Fig. 1. The Hellsjön converter station.

Direct Current Distribution Line Installed in Sweden

VB Elnat installation uses voltage-source converters.

By Tommy Hjort, Vasterbergslagens Elnat AB

Vasterbergslagens Elnat AB (VB Elnat), or actually its predecessor, was the home of the first commercial three-phase ac transmission in Sweden and probably in the world. The transmission began operation in 1893 and provided power from a hydro power plant at Hellsjön, Sweden, to the large iron ore mining operation at Grangesberg 10 km (6 miles) away. This transmission system replaced the mechanical reciprocating wooden beams and steam conduits that were used earlier.

The idea for a new technology involving dc transmission using voltage-source converters (VSC) was conceived in 1987 by ABB Power Systems. The concept involves series connection of many transistors, isolated gate bipolar transistors (IGBTs), their physical adaptation to demanding power industry standards and innovative control software and hardware. The technology extends the economical power range for dc transmission downwards to just a few MW. In addition, new possibilities exist for improving power quality in ac networks. The voltage source converter for HVDC Light is compact and robust, both mechanically and electrically. The main equipment is contained in a small moveable housing and is delivered fully assembled and factory tested (Fig. 2).

A proposal for a dc link between Hellsjön and Grangesberg brought ABB and VB Elnat to a cooperative agreement in which VB Elnat would provide use and

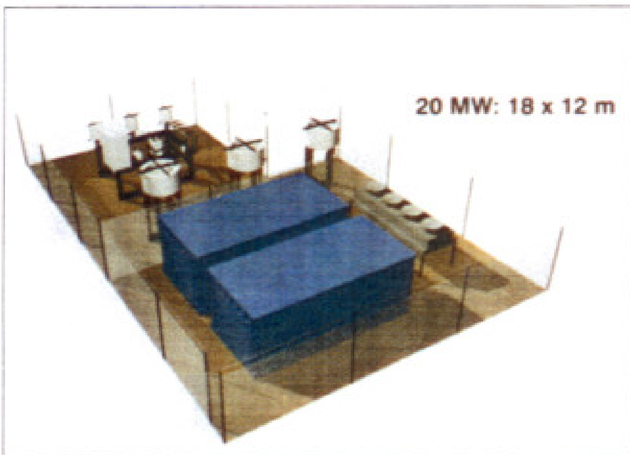

Fig. 2. HVDC Light equipment.

Fig. 3. Possible applications of the HVDC Light system.

adaptation of the facilities on each site, decommission the 55-kV ac line for project use and share in some of the expenses of the project involving station design, engineering, installation and testing.

By participating in this demonstration project, VB Elnat would gain experience in the new technology for future implementation when it becomes necessary to renew portions of the existing power grid. The technology could be especially useful in areas that are sensitive to power frequency magnetic fields and could be used to replace some 55-kV and 130-kV overhead lines with buried dc cable.

VSC Technology Features

Unlike conventional HVDC, the new VSC technology is independent of power grid characteristics and allows for easy relocation of equipment, if necessary. This feature is possible because the equipment is housed in lightweight ISO-standard containers for which the suitable infrastructure is available in almost every country around the world. Several VSCs may be connected to the same dc circuit in multi-drop configuration without the need for any master control or any communication between stations. In this way, dc power grids may be built in the same way as existing ac grids.

The VSC technology, with the transistors chosen with emphasis on current-carrying capability rather than voltage-stress capability, make up the Voltage Source VAR Compensator (VSVC). The technology uses the high-frequency switching of the transistors to mitigate power quality problems involving flicker, harmonics, spikes, dips and sags.

Since this class of problems must be solved by customers whose equipment is responsible for generating the problem, the first VSVCs will probably appear on the premises at electric arc furnaces and industries that use unsophisticated thyristor drives for their operations. When the larger offenders have solved their individual problems, the grid operator will be in a position to install VSVCs to take care of the smaller problems generated by residential and small commercial customers, who utilize equipment that is characterized by non-linear loads such as dimmers, computers, appliances and TV sets.

As the VSC converter is essentially a magic box, which enables the operator to easily choose the output from dc to several hundred Hz during islanding conditions, the technology could find application at airports, harbors and for large motor drives. Other applications include feeding of distant loads and connecting distant generating plants. By feeding a remote load from the main grid, it is feasible to shut down small, expensive local generating plants as well as eliminating the necessity for fuel transport (Fig. 3).

The voltage source converter is controlled by a pulse width modulated (PWM) control voltage with very low energy content and at a switching frequency in excess of 1 kHz . A sinusoidal voltage is formed without the need of large filter banks. With PWM it is possible to create any phase angle or amplitude, up to a predetermined limit, by changing the PWM pattern, providing the possibility for controlling both active and reactive power independently.

The technology may also be used by the parent company, VB Energi, in a future cogeneration plant as a variable speed electric gear box for a gas or steam turbine. For example, a generator could be connected to a VSC

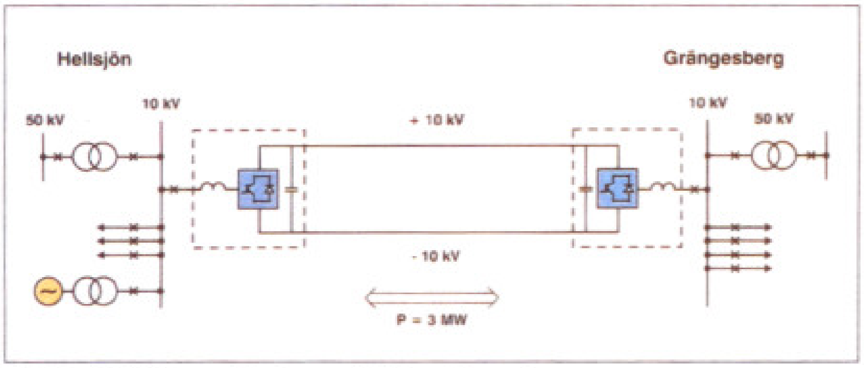

Fig. 4. The VSC HVDC transmission between Hellsjon and Grangesberg.

converter to feed 50 Hz power into the grid. Studies are under way to determine the potential benefits of such a system.

The Installation

Prior to delivery of equipment and during factory testing, the switchyards at the two sites were extended. The enlarged areas had buried conduit installed, as well as additional fencing and ground wire mesh. Wooden railroad ties were used as foundations. The railroad ties were placed directly on top of the station's gravel ground cover. In addition, the 10-kV indoor switchgear was extended to incorporate a dc-link feeder at each site and controls were modified to coordinate with the new equipment.

The dc cable, installed between the converters and the power line, was constructed by ABB High Voltage Cables. The extruded cable, with an aluminum conductor of 95 sq mm (approximately 187 kcirmils), was installed as a pair to economically transmit up to 30 MW at plus/minus 100 kV over distances in excess of 500 km (300 miles). The cable could easily be plowed into the ground, even in rough terrain.

Testing

The testing was set up to check out the systems, first with each station individually connected to the power grid as a VAR compensator. Later, the stations were connected in a back-to-back system configuration (Fig. 4), and any bugs in the system were found and eliminated. After the equipment was installed at the two sites, field testing was initiated. The power grids see the converters as synchronous machines and all combinations of active, and reactive power flows were successfully tested.

The transmission system runs in a fully automatic mode without the need for communications between stations or with any human intervention. The system operates continuously and, since the project is run as a demonstration of the new technology, emphasis is placed on monitoring the long-term behavior of the equipment. It is expected that it will be possible to demonstrate the ability of the generator at Hellsjon hydro station to be the sole supplier of power to the dc link, as well as to demonstrate the ability of the link to feed a passive grid during islanding. Staged fault tests will also be made.

Maintenance

The control system monitors the system continuously and has self-diagnostic features precluding the necessity for scheduled maintenance of the high-technology subsystems. Conventional equipment that include pumps, fans and water treatment systems will require periodic maintenance, as will the main circuit connections where thermovision techniques will be employed. **TDW**

What Is Light Technology?

The designation "Light" implies a converter station that uses VSC technology as compared to conventional dc technology. The station does not require vast filter and capacitor banks and can do without converter transformers, thus earning the designation of a "light" station, synonymous with "small." The VSC technology offers economic feasibility in the 1-100 MW power range, while conventional dc seldom is economical below 100 MW.

Studies show that for a 20 MW transmission, HVDC light plus buried cable is a more economical solution than ac plus a 60 mile (100 km) overhead line.

The converters have one ac side and one dc side, allowing power to flow in either direction. Control equipment directs the valves, which are stacks of series-connected transistors, to chop the dc into small elements that will form a sinusoidal power-frequency wave. The switching frequency is in excess of 1 kHz. The power flows from the valves through the phase reactors into the ac grid. As power is drawn from the dc circuit, the voltage at the transmitting converter drops and its control system allows power flow from its ac grid into the dc circuit to maintain the set voltage level, eliminating the need for communication links between the different converters.

The VSC converters have power transistors that can switch off current at any time. In conventional converters, the thyristors can only switch on current and then wait for the next zero crossing to switch it off. This feature allows the VSC converter to control the frequency and the voltage to feed even a power grid lacking its own generation and short-circuit power.

Studies show that for a 20 MW transmission, HVDC Light plus buried cable is a more economical solution than ac plus a 60 mile (100 km) overhead line. Also, cost-effectiveness can be realized for many remote diesel-powered ac grids if HVDC Light plus cable is used.

Tommy Hjort is planning manager at VB Elnat, which he joined in 1988. He has performed system planning and project management for transmission and distribution lines and substations as well as hydro plants and district heating systems. Previously at ABB Power Systems, he was involved in marketing, system studies, installation, commissioning, project engineering and management on several HVDC schemes in the United States, Brazil, Canada, Zaire and Scandinavia. He earned the MSEE at Chalmers Institute of Technology.