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HVDC LCC technology and power quality issues in cross-border electrical power transmission Russia – Finland

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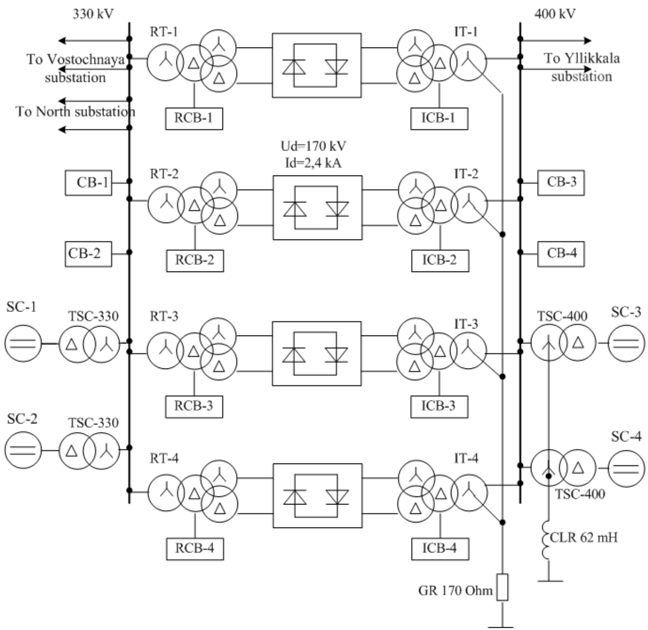
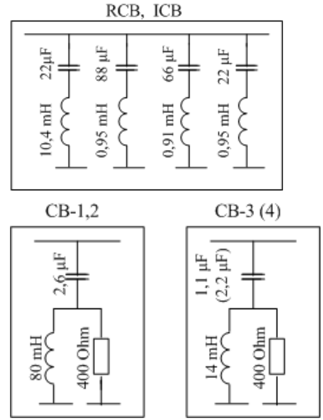
Circuit diagram of Russia - Finland cross-border connection





R(I)CB– rectifier (invertor) capacitor battery, CB - capacitor battery, SC – synchronous compensator, TSC - transformers of synchronous compensator, GR – grounding resistor, CLR - current-limiting reactor

The higher harmonics limitation in adjacent AC networks

The voltage and current harmonics at the connection point of Vyborgskaya converter station should not exceed the following limits:

- on both sides (sending and receiving), the voltage total harmonic distortion (THD) $THD_v \leq 2\%$;
- on the receiving side, in the 400 kV lines sum of r.m.s. harmonic currents must be:

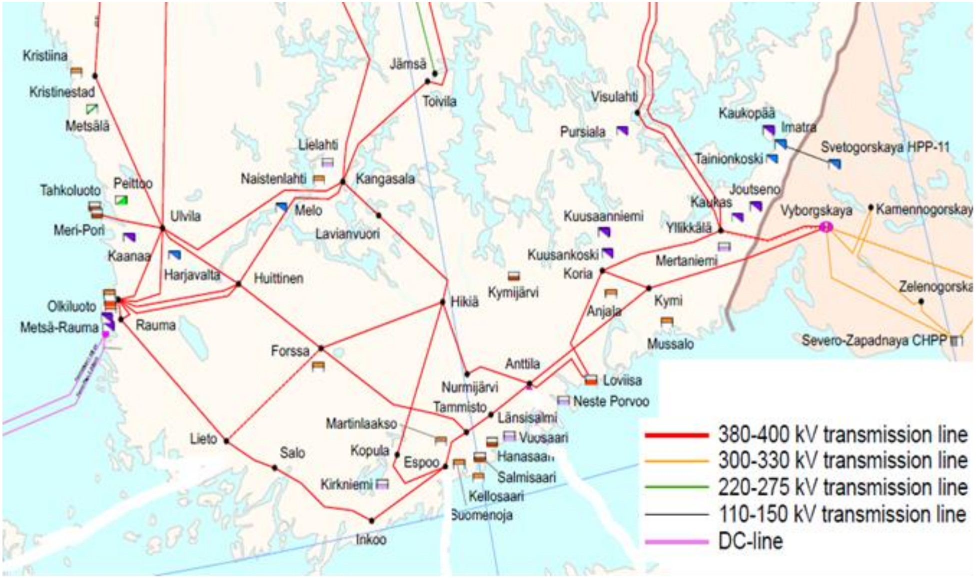
in the range 100-200 Hz, $I_{ef} \leq 20$ A;

in the frequency range (≥250 Hz) $I_{ef} \leq 20$ A;

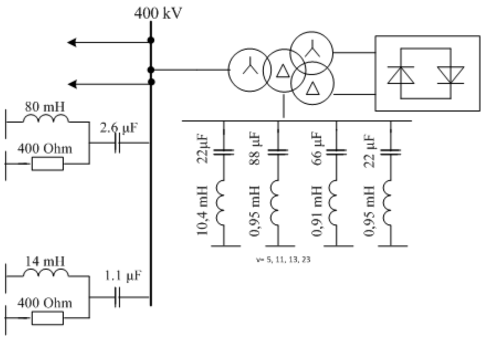
- psophometric value of phase current in the 400 kV lines was originally limited to $I_p \leq 1.5$ A (then due to the increase in transmitted power, $I_p \leq 2.5$ A).

The most strict requirements were imposed on the psophometric value of phase current in the 400 kV outgoing lines. The permitted psophometric value was 1.5-2.5 A, while for the rest of the 400 kV system the maximum permitted value of the psophometric current was 5 A.

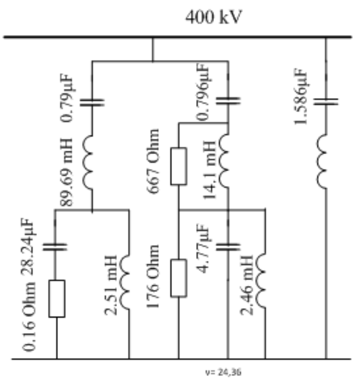
Part of the Finnish high-voltage power system



Comparison of filtration systems at Vyborgskaya and Rauma substations



Filtration systems at Vyborgskaya substation



Filtration systems at Rauma substation

Evaluation of Harmonic filtration efficiency

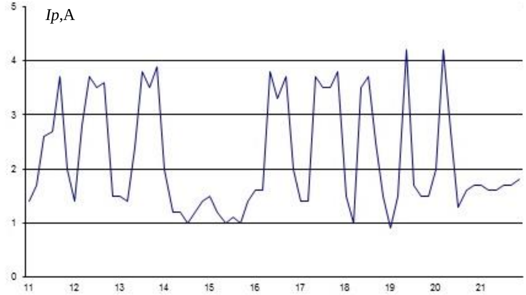
Estimation Method of the distribution of harmonic currents in a network is based on the use of network frequency characteristics.

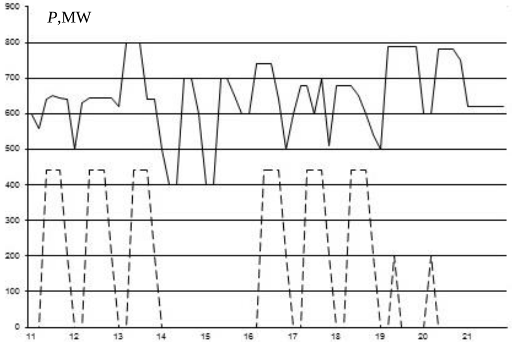
The following parameters and values were determined:

1. Input impedances of the network at point of common connection of Vyborgskaya and Rauma converters
2. Harmonic currents flowing into the 400 kV network form Vyborgskaya and Rauma converters
3. Harmonic currents in outgoing transmission line Vyborgskaya - Yllikkälya relative to the current flowing into network at the point of connection of the Vyborgskaya and Rauma converters to the 400 kV network. These calculations show how the electrical network amplifies (attenuates) the harmonic currents.
4. The shears of harmonic currents from the Vyborgskaya and Rauma converters flowing into outgoing transmission line 400 kV Vyborgskaya - Yllikkälya, taking into account filtering devices.

ν		11	13	23	25	37	39	47	49
$I_{Rauma}/I_{con.Rauma}$	%	17	11	4	24	9.5	5	32	23
$I_{Vyb}/I_{con.Vyb}$	%	2.1	2.0	0.4	0.6	1.9	4.6	1.4	7.9
$I_{Vyb}/I_{con.Rauma}$	%	3.6	7.0	7.3	17	6.3	2.1	8.7	16

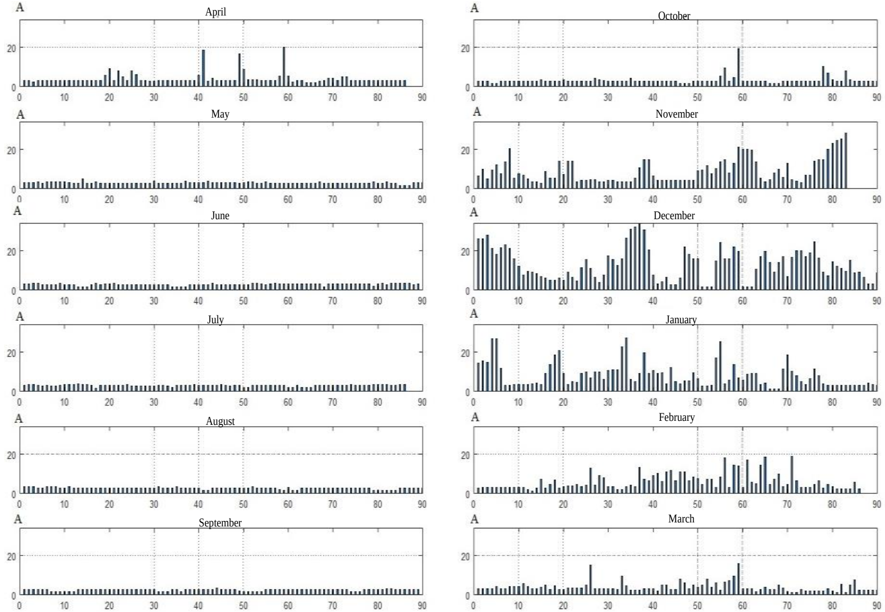
The field measurements





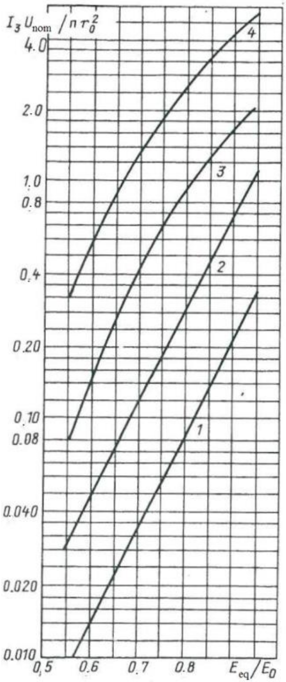
Psophometric current value in the Vyborgskaya – Yulikkalya 400 kV line as a function of the loads of the Vyborg (solid) and Rauma (dashed) converter substations

Corona effect as a source of the third harmonic and overload the neutral earthing of the converter transformers



Grounding resistor current (r.m.s) of inverter trtavsformers (averaged through 8 hours)

The nomograms for calculating the third harmonic of corona current for overhead lines 330-750 kV



Studies have shown that the third harmonic of the corona current was about 23% of the first harmonic. This ratio allows us to estimate the third harmonic of the corona current, based on corona power loss. The corona power losses depend on the weather conditions, the design of the overhead line and the relation between the equivalent strength of electric field on the wire surface and the initial strength of electric field of corona discharge in good weather condition. Figure shows a nomogram for estimating the third harmonic of the corona current, which are obtained from the ratio

$$I_3 = \eta \frac{P_{ph}}{U_{ph}}$$

where η ≈0.25, and nomograms for calculating the corona power loss.

I_3 - the third harmonic of the corona current in overhead line, A/km
n – number of wire in phase of AC line
r_0 – radius of wire, cm
U – AC line voltage, kV
E_{eq} - equivalent strength of electric field,
E_0 - initial strength of electric field of corona discharge.
1- good weather; 2 -dry snow; 3 -rain, sleet; 4-frost, ice, wet frozen snow.

Conclusions

- The increasing the current psophometric value at point of common coupling of Vyborgskaya back-to-back is related to external factors. The presence in the 400 kV network of only two (at the moment of research) powerful sources of harmonic currents (converter substations Vyborgskaya and Rauma) made it possible to identify the source of distortions.
- Theoretical and field studies shown that the harmonic currents are not properly filtered at the converter substation Rauma, propagate over the network and amplified at the Vyborgskaya converter substation.
- Harmonic currents in high-quality networks can propagate over long distances of the order of several hundred kilometers, and this must be taken into account when implementing HVDC projects.
- It is also shown that corona effect can be the source of the third harmonic and overload the neutral earthing of the converter transformers.

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THANK FOR YOUR ATTENTION!