

PREPARATIONS FOR PARALLEL SYNCHRONOUS OPERATION OF RUSSIAN INTEGRATED POWER GRID AND NORDEL

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ABSTRACT

Reported are technical issues which had to be solved while preparing a 450 MW combined-cycle generating unit (CCU) at a power plant of the Russian Northwest United Power System for parallel synchronous operation with NORDEL via Finland's power grid over a 330/400 kV AC interconnection line. A special feature of this particular CCU-1 is that its individual generators use different field control systems.

A solution was developed and suggested for semi-automatic switchover of the CCU-1 of the Northwest Co-generation Power Plant from its parallel synchronous operation with the NORDEL to parallel operation with the Russian Integrated Grid and back without shutdown, with 200 ms duration of parallel synchronous operation of the power pools.

Studied are possibilities and conditions of organizing hours-long parallel synchronous operation of two power pools using the existing grid and the available frequency and power control facilities.

KEY WORDS

Power system – Interconnection – Disturbance – Stability – Irregular oscillations – HVDC back-to-back – Parallel synchronous operation

1. INTRODUCTION

Over two decades the Russian Integrated Power Grid (EES Rossii) and Finland's power system, part of the NORDEL pool, have operated via the HVDC Back-to-Back at the Vyborgskaya Substation (SS) in Russia. In

2002 the HVDC link was supplemented by a 330/400 kV AC interconnection from the Northwest Co-Generation Plant (Russia) to the Ylikkälä SS (Finland). At present the power export grid comprises eight 330 kV lines, with a total transfer capacity of about 3000 MW, connecting the Vyborgskaya SS to the Vostochnaya SS, a major switchyard of the Northwest United Power System (NWUPS) of Russia. Three 400 kV lines, of about the same 3000 MW transfer capability, connect the Vyborgskaya SS to the power system of Finland. Shown in Fig. 1 is the circuit diagram of the Russia-Finland DC/AC interconnection assuring the most efficient use of the transfer capability of the 330-400 kV grid.

Under normal conditions, the combined-cycle generating unit CCU-1 of the Russian Northwest Co-Generation Plant (NWCGP) is isolated from the EES Rossii, operating synchronously with the Finnish power system and thus with the NORDEL at a load up to 450 MW; the maximum capacity of the Back-to-back's four rectifier/converter units (RCU-1, 2, 3, and 4) is 1400 MW.

In case of interruption for any reason of the AC tie between the NWCGP and the Ylikkälä SS the interconnection's reliability is enhanced by emergency (maintenance) configurations and procedures, including separation of the 330 and 400 kV busbars into two subsystems and isolation of RCU-3 or RCU-4 for operation with a 330 kV Vostochnaya-Vyborgskaya line and with a 400 kV line connecting the Vyborgskaya SS (Russia) to the Ylikkälä or Kymi substation (Finland). These and other emergency configurations are set up by operation of circuit breakers and disconnectors at the Vyborgskaya substation and the NWCGP.

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However, because the NWCGP is unable, under certain conditions, to assure all its auxiliaries, it can be switched over from parallel operation with the Finnish system to parallel operation with the EES Rossii and back only through its shutdown and restart. The

procedure depletes the service life of the power plant equipment and causes a considerable cutback, lasting as long as ten hours, in the transfer capacity of Russia-Finland interconnection which operates at the 1400 MW rating for about 7000 hours annually.

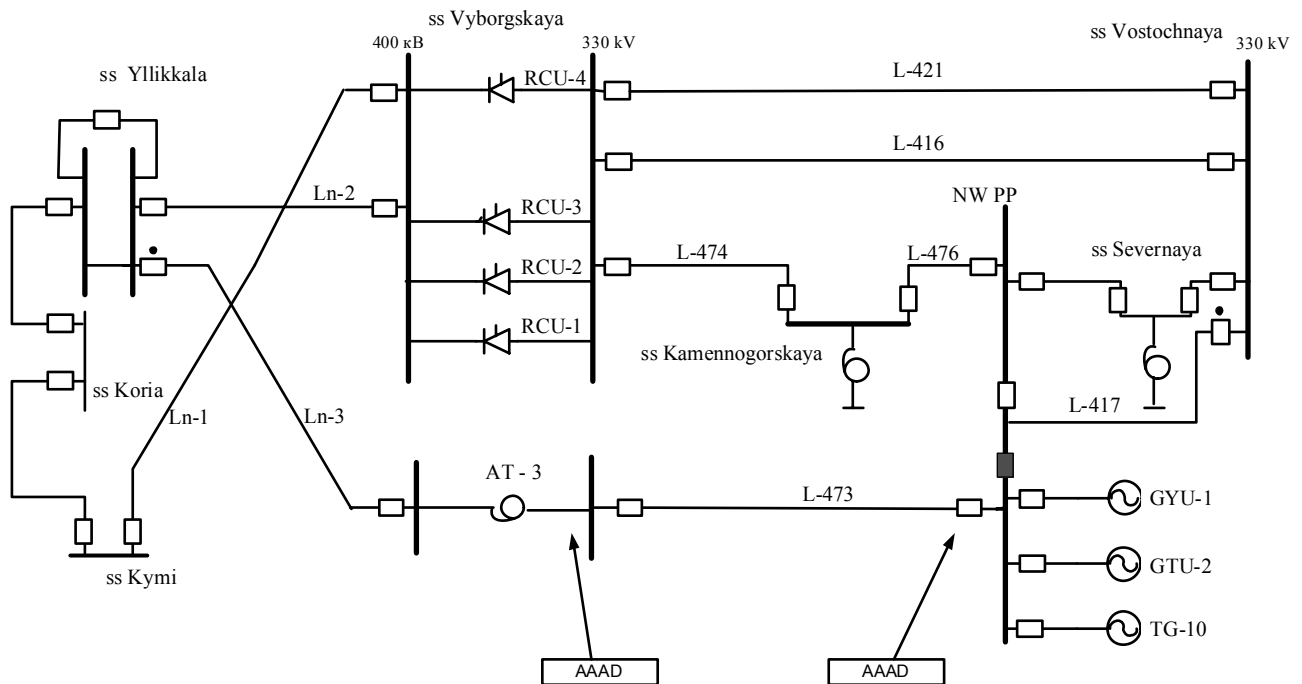


Fig. 1. Russia-Finland interconnection diagram

Note: • - Possible synchronization points

2. OPERATION OF NORTHWEST CO-GENERATION PLANT WITH FINLAND'S POWER SYSTEM

Parallel operation of the NWCGP with Finland's power system is a case of a power plant connected to a long-distance line, which calls for particularly efficient functioning of the power and voltage control systems of the power unit.

The combined-cycle generating unit (CCU-1) of the NWCGP features a combination of two gas turbines and one steam turbine whose generators use different voltage control and power stabilization systems. While the steam turbine-driven generator has a Russian Elektrosila automatic forced field controller, the gas turbine generators are provided with voltage controllers comprising Siemens power system stabilizers (PSS). The stabilization parameter used by the Russian controller is a linear stator voltage frequency

combination (frequency and its derivative); that used by the PSS is the generator's active power.

At the pre-commissioning stage, the settings of three field control systems were checked and refined during experimental operation of the NWCGP in a 350 km long 330 kV overhead line setup within the (NWUPS).

The test transit can be tracked in Fig. 1: the dark circuit breaker at the NWCGP and the 330/400 kV autotransformer AT-3 at Vyborgskaya SS were open; the CCU-1 at the NWCGP was connected to 330 kV lines L-474 and L-476 through the isolated 330 kV busbar at the Vyborgskaya SS and further to the Vostochnaya SS of the NWUPS.

The tests were carried out at two principal 70% and 100% generator active power loads, with full VAR absorption and with the minimum excitation limit channels in operation.

The test program covered the following:

- check of stability of voltage, frequency, and power control by each control system individually and all systems jointly; acquisition of transient characteristics of generators' field control systems and gas turbines' power controllers at test disturbances;
- check of group instability with simultaneous operation of voltage controller stabilization channels of three CCU-1 generators and with different sets of operating stabilizers at test disturbances;
- assessment of stabilization performance of automatic field control of three CCU-1 generators at the NWCGP at different states of the stabilization channels of the voltage controllers during all the external switching operations (energization and de-energization of the L-417 line, bridging of the L-474+L-476 set at the 330 kV busbar of the NWCGP, and some others);
- selection of optimum tuning parameters of the stabilization channels of the voltage controller of the steam-turbine-driven generator No. 3.

The performance of these field tests in the NWUPS made it possible to refine a number of characteristics of the CCU-1 control systems, to adjust the digital models of the generators and field controllers.

The test findings permitted, first time ever in the Russian and international practice, determination of the steady-state oscillatory stability for Siemens power system stabilizers, and selection of optimum tuning of the stabilization channels of the steam turbine-driven generator, with due allowance for settings of gas-turbine PSS units.

Pre-commissioning tests in the Finnish power system confirmed the suggested settings to be efficient and effective, assuring an adequate transmission stabilization and a good damping of major post-emergency oscillations, which made it possible to recommend the settings in operation of the AC interconnection tie.

Of particular interest were findings of the test with a 0.13 s three-phase transient fault on the 400 kV busbar of the Yliskäla SS.

The Control Center arranged for the test a special grid configuration resulting in a twice as high reactance at the busbar of the NWCGP (with a normal configuration, the short-circuit power of the Finnish power system at the 400 kV busbar of the Yliskäla SS is about 6000 MVA; in the test configuration it was around 3000 MVA).

Shown in Fig. 2 is an oscillogram of voltage variations on the 330 kV busbar at the NWCGP in a

short circuit test on the 400 kV busbar of the Yliskäla SS.

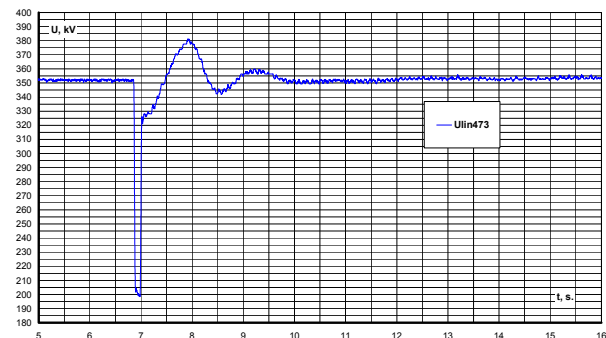


Fig. 2. Voltage variation on the NWCGP 330 kV busbar in short circuit tests

The chart makes clear that a 353 kV pre-fault voltage went down to 200 kV during the short circuit test but was restored within two cycles after the fault was cleared. The NWCGP keeps using the original settings up till now.

3. SWITCHING OF THE NWCGP TO PARALLEL SYNCHRONOUS OPERATION WITH THE FINNISH OR RUSSIAN POWER SYSTEM

At present, the NWCGP can be switched over from operating with the Finnish to the Russian power system and vice versa only through shutting it down completely. According to test findings, the switchover time is ten hours, with at least five hours needed to regain the rated power level.

This feature slows down considerably the NWCGP's mode changing procedure and leads to reduction of power exports to Finland through the switchover time. Besides, each shutdown and restart causes a considerable wear of the NWCGP turbines and worsens its technical and economical performance.

The challenge had to be met by developing or adapting a semiautomatic device making it possible to cut the switchover time of the NWCGP and to avoid the shutdown and restart of its turbine generators.

3.1. Algorithm of the device

The algorithm of the device is explained in Fig. 3. From its initial state when the NWCGP is linked to the Finnish grid it must be switched over to the Northwest United Power System (NWUPS).

1) The device is connected to the voltage circuits of the voltage transformers VT-1 of the BW, VT of the L-473 line, and VT of the L-417 line.

2) The device is connected to the close and open circuits

of the breakers CB 473/T3 and CB 417/T2.

3) The personnel carries out preparatory operations setting up the breakers CB 473/T5 and CB 417/T2.

4) On receiving the command the device:

- determines the instant when two power pools have to be switched to parallel synchronous operation making use of the settings of the voltage crest difference, the

frequency difference, and the permissible closing angle, and issues the command to close the CB 417/T2;

- issues, after checking that the CB 417/T2 closed normally, the command to open the CB 473/T3;

5) The personnel manually opens the line disconnector LD of the L-473 line, closes the CB 473/T3 and CB 473/T5, changes the position of the disconnectors D1 and D2, and switches the relay protection circuits.

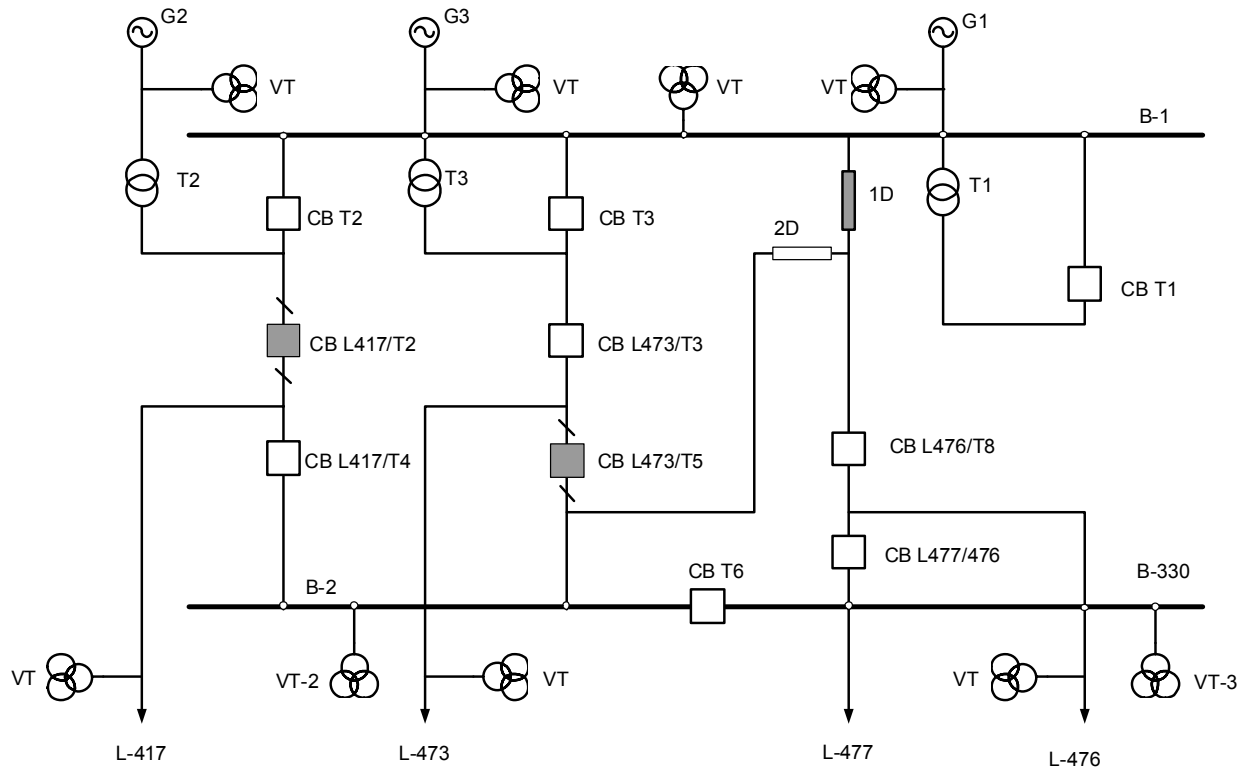


Fig. 3. 330 kV outdoor switchgear of NWCGP

The sequence of operations is similar when the NWCGP is linked to the Russian grid and must be switched over to parallel operation with Finland's power system.

3.2. Suggested device

The functions described above can be performed by a device known as 'automated busbar transfer system', such as the AUE 2 by Siemens AG or the REC 316*4 by ABB. The functioning algorithms of both systems are similar.

The device must be connected to the voltage circuits of three voltage transformers, viz. that of the generator busbars and those of the lines connecting the busbars to the grid of Finland or Russia (in this particular case, NWUPS).

The device determines the closing instant from the settings of the voltage crest difference (0-1.0 U_N in 0.1

U_N steps), the frequency difference (0-0.4 Hz in 0.1 Hz steps), and the permissible closing angle (0-90 degrees in 1 degree steps, and issues the command to close and open respective breakers, assuring that the parallel operation time of the breakers does not exceed 200 ms.

The breaker opening command is issued with provision for starting the breaker failure protection system in case the circuit breaker fails to open, and for opening an appropriate backup.

4. PROVISIONAL PARALLEL SYNCHRONOUS OPERATION OF EES ROSSII AND NORDEL

The provisional parallel synchronous operation of EES Rossii and NORDEL is understood here to mean experimental hours-long synchronous operation of two power pools.

The purpose of the experiments is to:

- demonstrate feasibility of this approach, even under existing grid and control conditions, and to set off thereby the technical and economical analysis for determining prospects of parallel synchronous operation;

- obtain data on performance characteristics of the EES Rossii and NORDEL, such as the value of irregular oscillations in a tie between the pools. These inputs are essential for developing digital models of the power pools for in-depth studies of their interconnected operation.

4.1. Principles of provisional parallel synchronous operation

1. The provisional parallel synchronous operation of EES Rossii and NORDEL assumes use of a single synchronous tie, which would comprise the NWCGP-Vyborg 330 kV line – 330/400 kV AT – Vyborg-Yliskälä 400 kV line package (see Fig. 1), within the existing grid, with the available frequency and power control facilities, and with the Back-to-Back remaining in service. All these would give the AC interconnection the status of an international intertie (II).

2. In order to assure safety of the II equipment and to prevent cascading emergencies, it is necessary to develop and implement a number of relay protection and emergency control measures on the assumption of loss of a 1000 MW unit in NORDEL, in particular:

- development and implementation of an overcurrent protection system for the 400/330 kV autotransformer at the Vyborgskaya SS;
- installation of an automatic asynchronism aborting device (AAAD) at the Vyborgskaya SS.

3. The parallel synchronous operation experiment must be preceded by preparation of an operating schedule for ties in the EES Rossii grid, other than those between Central Russia, Russian Northwest and Finland, on the assumption that the receiving/sending end load ratios will change for every monitored cut. Such scheduling will not call for additional research but can reveal a need for additional grid limitations.

Here the analysis can be started from assumptions of identical relative frequency steady-state coefficients for the EES Rossii and NORDEL, of a 1:3 pool load ratio, and a 350 MW amplitude of irregular active power oscillations in the international intertie.

According to [1], the amplitude of irregular oscillations in an interconnection line between two power pools with loads S_1 and S_2 is estimated to be $\sqrt{(S_1+S_2)/(S_1*S_2)}$ (MW). The above 350 MW estimate corresponds to a 60-

70 GW load in the NORDEL and a 180-200 GW load in the EES Rossii.

It is suggested that similar scheduling be also made for the NORDEL pool, if for no other reason that the Finnish power system becomes a wheeling utility.

4. Jointly with Fingrid dispatchers, a switchover program must be developed specifying synchronization points, permissible frequency difference during precision synchronization, etc. Symbol "•" in Fig. 1 shows likely synchronization points.

In particular, because the NORDEL pool does not use centralized frequency control, it is possible to use, for the frequency smoothing during synchronization, the control capabilities of the Back-to-back, whose loading can be adjusted by $\Delta f = 0$. With the power-frequency characteristic of NORDEL of some 6 GW/Hz, a frequency difference of ± 50 -100 mHz is acceptable.

In order to lower the frequency difference between NORDEL and EES Rossii by ± 50 mHz, the needed control range of the Back-to-Back must be within ± 300 MW. This can be attained with at least three RCU operating at within 700 MW. However, the Back-to-Back control from Finland must be blocked at the moment.

The above requirement on the frequency difference during synchronization is more stringent than that on guaranteed synchronization. According to [2], the permissible frequency difference at which synchronization can be assured is estimated as $50 \cdot \sqrt{P_{\max}/(2 \cdot H \cdot 314)}$, where $P_{\max}$ is the transfer capability of the international intertie, MW, related to the NORDEL load; H , the mechanical inertia constant of the smaller pool, s. With $P_{\max} = 1000$ MW and $H = 5$ s, the permissible synchronization frequency difference is about 0.1 Hz. The usual margin for EES Rossii is 0.1-0.2 Hz.

During provisional parallel synchronous operation of EES Rossii and NORDEL, the load schedule of a single synchronous tie, likely to take irregular power oscillations, must be planned to be light duty.

5. The power flow over an international intertie must be controlled by both parties applying the frequency action. However, during parallel synchronous operation of EES Rossii and NORDEL it would be sufficient that NORDEL as the smaller subsystem control the flow without using the frequency action.

6. The Back-to-back must operate in a deliberately stable mode, with a good margin of transfer capability assuring adjustment of the loading of 330/400 kV autotransformer.

4.2. DIGITAL DYNAMIC SIMULATOR STUDIES

In order to have a better insight into processes involved in the parallel synchronous operation of the NORDEL with EES Rossii, the Central Dispatching Office of the EES Rossii and the Northwest Energy Control Center ordered NIIPT (HVDC Power Transmission Research Institute) development of a digital model of the NORDEL and the EES Rossii.

The resulting three-phase dynamic model permits calculation of both electromagnetic and electromechanical transients in the two systems. It presents the Finnish and Russian Northwest power systems, which are directly connected to the international intertie, with sufficient detail. As to more remote parts of NORDEL and EES Rossii, they are presented as simplified equivalents.

The model gives much detail of the Back-to-Back and its control system, the voltage control systems of the generators, and the frequency and power control systems of the turbines at the NWCGP.

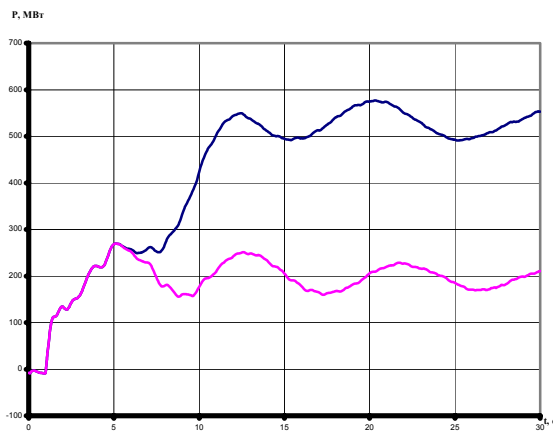


Fig. 4. International intertie power flow at 1000 MW shortage in Swedish power system and speed governor dead bands of: EES Rossii-0.15 Hz, NORDEL-0.15 Hz; EES Rossii-0.15 Hz, NORDEL-0.10 Hz

The research is at an early stage yet, permitting, however, a few important conclusions:

1. Use of frequency and power control systems and allowance for the dynamic transient can result in a smaller mutual aid flow at the specified 1000 MW emergency shortage in NORDEL. At the specified speed governor dead bands of 0.1 Hz in NORDEL and 0.15 Hz in EES Rossii, the mutual aid flow is estimated at 200 MW, rather than 750 MW mentioned above, see the pink curve in Fig. 4.

2. All the studied transients, including those associated with stability disturbances in the II, do not affect normal operation of the Back-to-Back (Fig. 5).

REFERENCES

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- [2] M. G. Portnoy, R.S. Rabinovich, Stability-Oriented Power System Control. Moscow, Energiya Publishers, 1978, p. 89

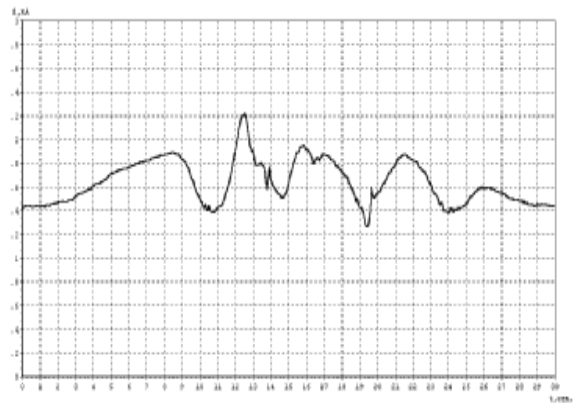


Fig. 5. Variation of Back-to-Back current during and after parallel asynchronous operation of International Intertie