COMPLEX SOLUTION
OF THE TASK IN ORDER TO INCREASE THE THROUGHPUT CAPACITY
OF POWER TRANSMISSION LINES BETWEEN THE POWER SYSTEMS
OF NORDIC COUNTRIES AND RUSSIA

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SUMMARY
Complex access to the creation of backbone ties, containing AC lines and controlled power transmission lines, including those with the usage of rectifier-inverter substations, makes it possible to reduce the expenditures for the increase of the throughput capacity of the intersystem power transmission lines, having ensured in so doing a retention of the transmission controllability and reliability for coordinated power flows. The effectiveness of the complex access is considered on the example of existing and planned interstate (Russia-Nordic countries) tie lines.

Keywords: interconnection lines, controllability, reliability, circular schemes.

1. FORMING OF RUSSIA-NORDIC COUNTRIES INTERCONNECTION LINES

The ties between the power systems of the Scandinavian countries were shaped more than 40 years ago. The formed “Nordel” union consists in the long main power transmission lines of 330 and 400 kV. The creation of the lines between the power systems of Finland and Sweden (“Petäjäkoski - Letsi” and “Keminmaa – Svartbyn” 400 kV overhead lines in the north and Fenno-Skan “Rauma – Forsmark” DC cable line in the south) as well as the AC lines between the power systems of Sweden and Norway (“Borgvik – Hasle” and “Skogssäter – Halden” 400 kV overhead lines in the south and “Narsprånget – Ofoten” in the north) has determined the forming of circular interconnection ties in the “Nordel” union. The tie of the Nordel union with the UCTE and CENTREL unions of the Western and Central European countries is only accomplished by DC cable lines.

Forming of Russia-Finland intersystem ties was started in the end of 70-ies and had a provision for the power transfer from Russia to Finland. The decision for the creation of the controlled tie was made by analogy with already operating power transmission lines between the power systems of the Scandinavian and Northern European countries. The design had a provision for the construction of rectifier-inverter converting substation (DC back-to-back) to ensure the voltage concordance for the main grid of UES of Russia (330 kV) and the power system of Finland (400 kV). The throughput capacity of this tie was initially planned for the annual electric energy transmission to Finland in amount up to 4 TWh with power flow up to 600 MW. 400 kV double-circuit transmission line (Vyborg - Ylikkälä) of about 60 km length
was constructed. The provision was made for installation (within Vyborg substation) of two converting units (with 350 MW rated capacity each), that were put in operation in the end of 1982. It was planned to increase the throughput capacity of Vyborg rectifier-converter complex (RCC) up to 1000 MW.

The necessity to increase the throughput capacity of the Vyborg RCC became evident during the operation and a decision to install 2-3 additional converting units has been made. By the 2002 there were 4 rectifier-converter units in operation with total throughput capacity of 1400 MW, which ensured more than 7 TWh of electric energy transmission with power flow up to 1000 MW.

On further designing of the Vyborg RCC extension the decisive aspect was the Nordel’s requirement to limit the value up to 1000 MW for the power flow, transmitted under the normal modes via individual feeding buses (one physical node of the network).

2. COMPLEX DEVELOPMENT OF INTERCONNECTION TIES

In the process of consideration and comparison of possible versions of intersystem links “Russia-Finland” development a decision has been determined to create a complex transmission link composed of a controlled transmission link and an AC line. In addition to operating controlled transmission, that was based on the rectifier-converter units with 1400 MW throughput capacity, the block-scheme was developed to ensure the operation of the Northern-Western heat & power plant generators in parallel with the power system of Finland. The block-scheme represents a single-circuit transit: «generator-transformer of the Northern-Western heat & power plant – 330 kV AC line – 330/400 kV autotransformer in the Vyborg substation – 400 kV AC line – Yllikkälä substation» (Fig.1). By then there was already positive experience of complex utilization of the AC ties and controlled power transmission between the Finnish and Swedish grids, which control is accomplished in accordance with the condition of the mode conduction for the Finnish power system as well as according to the loading condition of 400 kV backbone transmission lines of Sweden.

![Fig.1. Intersystem links “Russia – Finland”](image)

The complex of design solutions was realized in the end of 2002 and made it possible to ensure the joint operation of the controlled tie and AC power transmission. The scheme of deep sectionalization of the main grid with possibility of separate control of the power flows for two directions was practically realized on the transmission ties between the power systems of Russia and Finland. Total power flow, transmitted via the Vyborg RCC, was increased up to 1400 MW. In so doing the controlled transmission (rectifier-converter complex), operated
under the normal modes and design scheme, ensured the transmission of 1000 MW power flow, while the allotted units of the Northern-Western heat & power plant ensured the transmission of 400 MW power flow as per the block-scheme. It ensured the observation of the norms adopted in the Nordel union. The annual amount of electric energy export from Russia may reach 10 TWh via the realized complex scheme (with the observation of the norms and operational conditions adopted for the interstate transmission lines and coordinated with the Finnish side).

Power flow transmission of up to 1400 MW without a block-scheme operation of the N-W HPP’s units with the power system of Finland is being executed through a reserve scheme.

To fulfill the Nordel’s requirements (the transmission of no more than 1000 MW from one node) the emergency sectioning of the rectifier converter complex is provided in the reserve scheme. With this in mind the block-scheme is realized for the operation of one of the rectifiers with the adjacent lines both from the rectifier side (in block with 330 kV line) and from the inverter side (in block with 400 kV line).

The available experience of the Vyborg RCC operation has confirmed the reliability and effectiveness of the design solutions. Complex utilization of AC power transmission and controlled tie made it possible to increase the transmitted power at minimum expenditures. The allotment of the Northern-Western heat & power plant generators for parallel operation with the power system of Finland as per the block-scheme ensured the maintenance of the balances for the reactive power of the rectifier-inverter facilities and the voltage of AC power transmission line as well the observance of the standardized indices for the electric energy quality in the adjacent grids of the power systems of Russia and Finland.

3. INCREASE OF THROUGHPUT CAPACITY OF THE INTERCONNECTIONS

An increase of the throughput capacity of Russia–Finland lines will require the construction of new interstate links. An expediency of the creation of new power transmission lines and the creation of additional margins of the throughput capacity follows from the actual evaluation of the power balances in the Scandinavian countries.

The scales of planned long term as well as a short-term power exchange within the Nordel are to a large extent determined by the influence of the climatic conditions, including the cyclic recurrence of the low water and dry years. The forecast for the nearest winter maximum of 2003/2004 does not exclude the power deficit of more than 2000 MW in the Nordel union [1]. The necessity of the reserve creation for the throughput capacity of the interstate transmission lines is substantiated by the requirements to ensure the reliable power supply for the consumers (power safety) in some countries with the conditions of seasonal reduction of their own power resources.

Expert’s evaluation shows that the electric energy import growth to the Scandinavian power systems is depended on the strategy for the development of generating capacities adopted in these countries. In recent years volume of the main equipment demolishing is in excess of the commissioning of new capacities. As a result electricity balances’ fluctuations in the Scandinavian countries are determined by both structure of generating capacities and climatic conditions, so far as a total HPPs capacity in the Interconnection amounts to 60%. The forecast, prepared by the Nordel Balance Group, takes into account the possibility for the occurrence (in case of low water periods) of significant electric energy deficits. For example,
even for 2006 the design value of deficit in the union is evaluated as 10 TWh; in so doing one can not exclude an opportunity of extreme situations with the deficit increase up to 18 TWh [2].

An actual aspect is also the NORDRL countries’ interest in the extension of the intersystem exchange scale including the realization of the intersystem effect to greater extent. Even now the daily balance oscillations in the union are in excess of ±1500 MW resulting in the additional requirements to the throughput capacity of the interconnection ties and in the first turn to the provision of the sufficient margins and control of the circular power flows. Actual daily schedule of the balance variation in the Nordel is shown in Fig. 2. As it is seen, the nature of the balance variation differs significantly for individual systems, suggesting that there is principally different access to its maintenance.

All these aspects testify that there is regional interest in the creation of the conditions to ensure the long term electric energy import. For example, Finland plans in perspective the long term electric energy import in amount about 10 TWh. The realization of the program for the reduction of the power generation by the nuclear power plants may shift Sweden to the long-term importers of the electric energy. The construction of new ties creates an opportunity for the electric energy transmission by transit via the grids of Finland and Sweden power systems to the countries of the Northern Europe. An evaluation of the throughput capacities of existing 400 kV grid of the union confirms the possibility to accomplish the transit of large amounts of electric energy including the transmission in Finland - Sweden - Denmark - Germany direction.

The creation of the conditions for seasonal power exchange and provision of the transit reliability are expedient to be considered during the planning of the backbone grid development of the power system of Finland. A peculiarity of the formed structure makes it possible to realize the advantages of joint operation of the intersystem controlled ties and AC lines. The first step was the creation of the combined transmission tie (Russia – Finland). The fulfilled design developments determined the schematic solutions, which ensured the control of main parameters for the rectifiers and inverters of the converting substation (DC back-to-back). The experience, gained during more than 20 years of the Vyborg rectifier inverter converting substation operation, has confirmed the reliability and effectiveness of the design solutions.

4. DEVELOPMENT OF RUSSIA-NORDIC COUNTRIES INTERCONNECTION TIES
Real direction of new interstate power transmission lines is the construction of the lines from the Kola region to the northern regions of Finland and Norway. This direction is determined
by the export potential of the region as well as by the availability of convenient passages for the location of the routes of new power transmission lines. The construction has been considered for the interstate “Russia-Finland Power Bridge” transmission line, which is made up (at the first stage) of the single-circuit overhead AC transmission line for the connection of 330 kV grids of the Kola region and 400 kV grid of the northern part of the power system of Finland (Fig. 3).

![Fig.3. Development links between Nordel and Kola Region](image)

The main technical solutions have been developed for the interstate AC power transmission line - “Kniazhegubskaya hydraulic power plant (the Kola region of Russia) – Pirttikoski (Finland)”. The planned power transmission will make it possible to accomplish the electric energy export from the Kola region of UES of the North-West of Russia to Finland with annual amount up to 3.5 TWh and power flow up to 500 MW. The consideration has been also conducted for the construction of the network projects located at the territory of the Kola power system and territory of Finland and ensuring the transmission of the electric energy and power from the Kola power system to the grids of Finland power system including the aim of re-export to the power systems of the other Scandinavian countries and countries of Central Europe.

Hand in hand with this the construction of the lines from the Kola region to the northern regions of Finland will create complicated circular ties between the Russian and Nordel unions. In so doing the construction of the “Kola Power Bridge” - “Knizhegubskaya – Pirttikoski” will create the additional ring of about 2700 km total length, including 1200 km at the territory of Finland and about 1500 km at the territory of Russia. It will require an application of special means for the forced control of export flows in order to ensure the controlled re-distribution of the power flows for effective utilization of the throughput capacities of existing and newly constructed power transmission lines with minimum levels of the power and electric energy losses. Thus the creation of the controlled interstate power transmission has been considered at the stage of Technical-Economical Feasibility Study.
Hereinafter it is planned to create new circular tie, that will cover the north of the Kola power system and the power system of Norway. An application of effective power control in this ring is also planned for optimum distribution of the power flows between the interstate tie lines. Forming of several circular grids, that connect the power systems of UES of Russia and Nordel, will require the realization of the coordinated control for the power flows in this grid.

Forming of circular schemes of the main backbone grid will require the control organization for the power flows in this ring. The main tasks of the control are:
- elimination of mutual influence of neighboring power unions on the mode parameters;
- full utilization of the throughput capacities of existing grids, including the necessity exception for the creation and constant keeping of the reserve;
- elimination of appearance of requirements to the development and conditions of adjacent grids’ operation and to its configuration;
- possibility for full realization of the advantages of the electric energy free trade in competitive European market.

The balance variation in practically any node of Finland is perceived by the Northern and Southern direction with the factor of 0.3 and 0.7 respectively. It is determined by the fact that the grids of the Northern-Eastern region of Finland are significantly less developed than the grids of the Southern and Southern-Eastern directions. The design total resistance of equivalent tie between the border points of the Northern and Southern ties along the territory of Russia and Finland is approximately the same and is about 200 Ohms (related to 330 kV voltage). The balance variation even in frontier regions of Russia does not practically change the flow distribution between the Northern and Southern directions (ties).

5. CONCLUSION
The creation of new interstate power transmission lines (Russia - Finland), that contain the controlled ties and AC power transmission lines, represents the definite stage of further development of the NORDEL interconnection links. The operational experience of the interstate power transmission lines, that contain the controlled ties (DC back-to-backs) and AC power transmission lines, may form a basis for the design of reinforcement of the ties between the Nordel union and the adjacent power unions.

The investigations (conducted by the experts of "Fingrid Oyj" and "Energosetproject Institute") make it possible to have optimum design solutions for the creation of Russia – Finland dispersed controlled tie lines (from Vyborg to Kirkenes), which ensure the reliable joint operation with AC shunt network. The application of the effective means for control of grid modes and parameters, including the usage of the SMESes, controlled series and shunt compensation, FACTS and other progressive technologies, will make it possible to ensure the reliability of electric energy exchange under the normal and emergency conditions [3].

The complex of works on the investigation of the rational development of Russia – Finland intersystem transmission lines will have its effect in the works for the power engineering development of Baltic region.

6. REFERENCES: