Strategic cooperation of electric power systems of Russia and Central Asia for the creation of common Eurasian electric power space

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Abstract. The paper considers electric power integration projects realized and to be implemented on the territory of Eurasia, that include Russia and countries of Central Asia, neighboring regions of Caucasus, South Asia, and others. Studies are focused on the effectiveness of electric power integration of electric power systems of Russia and Central Asia in the long-term perspective, with account of electric ties with neighboring countries.

1 Introduction

Processes of electric power integration are characteristic both of Asian region, of Eurasia as a whole, and of the entire world. Asian and Caspian power grids are under consideration, electric power integration within the projects of Eurasian Economic and Customs Unions are being developed on the post-soviet area, European Supergrid is being formed. All of the projects contribute to the creation of Common Eurasian Electric Power Space in the future [1-3 et al.].

Although the development of these integration processes requires the solution of certain problems (ensuring the energy security of the countries participating in the integration, harmonization of their energy and power legislation, the creation of a multilateral body to promote the interstate power grid (ISPG), the construction of expensive and long interstate electric ties (ISETs), etc.), as a result of electric power integration, significant economic, energy and other benefits arise for all its participants [4].

Russia has ISETs with Kazakhstan and further via Kazakhstan with other countries of Central Asia (CA) for effective power exchange and for raising the reliability of power supply of consumers. Development of integration projects requires revision of the main parameters and operating modes of Russia-Central Asia ISETs as they will become major components of sub-regional ISPG covering the European part of Russia, Ural and Siberia, Central Asia and Asia Minor (AM), a part of Southern Asia (SA), and Middle East (ME). For that matter, effective parameters of those ties, expedient operating modes and ways of their use need comprehensive study.

2 Electric ties between Russia and Central Asia

Integration of Russia and countries of the region started with construction of power transmission lines between Russia and Kazakhstan and via Kazakhstan to other countries of Central Asia as early as at development of Unified Power System (UPS) of the USSR. After the USSR disintegration, Kazakhstan, Kyrgyzstan, Tajikistan and Turkmenistan formed an interstate Central Asian Power System. Today this interstate power grid operates within the power interconnection formed in the post-Soviet space and named IPS/UPS. A diagram of IPS/UPS and its external electric ties with foreign countries is given in Fig. 1. Exchange of power flows along the ties is given for the year 2017.

As is seen from the Figure, as of 2017, Russia was a net importer of Central Asia (Kazakhstan, to be more exact) receiving (into Interconnected Power Systems – IPSs – of Ural and Siberia) about 3.5 TWh/y of electric power. Total transfer capacity of transmission lines (TL) between IPS of Siberia, Ural, Middle Volga and South, on the one hand, and EPSs of different regions of the North Kazakhstan, on the other hand, made about 6.7 GW. Owing to considerable transfer capacity of ISETs, ability to exchange power flows, the systems benefits attained by cooperating countries might have been even higher, as well as the effectiveness of such cooperation.

3 Problem statement and research scenarios

Study of cooperation between EPSs of Russia and countries of Central Asia implies feasibility analysis of perspective amounts and operating modes of power flows between the named above power systems. Commissioning of generating capacities and modes of

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Fig. 1. A diagram of IPS/UPS and its external electric ties

their operation in the considered perspective are being optimized. The result is an optimum mix, amount and operating modes of generating capacities, optimum directions, amounts and modes of power flows between EPSs that ensure minimum costs (including capital, operating and fuel costs) for the grid as a whole.

Calculations were made using a mathematical model for EPS expansion and for its operating modes that was developed in Melentiev Energy Systems Institute (ISEM SO RAN) and widely used for studying the prospects and effectiveness of forming ISETs and ISPGs in the Asian region [4].

Consideration was given not only to EPSs of Russia and countries of Central Asia, but (taking into account rapidly developing electric power integration in Eurasia) to neighboring EPSs covering regions (and countries) of Caucasus (Armenia, Azerbaijan, Georgia), partially Southern Asia (Afghanistan, Pakistan), Asia Minor, and the Middle East (Turkey and Iran). A diagram that includes EPSs of the listed regions (countries) represented as nodes, and electric ties between them, is given in Fig. 2.

Subject of consideration was two scenarios of research that differ in the development level of interstate electric network infrastructure in the considered ISPG. In the first scenario the current values of transfer capacities of ISETs were assumed. The fact that electric tie between Turkey and Armenia (between nodes of Caucasus, Asia Minor and Middle East in Fig. 2) was tripped was taken into account. In the second scenario the transfer capacities of interstate electric ties that are being planned, constructed and will soon be

commissioned were additionally taken into account. Those are TL projects Russia-Georgia (500 kV), Armenia-Iran (400 kV), Azerbaijan-Iran (400 kV), Armenia-Iran (400 kV), Turkmenistan-Iran (400 kV), Turkey-Greece (400 kV), CASA-1000 (Tajikistan-Kyrgyzstan-Pakistan-Afghanistan), and others. It was assumed that TL between Turkey and Armenia was in operation. Potentials for Siberia-Kazakhstan-Ural TL retrofitting (its changeover from 500 kV to initial rated 1150 kV voltage with appropriate increase in transfer capability) were also given due regard for.

Fig. 2. The diagram of ISPG

Present-day state of power flow exchange given in Fig. 1 can actually be considered as ‘zero’ scenario. It can be a ‘reference point’ for scenarios 1 and 2.

Consideration period was taken to be up to 2035-2040 with account of uncertainty of power sector development rates in the countries under consideration.

4 Main input data

Table 1 presents forecast annual maxima of electric loads for the considered target year that are grouped by nodes on the diagram of ISPG (Fig. 2). They were obtained based on the analysis of materials on electric power sector expansion in the considered countries [5-10].

Table 1. Forecasted yearly peak load, 2040, GW.

Russia* (Center, Middle Volga, South, Ural)	Russia (Siberia)	Caucasus*	Central Asia*	Asia Minor and Middle East*	Southern Asia*
140.9	41.8	13.3	61.3	234.3	65.0

* The combined maximum

Table 2 presents present-day transfer capacities of transmission lines that form interstate electric network infrastructure of the considered ISPG..

Table 2. Present-day transfer capacities of interstate electric ties, MW.

Russia - CA	Russia- Caucasus	CA - SA	CA- AM &M E	SA- AM &M E	MA - Europe	Total
6700	1700	2300	460	80	1600	2400

Tables 3 and 4 present main economic indicators of power plants of different types and on different fuels [11-13].

Table 3. Specific capital investments, USD/kW

	Hydro	Pumped storage	Thermal, coal	Thermal, gas	Thermal, oil	Nuclear
Russia	3000	1100	1800- 2000	1200		2800
Central Asia	2100	1600	2150	1250		4300
Southern Asia	2600		1700	1200	1400	5200
Caucasus	1500		2000	1000	1500	5500
Asia Minor and Middle East	2250	1000	1800	670	1400	4500

Table 4. Fuel costs, USD/kW

	Thermal, coal	Thermal, gas	Thermal, oil	Nuclear
Russia	0.014-0.25	0.027-0.030		0.004
Central Asia	0.014-0.017	0.034-0.038	0.099	0.004
Southern Asia	0.034	0.041	0.100	0.006
Caucasus	0.030	0.050	0.100	0.010
Asia Minor and Middle East	0.034	0.050	0.090	0.007

Costs of interstate ties were not accounted and, hence, transfer capacities of those ties were not optimized since projects of those ties, according to the plans available, are predetermined and will be commissioned prior to the target year. The above mentioned 500 kV TL Siberia-Kazakhstan-Ural previously operated at 1150 kV was an exception. In the optimization model, when minimizing the costs for ISPG as a whole, the optimum transfer capacity of the line was determined with account of costs for its retrofitting.

5 Results of studies and analysis

Comparison of results of optimization for Scenarios 1 and 2 shows that enlargement of transfer capacity of interstate grid infrastructure (Scenario 2) allows reduction of total ISPG costs by more than 2 billion USD a year. Capital investments into power plants in this case are 4.7 billion USD lower, and demand for commissioning new power plants for the considered time span falls by 2.6 GW. As is seen from Table 5, enlargement of transfer capacity of ISETs has different impact on capacities of various nodes, (difference of commissioning of generating capacities for Scenarios 2 and 1). Additional power plant capacities are commissioned in the Caucasus node (Scenario 2), which proves that in case of enlargement of transfer capacity of this node, higher power generation is profitable (providing it is transported beyond the region). Installed capacity of power plants in the Central Asia (see the Table) does not change.

Table 5. Generating capacity benefit, GW.

Russia	Central Asia	Southern Asia	Caucasus	Asia Minor and Middle East
1.3	—	1.1	-2.8	3.0

Table 6 presents change in the power generation by the nodes of the diagram in Scenario 2 vs Scenario 1. Russia, despite its capacity benefit, increases power generation in Scenario 2, similarly to CA that has no that benefit. Caucasus node knowingly increases power generation in the second scenario as its capacity benefit is negative (it increases its generating capacities in the second scenario). The mentioned additional power generation is transmitted to the nodes of SA and AM&ME.

Table 6. Change in the power generation, TWh/y.

Russia	Central Asia	Southern Asia	Caucasus	Asia Minor and Middle East
10.1	11.3	-4.9	10.9	-23.0

Tables 7 and 8 show the amounts of power exchanges between nodes for the considered scenarios. Power flows in the second scenario grow as compared to the first one, especially in the direction Russia - Caucasus - AM&ME. Total amount of export-import power flows in Scenario 1 made about 240 TWh per year, whereas in Scenario 2

it was as high as 320 TWh/y, i.e., increased by one third. It should be kept in mind that those values do not reflect the entire amount of interstate power flows. Nodes of the diagram (with the exception of nodes representing EPSs of Russia) include several countries of a certain region, and power flows between those countries cannot be accounted in the model.

Table 7. Power flows exchange, Scenario 1, TWh/y

Nodes	Russia (Siberia)	Russia (Center, Middle Volga, South, Ural)	Central Asia	Southern Asia	Caucasus	Asia Minor and Middle East
Electric ties						
Russia (Siberia) - Central Asia	-11.5	-	12.4	-	-	-
Russia (Center, Middle Volga, South, Ural) - Central Asia	-	51.6	-50.1	-	-	-
Russia (Center, Middle Volga, South, Ural) - Caucasus	-	17.9	-	-	-17.4	-
Central Asia - Southern Asia	-	-	18.6	-17.9	-	-
Central Asia - Asia Minor and Middle East	-	-	4.9	-	-	-4.7
Southern Asia - Asia Minor and Middle East	-	-	-	-0.4	-	0.4
Caucasus - Asia Minor and Middle East	-	-	-	-	12.8	-12.7
Asia Minor and Middle East - Europe	-	-	-	-	-	4.0

(-) power received by a node, (+) power supplied by a node

Table 8. Power flows exchange, Scenario 2, TWh/y

Nodes	Russia (Siberia)	Russia (Center, Middle Volga, South, Ural)	Central Asia	Southern Asia	Caucasus	Asia Minor and Middle East
Electric ties						
Russia (Siberia) - Central Asia	-13.1	-	14.1	-	-	-
Russia (Center, Middle Volga, South, Ural) - Central Asia	-	53.2	-50.0	-	-	-
Russia (Center, Middle Volga, South, Ural) - Caucasus	-	27.1	-	-	-26.3	-
Central Asia - Southern Asia	-	-	23.5	-22.5	-	-
Central Asia - Asia Minor and Middle East	-	-	9.5	-	-	-9.2
Southern Asia - Asia Minor and Middle East	-	-	-	-0.6	-	0.6
Caucasus - Asia Minor and Middle East	-	-	-	-	32.6	-32.3
Asia Minor and Middle East - Europe	-	-	-	-	-	4.0

(-) power received by a node, (+) power supplied by a node

The highest growth of power flows in both scenarios is observed in case of comparison to a 'zero' scenario, i.e., present-day power flows given in Fig. 1. Thus,

power flows from Central Asia to Asia Minor and Middle East in Scenarios 1 and 2 grows almost threefold, that from Central Asia to Southern Asia grows actually tenfold.

As to cooperation between Russia and Central Asia countries, its power flows in Scenarios 1 and 2 were considerably enlarged as compared to the present-day ones. Thus, power flows from European Russia and Ural to Central Asia (Kazakhstan) grows to more than 50 TWh in the target year, and that from Central Asia (Kazakhstan) to Siberia makes 12-13 TWh/y. The obtained values of power flows are potentially feasible.

Table 9 gives transfer capacities of ISETs for Scenario 2 (for Scenario 1 they were given earlier in Table 2). As is seen, in Scenario 2 they are more than 5.5 GW higher and ensure corresponding growth of power flows exchange under this scenario (Table 8).

Table 9. Transfer capacities of interstate electric ties, Scenario 2, MW.

Russia - CA	Russia - Caucasus	CA - SA	CA - AM&ME	SA - AM & ME	Caucasus - AM&ME	AM - Europe	Total
7300	2580	3300	900	240	4230	2400	20950

6 Conclusion

Enlargement and effective use of interstate power network infrastructure between Russia and Central Asia, Caucasus, Asia Minor and Southern Asia, and partially Middle East contribute to intensification of power flows within this ISPG, and give systems benefits. ISETs in the study were limited by the existing, planned electric ties, and by ties under construction. Expansion of interstate network infrastructure is deemed to accelerate integration of the considered domestic EPSs and raise ISPG effectiveness in the area.

Further detailed and comprehensive feasibility studies are needed that may form the basis for developing the policy in the field of electric power integration of Russia, countries of Central Asia, and of neighboring regions, including Caucasus, Southern Asia, etc.

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