

DEVELOPMENT OF INTERCONNECTORS AND POWER TRANSFER BETWEEN FINLAND AND RUSSIA

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1. General

The energy transmission from the Soviet Union and later Russia to Finland has long traditions. Technical matters together with the history are the reason to the fact that the existing connections between Russia and Finland are realised either as power plants synchronised as separate islands to the Finnish system or through a HVDC link. Due to historical reasons, too, only electricity import is presently possible from Russia to Finland.

During the years the electricity transmission from Russia to Finland has increased remarkably. At present the connections cater for commercial import from Russia of 1300 MW at 400 kV and another 150 MW at 110 kV. The Russian company RAO UES has opened a sales office in Helsinki to play actively in the electricity market. New proposals dealing with the further strengthening of the tie lines/connections - including also the proposal to synchronise the RAO UES system with the Finnish and the Nordic system - have been presented.

The paper describes the different phases of the development of the co-operation between Finland and Russia and explains from the Finnish view point the reasons to the technical selections made between the different alternatives. Also a technical comparison of the synchronous and asynchronous interconnections is made.

2. Nordic power system and Fingrid Oyj

The Nordic power system is commonly known as the Nordel system. Nordel is an unofficial co-operation forum of the Nordic transmission system operators, whose primary objective is to create the prerequisites for, and

to develop further, an efficient and harmonised Nordic electricity market. Here, the term 'unofficial' means that legally binding contracts etc. can be signed only by individual TSO's and market players, not by Nordel. In spite of this Nordel co-ordinates the planning and operation of the Nordic power system by preparing common grid codes, connection terms for power plants, operation rules etc.

Fig. 1 shows the Nordel grid in its present form. For clarity reasons only lines with $U_m \geq 245$ kV are shown. Fig. 2, in turn, shows the power transmission capacities of the different tie-lines/interconnectors in 2003.

The power transmission systems of Finland, Norway, Sweden and eastern Denmark are synchronised to each other but the connection to the Western-Danish system is only through HVDC connections. Western-Danish system, in turn, is synchronised with the Western-European UCTE-system. Also the connections to Russia are realised only through HVDC link or via power plants synchronised to the Nordic system only (island operation mode). Consequently, the great majority of Nordic power system is neither synchronised with Western-European UCTE-system nor with the RAO UES system. No connection exists today to Iceland.

There are relatively strong tie-lines between the Nordic countries. A special and characteristic feature of the Nordic power system is the great number of HVDC-links between the countries i.e. DC-links within the AC-coupled system itself such as Fenno-Skan. The geography together with the technical possibilities has necessitated the use of these solutions.

Table 1 summarises the characteristic features of the Nordic power transmission system [1]. When the general trend of the electricity consumption in Nordic

countries in 2002 was decreasing, Finland and Iceland still showed a considerable increase in the consumption (3,3 and 4,7 % versus the Nordel average value -0,9 %).



Fig. 1. The Nordic power system in 2003 (400 and 220 kV lines only)

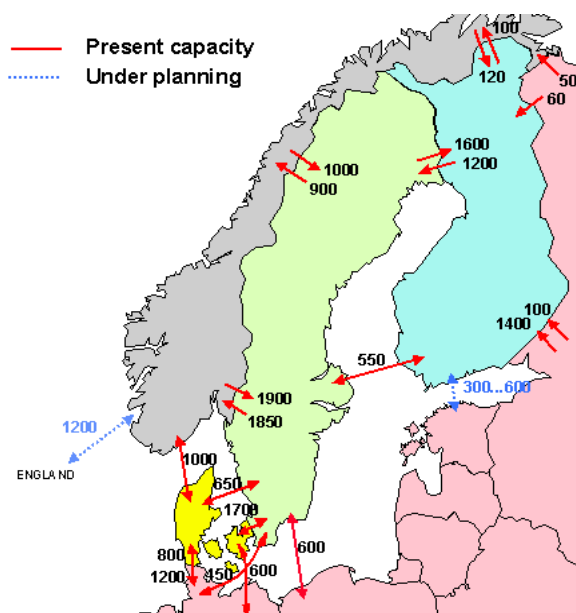


Fig. 2. The transmission capacities in Nordic power system in 2003

Fingrid Oyj is a privately owned company in its duties of the Finnish transmission system operator as well as of the transmission grid owner, which started its operations in 1997. The transmission grid means the grid consisting of 400 kV, 220 kV and meshed 110 kV lines as well as of substations connected to these lines.

Table 1. Key figures: Nordic power system in 2002 [1].

		Den	Fin	Icl	Nor	Swe	Nordel
Ins cap	MW	12632	16866	1474	27960	32223	91155
Gener	GWh	37260	71938	8404	130591	143361	391554
Import	GWh	9047	14577		5330	20108	49062
Export	GWh	11102	2654		15003	14750	43509
Consu.	GWh	35205	83861	8404	120918	148719	397107
Breakdown of electricity generation							
Hydro	%	0	15	83	99	46	55
Nucl.	%	-	30	-	-	46	22
Therm	%	87	55	0	1	8	21
Renew	%	13	0	17	0	0	2

The operational principles/obligations of Fingrid are summarised as follows.

- offer network services to all parties in equal terms and at a reasonable price (including control, operation and development of the Finnish grid and the present interconnectors between Finland and the neighbouring countries)
- develop the grid in accordance with the customer's needs, taking economic principles in to account
- operate and maintain the grid efficiently
- enhance the efficiency of the electricity market and
- take care of the momentary power balance between electricity consumption and production as well as balance settlement.

When making decisions, the company gives priority to the general interests of the electricity market and the system.

Fingrid Oyj has in total about 100 customers which represent power producers, power intensive industry and distribution companies. With the personnel amounting to 210 the annual turnover of the company is of the order of € 270 million, from which about 80 % is coming from the grid business and the rest from the power balance management.

The Electricity Market Act provides for a legal framework and details of the network operations of Fingrid. This means e.g. that Fingrid Oyj has been assigned obligations for connection, transmission and network development as well as for the system responsibility. In the Finnish system the construction of the high voltage grid is subject to licence but no company has a monopoly. Consequently, also other companies than Fingrid can construct transmission lines, even to neighbouring countries, but the system responsibility belongs always to Fingrid.

The Energy Market Authority controls reasonableness of the charges and impartiality of the operations. The transmission prices have not been regulated, which means that there does not exist at the main transmission grid level any upper limits or price formulas but the reasonableness of pricing is assessed case by case on the basis of company-specific information, benchmarking analysis etc.

3. Power transfer Russia-Finland

Figure 1 shows that at present power transfer from Russia to Finland takes place to four different locations. In two of these the power transfer takes place in greater amounts through the lines owned by Fingrid Oyj.

3.1. Development of the power transfer from Russia to Finland

"Small scale" AC-power transmission or delivery from Soviet Union, later Russia, to Finland has taken place in several occasions by synchronising local, relatively small power plants to the Finnish grid. First power delivery contracts were made already in the late 1950's. The connection of "island power plants" has especially taken place in the south-eastern and north-eastern parts of Finland. Usually the connections have been made using at most the 110 kV voltage level. The energy deliveries have therefore had a local and from the whole country's view point a marginal importance only in the order of magnitude of 100 MW and some hundreds of gigawatt-hours.

In 1969 negotiations were started with the aim to expand the scale of energy supplies. Joint preliminary technical studies were carried out in 1970...1972. In 1975 the negotiations resulted in a contract, providing for the construction of a transmission intertie with a maximum capacity of 1000 MW, and a normal operating capacity of 600 MW. It was decided to realise the intertie as a HVDC back-to-back (BtB) link, [2] and it was agreed to start the "large scale" power transmission in 1980 with the annual energy delivery of 4 TWh. Finally, as the term of the delivery contract became 1981...1989.

In reality, the intertie became ready in three steps during years 1981...1984. In each step a new high-voltage converter unit (HVCU) was commissioned and taken into operation. As long as the BtB-link did not have the total intended rating, also Russian thermal power plants in island operation were synchronised in the Finnish system so that the energy deliveries could be made according to the contracts.

Fig. 3 shows the development of the electricity import from Russia to Finland and to Norway [4]. The extensions of the Vyborg link are clearly seen in the curve W_{RuFiSE} . It is also seen that the electricity import from Russia to north-eastern Finland and to Norway has been an order of magnitude lower than the import via the Vyborg BtB-link.

Later the power delivery contracts have been renewed. In the same time the link has been modernised and upgraded. In the beginning of 2001 the fourth HVCU was taken into operation which enabled the increase of the installed capacity of the Vyborg BtB-link up to 1420 MW, [3]. In 2002 also the new gas-fired combined cycle power plant (3 x 150 MW) locating north-west of St. Petersburg was synchronised in island mode to the Fingrid's system.

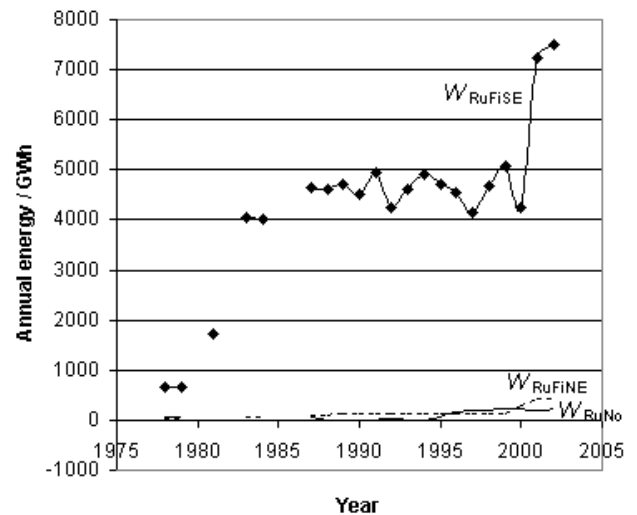


Fig. 3. Annual electricity imports from Russia to Finland and to Norway through different delivery points (source: annual Nordel Statistics, [4]).

3.2. Reasons to select a BtB-link

Initially the joint technical studies made in early 1970's concentrated in an AC interconnection. The following alternatives were considered:

- a 330 kV double-circuit transmission line from Leningrad (now St. Petersburg) to the Finnish border (about 200 km) with transformation into 400 kV there,
- a 750 kV single-circuit transmission line from Leningrad with transformation into 400 kV at the Finnish border.

The technical studies, however, revealed the following problems:

- Large, sustained power oscillations with a period 8...10 sec would occur after the faults. In order to solve this stability problem the power transmission should be limited and grid reinforcements in the Nordic grid would be needed even in the case where a 750 kV line would be used.
- Due to the frequency variations in the Russian and Nordic power systems the power transmission would fluctuate heavily between Finland and Russia and this fluctuation would be often reflected to the power transmission between Finland and Sweden, too. The simulations showed that there was a very high probability that such fluctuations would be as high as ± 400 MW.

The observed problems indicated that the commercial possibilities for the power transmission would have to be limited and the limitation would have reflected on the transmission over the tie-line between Finland and Sweden as well. As a result it was concluded to study solutions based on HVDC technology, because with this approach the frequency and voltage fluctuations would not travel from one system to another.

The alternatives selected were:

- A DC-transmission line with the rectifier terminal near Leningrad and the inverter terminal near Vyborg, from which a 400 kV AC-line would run to Finland.
- A DC back-to-back link with rectifier and inverter located at the same station in the neighbourhood of Vyborg, from where AC-lines would run towards Leningrad and the Finnish power system.

It turned out that from these alternatives the HVDC BtB-link was the more favourable, as the distance between the systems was too short for a DC-line [2]. According to the figures given out by the official Task Force of Energy Economics the BtB-interconnector (including also the new lines on the both sides) was only about 4 % more expensive than the 750 kV connection with transformation but about 120 % more expensive than the 330/400 kV interconnector based on a double-circuit overhead lines. (Remark: All the cost components in the past were not necessarily exactly comparable ones with those ones applied today.)

It can also be added that the reliability of the interconnector has been quite good and satisfactory. The energy availability of the BtB-link has been about 95,7 % which is about 2 %-units less than the corresponding world level value [5]. On the other hand, the mean time between failures (645 h) has been about 20 % less than the corresponding world-wide value. The good figures are partly explained by the energy utilisation figure which is about 43 %. Thunderstorms seem to cause some backflashovers in the Russian side where at poor grounding conditions relatively high double-circuit overhead-line (OHL) towers are used. During 18 years in altogether 14 lightning induced faults have taken place and 8 of these have caused a double-circuit fault which have been cleared with the rapid autoreclosing operation. Harmonic currents (especially 150 Hz) from the Finnish systems have occasionally caused overheating of neutral point resistors in the Russian side. However, long lasting major faults have not occurred.

3.3. Extensions of the interconnector

The properties of the link have been improved during the years [3]. The first reconstruction initiatives were started only after 5 years of operation. Most changes have concerned high voltage thyristor valves, control and protection equipment and AC-filters. The new stage of reconstruction started in the middle of 1990'ies. In this context the Vyborg BtB-link was also expanded so that now it's rated maximum capacity is 1420 MW. However, due to system security and power redundancy the basic power rating is only 1000 MW. Only the newest HVCU is equipped with such a control system that bidirectional operation is possible. At present, however, the market actors are only able to buy electricity from Russia.

When the link was expanded, also the tie lines to the AC-systems were strengthened. Originally there was a 330 kV double-circuit line from St. Petersburg to Vy-

borg and two parallel 400 kV lines going from Vyborg towards Finland. When the fourth HVCU was taken into operation, also two new 330 kV lines from St. Petersburg area to Vyborg were commissioned. From the Finnish side a third 400 kV line was constructed to Vyborg, too. Because also a new power plant (so called north-western power plant, 3x160 MW) was synchronised in the Finnish system, the substation Kymi was selected as the terminal station of the new line in the Finnish side. Simultaneously also some reconnections of the older tie-lines were made. Fig. 4 shows the connection of the lines in the border area. The present transfer capacity from Russia to Finland is after the modifications 1400 MW from which 100 MW is reserved for power system management purposes.

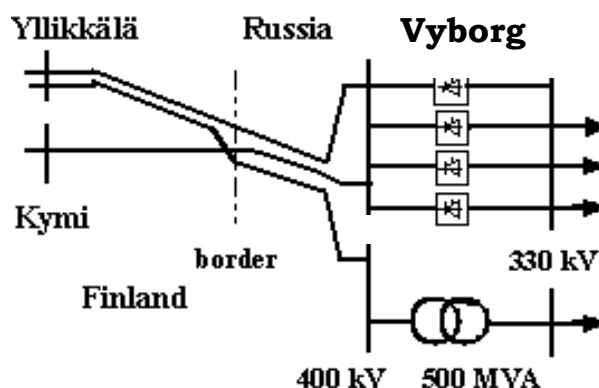


Fig. 4. Lines connecting the Vyborg HVDC BtB-link and the north-eastern power plant to the Finnish power system.

A system operation problem for RAO UES in the north-west power plant is, that in the 330 kV substation of the power plant the automation system is not in such a operation that would enable the fast change-over of the feeding direction of the plant. Therefore the change-over of the feeding direction takes now place, when necessary, by taking the plant down, disconnecting it from the Finnish system and synchronising it thereafter to the Russian power system. The process is naturally time consuming. The properties of these kind of commercial automation systems were not studied during the construction phase. A highly reliable system would be necessary due to the large capacity of the feeding point as a whole. Only a thoroughly tested and well proven solution can be accepted and commissioned.

4. About further development ideas

4.1. Kola interconnection

A question has been raised, how the export of electricity from Russia to Finland and thereby to the common Nordic electricity market could be increased. A special emphasis has been given to the import from the Kola peninsula region. The capacity in Kola peninsula would make possible the annual export of up to 4 TWh with the maximum power flow of 500 MW.

Fingrid Oyj and RAO UES formed a special task force in 2001 to study the Kola power bridge, through which the energy transfer could be made possible. The final report of the task force came out in spring 2003 [7].

Only HVDC connection alternatives were selected for the studies. They included BtB-links with connecting AC lines as well as conventional HVDC connections with DC-lines and point-to-point HVDC terminals both in Finland and Russia. A northern and a southern line routing alternative were studied taking into account the investment costs and grid losses but leaving out the operational costs of the alternatives. The reversible controlled (i.e. bi-directional) power transmission was taken as a starting point. Due to technical, geographical and environmental reasons only the northern alternatives were adequate enough. From these the solution based on BtB-link in the Russian territory turned out once again to be the most economic one [7].

The studies revealed, that in case of transmission line outages ((n-1)-security), a full import could not be guaranteed in all Nordic market scenarios. Hence, the estimated import amount from Kola region to Finland and planned capacity for the interconnector increase the transmission within the national grids of Russia and Finland in such an extent that enhancements in the main grids of the both countries would be required. These necessary investment costs were considered in the study.

The realisation of the power bridge would take 5...6 years which includes also the necessary environmental impact assessment procedure. The issues linked with energy policy, legislative regulation and granting of the construct licence need to be solved before the actual design of the new link, too. So far, no decision is made about the construction of the new link.

4.2. Synchronisation proposal

In summer 2002 RAO UES turned to Nordel and Fingrid Oyj proposing to study the possibilities for synchronous connection of the two systems and carry out a trial period for testing the synchronous operation. The change from present asynchronous mode to the synchronous coupling would mean that the Nordic and Russian systems would operate in the same frequency and according to the same technical grid standards. In practice, the Nordic system, being much smaller in size, would technically be merged into the Russian system.

Nordel welcomed the proposal to evaluate the different prospects and possibilities for existing and future interconnections. Nordel underlined the technical nature of the issue and stressed the importance of the system security and reliability. The development of the market conditions between Nordic and Russian regions was seen merely as a general and political question which has, even at most, a very limited relation to the technical questions.

It was decided that Fingrid Oyj as a responsible TSO having connections to the Russian system would make the necessary technical studies in co-operation with the Russian party. Preliminary meetings about the study were held and an agreement could be found on the content and scope of the study. From the very beginning the Finnish opinion was that no trial operation could take

place before studies have been brought to a satisfactory end. This view was finally approved also by the Russian party. However, after a good beginning and effective start of the common study project has been delayed. Major progress cannot be expected before adequate information and results from the corresponding assessment between Russia and continental Europe will become available.

5. Technical comparison of synchronous and asynchronous interconnections

The Nordic power system has not been operated in synchronism with any other larger power systems. In spite of this it has been completely possible operate the system within and at its capacity limits. Further, the Nordic TSO's have been in the front line of the development of modern electricity market systems.

Synchronous connection between Russia and the Nordic countries would mean a very thorough change in thinking as well as in the daily operation of the Nordic power system. The frequency control responsibility of the Swedish and Norwegian hydro power plants and the Finnish control of the power flow of the tie-lines to Sweden would get a completely new role when the power flow control should be made in border between Finland and Russia. The synchronous connection would probably also drastically change the present transmission capacities because effects of the faults in the Russian side would also be seen also in the Finnish side. These are the basic reasons why the Nordic countries do not necessarily see it only as a positive matter if the use of HVDC links between a very large and a smaller system would be totally abandoned.

The benefits and drawbacks of a HVDC interconnector as regards to an AC -interconnector are well known. The main drawback of the HVDC-interconnector, whether a BtB-link or not, is the price of the system, which is mainly caused by the price of the converter stations. In spite of the development of converter technology the HVDC solutions are still considerably more expensive than a corresponding normal AC-interconnector, although in real situations the economic comparison of HVDC and HVAC is not always very unambiguous. In case of single long overhead transmission lines or long submarine cable connections the HVDC system can be as a whole cheaper than the corresponding AC-system. But examples of China and India show, that HVDC is economic also in connecting to each others separate synchronous areas with same frequency.

HVDC is quite often selected due to purely technical reasons, too. An illustrative example is obtained by making reference to [6] where already after few years of operational experience of the Vyborg HVDC BtB-link the following advantages were recognised:

- Independent frequency regulation, which does not require any changes in ways of performing the regulation in the different systems.

- Accuracy in maintaining and adjusting the level of power transmission.
- Disturbances do not "travel" from one system to another.
- Fault currents remain on the same level as before in spite of the fact that the neutral earthing principles in Russia and in Finland are not similar.

Generally speaking, one of the technical advantages of DC transmission is that the interconnected AC-systems can be operated independent of each others as far as the frequency and load regulation are concerned. This is of particular importance when larger networks, networks with different principles for regulation or networks with different frequencies are to be interconnected [8]. Further, a DC-link does not transmit short-circuit power, which can be advantageous in networks with a high degree of load concentration.

The stability problem is simplified when DC is used for long distance transmission. The control methods are so refined and time constants are very low so that DC-links can be used to stabilise a parallel network. Naturally the same can be achieved also with the help of FACTS and STATCOM devices. It is also possible to get an optimal power flow division between AC and DC in parallel.

Finally, when DC is used for connecting the AC-systems, the capacity is well defined and not influenced by the conditions on the two AC-systems.

One of the special features of synchronously interconnected large systems is, that the physical nature of synchronous power systems with rotating masses causes significant dynamic interactions between the subnetworks and power plants. One type of dynamic interaction are the poorly damped inter-area oscillations which usually mean low frequency rotor swings between remote groups of generators. They are a common problem world-wide in extended power systems [9]. The oscillation frequency is typically in the range of 0,2...0,8 Hz. In the Nordic system several oscillation modes can be found [10]. In the case of Finland particular interest has the 0,3 Hz oscillation mode which the Finnish system has against the southern Norway and eastern Denmark. The oscillation modes of the Nordic system when synchronised to the Russian system have never been studied.

Inter-area oscillations can severely restrict system operations and can require curtailment of power transits as an operational measure. Even widespread system disturbances with regional black-outs have occurred [9]. In some extent the inter-area oscillations can be damped by applying suitably tuned power system stabilisers (PSS) in the excitation control systems of the generators. However, the PSS's should be retuned after major changes in the grid configuration or in the properties of the loads. A damping effect can be achieved with suitably positioned shunt connected FACTS devices, too.

A HVDC link does not transfer the inter-area oscillations and with suitable control signals the control system of a HVDC link can even damp the inter-area oscillations of the AC-systems.

6. Conclusions

The electricity trade between Russia and Finland has developed greatly during the years. At present the commercial capacity of 1300 MW at 400 kV is offered to the market. A major part of this capacity is due to powerful HVDC BtB links between Russia and Finland. Synchronous connection of two systems is not a prerequisite for the electricity trade.

The Nordic system as a whole does operate asynchronously against the neighbouring large AC-systems. This has not hampered the electricity trade between the Nordic countries and their neighbours. In fact, the Nordic countries have been in the front line in developing the electricity markets. Therefore it can be said that the asynchronous interconnectors have even promoted the effective operation of the Nordic electricity market.

There are several reasons speaking in favour of applying HVDC for interconnection of AC systems that deviate technically from each other or purely on the basis of their sizes. When connecting large systems to each other the better economy of the synchronous connection mode is not self-evident. Because of the certain risks included in the inherent properties of the synchronous interconnections, interconnection of large and smaller systems should be carefully studied before final decisions are made. This is valid also when the synchronous operation of the Nordic and Russian systems is considered.

7. References

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