World-class research facilities at Porjus Hydropower Center

Porjus Hydropower Center in northern Sweden is the only non-commercial training center in the world to be based on a functioning hydroelectric power plant. The center, founded in 1994 by Kvaerner Turbin AB, the Swedish State Power Board, Vattenfall, and ABB Generation AB, offers facilities for research and development in the hydropower field and for training staff in the operation and maintenance of hydroelectric plants under realistic conditions.

Porjus power station 1 began generating hydroelectric power on the banks of the Lule river in northern Sweden in 1910. In 1990, after eight decades of operation, it was closed down and finally replaced by New Porjus, a more efficient hydropower station with two modern 267-MVA turbine-generator sets 2 which had been inaugurated some ten years earlier. The old station was subsequently declared a landmark building and ideas were sought for its further use.

The Swedish state power board, Vattenfall, saw an opportunity to establish a center with resources for the training of operative and service personnel as well as for the development of new hydroelectric power technology. An invitation to Swedish-based Kvaerner Turbin AB and ABB Generation to participate in the project brought immediate positive response. At ABB it was recognized at once that there would be important advantages in having such a unique R&D resource for its generator technology, plus the possibility of other useful spin-offs. Discussions followed, and the parties subsequently established what was to become known as the Porjus Hydropower Center.

Two old generators are replaced

As a first step, it was decided to remove the old generators G8 and G9 and replace them with modern machines. The first stage of this project, designated U8, involved a model that had already provided ABB Generation with valuable support in the development of commercially viable products.

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The next step was to install a PC-based control system which would enable users to work more efficiently and at the same time provide the right level of development and training capability. It was decided to install the HPC Compact control system from ABB Generation. Vibration control was also incorporated in the form of ABB's VIMOS condition monitoring system for hydropower machines [1].

Finally, a brushless exciter was installed. Besides reducing the installation costs, a brushless exciter also requires less maintenance and lowers the risk of earth faults, since it produces none of the carbon dust that afflicts other types of exciter.

Sweden's most up-to-date hydropower station

The new R&D center at Porjus consists of two turbine-generator sets 3, each rated at 10 MW. One of the units, designated U8, is being used for development and training in maintenance work, while the other, U9, is earmarked for work serving the general advancement of hydropower technology. U9 features the Powerformer™ [2], a radically new type of rotating machine developed by ABB that does away with step-up transformers and generator circuit-breakers, as it can be connected directly to the power grid. The overall objective of the Porjus project is to promote hydropower technology in the coming century.

Plans also include the creation of university courses for undergraduate and graduate engineers, and opportunities for work on doctoral theses. Vattenfall's Jokkmokk School makes use of U8 for training in hydroelectric power generation.

Alongside the ultra-modern units in the machine hall is a museum based on the old power station. Its seven original turbines have been replaced by historic machines spanning nearly a century of electricity generation.

Porjus Hydropower Center is housed in an old hydroelectric power station in northern Sweden. The center was founded to provide facilities for R&D in the hydropower field and for training operative and maintenance staff under real-world conditions. *(Photo: Kurt Westfeldt, Jokkmokk)* **1**

Unique training opportunities

Training in the new center covers the full scope of hydropower generating activities, from care and maintenance of the water intake throttles to the supply of power to the grid. The really unique aspect of the center is that these facilities are available for training at all times, avoiding the usual situation of having to wait for an opportunity to arise in a commercial plant.

The risk of damage to the machines has also been a limiting factor in the past, with facilities only being made available for certain tests or for work carried out as part of a specific training schedule. It was precisely this opportunity for real-world testing of potentially commercial components that encouraged participation in the project. The value of such testing often depends on the progress a company has made in developing its infrastructure. As long as this is still being built up, it might seem more attractive to increase revenue by raising efficiency than to try and do so by improving maintenance. However, once a company has built up its infrastructure and moved on to running established stations, it will attach more importance to maintenance and to achieving the best possible results at the lowest possible cost.

The profitability of hydroelectric power stations can be potentially improved by raising efficiency, reducing investment and lowering maintenance costs. To try and quantify the improvements likely to be achieved as a result of development work at Porjus, the foundation has set a goal for the increase in profitability of Sweden's hydropower plants over a 30-year period:

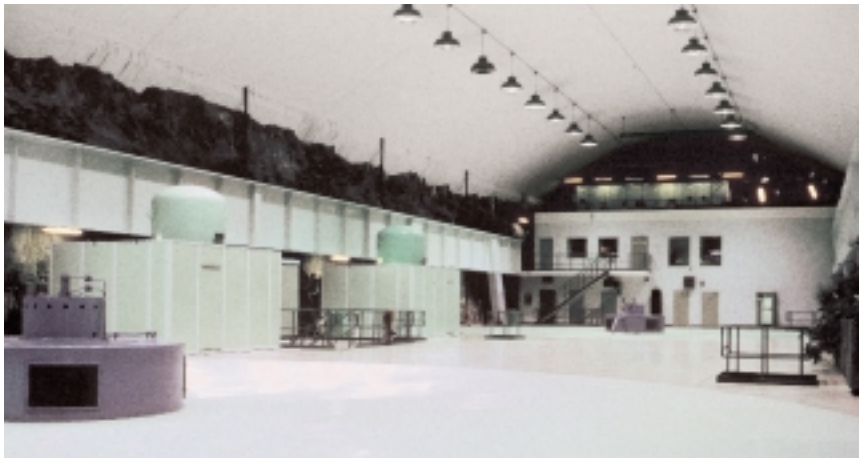
- 1 % higher efficiency approx US$ 75 million
- 10 % lower investment costs approx US$ 90 million
- 10 % lower operating and maintenance costs approx US$ 80 million

The total of nearly US$ 250 million over thirty years is strong evidence of the potential value of the Porjus Hydropower Center.

Generator U8

Porjus U8 **3** is of a new design, having been developed especially for small hydroelectric power stations (*Table 1*). The working group also decided that the generator should be fitted with a brushless exciter.

The new generator has been designed to meet every requirement that could be specified for a small, modern hydropower unit.



The New Projus hydropower station is one of the largest on the Lule river. The 267-MVA generating sets, with a diameter of more than 17 m and weighing 1,200 t each, rotate at a slow 83.3 rev/min. 2

Since easy servicing is given a high priority 4, the machine has been built with the same service features as large ABB generators. Heat recovery is also provided.

Brushless excitation

A special brushless exciter was built for Porjus U8. Manufactured to the same design as the brushless exciters used by ABB Generation in its larger generators, the stator has salient poles and the rotor has a three-phase AC winding along the shaft above the rotor of the generator.

The exciter has readily accessible sliprings. One ring is sufficient for customers who want a brush for connecting earth-fault protection; two rings are necessary for measuring the voltage across the generator rotor winding during operation of the machine.

The diodes have been positioned to allow easy inspection and replacement. Faults are indicated by the voltage regulator. In parallel with each diode is an RC circuit to reduce commutation overvoltage (reverse current protection).

The field winding of the brushless exciter is energized by a six-pulse rectifier bridge fed with local power, the generator terminals or an auxiliary exciter. Different kinds of excitation transformer are available to take account of variations in the power supply source.

Generator voltage control is provided by the fully digital HPC 840 regulator, which is based on ABB Advant hardware. The HPC 840 controls the rectifier supplying power to the field winding.

Improved profitability

Profitability is improved by the fact that a brushless exciter requires significantly less maintenance than a conventional static exciter. A big problem with most conventional exciters is the formation of carbon dust, more than a third of the earth faults occurring in a rotor being caused by fouling of the slipring device. The damage caused by repeated earth faults can be so severe that the equipment cannot be repaired and has to be replaced. Standstill due to exciter failure may run into months if a new exciter is not immediately available.

ABB Generation has developed exciters to suit most existing machines. The new exciter in Porjus is easy to install and also requires less auxiliary equipment than its predecessors, which had brushes.

Monitoring and ancillary equipment

To protect the critical parts of the generator from damage, monitoring equipment featuring alarms and stop functions, etc, has been installed.

Other systems incorporated in the generator include automatic compressed-air brakes and an oil pressure system. Some ancillary equipment is also provided, eg:

- Steel structures for concrete caps, with or without additional insulation for varying the sound-proofing
- An oil filter with bypass for continuous cleaning of the oil, intended for generators with plain bearings
- Heat recovery/temperature control equipment comprising a digital con-

Table 1:
Main characteristics of the Porjus U8 generator

Capacity	MVA	11
Power factor		0.9
Efficiency	%	97.7
Rated voltage	kV	10
Rated current	A	635
Rated speed	rev/min	428.6
Inertia constant set to		1.83
Air-gap diameter	mm	2,530
Height from shaft flange to generator baseplate	mm	3,700
Generator chamber diameter	mm	6,300
Weight of complete rotor	t	24
Weight of stator	t	23

troller and direct-acting thermostatic valves
- Standstill heaters
- Extra instrumentation to meet special customer requirements

PC-based control

The center's HPC Compact control system 5 features a modern computer and specially developed software modules for the best possible integration of the machines and functions. This integration also allows many functions to be controlled by the same hardware, which in practice reduces the amount of hardware and ancillary equipment that is needed.

Operator communication is via a standard PC featuring Windows and modular function blocks. Due to the use of the HPC Compact integrated control system only two cubicles are needed to perform all the required control functions.

Control equipment for training

The control equipment is designed to provide an overview of the computer-based control equipment in hydroelectric power stations and to help operators understand how it functions. Trainees can be instructed in how to run a power plant from an operator station or local control panels, as well as in software maintenance using computer-based tools. All functions normally involved in plant operation are implemented and any special functions not offered by the operator station can be simulated.

Operators gain a better understanding of the plant by scanning stored measured values, trends, mean values, etc, at an information storage and retrieval station.

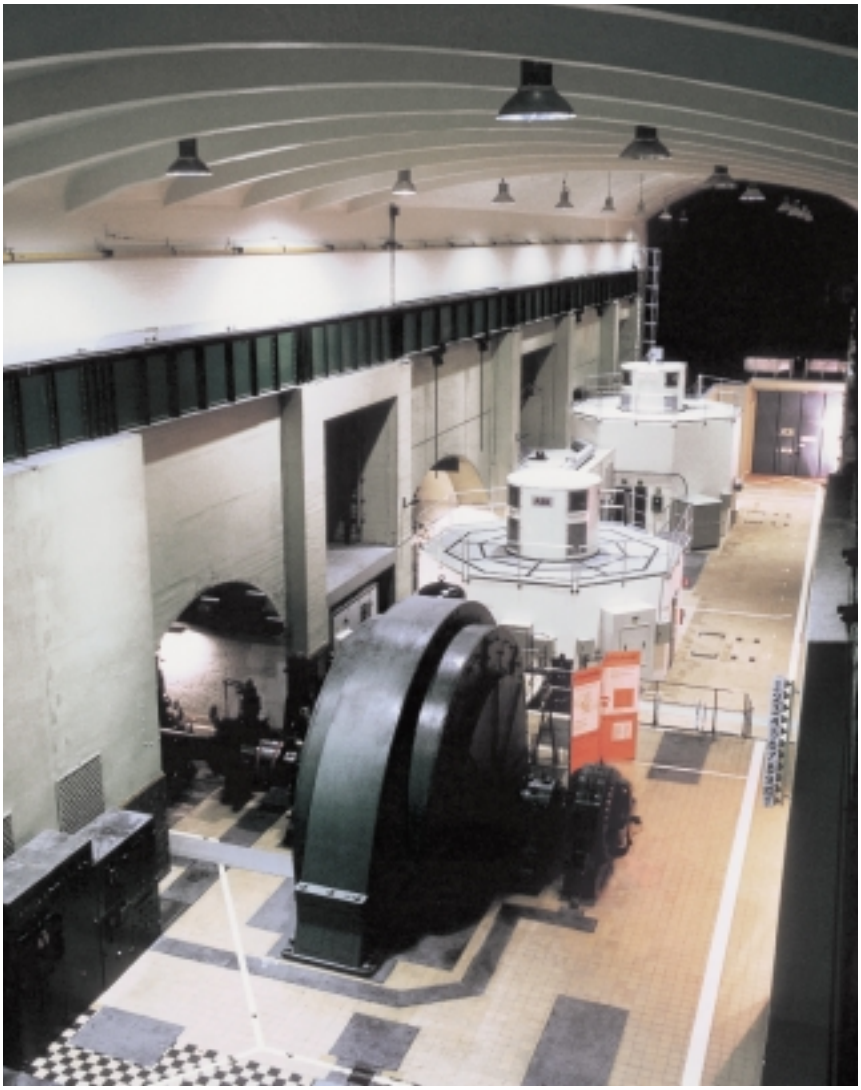
Control and monitoring

As already mentioned, the HPC Compact system 5 is used for control and monitoring. For the generating sets there is also separate equipment for handling the turbine control and voltage regulation, plus other functions. The plant control system includes functions for reservoir level control via the spillways and functions for monitoring and controlling the general operation of the station. For unit U8, the reservoir, spillways and a second generating set can be simulated to increase the scope of the training. An operator station is provided for the overall plant control. The equipment also includes an information management system (IMS), which stores the data.

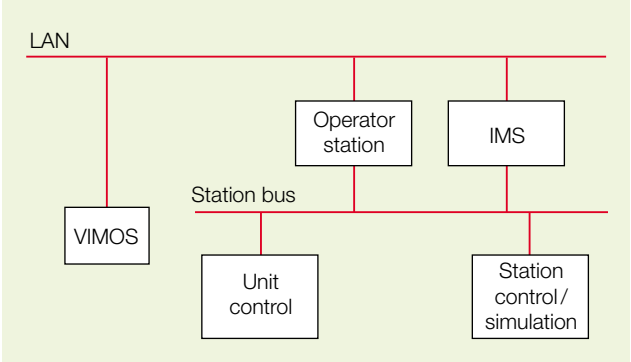
The systems for controlling U8 and the plant in general are based on computers which incorporate all of the required control and monitoring functions. There is also separate equipment for the protection functions. An alphanumeric VDU is used for the local control.

Typical functions of the overall plant control system include load sharing between the generating sets, the control of water levels and the flow rates through the turbines and down the spillways.

Communication between the operators and control systems is via PCs. The operator station offers functions for operation and indications 6 as well as for event and



The two new generators in Porjus Hydropower Center. In the foreground, behind the older machine, is unit U8, which is used for maintenance training and studies. Behind it is the radically new Powerformer, which was commissioned in 1998 as U9. 3



Block diagram of the HPC Compact control system installed for Porjus U8 **5**

IMS *Information management system*
LAN *Local area network*
VIMOS *Vibration monitoring system*

The generator set used for training has extra transducers for measuring vibrations and temperatures. Special apertures in the generator housing, metal covers and top of the machine make inspections easy. **4**

alarm handling. A separate IMS computer is used for reports and the long-time storage of operating data. Communication between the different items of control gear is over serial buses.

Vibration monitoring

U8 is also equipped with the VIMOS vibration monitoring system, mainly to supervise the machines and protect them from mechanical damage during operation. This system continuously monitors the operation of the machines and analyzes and displays evaluated measurement data on-line in engineering units. It also stores all data automatically at time intervals selected by the users.

Alarm and trip limits are set individually for each channel and method of evaluation. Alarm levels are set to indicate when it is time for maintenance work or repairs. This makes it easier to plan maintenance and reduces the risk of unexpected, emergency repairs. Trip signals are activated before mechanical safety margins are exceeded.

Information handling

Historical information is stored and displayed at one-minute intervals. The stored data contain information on measured values or indications, such as circuit-breaker positions. Storage is for a limited period, the data afterwards being compressed every hour in a predetermined manner (eg, by calculating a mean value, subtracting the highest value, calculating the number of operating hours, etc). This is repeated daily, monthly and yearly.

Data can thus be presented in the form of hourly, daily, monthly or yearly reports, eg to provide information such as the mean power per day or month.

Documentation

The facilities at Porjus can also be used to test new software. One area which benefits from such testing is the plant documentation filing and retrieval system. All drawings, specifications, maintenance documentats, etc, are stored digitally.

A VDU is used for the retrieval, the operator being able to freely select any topic on which he requires information **7**. Available data are then displayed in hierarchical form. The operator can either view the desired document on a monitor or have it printed out.

Remote control has benefits for ABB

The Porjus Hydropower Center is connected by modems and ordinary telephone lines to the Jokkmokk School, approximately 40 km to the south, and to ABB in

Västerås. This means that all the operator functions (VDU images and commands) can be accessed in all three locations. The Jokkmokk School also has remote control equipment for training purposes and for analyzing trends and measured data.

The link to ABB in Västerås enables a unique service to be provided. Via this link all the operator functions are accessible to the design and service department of ABB, which is situated more than 1,000 km from Porjus. Remote fault tracing, analyses and consulting services are therefore possible, as are remote-controlled repairs and upgrading of the station software. Software functions can also be continuously tested.

Remote control over the Porjus-Västerås link is relatively straightforward and has numerous benefits. The simple fact of being able to tap directly into the plant and its control and monitoring systems opens up many possibilities for the engineers at ABB.

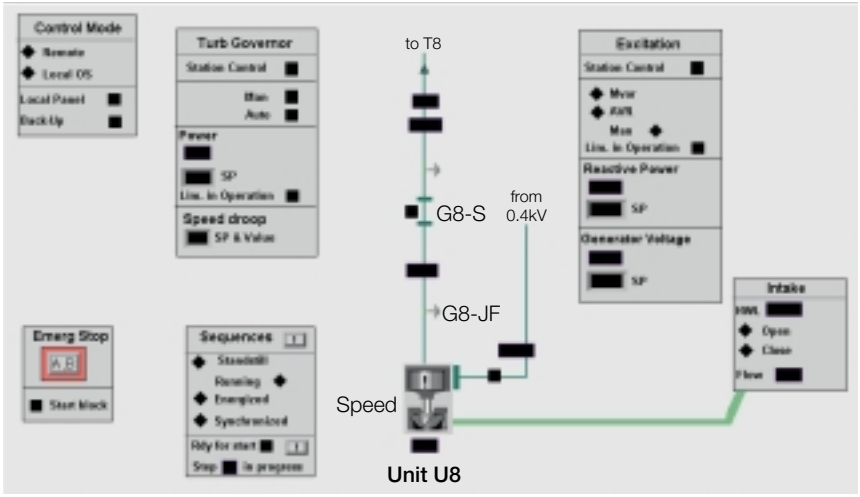
In the past, control and monitoring functions in hydroelectric power stations were dealt with by relay-based systems or local, simple computers. Porjus brings them together in larger, integrated systems, all of which can be accessed and influenced by remote control.

The remote control system at Porjus is seen as being generally applicable to hydropower stations, many of which are in remote locations. Keeping specialists and services available in the vicinity of remote sites is a problem that can be solved by installing such a system.

Future trends

Trends in the computerized control of hydroelectric power generation are likely to be as follows:

- Increased use of software modules
- Increased use of distributed units based on faster transmission and automatic controls
- Advanced control commands linked up to monitoring functions
- Improvements in diagnostic and maintenance functions



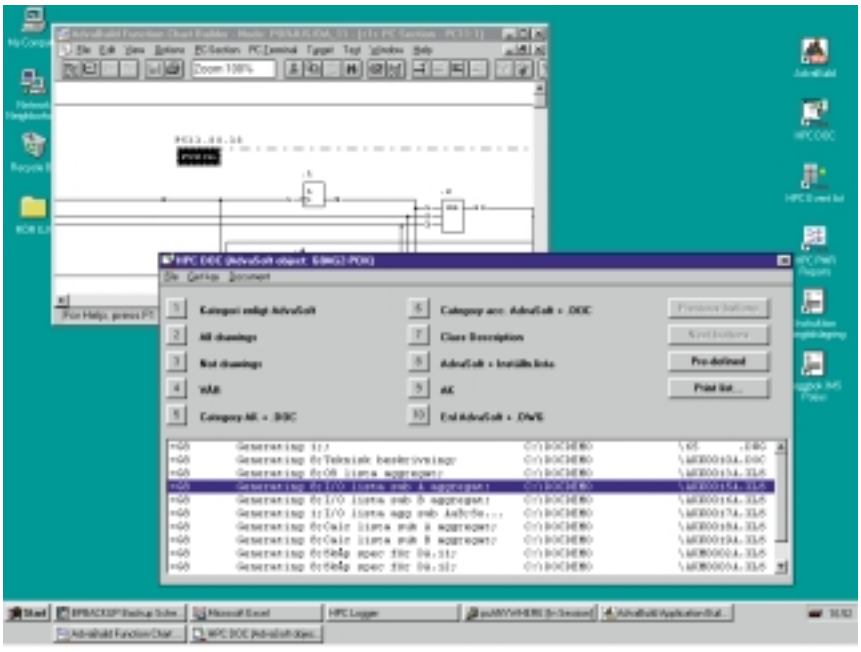
Operator station display showing an overview of the generator in turbine-generator set U8. 6

Outlook for future installations

Based on the increased use of function modules in the data systems, the concept employed at Porjus allows more efficient

Screenshot showing two functions in operation simultaneously 7

In the background is the engineering tool for documentation and maintenance of the control system software. Trouble-shooting, modification and addition of new functions are carried out using this display. In the foreground is the tool for searching through the plant documentation. In the image shown, documentation relating to generator G8 was the search target. The operator has marked the signal list in which he is currently interested, ie I/O list, sub A.



Certain operating information can be read directly off the control cubicles in the control room. Training is given by instructors from the Jokkmokk School, which can also access all the operator functions at the center via modems. 8

and precise control of hydroelectric power stations. The benefits of the technology are reflected in both the design and the space requirements of the equipment. Reliability as well as compatibility with the I/Os and advanced control systems of future installations is also improved.

Minisystems for the future

The products and systems described point to increasing importance being attached to systems with smaller machines taking up less space in the future. The scaled-down generator is an example of how ABB is addressing this issue. Alongside trouble-free, efficient operation, the power per unit surface area has the highest priority for hydroelectric plant owners.

Operation, maintenance and training

The efficient operation and maintenance of hydropower plants will become increasingly important due to its obvious economic significance.

Several developments are contributing to an improvement: for example, knowledge of the stresses occurring in machines has increased considerably, while temperature variations and vibrations are being measured with greater accuracy today. Also, improvements in the design of the auxiliary systems have helped to ensure uninterrupted operation.

The development of computer technology is also continuing unabated. Inexpensive systems with large functional capability can be used to store and process measured data, making it possible not only to determine why faults occur but also to identify their potential causes. In the future, trend analyses of measured data will provide the basis for repair and maintenance schedules. Machines will not need to be shut down for maintenance before the need arises and is confirmed by measured data. Shutdown times can therefore be reduced to a minimum.

Ongoing training of operators and maintenance personnel is becoming essential. Operating staff need to learn how to use new tools. Theoretical training, based on written descriptions of the facilities provided by new systems, is no longer enough. Training needs to be backed up by practical work conducted under realistic conditions 8.

More 'relevant' expertise will be expected of the station staff, while demand for skilful operators having practical experience of operation and maintenance will also increase.

Activities at the training center at Porjus are fully synchronized with these trends, making it not only a unique resource of expertise and technology but also a sound investment in the future of hydropower generation.

References

[1] K. Eriksson, S. Eriksson: VIMOS condition monitoring for hydro power machines. ABB Review 1/92, 15–20.

[2] M. Leijon: Powerformer™ – a radically new rotating machine. ABB Review 2/98, 21–26.

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