1.043 | 1.622 | 0.040 | 0.081 | 0.375 | 0.272 | 0.017 | 0.009 | 0.094 | 0.031 | **2.000** |
| Jvari | 0.182 | 0.237 | 0.373 | 0.487 | 0.015 | 0.033 | 0.061 | 0.053 | 0.002 | 0.011 | 0.001 | 0.018 | **0.688** |
| Tskaltubo | 0.231 | 0.260 | 0.440 | 0.535 | 0.016 | 0.036 | 0.067 | 0.059 | 0.002 | 0.012 | 0.002 | 0.020 | **0.759** |
| Stepantsminda | 0.169 | 0.464 | 0.258 | 0.962 | 0.064 | 0.115 | 0.093 | 0.013 | 0.002 | 0.040 | 0.016 | 0.095 | **1.128** |
| Batumi | 0.093 | 0.222 | 1.127 | 1.752 | 0.044 | 0.087 | 0.405 | 0.294 | 0.018 | 0.010 | 0.101 | 0.034 | **2.160** |

**Table 13.6 Results of harmonic analysis for normal operating mode (N) 2022 y.**

| 2 0 2 2 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | h5 | h7 | h11 | h13 | h17 | h19 | h23 | h25 | h29 | h31 | h35 | h37 | THD |
| Enguri | 0.182 | 0.237 | 0.369 | 0.419 | 0.015 | 0.028 | 0.055 | 0.055 | 0.007 | 0.015 | 0.001 | 0.018 | **0.639** |
| Zestaponi | 0.154 | 0.031 | 0.720 | 2.290 | 0.057 | 0.127 | 0.072 | 0.009 | 0.006 | 0.070 | 0.017 | 0.160 | **2.418** |
| Ksani | 0.171 | 0.468 | 0.261 | 0.972 | 0.064 | 0.116 | 0.094 | 0.013 | 0.002 | 0.040 | 0.017 | 0.096 | **1.139** |
| Gardabani | 0.151 | 0.463 | 0.448 | 1.879 | 0.037 | 0.024 | 0.061 | 0.072 | 0.002 | 0.026 | 0.046 | 0.140 | **2.000** |
| Marneuli | 0.156 | 0.437 | 0.255 | 1.422 | 0.013 | 0.057 | 0.118 | 0.092 | 0.013 | 0.035 | 0.079 | 0.024 | **1.528** |
| Akhaltsikhe | 0.086 | 0.206 | 1.043 | 1.622 | 0.040 | 0.081 | 0.375 | 0.272 | 0.017 | 0.009 | 0.094 | 0.031 | **2.000** |
| Jvari | 0.182 | 0.237 | 0.373 | 0.487 | 0.015 | 0.033 | 0.061 | 0.053 | 0.002 | 0.011 | 0.001 | 0.018 | **0.688** |
| Tsageri | 0.164 | 0.213 | 0.332 | 0.377 | 0.013 | 0.025 | 0.050 | 0.050 | 0.007 | 0.013 | 0.002 | 0.017 | **0.575** |
| Stepantsminda | 0.169 | 0.464 | 0.258 | 0.962 | 0.064 | 0.115 | 0.093 | 0.013 | 0.002 | 0.040 | 0.016 | 0.095 | **1.128** |
| Tskaltubo | 0.200 | 0.261 | 0.410 | 0.535 | 0.016 | 0.036 | 0.067 | 0.059 | 0.002 | 0.012 | 0.002 | 0.020 | **0.757** |
| Batumi | 0.093 | 0.222 | 1.127 | 1.752 | 0.044 | 0.087 | 0.405 | 0.294 | 0.018 | 0.010 | 0.101 | 0.034 | **2.160** |

**Table 13.7 Results of harmonic analysis for normal operating mode (N) 2023 y.**

| 2 0 2 3 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | h5 | h7 | h11 | h13 | h17 | h19 | h23 | h25 | h29 | h31 | h35 | h37 | THD |
| Enguri | 0.178 | 0.232 | 0.362 | 0.410 | 0.014 | 0.027 | 0.054 | 0.054 | 0.007 | 0.014 | 0.001 | 0.018 | **0.639** |
| Zestaponi | 0.151 | 0.031 | 0.706 | 2.245 | 0.056 | 0.124 | 0.070 | 0.009 | 0.005 | 0.068 | 0.016 | 0.157 | **2.418** |
| Ksani | 0.167 | 0.459 | 0.256 | 0.952 | 0.063 | 0.113 | 0.092 | 0.013 | 0.002 | 0.040 | 0.016 | 0.094 | **1.139** |
| Gardabani | 0.148 | 0.454 | 0.439 | 1.841 | 0.036 | 0.023 | 0.059 | 0.070 | 0.002 | 0.025 | 0.045 | 0.137 | **2.000** |
| Marneuli | 0.153 | 0.428 | 0.250 | 1.393 | 0.013 | 0.056 | 0.115 | 0.090 | 0.013 | 0.034 | 0.077 | 0.023 | **1.528** |
| Akhaltsikhe | 0.085 | 0.202 | 1.022 | 1.589 | 0.040 | 0.079 | 0.367 | 0.266 | 0.016 | 0.009 | 0.092 | 0.031 | **2.000** |
| Jvari | 0.178 | 0.232 | 0.365 | 0.477 | 0.014 | 0.032 | 0.059 | 0.052 | 0.002 | 0.011 | 0.001 | 0.018 | **0.688** |
| Tsageri | 0.160 | 0.209 | 0.326 | 0.369 | 0.013 | 0.024 | 0.049 | 0.049 | 0.006 | 0.013 | 0.002 | 0.016 | **0.575** |
| Stepantsminda | 0.166 | 0.454 | 0.253 | 0.943 | 0.062 | 0.112 | 0.091 | 0.012 | 0.002 | 0.039 | 0.016 | 0.093 | **1.128** |
| Tskaltubo | 0.196 | 0.255 | 0.402 | 0.525 | 0.016 | 0.036 | 0.065 | 0.057 | 0.002 | 0.012 | 0.002 | 0.020 | **0.742** |
| Batumi | 0.091 | 0.218 | 1.104 | 1.717 | 0.043 | 0.086 | 0.397 | 0.288 | 0.017 | 0.010 | 0.099 | 0.033 | **2.117** |

**Table 13.8 Results of harmonic analysis for normal operating mode (N) 2024 y.**

| 2 0 2 4 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SS | h5 | h7 | h11 | h13 | h17 | h19 | h23 | h25 | h29 | h31 | h35 | h37 | THD |
| Enguri | 0.173 | 0.225 | 0.351 | 0.398 | 0.014 | 0.026 | 0.052 | 0.052 | 0.007 | 0.014 | 0.001 | 0.017 | **0.608** |
| Zestaponi | 0.147 | 0.030 | 0.684 | 2.177 | 0.054 | 0.120 | 0.068 | 0.009 | 0.005 | 0.066 | 0.016 | 0.152 | **2.298** |
| Ksani | 0.162 | 0.445 | 0.248 | 0.924 | 0.061 | 0.110 | 0.089 | 0.012 | 0.002 | 0.038 | 0.016 | 0.091 | **1.083** |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gardabani | 0.143 | 0.440 | 0.426 | 1.786 | 0.035 | 0.023 | 0.058 | 0.068 | 0.001 | 0.024 | 0.044 | 0.133 | **1.902** |
| Marneuli | 0.148 | 0.416 | 0.243 | 1.351 | 0.012 | 0.054 | 0.112 | 0.087 | 0.012 | 0.033 | 0.075 | 0.023 | **1.453** |
| Akhaltsikhe | 0.082 | 0.196 | 0.992 | 1.542 | 0.038 | 0.077 | 0.356 | 0.258 | 0.016 | 0.009 | 0.089 | 0.030 | **1.902** |
| Jvari | 0.173 | 0.225 | 0.354 | 0.463 | 0.014 | 0.031 | 0.058 | 0.051 | 0.002 | 0.010 | 0.001 | 0.017 | **0.654** |
| Tsageri | 0.156 | 0.203 | 0.316 | 0.358 | 0.013 | 0.024 | 0.047 | 0.047 | 0.006 | 0.013 | 0.002 | 0.016 | **0.547** |
| Stepantsminda | 0.161 | 0.441 | 0.245 | 0.914 | 0.061 | 0.109 | 0.088 | 0.012 | 0.002 | 0.038 | 0.016 | 0.090 | **1.072** |
| Khudoni | 0.156 | 0.203 | 0.319 | 0.416 | 0.013 | 0.028 | 0.052 | 0.046 | 0.001 | 0.009 | 0.001 | 0.016 | **0.589** |
| Tskaltubo | 0.190 | 0.248 | 0.390 | 0.509 | 0.015 | 0.035 | 0.063 | 0.056 | 0.002 | 0.012 | 0.002 | 0.019 | **0.719** |
| Batumi | 0.089 | 0.211 | 1.071 | 1.665 | 0.041 | 0.083 | 0.385 | 0.279 | 0.017 | 0.009 | 0.096 | 0.032 | **2.054** |

**Table 13.9 Results of harmonic analysis for normal operating mode (N) 2025-27 y.**

| 2025-2027 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SS** | **h5** | **h7** | **h11** | **h13** | **h17** | **h19** | **h23** | **h25** | **h29** | **h31** | **h35** | **h37** | **THD** |
| Enguri | 0.169 | 0.221 | 0.344 | 0.390 | 0.014 | 0.026 | 0.051 | 0.051 | 0.007 | 0.014 | 0.001 | 0.017 | **0.595** |
| Zestaponi | 0.144 | 0.029 | 0.671 | 2.134 | 0.053 | 0.118 | 0.067 | 0.009 | 0.005 | 0.065 | 0.015 | 0.149 | **2.252** |
| Ksani | 0.159 | 0.436 | 0.243 | 0.905 | 0.060 | 0.108 | 0.087 | 0.012 | 0.002 | 0.038 | 0.015 | 0.089 | **1.061** |
| Gardabani | 0.140 | 0.431 | 0.418 | 1.750 | 0.034 | 0.022 | 0.056 | 0.067 | 0.001 | 0.024 | 0.043 | 0.130 | **1.864** |
| Marneuli | 0.145 | 0.407 | 0.238 | 1.324 | 0.012 | 0.053 | 0.110 | 0.086 | 0.012 | 0.033 | 0.074 | 0.022 | **1.424** |
| Akhaltsikhe | 0.059 | 0.212 | 0.912 | 1.560 | 0.022 | 0.057 | 0.263 | 0.195 | 0.009 | 0.001 | 0.049 | 0.025 | **1.852** |
| Jvari | 0.169 | 0.221 | 0.347 | 0.453 | 0.014 | 0.031 | 0.056 | 0.050 | 0.002 | 0.010 | 0.001 | 0.017 | **0.641** |
| Tsageri | 0.152 | 0.199 | 0.310 | 0.351 | 0.012 | 0.023 | 0.046 | 0.046 | 0.006 | 0.012 | 0.002 | 0.015 | **0.536** |
| Stepantsminda | 0.158 | 0.432 | 0.241 | 0.896 | 0.059 | 0.107 | 0.086 | 0.012 | 0.002 | 0.037 | 0.015 | 0.088 | **1.051** |
| Khudoni | 0.152 | 0.199 | 0.313 | 0.408 | 0.012 | 0.028 | 0.051 | 0.045 | 0.001 | 0.009 | 0.001 | 0.015 | **0.577** |
| Tskaltubo | 0.186 | 0.243 | 0.382 | 0.499 | 0.015 | 0.034 | 0.062 | 0.055 | 0.002 | 0.011 | 0.001 | 0.019 | **0.705** |
| Batumi | 0.064 | 0.229 | 0.985 | 1.685 | 0.024 | 0.062 | 0.284 | 0.211 | 0.010 | 0.001 | 0.053 | 0.027 | **2.000** |

## Analysis results for N-1 mode

**Table 13.10 Analysis results for N-1 mode 2017 y.**

| 2017 | | | | | |
|---|---|---|---|---|---|
| **THD** | **N-1 Zekari** | **N-1 Vardzia** | **N-1 Imereti** | **N-1 Kartli-2** | **N-1 Kartli-1** |
| Enguri | 0.4176 | 0.4002 | 0.3828 | 0.3654 | 0.3584 |
| Zestaponi | 1.5794 | 1.5136 | 1.4478 | 1.3820 | 1.3557 |
| Ksani | 0.7444 | 0.7134 | 0.6823 | 0.6513 | 0.6389 |
| Gardabani | 1.3069 | 1.2524 | 1.1980 | 1.1435 | 1.1217 |
| Marneuli | 0.9985 | 0.9569 | 0.9153 | 0.8736 | 0.8570 |
| Akhaltsikhe | 1.3068 | 1.2524 | 1.1979 | 1.1435 | 1.1217 |
| Jvari | 0.4495 | 0.4308 | 0.4121 | 0.3933 | 0.3858 |

**Table 13.11 Analysis results for N-1 mode 2018 y.**

| 2018 | | | | | |
|---|---|---|---|---|---|
| **THD** | **N-1 Zekari** | **N-1 Vardzia** | **N-1 Imereti** | **N-1 Kartli-2** | **N-1 Kartli-1** |
| Enguri | 0.4593 | 0.4402 | 0.4211 | 0.4019 | 0.3943 |
| Zestaponi | 1.7374 | 1.6650 | 1.5926 | 1.5202 | 1.4913 |
| Ksani | 0.8188 | 0.7847 | 0.7506 | 0.7165 | 0.7028 |
| Gardabani | 1.4376 | 1.3777 | 1.3178 | 1.2579 | 1.2339 |
| Marneuli | 1.0983 | 1.0525 | 1.0068 | 0.9610 | 0.9427 |
| Akhaltsikhe | 1.4375 | 1.3776 | 1.3177 | 1.2578 | 1.2339 |
| Jvari | 0.4945 | 0.4739 | 0.4533 | 0.4327 | 0.4244 |

**Table 13.12 Analysis results for N-1 mode 2019 y.**

| THD | N-1 Zekari | N-1 Vardzia | N-1 Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | | | | | | |
| Enguri | 0.528 | 0.506 | 0.484 | 0.462 | 0.453 | 0.453 | 0.481 | 0.462 | 0.476 |
| Zestaponi | 1.998 | 1.915 | 1.831 | 1.748 | 1.715 | 1.715 | 1.818 | 1.749 | 1.801 |
| Ksani | 0.942 | 0.902 | 0.863 | 0.824 | 0.808 | 0.808 | 0.857 | 0.824 | 0.849 |
| Gardabani | 1.653 | 1.584 | 1.515 | 1.447 | 1.419 | 1.419 | 1.504 | 1.447 | 1.490 |
| Marneuli | 1.263 | 1.210 | 1.158 | 1.105 | 1.084 | 1.084 | 1.149 | 1.106 | 1.138 |
| Akhaltsikhe | 1.653 | 1.584 | 1.515 | 1.447 | 1.419 | 1.419 | 1.504 | 1.447 | 1.490 |
| Jvari | 0.569 | 0.545 | 0.521 | 0.498 | 0.488 | 0.488 | 0.517 | 0.498 | 0.512 |
| Batumi | 2.232 | 2.139 | 2.046 | 1.953 | 1.916 | 1.916 | 2.031 | 1.954 | 2.011 |

**Table 13.13 Analysis results for N-1 mode 2020 y.**

| THD | N-1 Jvari Tskaltubo | N-1 Tskaltubo-Akhaltsikhe | N-1 Zekari | N-1 Vardzia | N-1 Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | | | | | | | | | | |
| Enguri | 0.671 | 0.655 | 0.639 | 0.613 | 0.586 | 0.559 | 0.549 | 0.549 | 0.582 | 0.560 | 0.576 |
| Zestaponi | 2.539 | 2.478 | 2.418 | 2.317 | 2.216 | 2.115 | 2.075 | 2.075 | 2.200 | 2.117 | 2.179 |
| Ksani | 1.196 | 1.167 | 1.139 | 1.092 | 1.044 | 0.997 | 0.978 | 0.978 | 1.037 | 0.998 | 1.027 |
| Gardabani | 2.100 | 2.050 | 2.000 | 1.917 | 1.834 | 1.750 | 1.717 | 1.717 | 1.820 | 1.751 | 1.803 |
| Marneuli | 1.604 | 1.566 | 1.528 | 1.465 | 1.401 | 1.337 | 1.312 | 1.312 | 1.390 | 1.338 | 1.377 |
| Akhaltsikhe | 2.100 | 2.050 | 2.000 | 1.917 | 1.834 | 1.750 | 1.717 | 1.717 | 1.820 | 1.751 | 1.803 |
| Jvari | 0.722 | 0.705 | 0.688 | 0.659 | 0.631 | 0.602 | 0.591 | 0.591 | 0.626 | 0.602 | 0.620 |
| Tskaltubo | --- | 0.639 | 0.623 | 0.597 | 0.571 | 0.545 | 0.535 | 0.535 | 0.567 | 0.545 | 0.561 |
| Stepantsminda | 1.256 | 1.226 | 1.196 | 1.147 | 1.097 | 1.047 | 1.027 | 1.027 | 1.088 | 1.047 | 1.078 |

**Table 13.14 Analysis results for N-1 mode 2021 y.**

| THD | N-1 Jvari-Tskaltubo | N-1 Tskaltubo-Akhaltsikhe | N-1 Zekari | N-1 Vardzia | N-1 Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | | | | | | | | | | |
| Enguri | 0.805 | 0.786 | 0.767 | 0.735 | 0.703 | 0.671 | 0.658 | 0.658 | 0.698 | 0.672 | 0.691 |
| Zestaponi | 2.646 | 2.583 | 2.520 | 2.415 | 2.310 | 2.205 | 2.163 | 2.163 | 2.293 | 2.207 | 2.272 |
| Ksani | 1.435 | 1.401 | 1.367 | 1.310 | 1.253 | 1.196 | 1.174 | 1.174 | 1.244 | 1.197 | 1.232 |
| Gardabani | 2.520 | 2.460 | 2.400 | 2.300 | 2.200 | 2.100 | 2.060 | 2.060 | 2.184 | 2.102 | 2.163 |
| Marneuli | 1.926 | 1.880 | 1.834 | 1.758 | 1.681 | 1.605 | 1.574 | 1.574 | 1.669 | 1.606 | 1.653 |
| Akhaltsikhe | 2.520 | 2.460 | 2.400 | 2.300 | 2.200 | 2.100 | 2.060 | 2.060 | 2.184 | 2.102 | 2.163 |
| Jvari | 0.867 | 0.847 | 0.826 | 0.791 | 0.757 | 0.722 | 0.709 | 0.709 | 0.751 | 0.723 | 0.744 |
| Tskaltubo | --- | 0.764 | 0.745 | 0.714 | 0.683 | 0.652 | 0.640 | 0.640 | 0.678 | 0.652 | 0.672 |
| Stepantsminda | 1.508 | 1.472 | 1.436 | 1.376 | 1.316 | 1.256 | 1.232 | 1.232 | 1.306 | 1.257 | 1.294 |
| Batumi | 2.467 | 2.466 | 2.406 | 2.306 | 2.206 | 2.105 | 2.065 | 2.065 | 2.125 | 2.117 | 2.168 |

**Table 13.15 Analysis results for N-1 mode 2022 y.**

| THD | 2022 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N-1 Jvari-Tskaltubo | N-1 Tskaltubo-Akhaltsikhe | N-1 Zekari | N-1 Vardzia | N-1 Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
| Enguri | 0.765 | 0.747 | 0.729 | 0.698 | 0.668 | 0.638 | 0.625 | 0.625 | 0.663 | 0.638 | 0.657 |
| Zestaponi | 2.514 | 2.454 | 2.394 | 2.295 | 2.195 | 2.095 | 2.055 | 2.055 | 2.178 | 2.096 | 2.158 |
| Ksani | 1.364 | 1.331 | 1.299 | 1.245 | 1.191 | 1.137 | 1.115 | 1.115 | 1.182 | 1.137 | 1.171 |
| Gardabani | 2.394 | 2.337 | 2.280 | 2.185 | 2.090 | 1.995 | 1.957 | 1.957 | 2.075 | 1.997 | 2.055 |
| Marneuli | 1.829 | 1.786 | 1.742 | 1.670 | 1.597 | 1.524 | 1.495 | 1.495 | 1.585 | 1.525 | 1.570 |
| Akhaltsikhe | 2.394 | 2.337 | 2.280 | 2.185 | 2.090 | 1.995 | 1.957 | 1.957 | 2.075 | 1.996 | 2.055 |
| Jvari | 0.823 | 0.804 | 0.784 | 0.752 | 0.719 | 0.686 | 0.673 | 0.673 | 0.714 | 0.687 | 0.707 |
| Tsageri | 0.689 | 0.672 | 0.656 | 0.628 | 0.601 | 0.574 | 0.563 | 0.563 | 0.597 | 0.574 | 0.591 |
| Stepantsminda | 1.432 | 1.398 | 1.364 | 1.307 | 1.250 | 1.193 | 1.171 | 1.171 | 1.241 | 1.194 | 1.229 |
| Tskaltubo | --- | 0.933 | 0.910 | 0.781 | 0.751 | 0.658 | 0.801 | 0.809 | 0.815 | 0.796 | 0.813 |
| Batumi | 2.344 | 2.343 | 2.286 | 2.191 | 2.095 | 2.000 | 1.962 | 1.962 | 2.019 | 2.001 | 2.060 |

**Table 13.16 Analysis results for N-1 mode 2023 y.**

| THD | 2023 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N-1 Jvari Tskaltubo | N-1 Tskaltubo-Akhaltsikhe | N-1 Zekari | N-1 Vardzia | N-1 Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
| Enguri | 0.727 | 0.709 | 0.692 | 0.663 | 0.635 | 0.606 | 0.594 | 0.594 | 0.630 | 0.606 | 0.624 |
| Zestaponi | 2.389 | 2.332 | 2.275 | 2.180 | 2.085 | 1.990 | 1.952 | 1.952 | 2.070 | 1.991 | 2.050 |
| Ksani | 1.296 | 1.265 | 1.234 | 1.183 | 1.131 | 1.080 | 1.059 | 1.059 | 1.123 | 1.080 | 1.112 |
| Gardabani | 2.274 | 2.220 | 2.166 | 2.076 | 1.986 | 1.896 | 1.860 | 1.860 | 1.971 | 1.897 | 1.952 |
| Marneuli | 1.738 | 1.696 | 1.655 | 1.586 | 1.517 | 1.448 | 1.421 | 1.421 | 1.506 | 1.449 | 1.492 |
| Akhaltsikhe | 2.274 | 2.220 | 2.166 | 2.076 | 1.986 | 1.896 | 1.859 | 1.859 | 1.971 | 1.897 | 1.952 |
| Jvari | 0.782 | 0.764 | 0.745 | 0.714 | 0.683 | 0.652 | 0.640 | 0.640 | 0.678 | 0.652 | 0.672 |
| Tsageri | 0.654 | 0.639 | 0.623 | 0.597 | 0.571 | 0.545 | 0.535 | 0.535 | 0.567 | 0.545 | 0.561 |
| Stepantsminda | 1.361 | 1.328 | 1.296 | 1.242 | 1.188 | 1.134 | 1.112 | 1.112 | 1.179 | 1.134 | 1.168 |
| Tskaltubo | --- | 0.804 | 0.784 | 0.752 | 0.719 | 0.686 | 0.673 | 0.673 | 0.714 | 0.687 | 0.707 |
| Batumi | 2.226 | 2.225 | 2.171 | 2.081 | 1.991 | 1.900 | 1.864 | 1.864 | 1.918 | 1.901 | 1.957 |

**Table 13.17 Analysis results for N-1 mode 2024 y.**

| THD | 2024 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N-1 Jvari Tskaltubo | N-1 Tskaltubo-Akhaltsikh | N-1 Zekari | N-1 OHL Vardzia | N-1 OHL Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
| Enguri | 0.691 | 0.674 | 0.658 | 0.630 | 0.603 | 0.575 | 0.564 | 0.564 | 0.598 | 0.576 | 0.593 |
| Zestaponi | 2.269 | 2.215 | 2.161 | 2.071 | 1.981 | 1.891 | 1.855 | 1.855 | 1.966 | 1.892 | 1.948 |
| Ksani | 1.231 | 1.201 | 1.172 | 1.123 | 1.075 | 1.026 | 1.006 | 1.006 | 1.067 | 1.026 | 1.056 |
| Gardabani | 2.161 | 2.109 | 2.058 | 1.972 | 1.887 | 1.801 | 1.767 | 1.767 | 1.873 | 1.802 | 1.855 |
| Marneuli | 1.651 | 1.611 | 1.572 | 1.507 | 1.441 | 1.376 | 1.350 | 1.350 | 1.431 | 1.377 | 1.417 |
| Akhaltsikhe | 2.161 | 2.109 | 2.058 | 1.972 | 1.887 | 1.801 | 1.766 | 1.766 | 1.872 | 1.802 | 1.855 |
| Jvari | 0.743 | 0.726 | 0.708 | 0.678 | 0.649 | 0.619 | 0.608 | 0.608 | 0.644 | 0.620 | 0.638 |
| Tsageri | 0.622 | 0.607 | 0.592 | 0.567 | 0.543 | 0.518 | 0.508 | 0.508 | 0.538 | 0.518 | 0.533 |
| Stepantsminda | 1.293 | 1.262 | 1.231 | 1.180 | 1.128 | 1.077 | 1.056 | 1.056 | 1.120 | 1.078 | 1.109 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Khudoni | 0.726 | 0.708 | 0.691 | 0.662 | 0.633 | 0.604 | 0.593 | 0.593 | 0.628 | 0.605 | 0.622 |
| Tskaltubo | 0.826 | 0.825 | 0.805 | 0.772 | 0.738 | 0.705 | 0.691 | 0.691 | 0.733 | 0.705 | 0.726 |
| Batumi | 2.116 | 2.115 | 2.063 | 1.977 | 1.891 | 1.805 | 1.771 | 1.771 | 1.822 | 1.806 | 1.859 |

**Table 13.18 Analysis results for N-1 mode 2025-27 y.**

| | 2 0 2 5 - 2 0 2 7 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| THD | N-1 Jvari Tskaltubo | N-1 Tskaltubo-Akhaltsikhe | N-1 Zekari | N-1 Vardzia | N-1 Imereti | N-1 Kartli-2 | N-1 Kartli-1 | N-1 Paliastomi2 | N-1 Paliastomi1 | N-1 Batumi-Shuakhevi | N-1 Batumi-Koromkheti |
| Enguri | 0.656 | 0.641 | 0.625 | 0.599 | 0.573 | 0.547 | 0.536 | 0.536 | 0.568 | 0.547 | 0.563 |
| Zestaponi | 2.156 | 2.104 | 2.053 | 1.967 | 1.882 | 1.796 | 1.762 | 1.762 | 1.868 | 1.797 | 1.850 |
| Ksani | 1.170 | 1.142 | 1.114 | 1.067 | 1.021 | 0.974 | 0.956 | 0.956 | 1.013 | 0.975 | 1.004 |
| Gardabani | 2.053 | 2.004 | 1.955 | 1.874 | 1.792 | 1.711 | 1.678 | 1.678 | 1.779 | 1.712 | 1.762 |
| Marneuli | 1.569 | 1.531 | 1.494 | 1.432 | 1.369 | 1.307 | 1.282 | 1.282 | 1.359 | 1.308 | 1.346 |
| Akhaltsikhe | 2.053 | 2.004 | 1.955 | 1.874 | 1.792 | 1.711 | 1.678 | 1.678 | 1.779 | 1.712 | 1.762 |
| Jvari | 0.707 | 0.690 | 0.673 | 0.645 | 0.616 | 0.588 | 0.577 | 0.577 | 0.612 | 0.589 | 0.606 |
| Tsageri | 0.590 | 0.576 | 0.562 | 0.539 | 0.515 | 0.492 | 0.483 | 0.483 | 0.512 | 0.492 | 0.507 |
| Stepantsminda | 1.227 | 1.198 | 1.169 | 1.121 | 1.072 | 1.023 | 1.004 | 1.004 | 1.064 | 1.024 | 1.054 |
| Khudoni | 0.689 | 0.672 | 0.656 | 0.629 | 0.601 | 0.574 | 0.563 | 0.563 | 0.597 | 0.574 | 0.591 |
| Tskaltubo | --- | 0.764 | 0.745 | 0.714 | 0.683 | 0.652 | 0.640 | 0.640 | 0.678 | 0.652 | 0.672 |

According to the results, THDs for all nodes are in their normal range both for N and N-1 scenarios. 13th harmonic is out of the normal range in some extent which does not have negative impact on network operation but performing of additional calculations is required.

The following figures illustrate results of harmonic analysis for 2017 including individually each 500 kV node, as 2025 estimated THD for SS Akhaltsikhe-500 busbar.

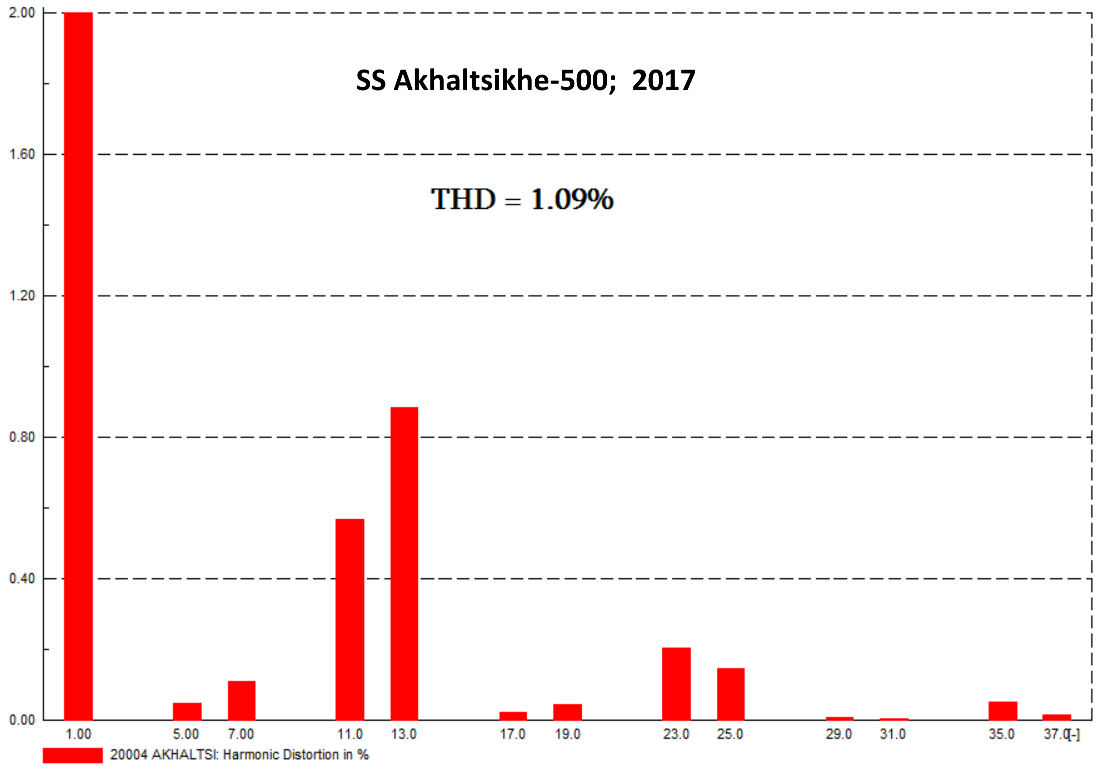



**Fig. 13.1. Harmonic components in SS Akhaltsikhe-500**

As seen from the diagram, in SS Akhaltsikhe, 13th harmonic is out of acceptable range (0.8%).

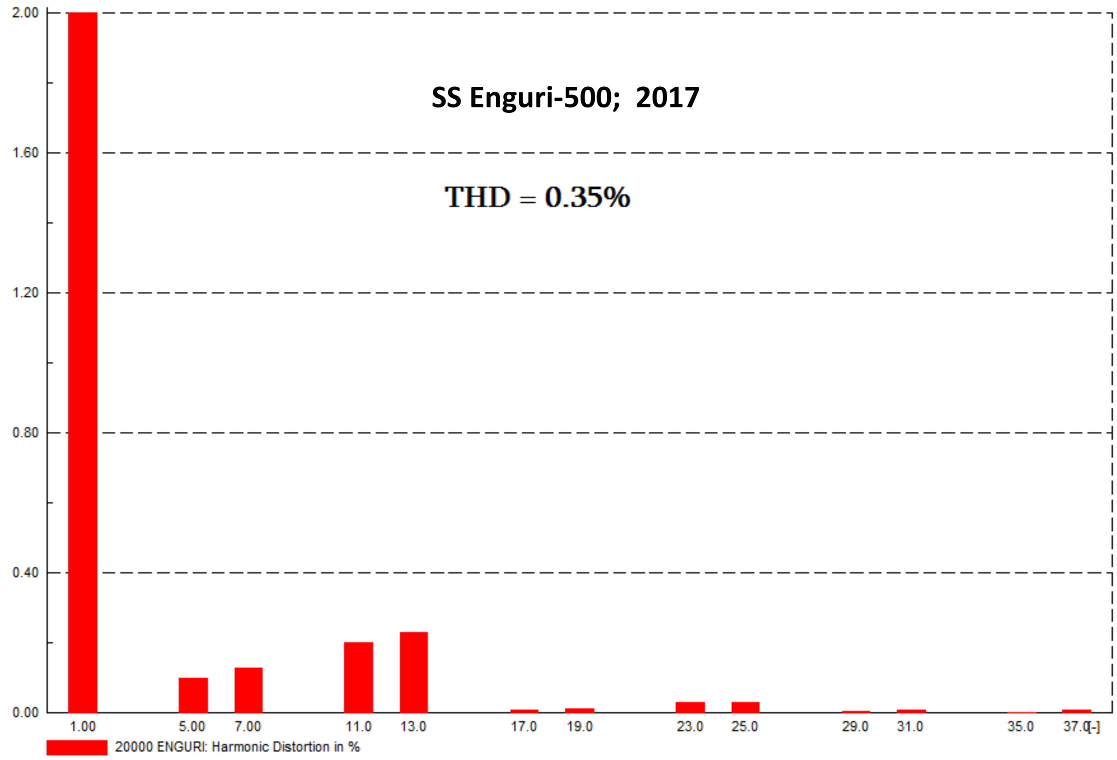



**Fig. 13.2. Harmonic components in SS Enguri-500**

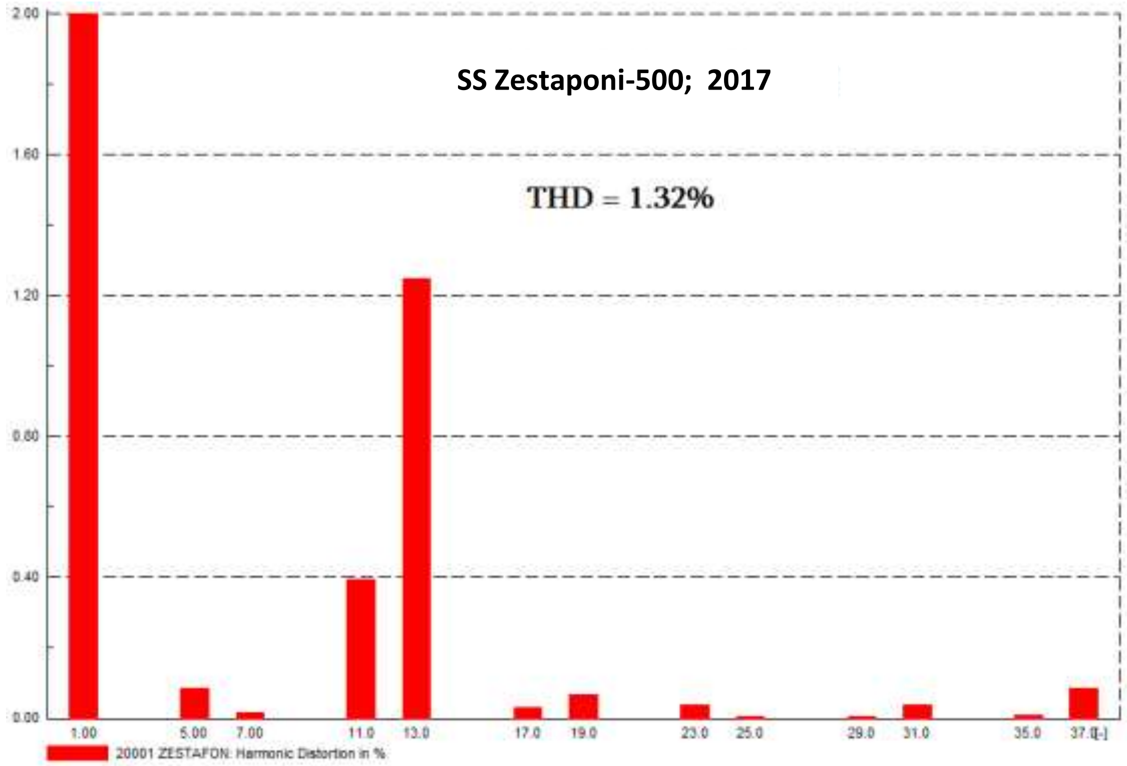



**Fig. 13.3. Harmonic components in SS Zestaponi-500**

The 13th harmonic is out of acceptable range in SS Zestaponi as well.

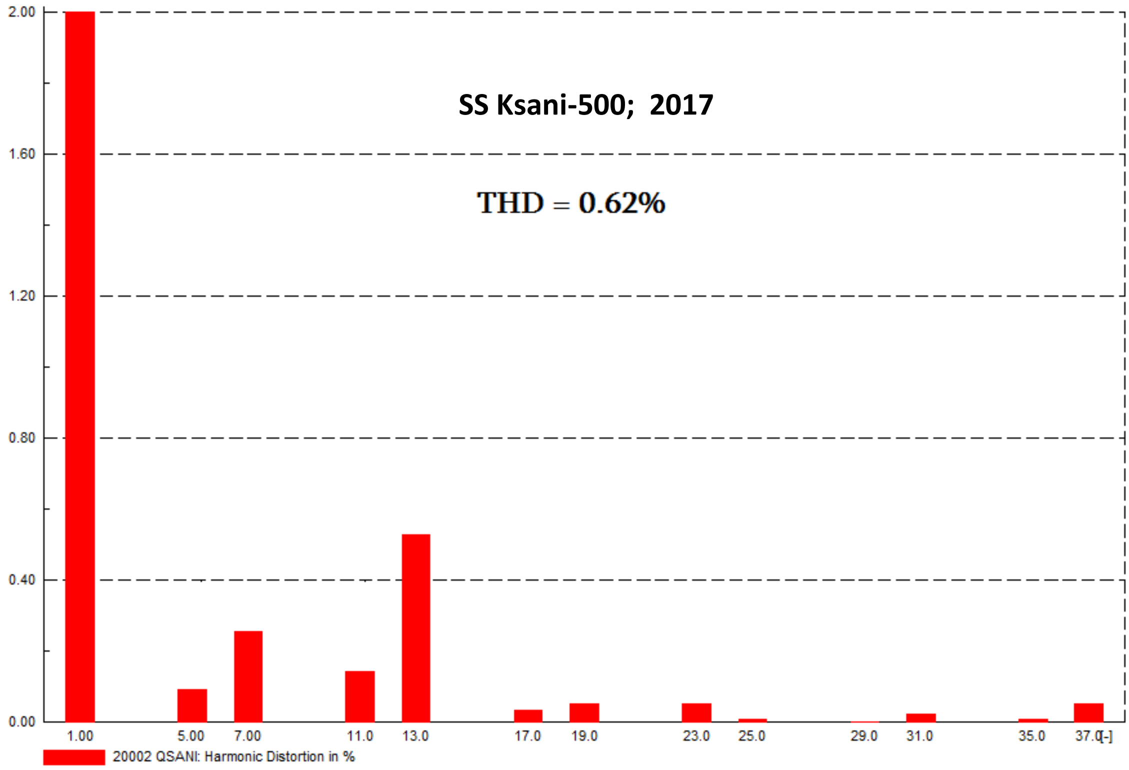



**Fig. 13.4. Harmonic components in SS Ksani-500**

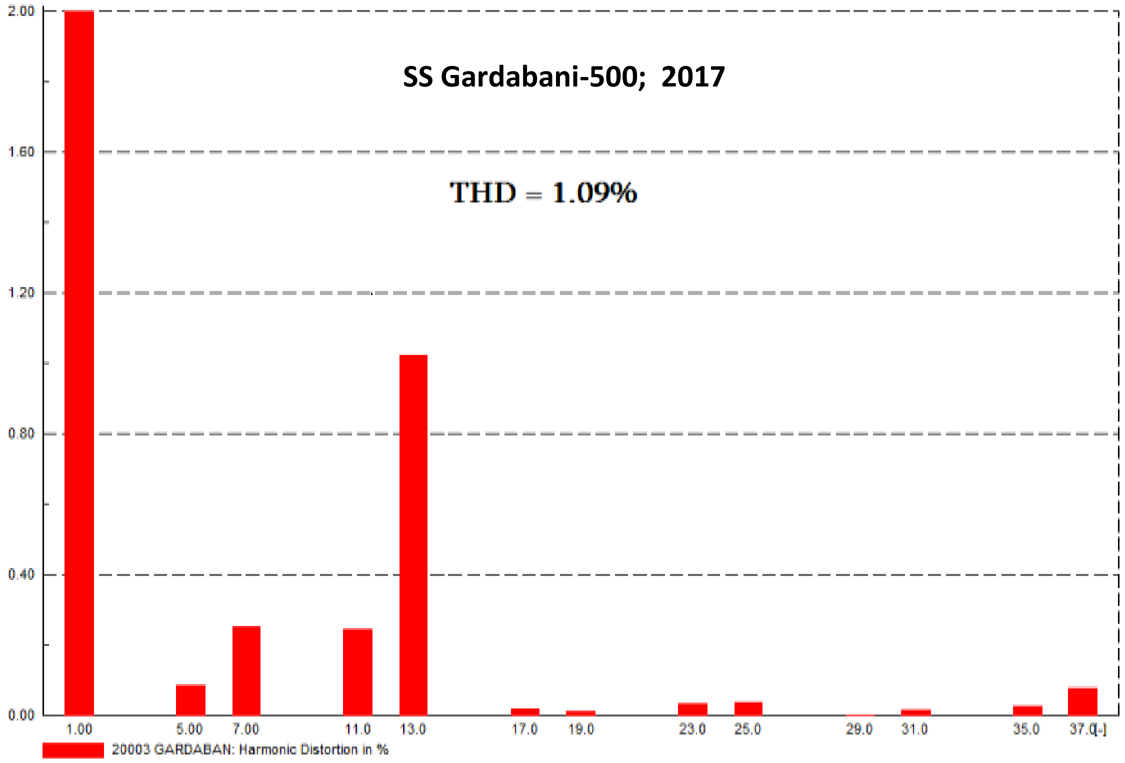



**Fig. 13.5. Harmonic components in SS Gardabani-500**

In similar to SS Akhalstikhe and SS Zestaponi, 13$^{th}$ harmonic is also out of acceptable range SS Gardabani.

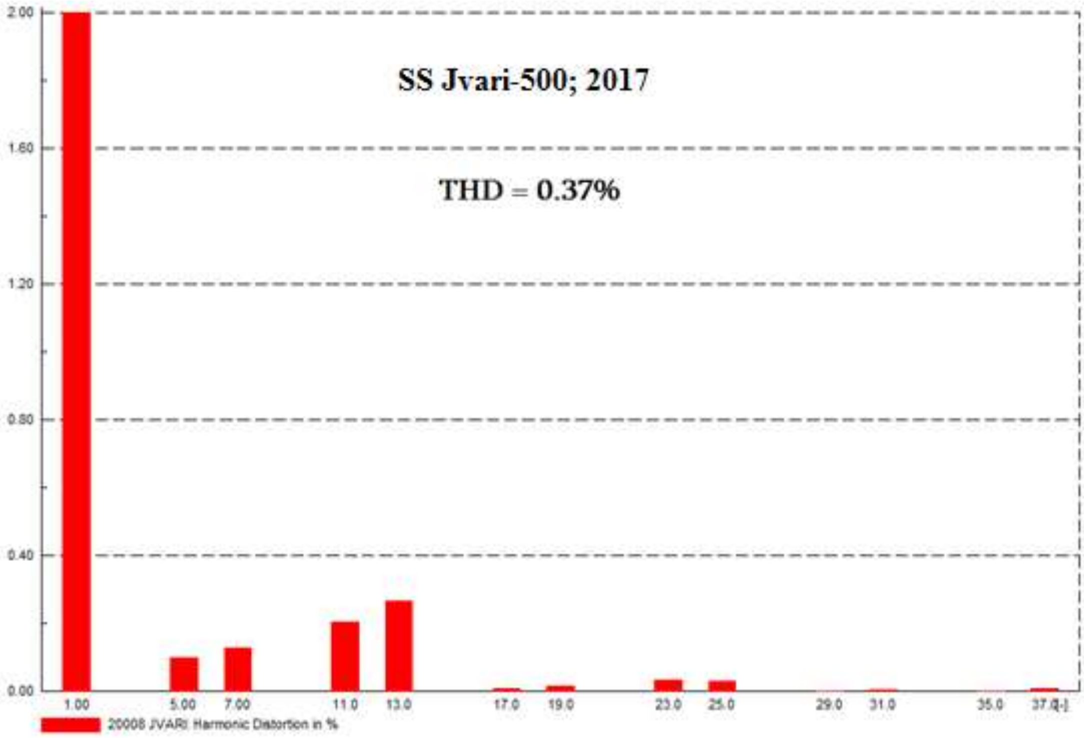



**Fig. 13.6. Harmonic components in SS Jvari-500**

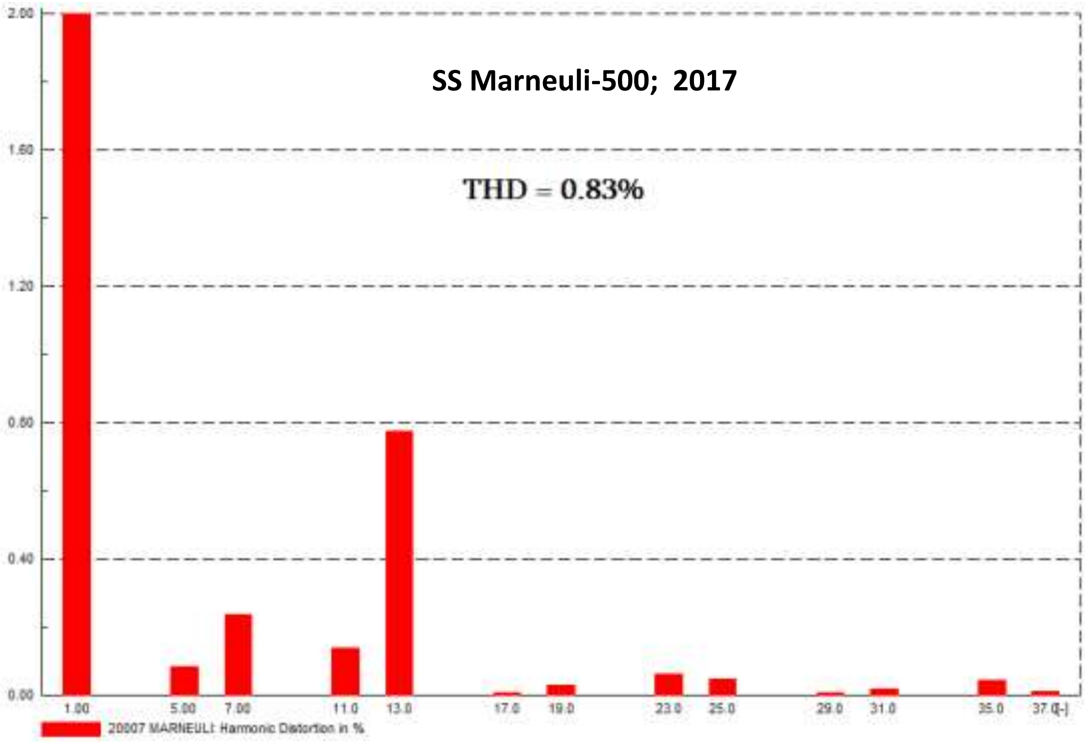



**Fig. 13.7. Harmonic components in SS Marneuli-500**

The following diagram illustrates composition of harmonics in SS Akhaltsikhe-500 for 2025.

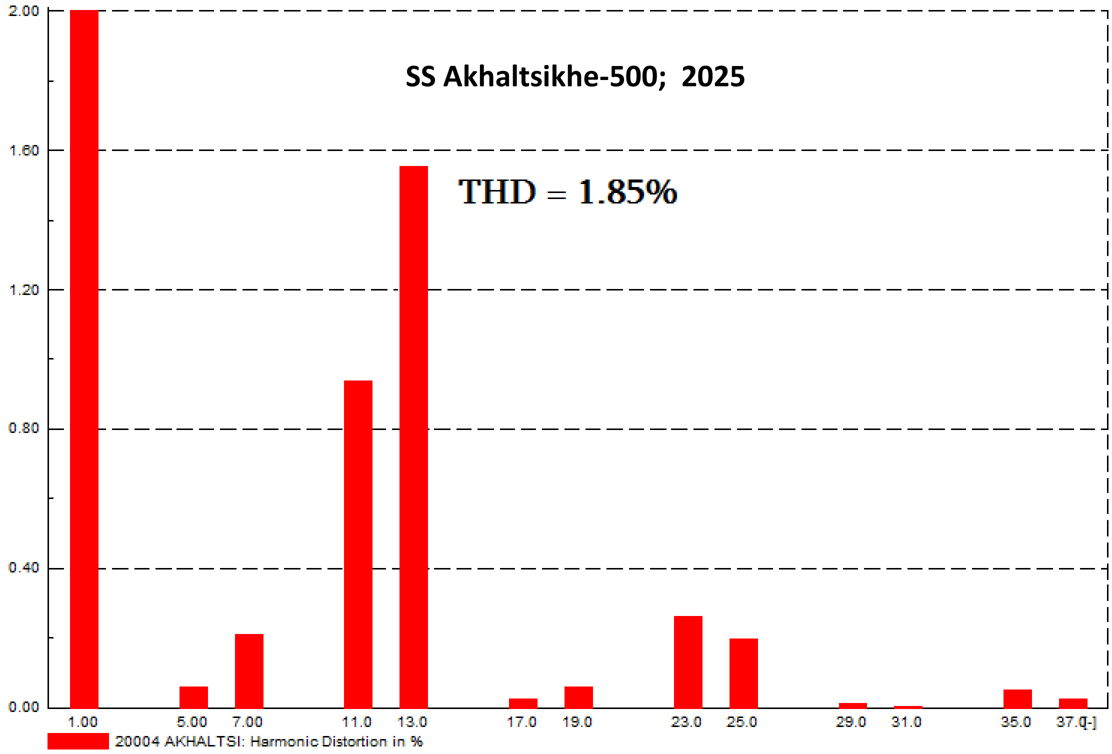



**Fig. 13.8. Harmonic components in SS Akhaltsikhe-500**

Only 11th and 13th harmonics are out of acceptable range, while the total harmonic distortion is within limits in all cases.

# 14 Georgian Transmission System Development Indicators for 2017-2027

Constructions of 500/400/220/154/110 kV OHLs and substations planned in Georgia for next 10 years are mainly driven by integration of the power plants, necessity of security of supply as well as improving stability, reliability and transit potential.

The present (2016) indicators of Georgian transmission network are given in the following table:

**Table. 14.1**

| Overhead Lines | | Substation autotransformers and Back-to-Back Links | |
|---|---|---|---|
| Rated Voltage (kV) | Length (Km) | Rated Voltage (kV) | Length (Km) |
| 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 500/400/330/220/154/110 kV transformers and autotransformers (MVA) and total length of transmission lines expressed in 500 kV OHL equivalent (km). The 500 kV was used as a reference voltage level for assessing the entire 500/400/330/220/154/110 kV transmission network. During calculation of equivalent lengths, it was assumed that the ratio of transmission capacities per unit length of different rated voltage lines approximately equals to the ratio of squares of their voltages. In result, the following conversion factors were used for calculating capacities of the equivalent 500 kV OHL:

**Table 14.2**

| Nominal Voltage (kV) | 400 | 330 | 220 | 154 | 110 |
|---|---|---|---|---|---|
| Conversion Factor | **1.56** | **2.30** | **5.17** | **10.54** | **20.67** |

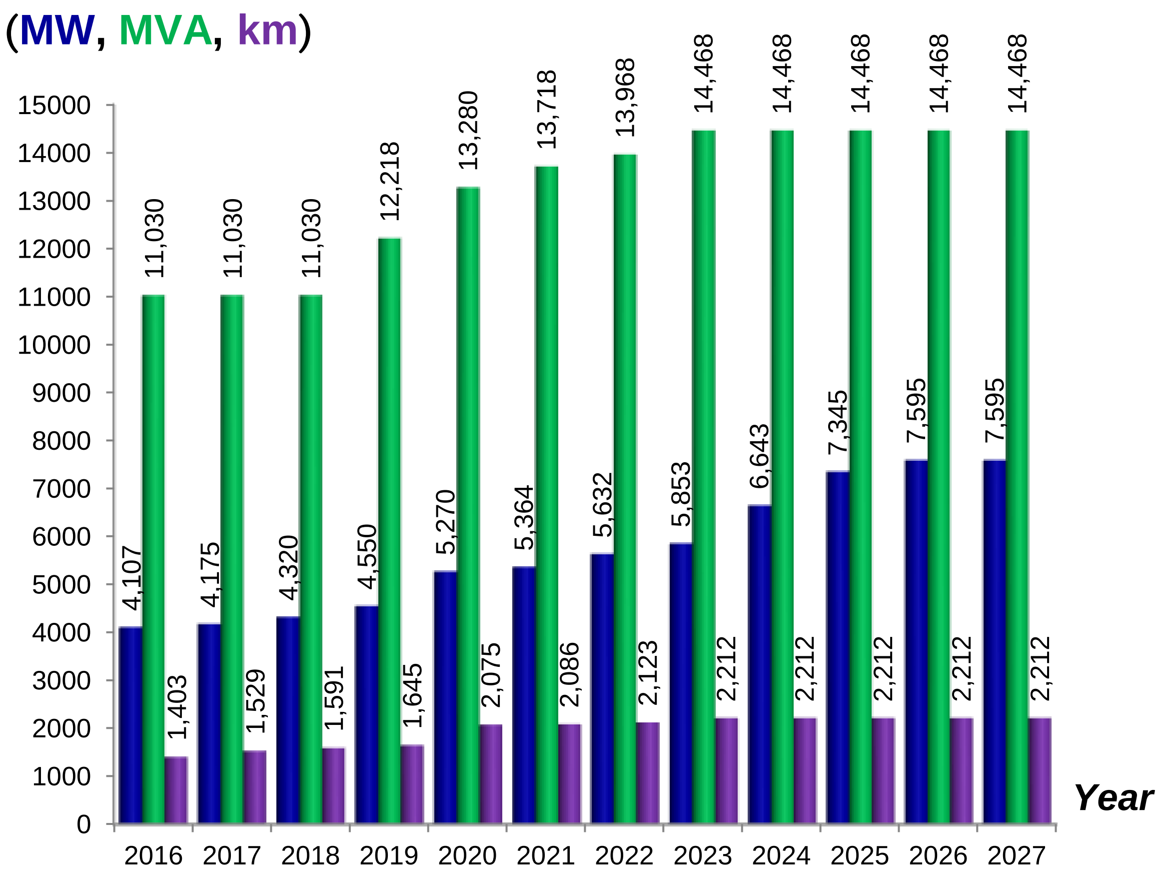



**Fig. 14.1 Dynamics of Georgian generation and 500/400/330/220/154/110 kV transmission infrastructure development during 2017-2027**

As shown on Fig. 14.1, during 2016-2019 time span the average annual generation growth is 147.6 MW. During the same period, total installed capacity of transformers and autotransformers in the substations will be increased intensively - in average by 396 MVA/year, and the length of the overhead lines (in 500 kV OHL equivalents) by approximately 80.6 km annally. This will be driven by need of both provision of desired level of security of supply and creation of necessity of prospective generation intergration.

During 2019-2022, generation will rapidly grow by 360.7 MW per annum in average that will be accompanied by more extensive development of transmission infrastructure. Specifically, total installed capacity of transformers and autotransformers installed in Georgian substations will grow approximately by 583.3 MVA per year, along with 159.3 km average annual growth of OHLs length (in 500 kV OHL equivalents).

During 2022-2027, annual generation growth is 392 MW, as for transmission infrastructure development - average annual growth of OHLs length (in 500 kV OHL equivalents) will be 17.8 km.

Fig. 14.1 allows estimation of several indicators describing development of Georgian transmission network, 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, with results shown on the following figure.

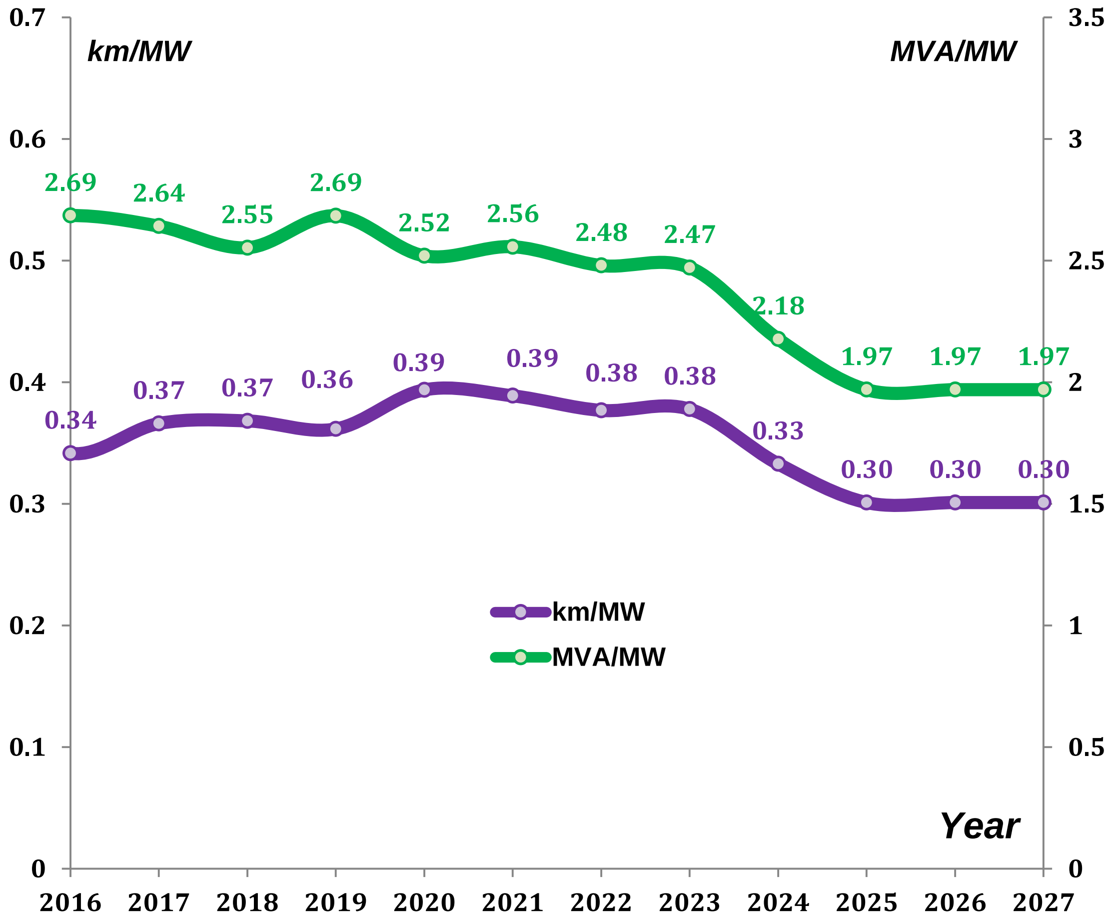



**Fig. 14.2 Relationship between development of Georgian transmission network and generation infrastructure**

As shown on Fig. 14.2, during 2016-2023, specific equivalent length of Georgian transmission network is more or less stable value. Such stabilisy is explained by assumption that integration of new HPPs during this period, including Shuakhevi HPP, Dariali HPP, Mtkvari HPP, Bakhvi HPP, Khobi HPP, etc., will be balanced by new transmission capacities provided by OHL Jvari-Khorga (220 kV), OHL Batumi-Akhaltsikhe (220 kV), OHL Ksani-Dariali (500 kV) etc. The same parameter for 2024 is much higher approaching 0.3 km/MW due to planned commissioning of Khudoni HPP, Namakhvani Cascade HPPs and Tskhenistskali Cascade HPPs.

The specific capacity of 500/400/330/220/110 kV (auto)transformers and back-to-back links per unit (1 MW) capacity of all generation facilities, up to 2023, undergoes smooth change in the range of 2.69-2.47 MVA/MW followed by rapid reduction and stabilization at 1.97 MVA/MW level.

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 2016-2019 time span. Therefore, it is apparent that improvement of the reliability is accompanied by improvement of network effectiveness and cost-efficiency.

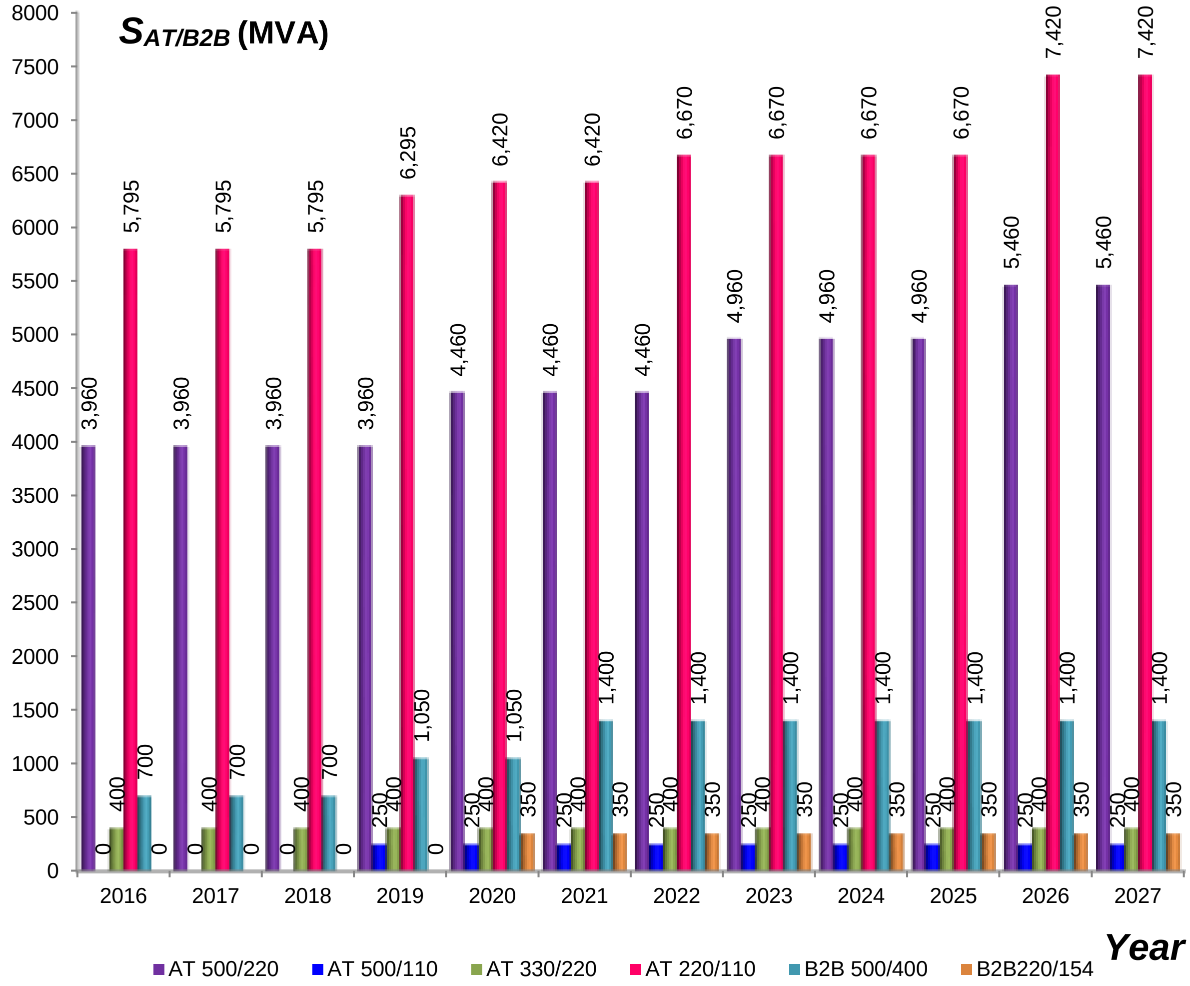



**Fig. 14-3 Relationship betwee deveopment of transmission infrastructure and generation in Georgia**

Fig. 14.3 shows forecasted dynamics of the installed capacities individually for 500/400/330/220/154 kV ATs and back-to-back links installed in Georgian transmission system (in MVA) for 2017-2027 period. The total (apparent) capacity of the back-to-back link is assumed to equal to the ratio of its active capacity and power factor of 0.8.

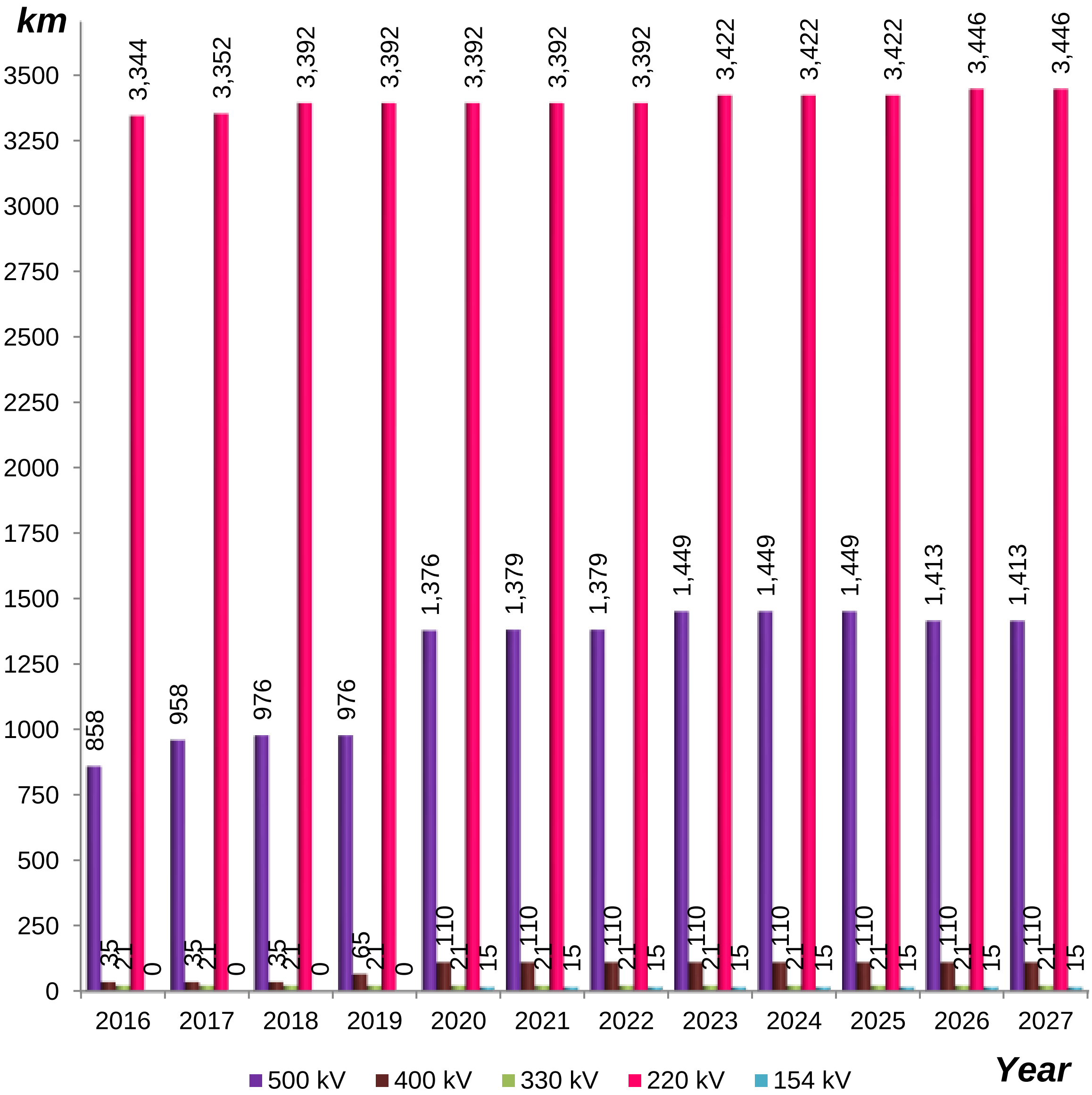



**Fig. 14.4. Lengths of 500/400/330/220/154 kV OHLs of Georgian transmission system for 2017-2027 period**

Fig. 14.4 shows dynamics of the 500/400/330/220/154 kV OHLs' lengths broken down by rated voltages as forecasted for 2017-2027. As may be seen from this figure, mainly the lengths of 500 kV and 200 kV lines will increase. This because these lines form the backbone of Georgian transmission network, while 400 kV, 330 kV and 154 kV lines are of insignificant lengths during the entire 10 year horizon since they are rated at the nominal voltages of interconnected neighbouring systems (Turkey, Azerbaijan), and hence are extended in Georgia only from the farthermost substation to the appropriate border.

# 15 Power Exchange capabilities with Neighbouring States and opportunities of connection of generation and consumption

Increase of Cross-border capacity of Georgian transmission network and capabilities of power exchange with other systems as well as power of generation which will be available from 500/220 kV busbars in case of commissioning all of HPPs considered in this 10-year development plan are represented in this chapter.

## 15.1 Capabilities of Power Exchange and NTC values for 2017-2027

### 15.1.1 Capabilities of Power Exchange

Due to convenient geographic location, Georgian transmission network has the potential to serve as regional energy hub and become strategic figure to resolve issues of integration of Caucasus and Black Sea Countries. This means to assembly-distribute powers of neighbouring states and energy exchange and trade among them through Georgian transmission network.

Total generation of HPPs considered in this Plan is much higher than consumption of Georgian power system starting from 2020. Hence, this power should be transmitted to neighboring countries because of their interests receive energy from Georgia.

As a result of joint cooperation of specialists from Georgia and its neighboring countries (Georgia-Turkey, Georgia-Armenia) and performed calculations, necessity of reinforcement of Georgian transmission network has been revealed, in particular:

1. Installation of new 350-350 MW units of Back-to-Back stations in substations Batumi and Akhaltsihke with construction of 154 kV Batumi-Muratli and 400 kV Akhaltsikhe-Tortum cross-border lines respectively;

2. New 500 kV interconnection line Ksani-Stepantsminda-Mozdok with Russia;

3. New 500 kV OHL Marneuli-Airum between Georgia and Armenia;

4. There is no reinforcement of connection with Azerbaijan is planned because exchange capacity between these countries is about 1000 MW.

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, their transfer capacities are restricted by acceptable operating modes of national power system (Tables 15.1).

**Table 15.1. Capabilities for power exchange 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.

### 15.1.2 NTC values to neighboring states for 2017-2027 time span

Capacity calculation is always related to a given power system scenario, i.e.: generation schedule and pattern, consumption pattern and available network state. These constitute the data allowing building up a mathematical model of the power system (load flow equations). The solution of this model leads to the knowledge of the voltages at the network nodes and the power flows in the network elements which are the parameters being monitored by a TSO to assess system security. The solution of this model is the so-called “**Base Case**” and is the starting point for the computation. This Base Case can already contain exchange programs between TSOs and control areas. These are the various transactions likely to exist in the forecasted situation according to what has been observed in the past.

All kinds of power to be transmitted – **TTC** (Total Transfer Capacity), **NTC** (Net Transfer Capacity), **BCE** (Base Case Exchange) are the EXCHANGE PROGRAM values; these are not the physical flows, and generally differ from the physical flows at the interconnection lines (except in particular cases of radial operation).

These capacities can give indications about weak points of the transmission network and can be used to evaluate the influence of network development plans and new planed network reinforcements. They are used as constraints in the transaction-based (or ”ATC-based”, or “NTC-based”) allocation procedures, explicit and implicit auctions, market-splitting and market coupling, based on the transactions reported at the respective borders.

In the Base Case mode, for a given pair of neighboring control areas, A and B, for which capacities are to be computed, a global cross-border exchange program called Base Case Exchange (BCE) can exist, as a starting point for the NTC calculation.

As the result of the calculation procedure, TTC equals the maximum exchange program between the two areas being considered.

**Total Transfer Capacity (TTC)** is the maximum exchange program between two areas, compatible with operational security standards applicable at each system, if future network conditions, generation and load patterns were perfectly known in advance.

$$\boldsymbol{TTC = BCE + \Delta E_{max}}$$

The maximum additional program exchange (over the BCE) that meets the security standards is marked with $\boldsymbol{\Delta E_{max}}$.

The evaluation of TTC between two electrical areas requires:

- Choice of local power system scenario
- Definition of a base case, which involves the sharing of full information amongst TSOs to

  build up the global (merged) load flow model

- Application of an agreed procedure for carrying out the calculations

The uncertainties associated with the forecast of the power system state, for a given time period in the future, may decrease according to the selected time frame. Therefore the TTC value may vary (i.e. increase or decrease) when approaching the time of program execution as a result o f a more accurate knowledge of generating unit schedules, load pattern, network topology and tie-lines availability.

**Transmission Reliability Margin (TRM)** is a security margin that deals with uncertainties on the computed TTC values arising from:

- Unintended deviations of physical flows during operation due to the physical functioning of load-frequency control (LFC);

- Emergency exchanges between TSOs to deal with unexpected unbalanced situations in real time;
- Inaccuracies, e. g. in data collection and measurements

TRM is associated with the real-time operation and its value is determined by each TSO, in order to guarantee the operation security of its own power system.

TRM may vary seasonally or may be updated according to possible modifications occurred in the power system.

**Net Transfer Capacity (NTC)** is defined as:

$$NTC = TTC - TRM$$

NTC is the maximum exchange program between two areas compatible with security standards applicable in both areas, taking into account the technical uncertainties on future network conditions.

Figure 15.1 below gives the graphical explanation of defined program values, using an example of transfer capacities calculation between areas A and B, with already existing Base Case Exchange from A towards B.

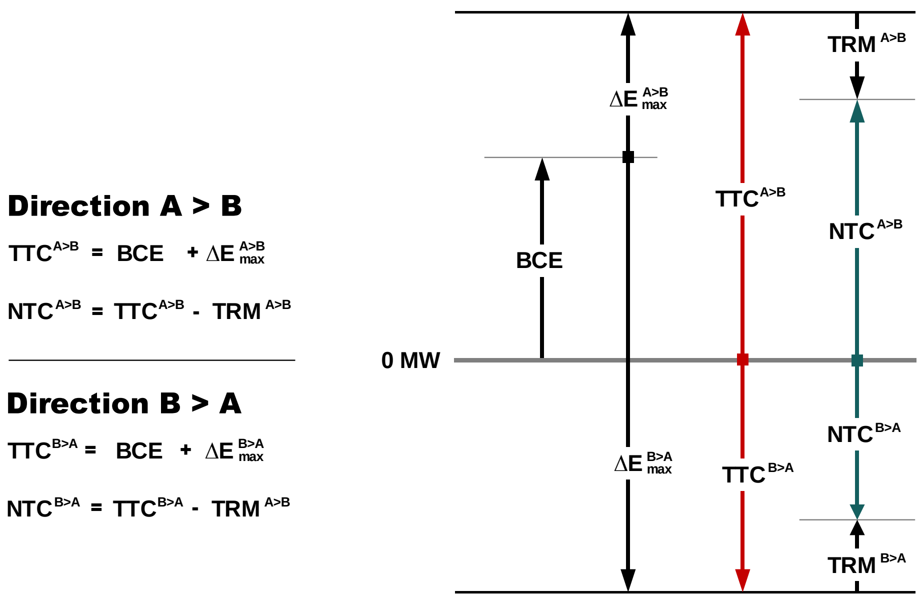



**Fig. 15.1 Graphical presentation of transfer capacities and their analytical relations**

Calculations of Capacity Exchanges (Net Transfer Capacities) have been performed in planned time span according to above mentioned methodology and Power balances represented in chapter 7. In addition, it has been considered that in summer maximum scenarios when there is the water flooding in Georgian system, replace of internal generation of Georgia by import from neighboring countries will be possible if this will be economically justified and will meet stability criteria of Georgian power system.

**Table 15.2 Exchange capacities for 2017-2027 time span**

| YEAR | TRANSFER | TURKEY | | | | RUSSIA | | | | AZERBAIJAN | | | | ARMENIA | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | WIN MAX | WIN MIN | SUM MAX | SUM MIN | WIN MAX | WIN MIN | SUM MAX | SUM MIN | WIN MAX | WIN MIN | SUM MAX | SUM MIN | WIN MAX | WIN MIN | SUM MAX | SUM MIN |
| 2017 | **IMPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 150 | 150 | 150 | 150 |
| | **EXPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 150 | 150 | 150 | 150 |
| 2018 | **IMPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 150 | 150 | 150 | 150 |
| | **EXPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 150 | 150 | 150 | 150 |
| 2019 | **IMPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 350 | 350 | 350 | 350 |
| | **EXPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 350 | 350 | 350 | 350 |
| 2020 | **IMPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 1000 | 1000 | 1000 | 1000 | 350 | 350 | 350 | 350 |
| | **EXPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 1000 | 1000 | 1000 | 1000 | 350 | 350 | 350 | 350 |
| 2021 | **IMPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 700 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| 2022 | **IMPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| 2023 | **IMPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| 2024 | **IMPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| 2025 | **IMPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| 2026 | **IMPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| 2027 | **IMPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |
| | **EXPORT** | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1400 | 1000 | 1000 | 1000 | 1000 | 700 | 700 | 700 | 700 |

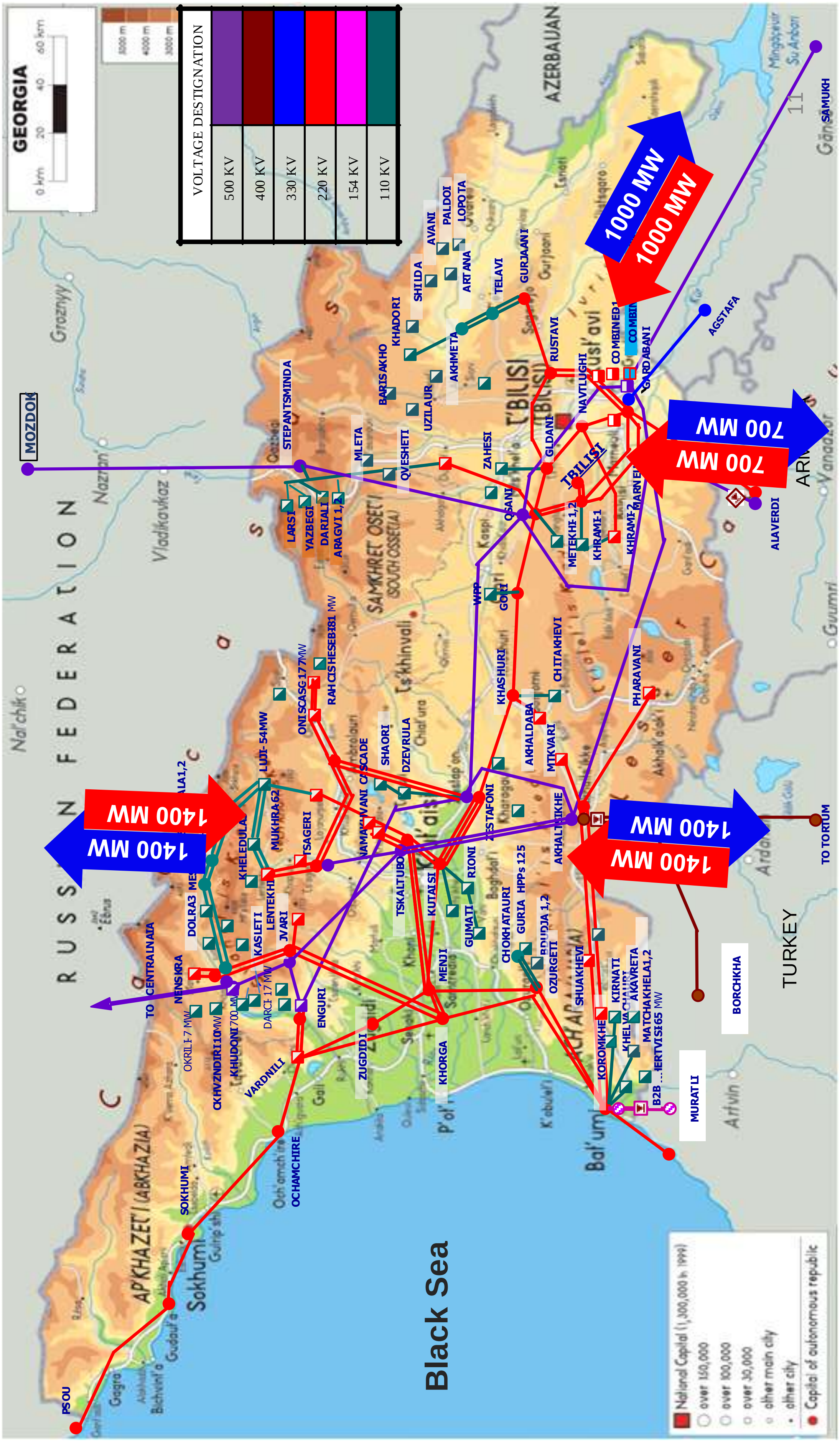



Fig. 15.2 Cross-border transfer capacities between power systems of Georgia and its neighbouring countries as for 2027

## 15.2 Opportunities of connection of new power to transmission network

*According to 39[4] article of Grid code, in order to promote competition on Energy market and transmission network development by transparent and non-discriminatory manner, nodes of transmission network where there is optimal to connect new power plants and/or other beneficiary, should be presented in ten-year network development plan.*

Power exchange among power system regions are realized by excess generation in one of the district in order to supply excess consumption in other district. This exchange and power transmission is implemented by Georgian transmission network in such manner which ensures possible optimal proportion between economy and system stability which is better when higher number of generators are in service (especially in energy-deficit region); This means that if generation and consumption are balanced in one of the region then there is no need to export/import power to/from another region and as a result interregional OHLs are less loaded (stressed). On the other hand, high number of generators in operation results decrease of economy, use of generation of Thermal Power Plants is especially economically unjustified if there is a possibility to use energy of HPPs.

Georgian transmission network implements power transmission from Power Plants to consumption centers, mainly from excess generation region to energy-deficit one. This process in presence as well as in future should be performed through safe and economy manner. This is the main driver of reinforcement of 500/220 kV network which is represented in this “10-year plan”.

In order to make clear for potential investors from which part is justified acceptance of generation, adding of capacity to 500/220 kV bus bars of Georgian transmission network has been modeled. This was done by us of PSS/E software.

The following tasks were checked/analyzed during this calculation:

1. System reliability criteria N-1;
2. Long-term allowed and emergency ranges of transmission network elements (OHLs, transformers and autotransformers);
3. Voltage levels;
4. Influence on system stability;
5. Probability of Sub-synchronous resonance.

**Opportunity of adding generation power.** Transmission network of Georgia has been provisionally divided into 12 electrical district (fig. 15.3). Opportunity of connecting generation to each of them along with consideration of opportunity of evacuation of power from respective zones has been analyzed (tab. 15.3).

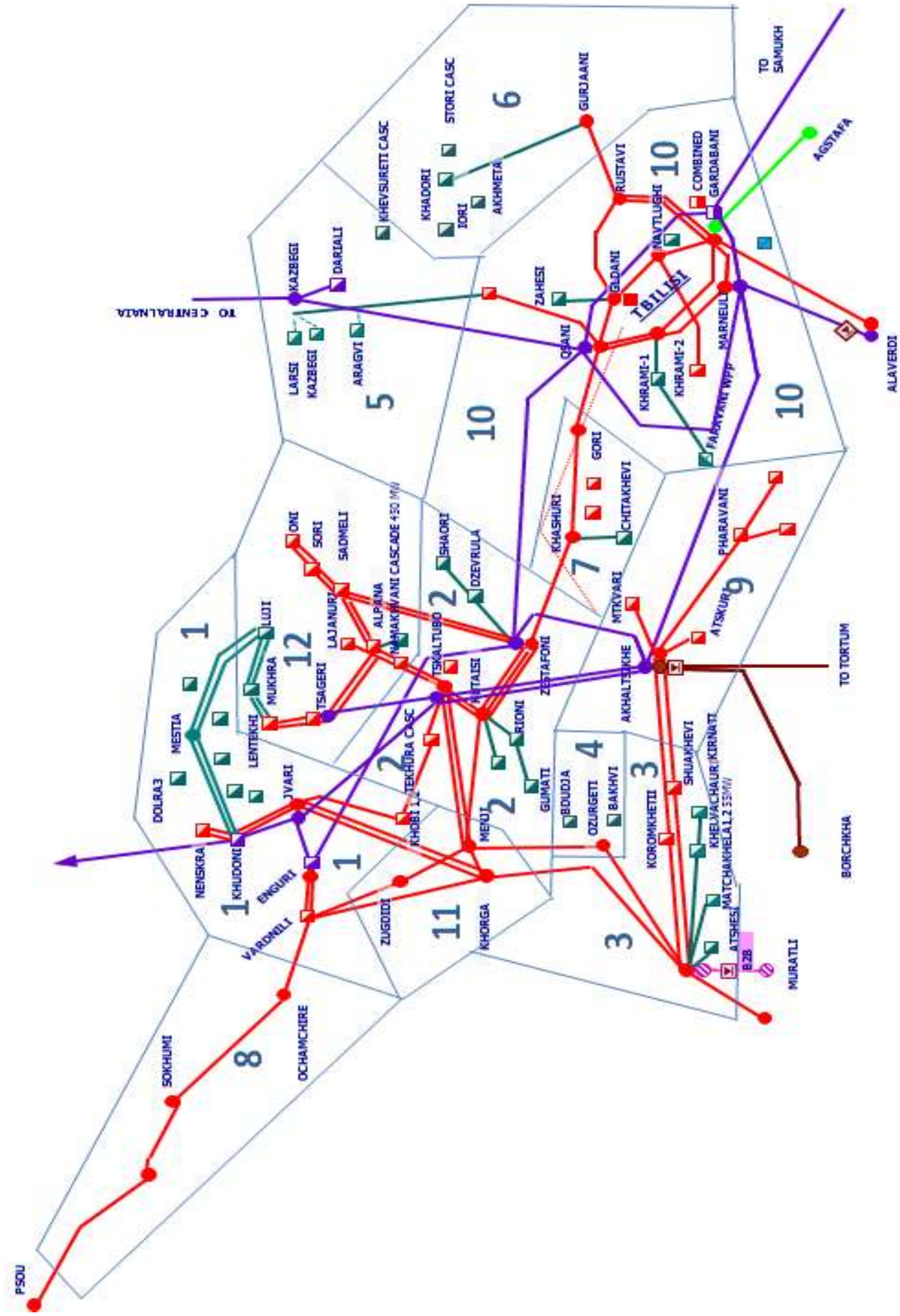



Fig 15.3 Electrical zones of transmission network of Georgia

**Table 15.3 Opportunities of connection of new generation power to transmission network**

| REGION | SUBSTATION | KV | ADDITIONAL GEN (MW) | | | REGION | SUBSTATION | KV | ADDITIONAL GEN (MW) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2017 | 2020 | 2027 | | | | 2017 | 2020 | 2027 |
| *ENGURI-KHUDONI-JVARI-UPPER SVANETI (1)* | ENGURI | 500 | 48 | 69 | 69 | *SAMTSKHE-JAVAKHETI (9)* | AKHALTSIKHE | 500 | 1000 | 1000 | 1000 |
| | ENGURI | 220 | 97 | 138 | 138 | | AKHALTS-INV | 400 | - | - | - |
| | VARDNILI | 220 | 97 | 138 | 138 | | AKHALTSIKHE | 220 | 270 | 400 | 400 |
| | JVARI | 500 | 24 | 69 | 69 | | MTKVARI | 220 | 50 | 50 | 50 |
| | JVARI | 220 | 85 | 172 | 172 | | FARAVANI | 220 | 30 | 30 | 30 |
| | KHUDONI | 500 | - | - | 69 | | ***REGION 9 TOTAL*** | | ***1350*** | ***1480*** | ***1480*** |
| | KHUDONI | 220 | - | 69 | 69 | *TBILISI-KSANI-KVEMO KARTLI (10)* | QSANI | 500 | 231 | 399 | 518 |
| | NENSKRA | 220 | - | 7 | 7 | | QSANI | 220 | 93 | 120 | 259 |
| | MESTIA | 110 | 0 | 0 | 34 | | JINVALI | 220 | 32 | 28 | 36 |
| | KHOBI-2 | 220 | 24 | 34 | 34 | | GARDABANI | 500 | 231 | 399 | 518 |
| | ***REGION 1 TOTAL*** | | ***327*** | ***627*** | ***800*** | | GARDABANI | 330 | - | - | - |
| *IMERETI (2)* | ZESTAFONI | 500 | 700 | 1000 | 1000 | | GARDABANI | 220 | 231 | 279 | 363 |
| | ZESTAFONI | 220 | 400 | 550 | 700 | | GLDANI | 220 | 116 | 299 | 415 |
| | TSKHALTUBO | 500 | - | 1000 | 1000 | | NAGTLUGHI | 220 | 139 | 219 | 259 |
| | TSKALTUBO | 220 | 50 | 300 | 300 | | LISI | 220 | 139 | 160 | 207 |
| | QUTAISI | 220 | 50 | 300 | 300 | | DIDUBE | 220 | 139 | 160 | 207 |
| | TEKHURI | 220 | - | - | 100 | | MARNEULI | 220 | 93 | 279 | 363 |
| | ***REGION 2 TOTAL*** | | ***1200*** | ***3300*** | ***3500*** | | KHRAMI-2 | 220 | 46 | 40 | 52 |
| *ADJARA (3)* | BATUMI | 220 | 200 | 600 | 900 | | RUSTAVI | 220 | 185 | 219 | 285 |
| | KOROMKHETI | 220 | - | - | 70 | | MARNEULI | 500 | 324 | 399 | 518 |
| | SHUAKHEVI | 220 | - | - | 20 | | ***REGION 10 TOTAL*** | | ***2000*** | ***3000*** | ***4000*** |
| | ***REGION 3 TOTAL*** | | ***290*** | ***690*** | ***990*** | *SAMEGRELO (11)* | KHORGA | 220 | 300 | 500 | 700 |
| *GURIA (4)* | OZURGETI | 220 | - | 40 | 40 | | ZUGDIDI | 220 | 150 | 150 | 160 |
| | REGION 4 TOTAL | | - | 40 | 40 | | MENJI | 220 | 200 | 250 | 300 |
| *DARIALI (5)* | STEPANTSMINDA | 500 | - | - | 900 | | ***REGION 11 TOTAL*** | | ***650*** | ***900*** | ***1160*** |
| | ***REGION 5 TOTAL*** | | ***-*** | ***-*** | ***900*** | *RACHA-LECHKHUMI-KVEMO SVANETI (12)* | TSAGERI | 500 | - | - | 200 |
| *KAKHETI (6)* | GURJAANI | 220 | 17 | 17 | 17 | | TSAGERI | 220 | - | - | 20 |
| | REGION 6 TOTAL | | 17 | 17 | 17 | | LAJANURI | 220 | 20 | 20 | 20 |
| *SHIDA KARTLI (7)* | KHASHURI | 220 | 12 | 12 | 12 | | ALPANA | 220 | - | - | 20 |
| | GORI | 220 | 12 | 12 | 12 | | SADMELI | 220 | - | - | 20 |
| | ***REGION 7 TOTAL*** | | ***24*** | ***24*** | ***24*** | | ONI | 220 | - | - | 0 |
| *ABKHAZETI (8)* | TKVARCHELI | 220 | - | - | - | | LENTEKHI | 220 | - | - | 0 |
| | SOKHUMI | 220 | - | - | - | | TVISHI | 220 | - | - | 10 |
| | BZIFI | 220 | - | - | - | | NAMAKHVANI | 220 | - | - | 10 |
| | ***REGION 8 TOTAL*** | | ***-*** | ***-*** | ***-*** | | ***REGION 12 TOTAL*** | | ***20*** | ***20*** | ***300*** |

***Table 15.3 shows data for the year 2017 regarding connection of new generation. This data might be corrected in 2018.***

Simultaneous adding of generation in several region is not considered.

**Opportunity of adding consumption (load) power.** Connection of load to 500/400/330/220 kV nodes year-by-year has been analyzed (fig. 15.4).

**Table 15.4 Opportunities of connection of new consumption to transmission network**

| SUBSTATION | KV | ADDITIONAL LOAD (MW) | | | SUBSTATION | KV | ADDITIONAL LOAD (MW) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2017 | 2020 | 2027 | | | 2017 | 2020 | 2027 |
| ENGURI | **500** | 500 | 700 | 1000 | **QSANI** | **220** | 45 | 45 | 45 |
| ZESTAFONI | **500** | 500 | 700 | 1000 | **JINVALI** | **220** | 70 | 70 | 70 |
| QSANI | **500** | 500 | 700 | 1000 | **GLDANI** | **220** | 30 | 30 | 30 |
| GARDABANI | **500** | 500 | 700 | 1000 | **GURJAANI** | **220** | 40 | 40 | 40 |
| AKHALTSIKHE | **500** | 500 | 700 | 1000 | **NAGTLUGHI** | **220** | 25 | 25 | 25 |
| MARNEULI | **500** | 500 | 700 | 1000 | **GARDABANI** | **220** | 15 | 15 | 15 |
| JVARI | **500** | 1000 | 1000 | 1000 | **MARNEULI** | **220** | 30 | 30 | 20 |
| STEPANTSMINDA | **500** | - | - | 250 | **LISI** | **220** | 15 | 15 | 15 |
| TSAGERI | **500** | - | - | 700 | **DIDUBE** | **220** | 15 | 15 | 15 |
| KHUDONI | **500** | - | 600 | 750 | **KHRAMI-2** | **220** | 25 | 25 | 25 |
| TSKHALTUBO | **500** | - | 700 | 750 | **RUSTAVI** | **220** | 20 | 20 | 20 |
| AKHALTS-INV | **400** | - | - | - | **AKHALTSIKHE** | **220** | 200 | 400 | 400 |
| GARDABANI | **330** | - | - | - | **MTKVARI** | **220** | 40 | 40 | 40 |
| ENGURI | **220** | 2 | 10 | 15 | **FARAVANI** | **220** | 50 | 50 | 50 |
| VARDNILI | **220** | 15 | 15 | 15 | **JVARI** | **220** | - | 300 | 500 |
| TKVARCHELI | **220** | - | - | - | **KHOBI-2** | **220** | - | 40 | 100 |
| SOKHUMI | **220** | - | - | - | **KOROMKHETI** | **220** | - | 250 | 250 |
| BZIFI | **220** | - | - | - | **SHUAKHEVI** | **220** | | 250 | 250 |
| KHORGA | **220** | 30 | 30 | 30 | **MESTIA** | **110** | | 100 | 100 |
| BATUMI | **220** | 30 | 30 | 30 | **KHUDONI** | **220** | - | 400 | 400 |
| ZUGDIDI | **220** | 20 | 20 | 20 | **ALPANA** | **220** | - | - | 250 |
| MENJI | **220** | 15 | 15 | 15 | **SADMELI** | **220** | - | - | 250 |
| GURIA | **220** | - | 12 | 15 | **ONI** | **220** | - | - | 250 |
| TSKALTUBO | **220** | 12 | 12 | 12 | **TSAGERI** | **220** | - | - | 400 |
| QUTAISI | **220** | 25 | 25 | 25 | **TEKHURI** | **220** | - | - | 250 |
| ZESTAFONI | **220** | 40 | 35 | 30 | **LENTEKHI** | **220** | - | - | 200 |
| LAJANURI | **220** | 7 | 5 | 5 | **TVISHI** | **220** | - | - | 250 |
| KHASHURI | **220** | 15 | 15 | 15 | **NAMAKHVANI** | **220** | - | - | 400 |
| GORI | **220** | 25 | 25 | 25 | **NENSKRA** | **220** | - | 280 | 280 |

Table 15.4 shows data for the year 2017 regarding free capacities. This data might be corrected during 2018.

Each node has been analyzed separately, no simultaneous adding of loads in these nodes are considered. Power to be connected to the nodes of 110 kV and lower voltage will be additionally restricted by capacity of respective 220/110 kV transformers/autotransformers (paragraph 10.4).

**Summary:** As far we know, west part of Georgia is characterized with excess generation, in east part of Georgia the main consumption centers are located. The same picture will be maintained in next years, high number of Hydro Power Plants are considered in west part of Georgia, demand in east Georgia will continuously grow, especially if we consider that cross-border lines of Georgia and Turkey, Russia as well as Armenia will also practically increase consumption of east Georgia. Significant reinforcement of west part of Georgian transmission infrastructure will be partly difficult in 2017-2027 due to the difficult relief and harsh environmental conditions in north-west Georgia (Upper and lower Svaneti, upper and lower Racha). Hence, additional power evacuation from these districts besides of Power plants considered Ten year development plan will not be justified by system stability and economy point of view. As represented table 15.3 shows, adding of new generation without transmission network reinforcement is justified in 500 kV nodes which are located in ss Zestaponi and its right side, in powerful consumption centers of both east and west part of Georgia (Khorga, Vardnili, Kutaisi, Tskaltubo, Zestaponi, Batumi, Gldani, Navtlugi, Lisi, Didube, Rustavi, Gardabani). Reserve of power integration after commissioning of power plants represented in table is almost exhausted in substations of upper and lower Svaneti, Racha-Lechkhumi and Shida Qartli. The results are logical: Mobilization of human and technical resources near the consumption center is simple task, transport, energy, water and communication infrastructure are available. In addition, if new generation capacity is connected to east part of Georgian transmission network, this will more or less result balance between generation and consumption and therefore less loading of transmission grid during power flow between east and west regions. On the other hand, if we look at opportunities of consumption growth, this value is the highest for “North Ring-Tskaltubo” project region where there is the fewest possibility of generation growth.

Opposite situation is for increase of consumption, as it is shown from tab. 15.4, growth of consumers is reasonable in regions rich with generation (especially, Enguri-Jvari-Khudoni-Upper Svaneti and Racha-Lechkhumi-Lower Svaneti) and there is less reserve in power consumption centers (Tbilisi substations).

# 16 Ten Year Plan of SCADA and Information Technologies (IT) Development

## 16.1 Ten Year Plan of SCADA and Information Technologies (IT) Development

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.

The development of fiber optic cables, communications systems (radio relay, high-frequency PLC), Level I SCADA elements, Level II and Level I SCADA systems, energy and other software and hardware applications must strictly follow the Ten-Year Network Development Plan of Georgia.

**Below is the schematic format of the ten-year plan for fiber optic cables, communications systems (radio relay, high-frequency PLC) development.**


**Fig. 16.1 Map of fiber optic cables, communications systems, 2016**


**Fig. 16.2 Map of fiber optic cables, communications systems, 2017**


**Fig. 16.3 Map of fiber optic cables, communications systems, 2018**


**Fig. 16.4 Map of fiber optic cables, communications systems, 2019**


**Fig. 16.5 Map of fiber optic cables, communications systems, 2020**


**Fig. 16.6 Map of fiber optic cables, communications systems, 2021**


**Fig. 16.7 Map of fiber optic cables, communications systems, 2022**


**Fig. 16.8 Map of fiber optic cables, communications systems, 2023**


**Fig. 16.9 Map of fiber optic cables, communications systems, 2024-27**


**Fig. 16.10 Map of fiber optic cables, communications systems, 2016-27**

Projects and tasks under the Ten-Year Plan

**Table 16.1 Projects under the Ten-Year Plan**

| Year | Project | Presumable performer | Presumable cost (EUR) | Description/ note |
|---|---|---|---|---|
| 2017 | Approval of draft amendments to the Network Code in terms of connection to SCADA | JSC GSE, GNERC | | |
| 2017 | Construction of new server rooms, and purchase and installation of servers | JSC GSE | 600000 | |
| 2017 | Renewal of local management system of Zestaponi 500 substation (Level II SCADA) | JSC GSE | 150067 | |
| 2017 | Optic cable between Khelvachauri HPP and Kirnati HPP substations | Investor | Included in the OHL construction project cost | |
| 2017 | Arrangement of Level I SCADA element in Kirnati HPP | Investor - JSC GSE | Included in the project cost | |
| 2017 | Optic cable on Odisha OHL | JSC GSE | Included in the OHL construction project cost | |
| 2017 | Optic cable on Derchi OHL up to Lajanuri HPP | JSC GSE | 221000 | 121000 |
| 2017 | Upgrade of Level I SCADA element in Lajanuri HPP | JSC GSE | 34615 | |

| | | | | |
|---|---|---|---|---|
| 2017 | Optic cable from Rachkha HPP to Lajanuri HPP | Investor | Included in the OHL project cost | |
| 2017 | Arrangement of Level I SCADA elements in Rachkha HPP | JSC GSE | 5800 | |
| 2017 | Connection of optic cable to the Azerbaijan energy network | JSC GSE | 5000 | |
| 2017 | Launch of Stage II WAM software | JSC GSE | 255178 | |
| 2017 | Update of corporate webpage | JSC GSE | 115523 | |
| 2017 | Introduction of information security management standard (ISO 27001) and certification | JSC GSE | 250000 | |
| 2017 | Optic cable between “Batumi-220” substation and Shuakhevi HPP | JSC GSE | Included in the OHL project cost | |
| 2017 | Arrangement of Level I SCADA element in Shuakhevi HPP | JSC GSE - Investor | Included in the project cost | |
| 2017 | Optic cable between Ksani substation and Stepantsminda substation | Energotrans | Included in the OHL project cost | |
| 2017 | Arrangement of Level II and Level I SCADA elements in Stepantsminda substation | JSC GSE | Included in the total project cost | |
| 2018 | Connection of optic cable to the Armenian Power System | Armenian Power System | 5000 | |
| 2018 | Optic cable between Khobi II HPP and Khobi I HPP | Investor | Included in the OHL project cost | |
| 2018 | Arrangement of Level I SCADA element in Khobi I HPP | JSC GSE | 34615 | |
| 2018 | Launch of Stage III WAM software | JSC GSE | 169197 | |
| 2018 | Optic cable between Jvari Substation and Khobi II HPP | JSC GSE | Included in the total project cost | |
| 2018 | Arrangement of Level I SCADA element in Khobi II HPP | JSC GSE | 34615 | |
| 2018 | Laying of optic cable in “Beshumi 110” substation from Shuakhevi-Batumi line and activation of the existing Level I SCADA element | JSC GSE | 10000 | |
| 2018 | Optic cable between Shuakhevi HPP and Akhaltsikhe 500 substation | JSC GSE | Included in the OHL project cost | |
| 2018 | Upgrade of central SCADA (Level I) server infrastructure and software | JSC GSE | 2950000 | |
| 2018 | IT platform for the exchange of energy | JSC GSE | 184615 | |
| 2019 | Entry of Paliastomi OHL optic cable in “Ozurgeti 220” substation | JSC GSE | Included in the OHL project cost | |
| 2019 | Optic cable between “Khudoni 220” substation and “Jvari 500” substation | JSC GSE | Included in the total project cost | |
| 2019 | Arrangement of Level I SCADA element in “Khudoni 220” substation | JSC GSE | Included in the OHL project cost | |

| | | | | |
|---|---|---|---|---|
| 2019 | Optic cable between “Khudoni 220” substation and “Mestia 110” substation | JSC GSE | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA element in “Mestia 110” substation | JSC GSE | 34615 | |
| 2019 | Arrangement of Level II and Level I SCADA elements in “Ozurgeti 220” substation | JSC GSE | Included in the OHL project cost | |
| 2019 | Optic cable between Neskra HPP and “Khudoni 220” substation | JSC GSE | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA element in Neskra HPP | JSC GSE | 34615 | |
| 2019 | Optic cable between Mtkvari HPP and Akhaltsikhe 500 substation | Investor | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA element in Mtkvari HPP | JSC GSE | 34615 | |
| 2019 | Optic cable between “Ozurgeti 220” substation and “Chokhatauri 110” substation | JSC GSE | Included in the OHL project cost | |
| 2019 | Arrangement of Level II and Level I SCADA elements in “Chokhatauri 110” substation | JSC GSE | Included in the OHL project cost | |
| 2019 | Optic cable between Mestiachala 2 HPP and Sada Ipar | Investor | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA element in Mestiachala 2 HPP | JSC GSE | 15000 | |
| 2019 | Optic cable between Natanebi Cascade HPP and “Ozurgeti 220” substation | Investor | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA element in Natanebi Cascade HPP | JSC GSE | 34615 | |
| 2019 | IT platform for system services | JSC GSE | 1846154 | |
| 2019 | Laying of optic cable between Akhmeta and Telavi substations | JSC GSE | Included in the OHL project cost | |
| 2019 | Laying of optic cable between Telavi and Tsinandali substations | JSC GSE | Included in the OHL project cost | |
| 2019 | Laying of optic cable between Tsinandali and Gurjaani substations | JSC GSE | Included in the OHL project cost | |
| 2019 | Laying of optic cable between Telavi substation and Stori-1 HPP | JSC GSE | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA elements in Stori-1 HPP | JSC GSE | Included in the OHL project cost | |
| 2019 | Laying of optic cable between Akhmeta substation and the Cascade of Samkuristskali HPPs | JSC GSE | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA elements in the | JSC GSE | Included in the OHL project cost | |

| | | | | |
|---|---|---|---|---|
| | Cascade of Samkuristskali HPPs | | | |
| 2019 | Arrangement of optic cable between Kheledula-3 HPP and Jakhundera-Lajanuri HPP | JSC GSE | Included in the OHL project cost | |
| 2019 | Arrangement of Level I SCADA elements in Kheledula-3 HPP | JSC GSE | Included in the OHL project cost | |
| 2020 | Optic cable between Jvari 500 and Tskaltubo 500 substations | Energotrans | Included in the OHL project cost | |
| 2020 | Optic cable between Tskaltubo 500 andAkhaltsikhe 500 substations | Energotrans | Included in the OHL project cost | |
| 2020 | Arrangement of Level II SCADA element in Tskaltubo 500 substation, integration into Level I SCADA element | JSC GSE, Energotrans | Included in the OHL project cost | |
| 2020 | Laying of optic cable between Akhaltsikhe 500 substation and Tortum in Turkey | JSC GSE, Turkish Power System | Included in the OHL project cost | |
| 2020 | Expansion/imrpovement of WAM software, purchase of licenses | JSC GSE | 169197 | |
| 2020 | Optic cable between “Batumi-220” substation and Muratli substation in Turkey | JSC GSE, Turkish Power System | Included in the OHL project cost | |
| 2020 | optic cable between Darchi HPP and “Khudoni-220” substation | Investor | Included in the OHL project cost | |
| 2020 | Arrangement of Level I SCADA element in Darchi HPP | JSC GSE | 15000 | |
| 2021 | Optic cable between Ksani 500 substation and Metekhi I HPP | Investor | Included in the OHL project cost | |
| 2021 | Arrangement of Level I SCADA element in Metekhi I HPP | JSC GSE | 15000 | |
| 2021 | Optic cable between Metekhi II HPP and Metekhi I HPP | Investor | Included in the OHL project cost | |
| 2021 | Arrangement of Level I SCADA element in Metekhi II HPP | JSC GSE | 15000 | |
| 2021 | Optic cable between Machakhela-I HPP, Machakhela-II HPP and “Batumi 220” substation | Investor | Included in the OHL project cost | |
| 2021 | Arrangement of Level I SCADA element in Machakhela-I HPP and Machakhela-II HPP | JSC GSE | 30000 | |
| 2021 | Connection of Dolra-3 HPP with optic cable to “Mestia-110” substation or Nenskra HPP – Khudoni HPP optic cable | Investor | Included in the OHL project cost | |
| 2021 | Arrangement of Level I SCADA elements in Dolra-3 HPP | JSC GSE | 15000 | |
| 2021 | Entry of optic cable of “Batumi-220” – “Akhaltsikhe- | JSC GSE | Included in the OHL project cost | |

| | | | | |
|---|---|---|---|---|
| | 500” substations in Koromkheti HPP | | | |
| 2021 | Arrangement of Level I SCADA elements in Koromkheti HPP | JSC GSE | 34615 | |
| 2021 | Optic cable between Dariali HPP and Stepantsminda 500 substation | JSC GSE | 104000 | 104000 |
| 2021 | Arrangement of Level I SCADA elements in Dariali HPP | JSC GSE | 34615 | |
| 2021 | Optic cable between Mestiachala 2 HPP and Mestiachala 1 HPP | Investor | Included in the OHL project cost | |
| 2021 | Arrangement of Level I SCADA elements in Mestiachala HPP | JSC GSE | 15000 | |
| 2021 | Optic cable between Enguri HPP and the Cascade of HPPs in Maganalekarde | Investor | Included in the OHL project cost | |
| 2021 | Arrangement of Level I SCADA elements in the Cascade of HPPs in Maganalekarde | | 15000 | |
| 2022 | Optic cable between Oni Cascade HPP and Zestaponi 500 substation | Investor | Included in the OHL project cost | |
| 2022 | Arrangement of Level I SCADA elements in Oni Cascade HPP | JSC GSE | 34615 | |
| 2022 | Optic cable between “Chokhatauri 110” substation and Zoti HPP | | Included in the OHL project cost | |
| 2022 | Arrangement of Level I SCADA elements in Zoti HPP | | 34615 | |
| 2022 | Optic cable between Khertvisi HPP and “Batumi 220” substation | Investor | Included in the OHL project cost | |
| 2022 | Optic cable between “Khashuri 220” substation and Akhaldaba HPP | JSC GSE | Included in the OHL project cost | |
| 2022 | Arrangement of Level I SCADA elements in Akhaldaba HPP | JSC GSE | 34615 | |
| 2022 | Arrangement of Level I SCADA elements in Khertvisi HPP | JSC GSE | 15000 | |
| 2023 | Optic cable between Supsa Cascade HPP and “Chokhatauri 110” substation | Investor | Included in the OHL project cost | |
| 2023 | Arrangement of Level I SCADA elements in Supsa Cascade HPP | JSC GSE | 34615 | |
| 2023 | Entry of optic cable of Oni Cascade HPP and Zestaponi 500 substation into “Sadmeli 220” substation | JSC GSE | Included in the OHL project cost | |
| 2023 | Arrangement of Level II and Level I SCADA elements in “Sadmeli 220” substation | JSC GSE | Included in the OHL project cost | |

| | | | | |
|---|---|---|---|---|
| 2023 | Optic cable between Namakhvani Cascade and “Tskaltubo 220” substation | Investor | Included in the OHL project cost | |
| 2023 | Optic cable between Tvishi HPP and Namakhvani HPP | Investor | Included in the OHL project cost | |
| 2024 | Arrangement of Level I SCADA elements in Tvishi HPP | JSC GSE | 34615 | |
| 2024 | Arrangement of Level I SCADA elements in Namakhvani Cascade HPP | JSC GSE | 34615 | |
| 2024 | Optic cable between Ipari and Jakhundera substations | Investor | Included in the OHL project cost | |
| 2024 | Arrangement of Level I SCADA element in Tskhenistskali Cascade (Luji HPP, Mukhra HPP, Lentekhi HPP) | JSC GSE | 34615 | |
| 2024 | Optic cable between Tskhenistskali Cascade HPP and Tsageri substation | JSC GSE | Included in the OHL project cost | |
| 2025 | OHL on the Caucasus Mountains, between Jvari substation and Khudoni HPP | JSC GSE, or Energotrans | Included in the OHL project cost | |
| 2025 | Arrangement of Level I SCADA element in Khudoni HPP | JSC GSE | 34615 | |

**Estimated total investment for 10 years: EUR 7 640 725**

# 17 State-of-the-Art Technologies

## 17.1 Emergency Control System (ECS)

The modern power systems are automated and their operation without automatic control devices is impossible. From these, one of the most important are devices building Emergency Control System..

For improving operating stability of the national power system and enhancing power exchange with neighbouring countries, Emergency Control System (ECS) has been installed. The ECS aims at ensuring reliable and uninterrupted power supply to the customers, and localization of contingencies to avoid their propagation and growth into the system wide emergency. In addition, ECS targets maximum use of the national energy resources and power re-export potential, provided that under single N-1 regime full collapse of the regional network should be avoided.

The ECS devices maintain static, dynamic and resultant stability of the power system. They respond in both cases, when the network is operating in steady mode, or when one of the transmission lines is under maintenance outage.

Under the single contingency (N-1), in case of active power excess in the system, ECS will initiate rapid automatic reduction of the active power generation in Enguri HPP, while in case of active power shortage, will shed the load (in the country) and, if needed, the export (re-export) by remote control commands sent via fiber optic communication network.

ECS devices continuously monitor the status and operating regimes of the system elements, identify and record hazardous events or abrupt violation of the normal regimes, assess their severity and, in case of emergencies, send signals to the logic processor that compares sequence and intensity of the signal and selects the relevant response command (generation reduction, load shedding or both). After the command is selected, ECS identifies relevant circuits, and if emergency is confirmed, sends generation reduction and load shedding signals to executing equipment. Fast reaction of ECS devices reduces possibility of stability failure.

## 17.2 Akhalstikhe HVDC Back-to-Back Station

One of the most important modern technologies introduced into Georgian power system is represented by HVDC converter ("back-to-back) station installed in SS Akhaltsikhe. This converter station allows asynchronous parallel operation of Georgian and Turkish power systems. Its major function is transfering of the power from Georgia and its neighbouring countries to Turkey, however, if needed, the same station may also be operated in reverse direction. One of the advantages of the back-to-back station is in flexible and accurate control of the power flow allowing as fixed power transfer during steady regimes, so its desired variation in case of emergency according to pre-defined algorithm.

This back-to-back station (part of SS Akhaltsikhe) is located near city of Akhaltsikhe, in the south Georgian region, 25 km apart from Georgia-Turkey border, at 1100 m above sea level. Its buildings and structures are designed against earthquake with magnitude of 8 per Richter Scale. The total capacity of the back-to-back station (2 HVDC links) is 2×350 MW. Akhalstikhe substation, including back-to-back links occupy an area with dimensions of 800m × 400m. It is connected to Zestaponi and Gardabani substations via 500 kV OHLs Zekari and Vardzia, and to Turkish system (SS Borchka) via 400 kV OHL Meskheti.

During exporting the power from Georgia to Turkey, 500 kV alternating current is converted in the converter station into 96 kV direct voltage and then back into 400 kV alternating current, with reversed sequence during power import.

Energy is converted in line-commutated (LCC) high voltage thyristors controlled by laser signals. Each thyristor group of back-to-back links consist of 15 thyristors connected in series. In total 720 thyristors are engaged in energy conversion process.

During operation, back-to-back links require reactive power supply amounting to 50-60 percent of converted active power. In addition these links generate high harmonics. Therefore, AC filters are installed at both sides of converter station (4×85 Mvar + 72 Mvar at Georgian (500 kV) side and 4×85 Mvar at Turkish (400 kV) side) to suppress the generated harmonics and dully supply converter with reactive power. These filters minimize reactive power exchange between AC systems and converter station.

For responding to reactive power demand of the back-to-back links and supporting to voltage stability in the system, 3×65 Mvar synchronous condenser is installed in 400 kV switchyard of SS Akhaltsikhe.

Besides accurate power flow control, Akhalstikhe back-to-back station also has number of other advantages. It improves dynamic stability of the system and can participate in frequency control. When needed, it is also capable to operate in overloaded mode. In addition, converter station undertake power swing damping function.

The elements of converter station are manufactured and installed according to IEC, ISO and IEEE standards and CIGRE's recommendations.

The station may be controlled as from the local control panel, so remotely from the control room of National Dispatch Centre.

***Reasons for Using Back-to-Back Links at South Direction***

Georgian and Turkish power systems are interconnected via Akhaltsikhe HVDC back-to-back station. Such connection ensures more stable operation, since allows accurate and comprehensive control of the power flows that is impossible with conventional AC connection. Such possibility is of decisive importance considering weakly developed transmission network in Turkish region bordering Georgia. Besides above, HVDC link simplifies dispatch of the interconnected systems.

In similar to Turkey, Georgia plans asynchronous parallel operation with Armenian power system. For this, other HVDC converter station will be installed at Airum (Armenia), several kilometres apart from the Georgian border. Armenian power system is synchronously interconnected with Iran. Technical control of Iranian power system differs from the same of Georgian network. In addition, during synchronous parallel operation of Georgian and Armenian power systems interconnected via AC lines, power swings occur under emergencies. Particularly, due to above reasons, it has been decided to establish asynchronous link between Georgia and Armenia through HVDC link that will be capable to support stability of the system voltage and feed the passive network, i.e. in case of blackout of any of the interconnected systems, it may be energized and loaded from the neighbouring system.

## 17.3 SCADA

### Central SCADA Software Support and Server Update Project

Implementation of Central SCADA software support and Server Update project is planned at GSE, on the basis of SINAUT SPECTRUM 7, as a result of current requiremenets for SCADA.

Intesnive development of electric grid, as accompanied by integration of new objects into the system and, therefore, increased number of signals are primary prerequisites. The desigh of the existing equipment does not support such volume of load and thus causes server/equipment overloads, which, by itself, serves as an obstacle for effective dispatching.

Updated SCADA/EMS (Energy Management System) high level architecture comprises SCADA functions, transmission line control and monitoring, intellectual functions and operator training simulator and covers several useful applications. One of such functions implies automatic switching by predetermined sequence as well as automatic video monitoring option. Besides, operations personnel will be able analyse, in real time, electrical system established regime safety (n-1) and short circuits, calculate network thermal losses and dynamic capacity of transmission line. constant control of reactive power and voltage level application is also considered. Dispatchers will be able to switch the system from real time to traning mode and ensure management of generation with the help of optimal distribution of flow. Also, control of the amount of harmonic distortion, by quality monitoring devices, which on their hand reduce losses in the system. By status evaluation application, measurements actually received by SCADA will be rechecked, based on the predefined formulas. In case of false data, the application will check, on the basis of repeated calculations, each nod, reveal damaged areas and replace the data received from this nod with theoretical data.

**Fig. 16.11**

Unlike existing system, the renewed system will be capable of integrating more objects – Automated Geceration Control application  (AGC). besides, it will be possible to determine system service categories (initial, secondary and tertiary reserves) in accordance with ENTSO-E standards.

Along with SCADA/EMS renewal, 3 independent data processing centres (distanced from each other geographically) are prepared. Virtual server environment will be created in each of these centres, where certain number of virtual servers will be configured. If necessary, computational capability might be enhanced at any time. It shall be noted that close information exchange will be provided between data processing centres and virtual environment shall no longer be depended on the damage of physical servers. All the above ensures enhanced information reservation, optimal allocation of resources and cost reduction.

The updated program differs visually as well. SCADA/EMS system will be able to reveal generation objects operating in island mode. Besides, to visualize (on the geographical map) damaged area using data received from RTU/SMCS Gateway device. Weak points will be revealed easily and help the dispatcher to assess measures to be taken. New reporting system provides sending of information to the interested parties by e-mail, as well as SMS notifications in case of significant accidents on transmission lines.

SCADA/EMS update project includes introduction of dynamic stability analysis (SIGUARD DSA) software. Using this software, operators will be able to simulate accidents in real time, in order to predetermine results of actions taken by them. Application provides real time assessment of anticipated risks as well as offers the operator certain measures to be taken in order to maintain system stability.

Besides, operator training simulator (virtual copy of the existing system) may be considered as one of the significant innovations. This simulator will enable dispatchers model predetefined normal and emergency modes. This will help operators to imrove system management skills and take quick and adequate decisions in real time.

**Fig. 16.12**

Updated SCADA/EMS software and hardware will significantly improve process of safe and reliable management of electric power system.

# 18 Opportunities of integration renewable energy sources into the Georgian power system

## 18.1 Foreword

Georgia is rich by renewable resources. Among them, Hydro energy has the biggest potential, perspective as well as priority due to the number of advantages like stability, high flexibility, provision of power and energy reserves which is critically important for the small power systems like Georgian one. Wind and solar energy also has some potential but nowadays there is no practical assimilation of their energy in Georgia.

## 18.2 Contributing factors of assimilation of Wind and Solar energy

Net cost of Wind turbines and Solar panels are being more and more decreasing resulting use of Wind and solar energy to become more attractive. Construction of their power plants takes significantly less time compared to hydro ones (due to the absence of dam and pressurized system). Operational costs (the ones during operational period) for them are also minimal.

## 18.3 Challenges of power system in case of wind and solar energy integration

Wind and solar power plants have number of characteristics, which have negative effect to system stability, in particular generation variation. This problem is less presented in solar power plants because their generation is more depended on calendar than on weather. Another positive issue for solar energy is that their generation can be correlated to the consumption, which is usually increasing during day hours. As for wind energy, its generation is sharply depended on weather and on wind in particular. It is especially noteworthy stopping of wind turbines in case of appearing strong wind resulting power deficit and generation of harmonic distortion in transmission network. At the same time, there is no practical possibility of correlation of their generation to the consumption. Hence, in order to ensure reliable operation of power system, fulfill of special requirements will be necessary in case of integration of wind and solar energy, which will be even bigger challenge for Georgian system due to the difficulty of voltage and frequency control. Except Grid Code requirements, Wind farms should satisfy limitations related to the present Georgian power system in order to connect them to the transmission network.

## 18.4 Necessary factors for integration of large wind and solar power plants

Based on the best European experience, countries implementing large capacity integration of wind and solar power stations into their System should have these characteristics:

- Power balances, enough inertia constant (total installed capacity of operating generation units in power system);
- Large and mutually reserved internal and cross-border transmission network;
- Power system Flexibility, enough capacity to Primary, Secondary and Tertiary reserves, pumped-storage power plants and fast-acting reactive power compensator sources;

- Accurate Wind forecast; Modern methods for planning of Power System operation and programs integrated to SCADA;
- Integration of power system into the united energy market.

**Wind energy potential.** Wind energy is one of the fast growing sector in the world. Its part in total generation in some countries is almost 50%.

Georgia has important potential of wind energy, in numbers 4 bln kWh annually. There are nine zones where the wind farms can be constructed.

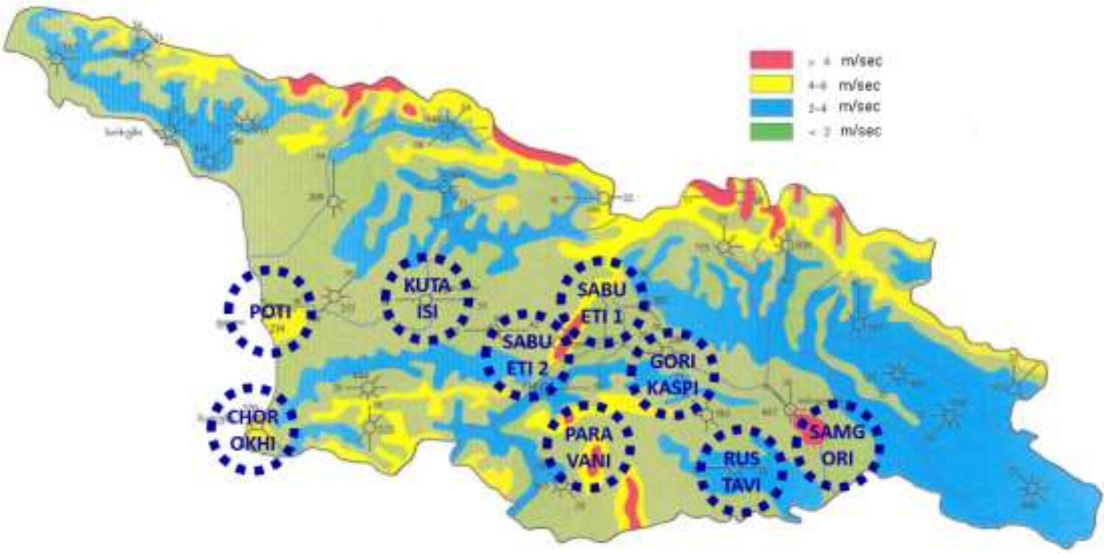



**Fig. 18.1 Geographical zones of wind**

These zones with their respective power potential and annual output are presented in tab. 18.1 below:

**Table 18.1**

| No | Location | Installed capacity (MW) | Annual output (mln kWh) |
|---|---|---|---|
| 1 | Poti | 50 | 110 |
| 2 | Chorokhi | 50 | 120 |
| 3 | Kutaisi | 100 | 200 |
| 4 | Mountain-Sabueti I | 150 | 450 |
| 5 | Mountain-Sabueti II | 600 | 2000 |
| 6 | Gori-Kaspi | 200 | 500 |
| 7 | Paravani | 200 | 500 |
| 8 | Samgori | 50 | 130 |
| 9 | Rustavi | 50 | 150 |
| | **Sum** | **1450** | **4160** |

**Solar energy potential.** With the consideration of geographical location of Georgia, effective and long-term radiation of sun is quite high. Annual duration of sunlight varies from 250 to 280 days in most regions of Georgia, which equals to 1900-2200 hours by day duration annually. Total annual sun radiation by regions in Georgia varies in 1250-1800 kWh/$m^2$ range, as for daily – 4.2 kWh/$m^2$. Summary potential solar energy in Georgia is assessed as 108 MW, which is equivalent of 34 thousand tons of conventional fuel.

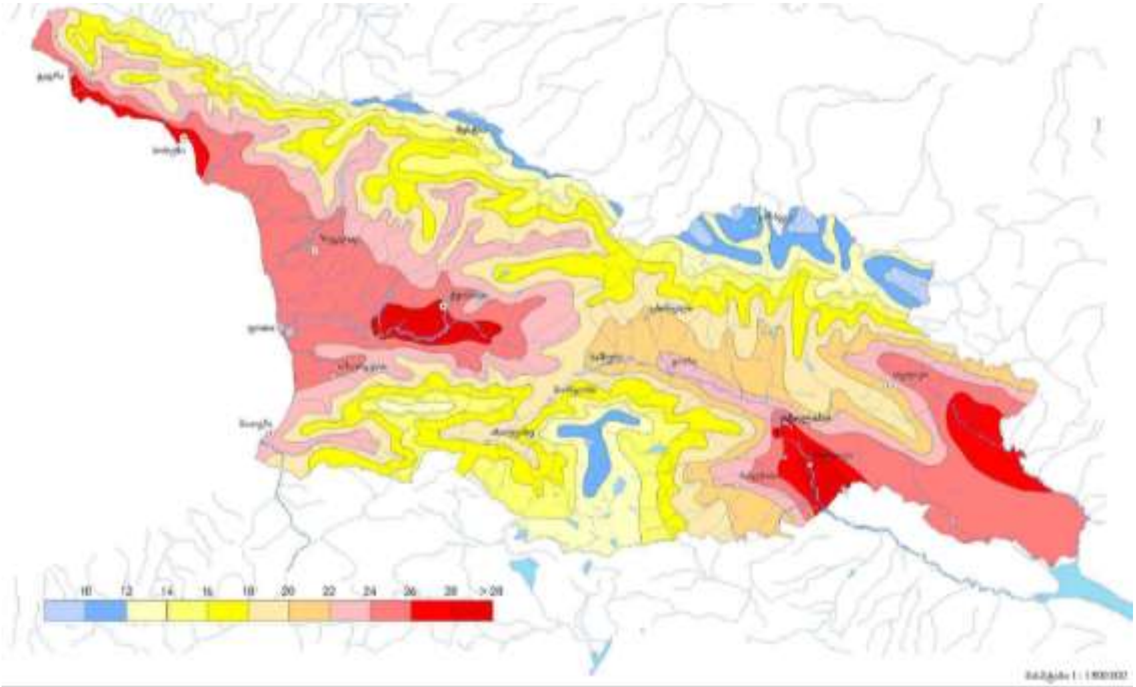



**Fig. 18.2 Maximum temperatures in summer. Potential regions for solar power plants**

It should be noted that west Georgia is significantly sunny compared to east part. In the last years of recent century, solar heating systems have been widespread in Georgia.

There is opportunity to receive water of 40-50$^0$C temperature by use of solar energy in Georgia. Solar energy converters are optimal solution in order to supply difficult to access little villages (located in the hilly and mountainous areas), shepherds, mining works, military-field conditions, communication (telecommunications) retransmission unit stations, emergencies in Georgia.

## 18.5 Research results

### 18.5.1 Possibility of integration of wind power plants

Shortcoming of wind energy is variation of its generation, which exceeds consumption alternation. This results in increase of regulating amount of power.

Integration of variable generation source into the network is relatively less difficult if they will be naturally diversified. Wide geographical scattering of wind lead “smoothing effect” which reduces both variation of such type of generation in power system and probability of decrement of amount of power generated by variable energy sources (wind) down to zero and its peak generation as well.

With the consideration of present topology, composition, possibility of reserves provision in Georgian power system, in order to ensure stability and security as well as to avoid new sources of emergency evolution, worsening power quality and restrict consumers, integration of wind energy into the Georgian transmission network should be realized in parallel with development of power system reserves and transmission network, in particular, along with consideration of the following conditions:

Till 2020, total amount of installed capacity of wind farms in Georgian power system must not exceed 100 MW but only with the consideration of below presented conditions:

1. Rehabilitation of both speed governors in existing HPPs with water reservoir (Lajanuri, Shaori, Dzevrula, Gumati-1,2, Rioni, Vartsikhe-1 and excitations systems in 1 MW and greater generation units;
2. Distribution of Integrated wind farms as equal as possible;
3. Integration into the European energy market.

Starting from 2021 up to 2030, sum installed capacity of wind farms in Georgian power system must not exceed 400 MW but only with the consideration of below presented conditions:

1. Commissioning of 500 kV highway "Jvari-Tskaltubo-Akhaltsikhe" parallel of 500 kV OHL "Imereti";

2. Commissioning of second 500 kV OHL connecting Georgia to Russia;

3. Commissioning of seasonal regulating large hydro power plants (such as "Khudoni", "Namakhvani", "Nenskra", "Tskhenistskali");

4. **Diversification of 400 MW power coming from the wind power plants on the existing wind zones in such way that maximum amount of power in each zone must not exceed 45 MW;**

5. Assimilation of the special program complex in order to implement wind forecast with very high precision as well as to conduct analysis of connection wind power, which is already integrated to SCADA.

**Table 18.2**

| | Total permissible capacities by years (MW) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Region | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 |
| Poti | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Chorokhi | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Kutaisi | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Mountain-Sabueti I | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Mountain-Sabueti II | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Gori-Kaspi | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 28 | 33 | 39 | 44 | 45 | 46 |
| Paravani | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Samgori | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |
| Rustavi | 8 | 9 | 9 | 10 | 11 | 12 | 16 | 22 | 28 | 33 | 39 | 44 | 45 | 46 |

In order to integrate wind station having capacity higher than the acceptable capacity given in Table 18.2, relevant company shall build a storage plant or battery, which will, for at least 8 hrs, provide accumulation (consumption) of such power, by which its' wind station capacity will exceed the differnce between acceptable value given in Table 18.2 and the already utilized capacity.

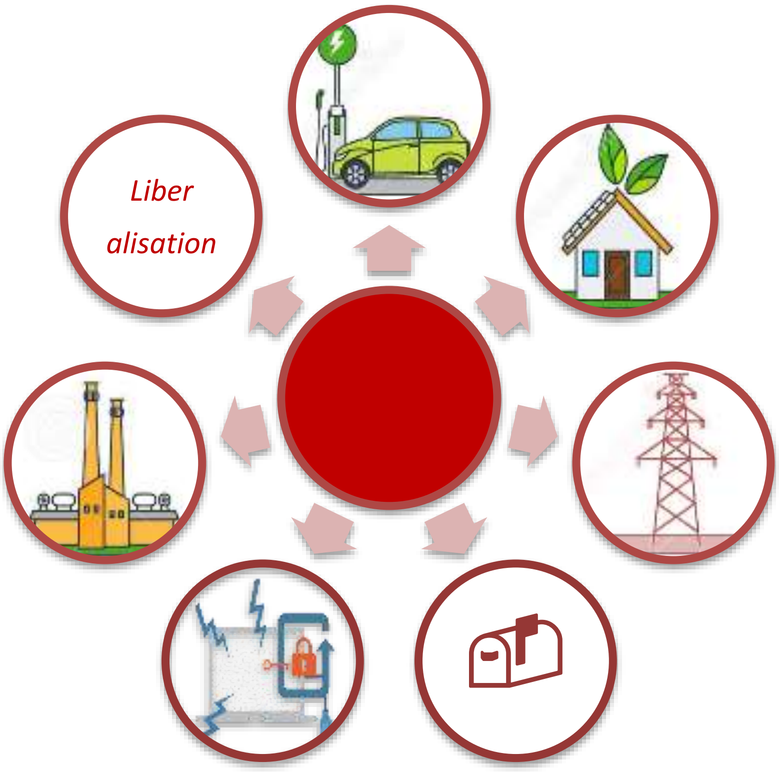
### 18.5.2 Possibility of integration of solar power plants

Solar generation is less variable compared to wind one. In addition, it can be correlated to the consumption variation. The particular positive thing is that maximum correlation is implemented during summer when loading of cooling systems are realized by increase of temperature. According to the preliminary assessment, maximum amount of 50 MW solar plants can be constructed on “Iveria” flat, in particular in regions of lower Kartli and Shiraqi.

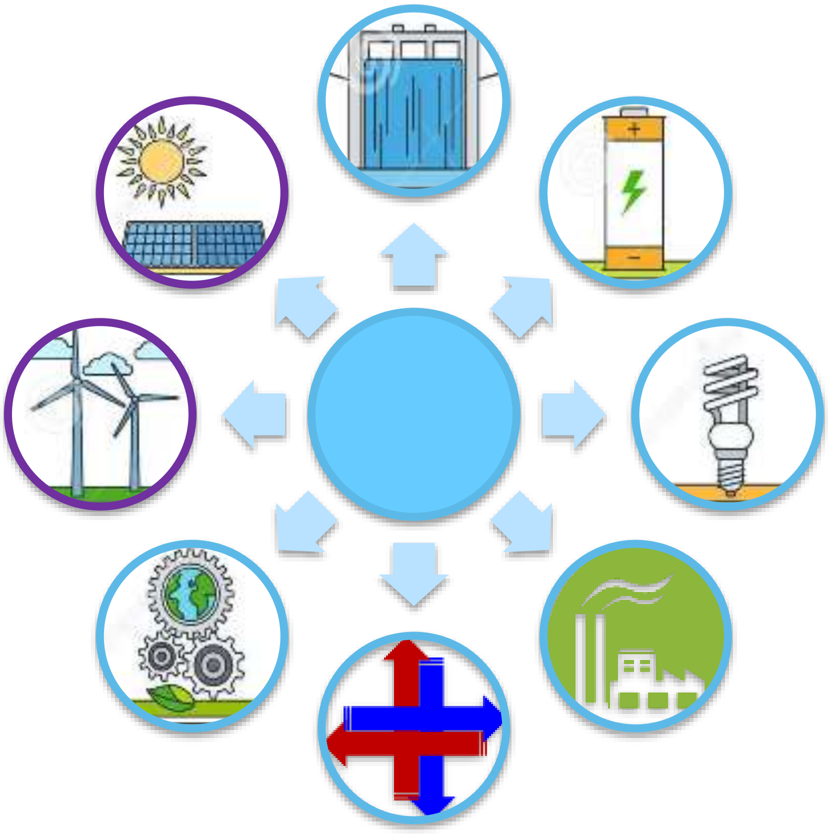
As per preliminary estimates, ten wind stations of 10 MW installed capacity can be constructed in regions distanced by 10 km from each other. This capacity may be increased to 50MW, in case all large regulatory stations are put into operation by 2030.

# 19 Vision about Development for future 2029-2050 Time Span

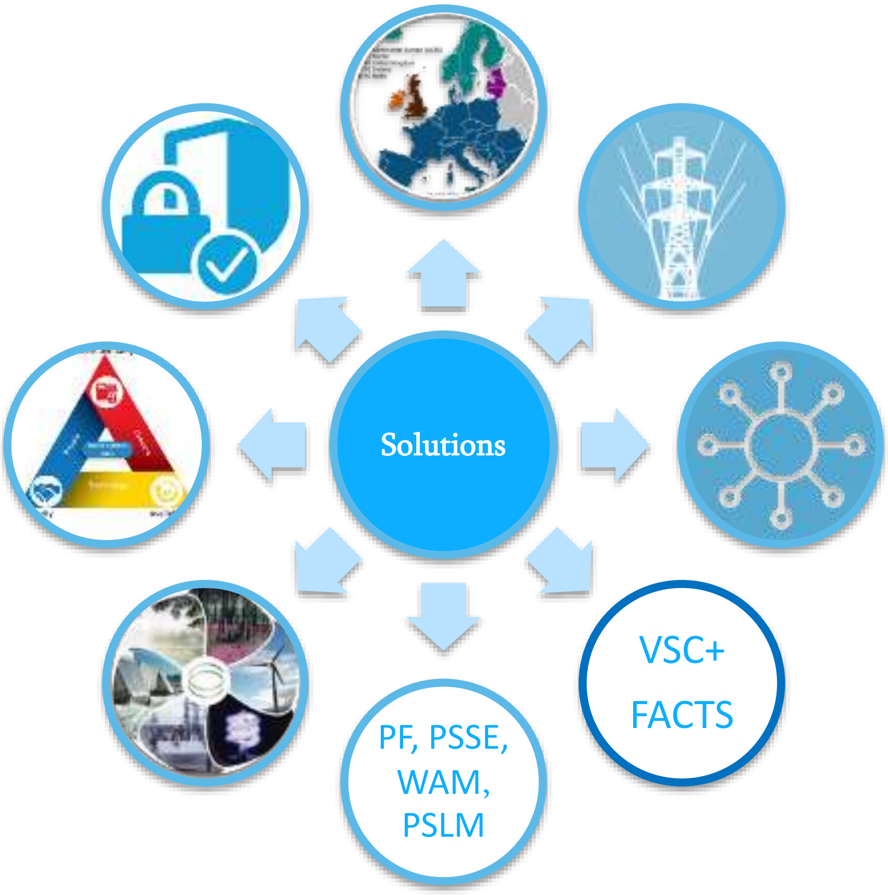
**19.1 New challenges.** Georgian power system will have to overcome not only challenges connected with the existing radial infrastructure, consumption growth, integration of generation and utilization of transit potential, but also challenges emerged in modern world, due to the necessity of power market liberalization and mitigation of climate changes. Power market liberalization caused limitation and systematization of reserves, as well as day-before, during-day, hourly, 15-minute and 5-minute trade. On the one hand, this withdrawed system operation from dispatchers' comfort zone, and on the other hand, caused full automation and computerisation of electricity trade/exchange. This caused risks of cyber attacks and informational safety hazards. For the purpose of mitigation of climat changes, despite unfavorable physical characteristics, thermal and nuclear plants started to be replaced by wind and solar variable generation plants, having no inertia. Additionally, creation of prosumers became more attractive, such as factories, institutions or private houses having their own source of wind or solar energy, selling excess generation to the network, and filling the deficit from the network and which additionally create instability in the system and impede consumption forecasting. Increasing number of electomobiles, as another challenge, may significantly increase peak consumption, unless counter measures are taken. Finally, production facilities having highly variable consumption, mainly metallurgical plants, which cause significant adverse effect on quality and stability of electricity.




**19.1**



19.2




19.3

Primary challenges include:

1. **Electromobiles** replace internal combustion engine vehicles worldwide. This, on the one hand, causes peak consumption growth and, on the other hand, distortion of quality of electric power (harmonics). Around 1 million vehicles are registered in Georgia as of today. As per preliminary optimistic estimates, 5% of vehicles in Georgia will be replaced by electromobiles during next 5 years, 20% during next 10 years, 50% during 15 years and 100% of vehicles during 20 years. This may cause peak consumption growth 250MW – by 2022, and further growth may be even higher. Georgian power system will be able to provide such capacity in summer regimes, under optimistic scenarios of station integrations only. Under other scenarios, short-term but rapid increase of import might become necessary during peak hours. To avoid the above, powerful storage plant or storage battery may be constructed within power supply system.
2. **Prosumers.** Even more institutions, enterprises and population try to create autonomous power supply system, which will be connected with distribution and transmission network. They will be able to export or import electric power to and from the network as needed. Such are called "prosumers". This might, on the one hand and under certain conditions, have positive effect on the consumption, but on the other hand, will have significant adverse effect on the quality of electricity and ability to balance the system. This process causses decentralization of the power system and its management becomes increasingly difficult. During rain or storm, large Prosumers' own source generation will be cut and they will immediately request supply from the power system. In case of insufficient reserve power, significant power deficit may take place in the system and thus create threat of emergency. On the other hand, distribution networks which were designed to supply power from the high voltage side to the end user through their own network, might appear in such situation where they will have to supply power from the "customers" towards distribution network. This might cause high voltages and losses. Therefore, exact number of decentralized customers shall be determined, relevant re-equipment of distribution and transmission system networks, construction of enough reserve sources in the system or provision of this reserve with import, arrangement of system automatics and finally, request optimal parameters of storage batteries for (from) prosumers.
3. **Difficulties associated with the construction of new transmission infrastructure.** Due to difficulties associated with environmental requirements and land purchases, contruction of transmission infrastructure in new corridors becomes increasingly difficult. Population and NGOs frequently obstruct contruction of transmission lines at new routes.
4. **Information safety violations** represent significant risk for modern companies, especially for transmission system operators. This may have significant negative influence on such operators' interests as well as on those of the Country.
5. **Cyber attack threats.** Georgian transmission system operator GSE ensures (in real time) consumption/supply balance of Georgian power system. Protection of GSE's information systems from cyber attacks is a vital goal, in order to avoid interruption of power supply to the customers of the region and the power system as a whole.
6. **Metallurgical plants** represent huge challenge for power systems. Due to rapid and complex changes in active and reactive power consumption, such plants cause large-scale changes in voltages and currents. Besides, they also serve as a source of harmonic distortion.

Challenges with the potential of becoming opportunities:

1. **Solar power plants.** Solar power plant generation may be correlated with Country's consumption and used to smoothen daytime peak hours. But, on the other hand, when clouds move over solar plants, generation will change drastically, that will create necessity for additional quick reaction reserves in the system, to balance solar power generation instability. In order to meet this challenge, storage batteries might be used together with solar plants, with such optimal parameters which ensure stable generation at solar plants.

2. **Wind power plants.** Unlike solar power plants, wind energy is not usually connected with power consumption. Moreover, during peak consumption, wind may stop and/or commence suddenly during minimal consumption. On the other hand, wind generation occures generally during periods when hydrogeneration deficite occures. Therefore, in case wind energy is balanced on an hourly and shorter basis, wind energy generation might have positive effect on Georgian power system generation adequacy.

Solutions for the above challenges are as follows (Table 19.2):

1. **Construction of power plants with large water reservoirs.** Rehabilitation / modernization of the existing electic power stations. HPPs with reservoirs provide more power reserves on the one hand, and system reliability (inertia) on the other hand. Their ability to cover peak consumption should be noted, which might be especially critical while operating electromobile chargers, as well as during integration of solar and wind stations.
2. **Construction of energy storage stations.** Including storage stations and batteries. Such stations provide leveling of consumption schedule, as well as possibility to cover increased peak consumption, balance power system in general – of excess consumption (peaks, loss of generation), as well as excess generation (sudden wind bursts, loss of consumption). Installation of storage batteries might be the solution to integrate variable customers into the network.
3. **Enhanced power efficiency** provides optimization of power system consumption and reduction of peak loads, which is extremely important to meet paragraph 1 of the challenges.
4. **Construction of thermal plants**. In case timely contruction of hydro power plants and other surces of renewable energy will not possible in Georgia, peak loads and further increase of consumption (in general) shall be solved through construction of thermal plants operating on imported power resources.
5. **Construction of inter-system transmission infrastructure.** Since the possible disbalance of generation and consumption is increasing, it is essential that the power system is equipped with inter-system infrastructure, having adequate conductivity, for the purpose of power export in case of excess generation, and for the purpose of power import in case of lack of generation. It is anticipated by 2023-2025 that the potential for inter-system exchange will be at least doubled: up to approx. 5000 MW.
6. **Smart control and operation system.** Power system operation becomes increasingly nonpredictable and continues to fall beyond comfort zone of operators. Therefore, to ensure customer stability, transmission system operator shall have precise information regarding real time system stability level and required reserves. For this purpose, Georgia's power transmission system operator GSE is working on renewal of control and data assessment system SCADA and conform it with European standard safety requirements on the one hand, and successfully meet current and future challenges on the other hand. Namely, the new SCADA will, together with other standard capabilities, have the ability to assess in every 15 minutes (on the basis of dynamic model) the effects of system elements disconnection on the stability of power system; receive information on the readiness and necessity of reserve powers; receive information about anticipated storms and critical climate conditions in the country, which might be a signal for stations redispatching, in order to release load on transmission infrastructure within storm zones. Besides, GSE will constantly renew its anti-emergency automatics, which, in case of emergencies, conducts in real time such disconnections of generation and consumption, which will ensure power balance in the system and maintain transfer of load on all remaining operational elements within acceptable limits.
7. **Integration with European internal power market. Adapt ENTSOE network rules.** Georgian State Electrosystem aims at integration with European power market, which will enable our power system to exchange electric power with Europe. This will become an additional possibility for integration of renewable power sources into the network, as well as for coverage of peak consumption. For this purpose, GSE created the concept for the provision of system services and is preparing relevant software platform for trading with Europe before-day and hourly trade. Besides, GSE specialists are working to harmonize network rules with ENTSOE networc code, by which the requirements will be set

(along with generation) to consumption objects and the variety of their requests is limited within the range acceptable for system operator.

8. **Challenges associated with utilizing new routes.** GSE aims to provide customers with reliable and high quality power supply, on the one hand, and to ensure that the infrastructure has minimum adverse effect on the environment. By the end of next decade, possibility of using visual-friendly towers on certain sections (mast/sail shaped), to run cable lines in some cases, as well as install several voltage conduits on single tower.
9. **Smart networks.** While the generation–transmission–storage–consumption process becomes more intense and nonpredictable, it is essential that distribution system operators are able to control the load of the customers connected; Transmission system operator shall also be able to control consumption of the customers connected and the consumption of the distribution system operator. For this purpose, each component of generation–transmission–storage–consumption process shall be united in a smart network, which provides control of different stage consumption and generation, in such manner to avoid reduction of power system reliability.
10. **FACTS, VSC + equipment**. Due to the geographical distance of generation-consumption objects of the radial network of Georgian power system, under high network load conditions, during the loss of the system's 500 kV lines as well as during sudden reduction of autonomous generation, large reactive power deficite may occure. One way to eliminate this is to install FACTS. Besides, Georgian power system suffers from the deficit of constant inertia. During the loss of generation (import) having 300MW+ capacity, as a result of which the system will switch to isolated mode, the frequency will start to reduce due to low inertia of the system. To avoid this, VSC PLUS can be used, which includes, along with rapid voltage regulator, includes large capacity, which, in case of power deficit, will be charged for about 10 minutes and maintain active power balance. This time forward, hydro and thermal power plants regulate power continuously.
11. **Power system planning and modelling programs.** GSE, as the operator of Georgian power transmission system, provides the operation as well as short and long term planning of the system. Generation planning programs are used, such as VOLORAGUA, GTMAX, system planning programs POWER FACTORY, PSS/E, network modelling programs PLS-CAD, and works and primary tools management system WAMS, which controls GSE network component parameters and determines repair and update requirements. Thus, it determines repair necessity in a timely manner, before damage occures, and avoids unnecessary repair costs. GSE ensures that up-to-date programs are used for power system planning/modelling and adequate level of qualification of its engineers and specialists is ensured.
12. **Analysis of renewable energy source integration.** In order to ensure that integration of solar and wind power sources is not a challenge for Georgian power system and rather becomes an opportunity, GSE will study the possibility of integration of renewable power sources into the network, with the help of European consulting company DIgSILENT. It shall be studied as to at what maximum capacity wind and solar energy stations can be integrated, under conditions of maintaining safe and reliable operation of the network.
13. **Information Safety** represents one of the main goals for GSE. For this purpose, personnel awareness and introduction of ISO 27001 safety standard is impemented.
14. GSE specialists provide **cyber security** at all times. Specialists receive regular consultations from western countries as well as from the countries of the region with relevant experience.

**Resume.** With regard to new challenges, such as electromobiles, possible drastic increase of peak loads, prosumers, system decentralisation and nonpredictability, customers having changing requirements – GSE aims to ensure that Georgian power system responds with such measures as construction of HPPs with reservoirs, enhanced power efficiency, introduction of storage stations and batteries, construction of thermal plants and inter-system transmission infrastructure, upgrade of control and operation system, introduction of "smart networks", optimum integration of wind and solar power plants (possibly with storage batteries), possible introduction of VSC PLUS and FACTS equipment, utilize up-to-date planning and modelling programs. Challenges associated with the construction of new routes are met by GSE by project strategic environmental assessments and construction of such infrastructure, which, along with reliable supply of customers, provides minimal influence on the environment. Arrangement of visual friendy constructions is also considered, installation of multivoltage towers and, in some exceptions, construction of cable transmission lines. GSE responds to market liberalization challenges by renewal of system management program and reradiness for day-ahead and intra-day trade with European internal power market; as well as by rehabilitation of the existing electric power plants according to systemic services concept. In order to respond to possible cyber attack and informational safety risks, personnel awareness and introduction of ISO 27001 safety standard is implemented in GSE. Foreign cyber security experience is also adopted. Relevant GSE specialists are constantly working to ensure cyber security.

**19.2 Possible network enhancement directions.** Svaneti region has the biggest hydrological potential in Georgia. Besides Khudoni HPP and Nenskra HPP, Khaishi HPP, Pari HPP and Tobari HPP projects existed, with total installed capacity of up to 1000 MW. Update of these projects might be discussed, considering minimal environmental impact. Total capacity of updated projects of these HPPs can be anticipated within 500 MW, that will obviously cause network enhancement in order to evacuate power from them. Most part of such HPPs is recommended to be gathered at single nod, near Khudoni HPP, at “Khaishi” substation conditionally. West part of the currently planned 500 kV network will be loaded enough and will meet N1 criteria with small reserve. Therefore, further network enhancement will be required, namely to construct double-circuit 500 kV OHL “Khudoni – Khaishi – Lajanuri” and to convert “Lajanuri – Tskaltubo” section to double-circuit. This will ensure reliability of power withrdawal from Svaneti potential HPPs and increase reliability of power withdrawal from Khudoni HPP. In case of further addition of power into Enguri not, it might become necessary to convert 500 kV OHL “Imereti” to double-circuit, or to replace its conduit with special high conductivity conduit. In case of possible increase of the flow from the west to the east, conductivity shall be increased from Zestaponi towards Tbilisi, which will also require to convert 500 kV OHL “Klartli-2” to double-circuit, or to install special conduit on it.

Significant consumption growth is anticipated during following years in Turkey. In order to support this growth, transmission network connecting to Turkey might be enhanced. Namely, construct new 500/400/220 kV SS “Akhalkalaki”, 3x350 MW 500/400 kV, tie to 500kV OHL “Vardzia”, with one more additional 500kV connection with substation “Akhaltsikhe”, with tie-line to 400kV OHL “Akhaltsikhe-Tortumi” and to convert Turkish section of this line into double-circuit.

As long as exchange with Turkey is maintained within 2500 MW, it might be anticipated that synchronic parallel operation is established with Turkey, which means parallel operation with united European system. HVDC may be installed on 500 kV OHL’s connecting with Russia, which will provide better quality of control and avoid circular flows, which may occur after connection of 500kV OHL “Ksani – Stepantsminda – Mozdok”.

Necessity of enhancing electric power exchange at north-south direction is also probable (Russia – Georgia – Armenia – Iran). For this purpose, convertion of 500 kV OHL connecting with Armenia into double-circuit or construction of new OHL might be considered. Also, it might be also considered to convert 330 kV OHL “hardabani” (with Azerbaijan) to double-circuit, in order to fully reserve 500 kV OHL “Gardabani – Samukhi”

For the purpose of increasing network reliability, it is reasonable to construct 220 kV trunk transmission line “Khrami-2 HPP – Paravani HPP – Akhalkalaki – Khashuri”. This trunk line will also provide reinforcement of the reliability of Shida Kartli and Samtskhe-Javakheti transit and supply reliability. 220 kV OHL “Aragvi” may be converted into double-circuit and new 220 kV substation

"Varketili" may be constructed (which will intrude into 220kV OHL "Varketili" and connect to substation "Navtlughi") to ensure reliable supply to Tbilisi.

Kakheti region is one of the best regions to develop agricultural production. Direct geographical vicinity with Tbilisi, existing natural conditions and recent trend of Tbilisi population growth, will most likely require construction of canneries and fruit processing industries in Kakheti, as well as construction of production storage refrigerators. This will mainly provide Tbilisi supply. Thus, Kakheti electric power consumption is anticipated to be increased significantly. For this purpose, 220 kV SSn "Telavi" and relevant 220 kV OHLs "Zhinvali – Telavi – Gurjaani" shall be constructed which will ensure reliable supply of these regions.

In order to ensure consumption-generation balance in winter regimes, thermal plants may be constructed at such locations which offer best options for power generation (Table 15.3) – in Zestaponi, Ksani and Gardabani.

In order to eliminate imbalance caused by supply-consumption and renewables, as well as to control quality of electricity and increase system flexibility, storage station may be constructed in Khrami-Paravani region and at Enguri HPP, as well as powerfull electric batteries near Tbilisi (at substation "Gardabani-500).

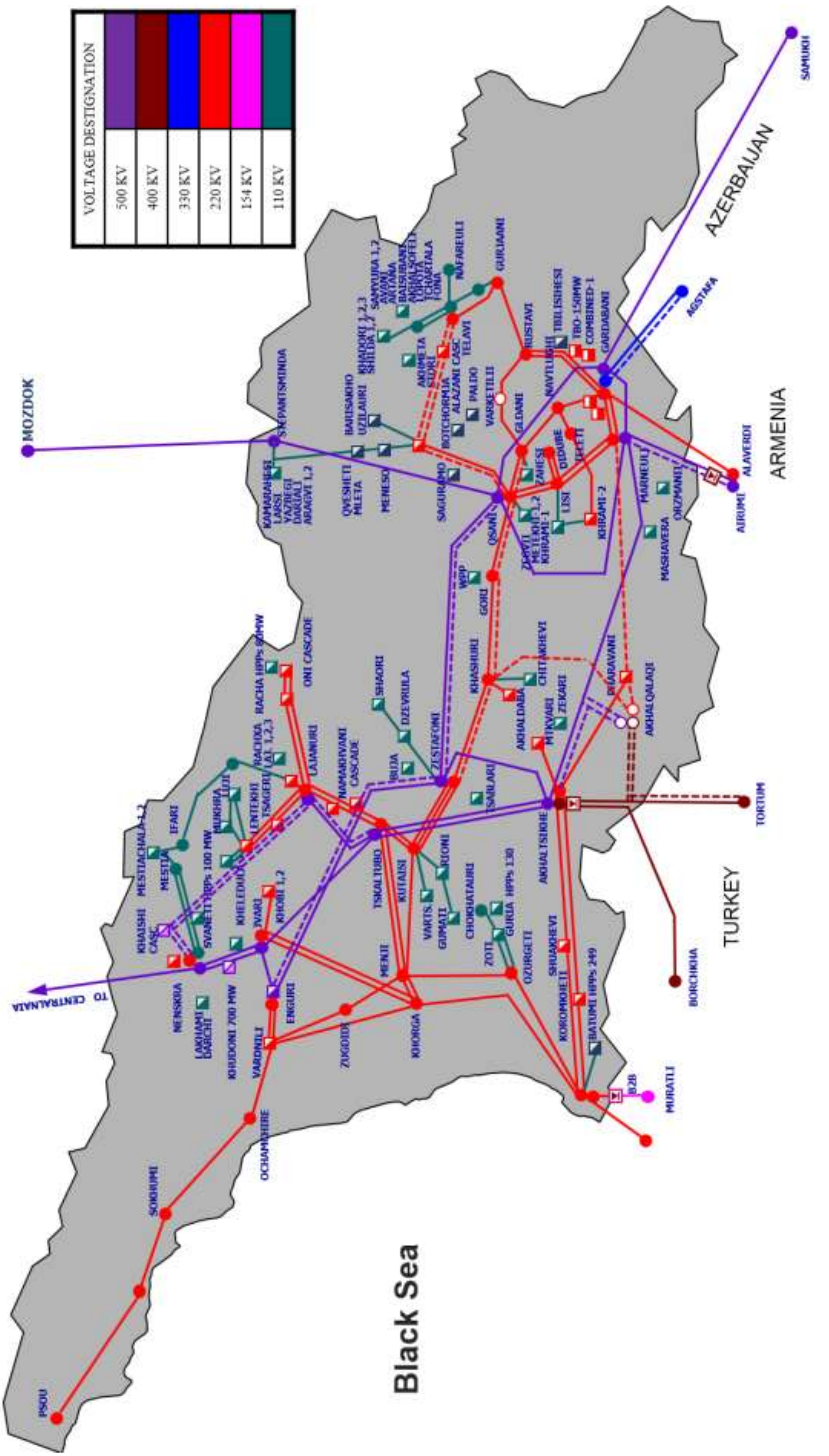



Fig 19.3 Georgian transmission Network in 2029-2050

# 20 Conclusions and Recommendations

1. Security of Supply is the most critical problem for Georgian transmission network. Increasing security of supply / system reliability will be the main aim for Georgian transmission network next ten years.
2. In order to avoid significant decrease of security of supply, it is necessary to:
   a) Increase reliability of power transmission from Enguri to eastern part of Georgia, 500 kV parallel OHL of "Imereti".
   b) Timely construct of cross-border infrastructure.
   c) Avoid deferment of commissioning dates of perspective power plants.
   d) Existing generation objects must (!) be in full technical readiness;
   e) Timely building of hydro power plants with water reservoirs (such as "Khudoni", "Nenskra", "Namakhvani", "Tskhenistskali") in order to use saved hydro power in winter months during the lack of hydro resources.
   f) Construction of storage station, which will enhance system adequacy, reliability, flexibility and create possibility for integration of additional power of variable generation (solar and wind);
   g) Conduct other measures to ensure power efficiency and mitigate consumption growth.

3. According to results of power flow and stability analyses, the planned network is reliable under any N and N-1 operating regimes. Power flows and voltages in the nodes do not exceed the limits set forth in the Grid Code. However, prior to 2020, loss of 500 kV OHL Imereti will require activation of the emergency control system, while starting from 2021, after commissioning of OHL Jvari-Tskaltubo-Akhalstikhe, this will be needed only during repair maintenance of certain OHLs.

4. Based on voltage analysis, data received as a result of outages of R-1 reactors shows that voltage volumes are maintained within acceptable limits;
5. In steady state mode, the losses in 500/400/330/220 kV network vary in the range of 2.27%-4.76%.

6. Development of transmission network will lead to increased short circuit currents. In some nodes, such growth will be 100% comparing to the present values. Therefore, electrodynamical and thermal ratings of the equipment installed in power plants and substations should be verified.

7. For 2021, HVDC converter stations with total installed power exceeding 2000 MW will be operated in Georgian and its neighbouring networks. These facilities act the sources of harmonics. Despite this, according to results of harmonic analysis, the total power distortion will remain within acceptable limits, except in cases of certain higher harmonics. Therefore, the detail analysis shall be performed followed by implementation of required measures prior to installing the new HVDC links.

8. According to appraisal of the planned projects applying CBA methodology, the highest ranked interconnection projects (implying the most needs) are **Jvari-Tskaltubo-Akhaltsikhe** integrating up to 2100 MW hydropower into the network, increasing network transfer capacity and reliability and ensuring compliance with N-1 criterion, and **Ksani-Stepantsminda-Mozdok** that 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 and **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.

9. In case of 5% or higher growth of consumption, it will be necessary to increase the capacity of 220/110 kV autotransformers of Tbilisi substations.

10. For 2027, unit equivalent length of the transmission network and specific capacity of (auto)transformers per evacuated 1 MW generation are reduced comparing to the current values. However, as the calculations show, during 2024-2027, Georgian power system will be more stable comparing to 2017-2020 time span. Therefore, it is apparent that improvement of the reliability is accompanied by improvement of network effectiveness and cost-efficiency.

11. Integration of Wind and Solar power plants should be implemented by safe and reliable manner, by distribution of them on geographical regions as much as possible.

12. In order to provide sufficient level of generation adequacy, it's recommended to avoid postponing of commissioning of hydro power plants with water reservoirs. 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.

13. The nameplate capacity of 500/400/330/220/110 kV autotransformers installed in Georgian transmission network will increase by about 5000 MVA, and the total length of 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 more than 4000 MW hydropower into the network. Total forecasted investment value of the foregoing projects amounts to 750 million Euros.

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

15. New challenges, such as:
    a. Electromobiles – Possible drastic increase of peak load, prosumers – system decentralization and nonpredictability and users with changing requirements. GSE ensures that the system responds with construction of HPPs with reservouis, increase of energy efficiency, introduction of energy storage stations and batteries, construction of thermal plants and inter-system power transmission infrastructure. Completion of control and operation system, introduction of smart networks, introduction of dynamic patency of transmission lines, optimal integration of wind and solar stations (possibly with storage batteries), introduction of VSC PLUS and FACTS, usage of up-to-date planning and modelling devices;
    b. Challenges associated with the construction of new routes are met by GSE by project strategic environmental assessments and construction of infrastructure which provides minimal influence on the environment. visual friendy constructions are also considered, installation of multivoltage towers and, in some exceptions, construction of cable transmission lines.
    c. GSE responds to market liberalization challenges by upgrading system management program and ensuring readiness for trade with European internal power market; as well as by rehabilitation of the existing electric power plants according to systemic services concept.
    d. In order to respond to possible cyber attack and informational safety risks, personnel awareness and introduction of ISO 27001 safety standard is implemented in GSE. Foreign cyber security experience is also adopted. Relevant GSE specialists are continuously working to ensure cyber security.

16. GSE aims at providing reliable and high quality service for its customers and develop such transmission infrastructure as will be required for the support of Georgia's economic development.

Projects covered in these development plans provide adequate response to economic and power system environment. GSE believes that implementation of these projects will satisfy needs of Georgian society; Country's economy will overcome challenges dilligently and ensure better future.

# Abbreviations

| | |
|---|---|
| **GSE** | Georgian State Electrosystem |
| **Ministry** | Ministry of Energy of Georgia |
| **GNERC** | Georgian National Energy and Water Regulatory Comission |
| **GTU** | Georgian Technical University |
| **OHL** | Overhead transmission line |
| **SS** | Substation |
| **AT** | Autotransformer |
| **TR** | Transformer |
| **PP** | Power Plant |
| **HPP** | Hydro Power Plant |
| **SPP** | Solar Power Plant |
| **WPP** | Wind Power Plant |
| **RES** | Renewable Energy Source |
| **TPP** | Thermal Power Plant |
| **GT** | Gas Turbine Power Plant |
| **CCGT** | Combined Cycle Gas Turbine Power Plant |
| **CT** | Current Transformer |
| **VT** | Voltage Transformer |
| **ECS** | Emergency Control System |
| **UFR** | Underfrequency Relay |
| **B2B** | back-to-back |
| **SC** | Short Circuit |
| **mln** | million |
| **bln** | billion |
| **KW** | kilo watt |
| **MW** | mega watt |
| **MVAR** | Mega volt-ampere reactive |
| **MVA** | Mega Volt-Amper |
| **hr** | hour |
| **kV** | Kilovolt |
| **KA** | Kiloamper |
| **KM** | Kilometer |
| **HZ** | hertz |
| **Nom** | Nominal |

| | |
|---|---|
| **pu** | Per units |
| **Sea** | Strategic environmental assessment |
| **REN** | Electric power transmission operator in Portugal |
| **EIRGRID** | Electric power transmission operator in Ireland |
| **PSS/E** | Power System Simulator for Engineering |
| **OPF** | Optimal Power Flow |
| **CIGRE** | International Council on Large Electric Systems |
| **HVDC** | High Voltage Direct Current |
| **IEC** | International Electrotechnical Commission |
| **IEEE** | Institute of Electrical and Electronics Engineers |
| **ISO** | International Organization for Standartization |
| **CBA** | Cost Benefit Analysis |
| **ENTSO-E** | European Network of Transmission System Operators for Electricity |
| **NCC** | National Control Center |
| **SCADA** | Supervisory control and data acquisition |
| **AGC** | Automatic Generation Control |
| **JC** | Joint Control |
| **TSO** | Transmission System Operator |
| **USAID** | United States Agency for International Development |
| **USEA** | The United States Energy Association |
| **FACTS** | Flexible AC Transmission Systems |
| **SVC** | Static VAR Compensator |
| **TTC** | Total Transfer Capacity |
| **NTC** | Net Transfer Capacity |
| **TRM** | Transfer Reliability Margin |

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