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NEW INTEGRATED CONTROL AND PROTECTION SYSTEM FOR VYBORG BACK-TO-BACK HVDC LINK

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SUMMARY

The Vyborg back-to-back HVDC link, providing asynchronous connection between power networks of Russia and Finland, is in operation since 1981. After more than twenty years of successful operation, the urgent necessity for the essential reconstruction of the station control and protection systems became ripe. The main reasons of such necessity were as follows: moral ageing and physical deterioration of the control and protection hardware; increase of the number of converter units up to four; construction a new AC connection to Finland network from the isolated generator at Severo-Zapad thermal power plant via new AC line; installing the additional AC filter batteries on the tertiary of converter transformers; new contract terms forbidding power transfer more than 1000 MW to Finnish grid from a single AC bus; the necessity to increase the automation degree of the station and to correct the algorithms of power flow control.

By the reasons mentioned above the total replacement of the station control and protection system using contemporary microprocessor-based hardware was realised step-by-step during some last years. The new integrated control and protection system consists of:

- Automated technological process control system (PCS) - upper control level, including a set of microprocessor-based AC side protections;
- Microprocessor-based faults and transients recorders;
- Subsystems of on-line control, monitoring and diagnostics of the transformers, DC reactors, synchronous condensers, thyristor valves and cooling systems;
- New fast response control and protection systems of all four HV converter units (HVCU);
- Equipment set for controlling the overall station active and reactive power flows (PFC), with its own subsystem of currents, voltages, active and reactive power measurements (PFMS).

Duplicated PFC equipment consists of two identical cubicles of power flow controllers with duplicated connections to PFMS, and the third cubicle, containing

- the communication controller providing the triplicated connections of both power controllers to each of four majorized KURB's;

- the build-in workstation for debugging the power controllers and for autonomous operative power control under the PCS fault conditions;

- the additional computer serving as the digital simulator of the station; the simulator realizes the detailed representation of all four HVCU (valve-by-valve), the full models of four synchronous condensers of the station by Park-Gorev equations, the chain equivalents of seven joined AC lines, models of all HVCU and SC control systems and power controller.

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The digital simulator can be used either autonomously for debugging and checking the control algorithms, or with the real power controller for testing its hardware at the maintenance stage, after the repair and after the software renewing. The opportunity enabled to use the simulator with any one of two power controllers when the other is in real operation or with full duplicated power controllers set when the station is out of operation for the scheduled maintenance.

Depending of the demanded response rate, the various data exchange protocols are used within different control and monitoring systems. The largest volume of information is related to the numerous equipment conditions on-line monitoring. Integration of those systems to PCS is realized via special gate computers using standard OPC technology (OLE for Process Control).

All new control and protection systems were successfully tested, commissioned and are in operation now.

Within some next years the work is proposed to be done in order to improve the algorithms of power flow control taking into account the opportunity of power flow direction reversal.

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KEYWORDS

HVDC – Back-to-Back – Vyborg – Reconstruction – Power flow – Control – Protection – Integration

1. Introduction

The Vyborg back-to-back HVDC link [1,2], providing the asynchronous connection between power networks of Russia and Finland, is in operation since 1981 when the first 355 MW High Voltage Converter Unit (HVCU) was commissioned. Till 1984 in accordance with the initial project two next HVCU were put into operation, which enabled the average annual energy transfer for the next years on the level about 4500 GWh. After more than twenty years of successful operation, to the beginning of the new century the urgent necessity for the essential reconstruction of the station control and protection systems became ripe. The main reasons of such necessity were as follows:

- Moral ageing and physical deterioration of the control and protection hardware, that was developed at the end of 70-th using the circuitry of the small and middle scale integration with the hard logic;
- An increase in the converter units number up to four in 2001 [3] and construction of a new AC connection to Finland network from the isolated generator at Severo-Zapad (North – West) thermal power plant via new AC line (2003), with increase in the maximum total transmitted power up to 1400 MW; the average energy transfer grew up to the level of 10300 GWh per year;
- Increased number of AC filter batteries, including the additional batteries on the tertiary of converter transformers (38,5 kV); The simplified main circuit diagram of the station after reconstruction and expansion is shown on Fig.1;
- New contract terms forbidding power transfer more than 1000 MW to Finnish grid from a single AC bus; four different station bus and lines configurations were stated – basic and three reserve ones.

The last three points demanded the overall revision of the algorithms of control of active and reactive power flows, which was impossible without full replacement of the station power control hardware.

By the reasons mentioned above the total replacement of the station control and protection system was realised step-by-step during some last years using contemporary microprocessor-based hardware.

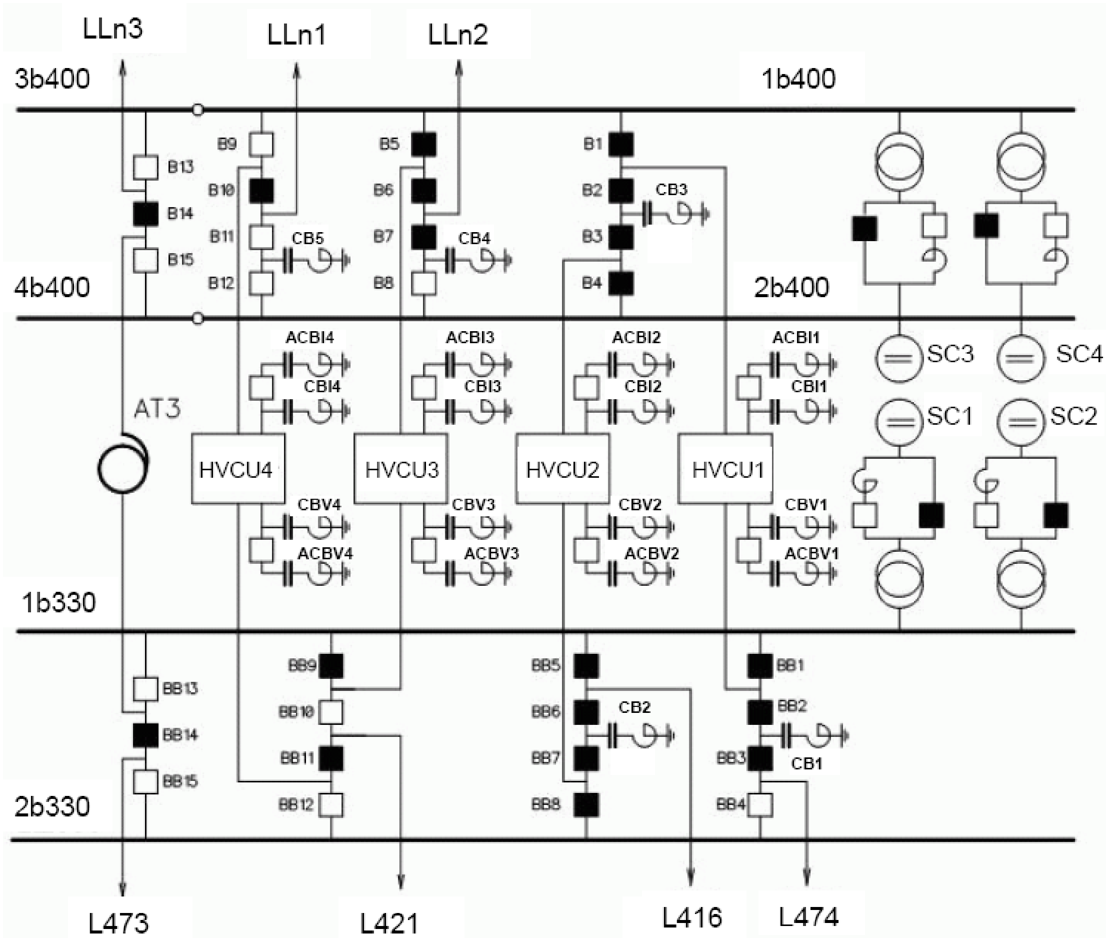

Figure 1. The main circuit diagram of the Vyborg station after reconstruction and expansion
1b330, 2b330, 1b…4b400,– 330 kV and 400 kV busbars; LLn1..3 - 400 kV OH lines to Fingrid; L416..L474 - 330 kV OH lines on Russian side; SC – synchronous condensers; CB, CBV, CBI – the main AC filters batteries; ACBV, ACBI – additional AC filters on the transformers tertiary on the rectifier and inverter sides; AT3 – new autotransformer for AC tie to the isolated generator.

2. Structure of the station Process Control System

The total structure diagram of the Vyborg station Integrated Process Control System (IPSC) is shown at Fig.2. ICPS is built around the duplicated main server with two local area networks connected to it. LAN1 consolidates the equipment, directly concerned with the station control, protection and monitoring functions. Next subsystems are connected to this net through the special gateway computers:

- Programmable logic controllers (PLC) for control and protection (C/P) of the AC side equipment;
- Four HVCU C/P hardware and Power Flow Controller (PFC);
- AC and DC side transients and faults recorders;
- The station equipment on-line monitoring hardware;
- Workstations of the station operator, protection service and ICPS engineer.

LAN2 gives the access to the different current data, archives and reports to nonoperative services personnel, not allowing the interference to the station control functions.

Three separate SCADA projects using WinCC SCADA system were developed for realizing all IPCS functions, as it is shown at Fig2:

project No1 – for the station operative control;
project No2 – for accessing archives and for nonoperative services workstations;
project No3 – for IPCS engineer workstation.

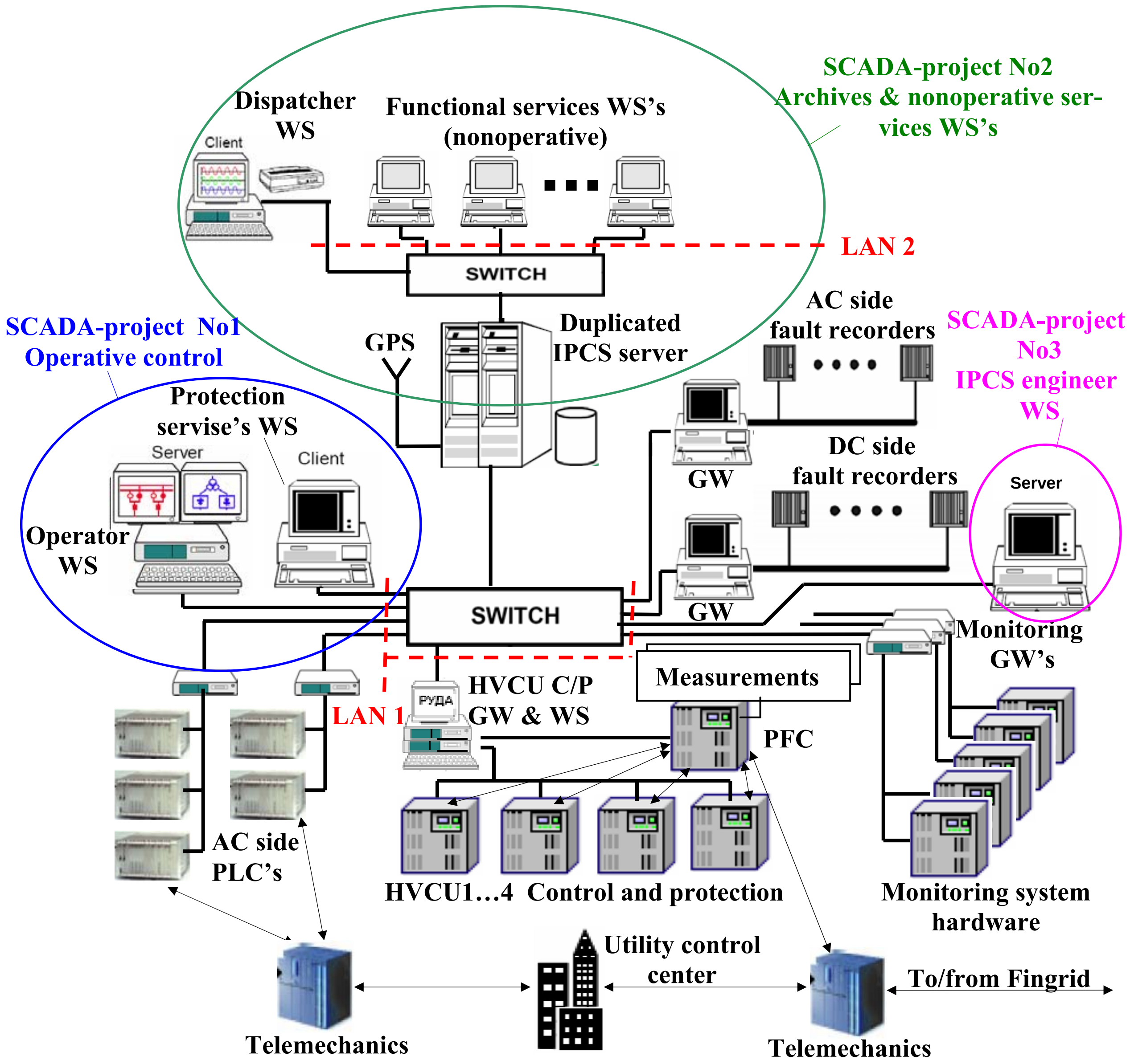

Figure 2. The total IPCS structure diagram of the Vyborg station
GW- gateway, C/P - control and protection, LAN1 – local area network of operative level, LAN2 – local area network of nonoperative level, PFC – Power Flow Control, WS – workstation.

Depending of the demanded response rate, the various data exchange protocols are used within different control and monitoring subsystems. The largest volume of information is related to on-line condition monitoring of the numerous station equipment. Integration of those systems to IPCS is realized via special gateway computers. The total volume of information circulating within IPCS is very large and tags amount run up to several tens of thousands, which was near the WinCC limits at the moment of system launching. The serious additional job was done by WinCC designers (Siemens) to force the system to operate properly.

3. Control and protection of converter units

The main features of the new Vyborg HVCU control and protection system was reported already [4] and here we will only remind its principal functions:

- Automatics of HVCU startup and blocking operations;
- DC constant current control operating the rectifier delay angle and inverter extinction angle order when necessary;
- Inverter extinction angle control;
- Rectifier delay angle and tertiary voltage control operating the rectifier transformer OLTC;
- Rectifier and inverter protections (overcurrent, commutation failures etc.);
- HVCU and controller signals recording under transient and fault conditions;
- Events archiving with the accurate time marks;
- Selfdiagnostics.

HVCU C/P hardware was designed as a triplicated system for the reliability increase. The voting methode “two from three” was realized on both hardware and software levels. The controllers hardware uses basically the commercially available 300 MHz x86-type processor board and I/O PCB’s, and only extinction angles measuring units were designed specially using programmable LSI’s. Each of three hardware sets has its own serial interface line to the higher level Power Flows Controller.

4. Power Flows Control

The main functions of Vyborg station Power Flows Controller (PFC) are as follows:

Support of the total active power being transmitted through all three 400 kV OH lines to Fingrid on the prescribed level;

Correction of the total active power flow order according with the remote signal from Finnish power system control;

Control of the active power flow level using the signals of counterfaults automatics of the transmitting power system (five levels of power decrease) and the local counterfault algorithms;

Limitation of the transmitted active power according to the safety conditions at the receiving power system;

Distribution of the summary needed DC current between the operating HVCU’s, taking into account the current limitation levels of each HVCU under its real operational conditions (cooling water temperature and so on).

Support of the total reactive power flow of 400 kV OH lines at the minimum possible level at the point of crossing the state frontier; the value of reactive power at this point is calculated using the lines parameters and the lines reactive power values measured at the station 400 kV buses;

Support of the total reactive power flow on the station 330 kV busbars at the allowable level.

For the active power flow control PFC acts upon the HVCU’s DC current orders; for reactive power control PFC affects:

- the set points of the synchronous condensers excitation control (330 kV and 400 kV sides);

- the minimum extinction angle orders of HVCU C/P;

- the additional tertiary side AC filter batteries switching on/off.

Additionally, PFC can give the recommendations for the station operator concerning switching on/off the 330 kV and 400 kV side condensers batteries. Automatic commutation of those batteries is not provided.

For supply all necessary information to the PFC the special duplicated measuring subsystem (PFMS) was realized, separated from commercial power measurements.

PFC is realized as duplicated system; its hardware (Fig.3) consists of:

- two identical control cubicles, each containing industrial PC for power flow control, with duplicated connections to power flows measuring system, and the communication controller providing the triplicated connections of PFC to each of four majorized HVCU’s C/P sets;

- the third cubicle, containing:
  - the built-in workstation for debugging the power flows controllers and for autonomous operative power control under the IPCS fault conditions;
  - the additional computer serving as the digital simulator of the station; the simulator realizes detailed representation of all four HVCU (valve-by-valve), AC filters, the full models of four synchronous condensers of the station by Park-Gorev equations, the chain equivalents of seven joined OH AC lines, models of all HVCU and SC control systems and PFC itself;
  - additional computer for simulating HVCU C/P communication channels when the main simulator operates with the real PFC hardware.

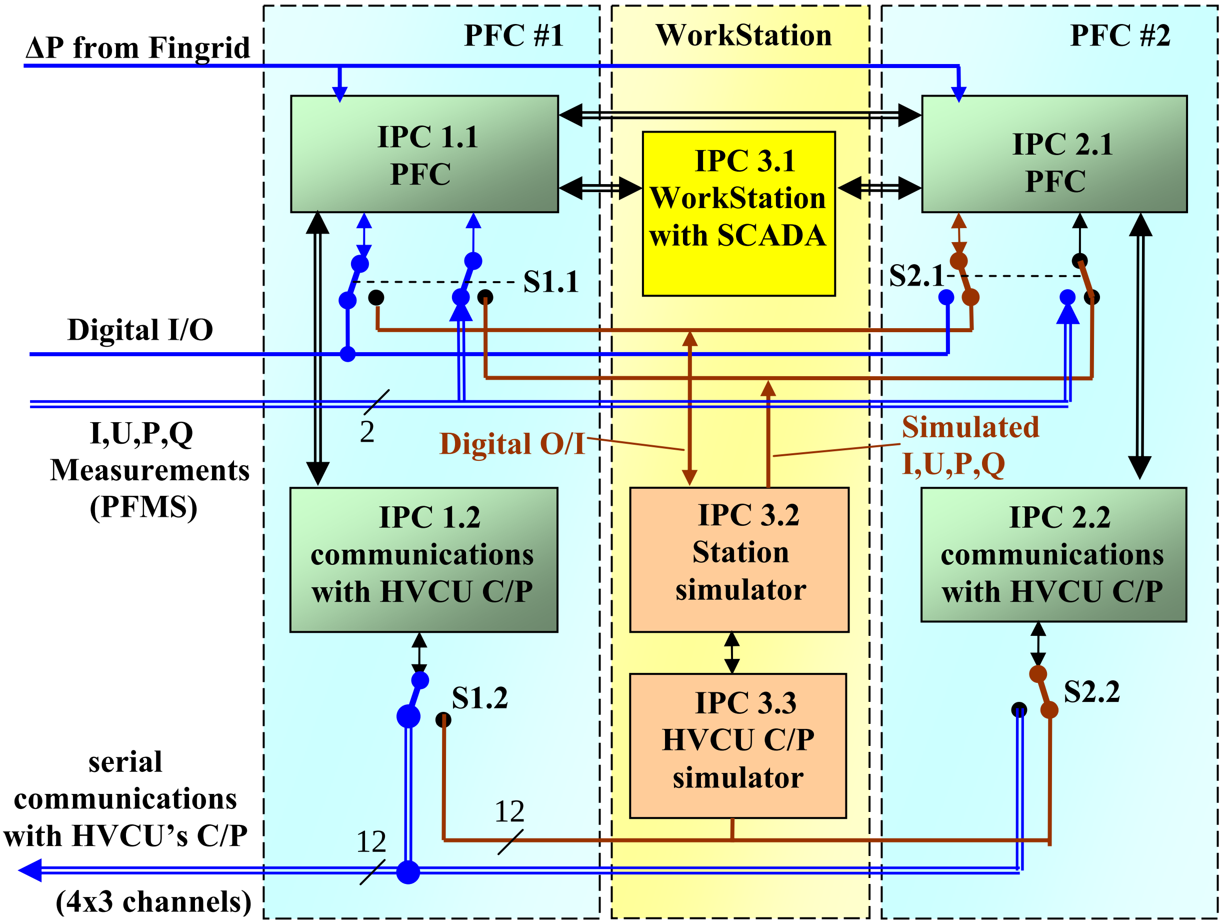

Figure 3. PFC hardware structure diagram

IPC – Industrial Personal Computer, PFMS – duplicated Power Flows Measuring Subsystem

When the duplicated mode of PFC operation is in use, only one of the PFC sets controls the station and initiates the information exchange with the PFMS and HCPU C/P. The second PFC listens to all messages at these communication channels and adjusts its own current data storage. If there were no messages during preset time interval, this PFC decides "the commander is killed, I shall command now!", sends the hardware signal to block control functions of other PFC and unblocks its own control outputs, corresponding information being send to the station operator.

The digital simulator can be used either autonomously to debug and to check the control algorithms, or with real power controller for testing its hardware at the maintenance stage, after repair and after software upgrade. The opportunity is enabled to use the simulator with any one of two power controllers when the other one is in real operation or with full duplicated power controllers set when the station is out of operation for the scheduled maintenance. The necessary wiring switching is shown conditionally by the switches Si.j at Fig.3. At this picture the left PFC set is in real operation and the right one is connected to the simulator.

To accelerate calculations the simulator software was specially written using Visual C++ environment (by the group of former cooperatives of R&D Institute on AC and DC Power Transmission (NIIPT), St.Pitersburg, under the leadership of the late dr. V.A.Andronov). Nevertheless, the simulation speed is about 1/10 of the real time rate. If the simulator is working with real PFC, the special procedures of mutual synchronizing are provided. After finishing the next control calculation cycle (each 20 ms interval of real time scale), PFC sends the request for a fresh "measured" data to simulator, stops all calculations and wait for a new data. At the real control mode these data arrive within 20 ms interval, and when PFC is working with the simulator this interval can increase up to 200-240 ms. It is important to notice that such an opportunity appears only with the digital controller that does all calculations at discrete time moments and can "freeze" its state to wait for the simulator data availability.

Connections of both main PFC computers and PFC workstation to IPCS are realized via special gateway using standard OPC technology (OLE for Process Control).

The presence of special workstation with its own SCADA allows the PFC to operate autonomously under operator control when any problems in rather sophisticated and large IPCS would arise.

The diagram at Fig.4 illustrate the PFC performance.

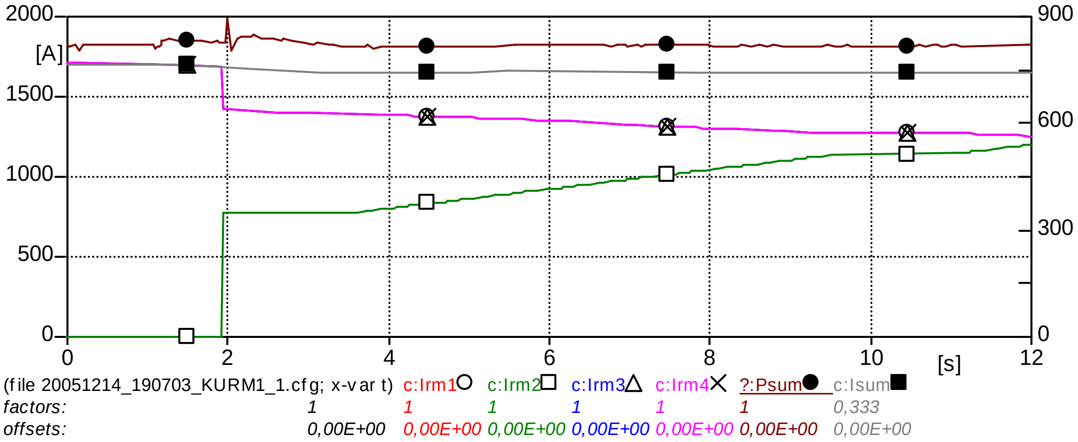

Figure 4. HVCU 2 switching on when HVCU1, 3 & 4 are in operation
Irmi – HVCUi current order, Isum – sum of all Irmi (1:3 scale), Psum – total active power flow

Fig.4 shows the process of HVCU2 switching on when three other HVCU's are in operation with the DC current orders 1700A each. At the start moment the current order of HVCU 2 is set to minimum value 770A and current orders of the rest units decrease so that Isum would not change. Then PFC equalize current orders of all HVCU's gradually with Isum=const. It is seen on the diagram that the total transmitted power Psum has only slight swings at the process.

5. On-line monitoring and diagnostics of the station equipment conditions

Subsystems of on-line control, monitoring and diagnostics of the main and auxiliary equipment of the station include for the moment:

- State monitoring and cooling control of the converter transformers and DC reactors (12 tanks of 32 at the beginning of 2007); for this system special devices were designed to convert the signals of the old selsyn type AC driven sensors of the rectifier transformers OLTC position to digital form.
- Monitoring the condition of the High Voltage Thyristor Valves (HVTV) of all four HVCU and permanent monitoring of the HVCU water cooling systems;

- State monitoring of four synchronous condensers (SC) - two 160 MVA units on 400 kV side and two 100 MVA units on 330 kV side - and permanent monitoring of the operational parameters and gases content in air in the room of electrolyze installation, that provides the hydrogen production for SC cooling.

Each of those three subsystems has its own RS485 local network with the special compact firmware communication protocol DIAGNET-M. Each subsystem is connected to IPCS via separate gateway computer (look at Fig.2) using OPC technology.

6.Conclusion

All new control and protection systems were successfully tested, commissioned and now are in operation.

Within some next years it is planned to equip the rest station transformers with new control and monitoring systems (20 tanks of converter transformers and DC reactors, four synchronous condensers transformers, two 330/110 kV autotransformers of auxiliary feeding and 400/330 kV autotransformer of the isolated AC intertie).

Originally Vyborg back-to-back link was created to transmit the power in only one direction – from Russia to Finland. Now in accordance with the request of Fingrid authorities the opportunity of power flow reversing is being studied. Also the work is proposed to be done in order to improve the algorithms of power flow control and counterfault actions taking into account the accumulated operating experience. The new specifications are being discussed now.

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