Aswan 1 hydropower plant refurbished after 30 years' service

In the late 1980s the Egyptian government decided on a radical modernization of the Aswan 1 hydroelectric power plant, which had been in operation for more than 30 years at that time. The project was to cover the seven turbine-generator units, each rated at 47 MW, the complete electrical equipment, and the water passages. A special challenge was presented by the need to keep the plant running while work was being carried out on the individual machines. This meant that during the entire rehabilitation project no more than two out of the seven main machines could be shut down. In August 1996, the biggest rehabilitation project in the history of Egypt's hydroelectric power industry had been successfully completed.

After construction of the Aswan 1 hydroelectric power plant south of the town of Aswan in 1960 **1** and of the Aswan High Dam in 1967, the state-owned power utility *Egyptian Electricity Authority* (EEA) first built several thermal power stations, thus shifting the main focus of its power generation strategy. However, over the past 15 to 20 years, it has expanded its hydroelectric power capacity and followed a policy of refurbishing its older hydroelectric plants.

Detailed studies and surveys carried out in the late 1980s by the Swedish consultant SWECO showed that the Aswan 1 hydroelectric power plant was in need of rehabilitation **2**. In 1991, a German/Austrian consortium headed by ABB Kraftwerke AG, Mannheim, and including Sulzer-Hydro, Ravensburg, and Waagner-Biró, Vienna, was awarded the contract to rehabilitate the Aswan 1 hydroelectric power plant (see box on page 40), around 900 km south of Cairo, towards the head waters of the Nile. The consultant engineers were Lahmeyer International GmbH, Frankfurt am Main, Elektrowatt Engineering Services Ltd, Zurich, and Utility Consultants International GmbH, Frankfurt am Main. Unlike the mechanical parts, the electrical equipment and the electronics needed to be replaced in their entirety. The main parts involved were the medium- and low-voltage installations, the entire cabling and the instrumentation and control system, which monitors and controls all of the power plant functions.

At Aswan 1 seven generators produce more than a billion kWh of electricity every year. Through the dam's top inlets, up to 2.44 million m^3 of water an hour pass through seven 30-meter-long penstocks. After 30 years of operation, these feed channels were exhibiting severe unevenness, thus reducing the water flow velocity – and therefore the output of the power plant – to such an extent that the intake tubes had to be repaired.

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After driving the turbines, the water flows into the underwater basin located behind the power plant and is passed back into the Nile via four tunnel pipes with an average length of 826 meters that lead downstream past the old Aswan Dam, enabling it to be used by farmers to irrigate their fields. The electrical energy is fed into the grid of the EEA via transmission facilities.

Dam and power house

The intake dam is 36 m high and 330 m long **3**. It essentially consists of granite rubble masonry and is protected by a waterproof, steel-reinforced concrete construction. Before the Aswan High Dam was built, the water levels – and with them the heads – fluctuated between 15 and 31 m. Today, the heads can be maintained at values between 18 and 23 m.

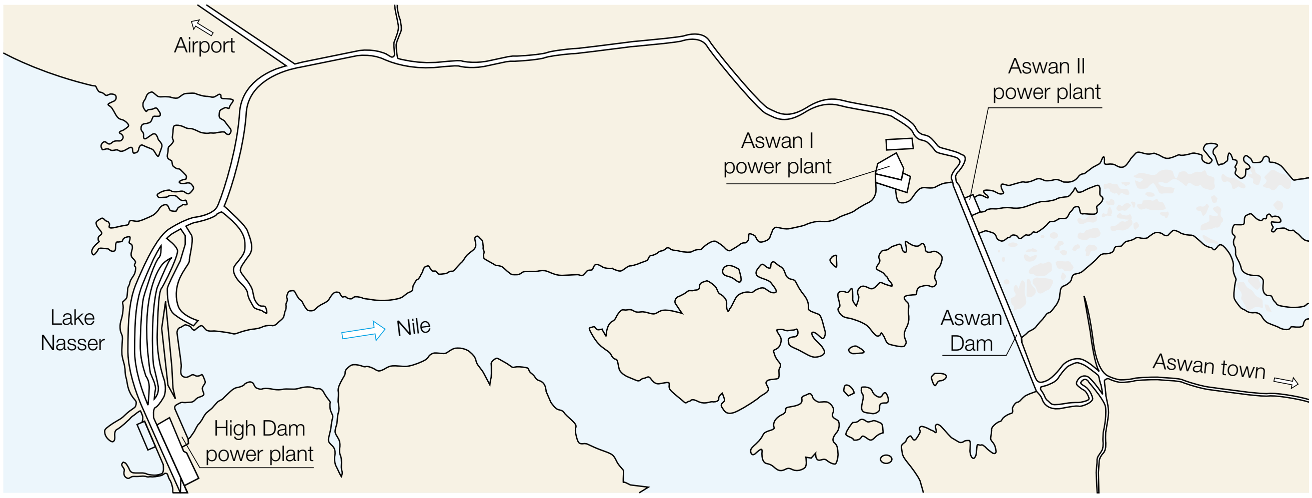
Immediately behind the dam, separated only by an access road, is the power house **4** with seven generators of conventional design. Each of the machines is installed in a concrete housing protuding from the generator level. The steel construction of the stator holds the laminated core, and externally supports the twelve air-water coolers for the closed cooling air circuit of the generator.

Generator rehabilitation

The round-packing method

The work required for the seven generators **5** was particularly challenging (*Table 1*), since it involved re-insulation of the rotor coils and replacement of the stator core, stator winding and the excitation system.

A total of 65 t of high-quality, protection-coated steel sheets was re-inserted in each machine using a special stacking procedure. The use of the improved steel



Hydroelectric power plants on the Nile at Aswan, Upper Egypt **1**

sheets reduced the core losses by around 32 percent.

After the 're-coring', two Roebel bars were inserted in each slot. The winding bars were inserted using the ABB round-packing method. This technique guarantees that the winding is securely embedded in the stator, and thus extends the machine's useful lifetime.

To protect the new laminated cores and windings of the stators from the dust and dirt produced during sandblasting of the turbines, the shaft between the turbine and generator of each machine had to be covered with a special platform. This struc-

Aswan 1 hydroelectric power plant; in the background is the old Aswan Dam **2**

ture, which can take a load of up to 40 t, was designed and built by staff on site. In addition, the old generator coolers, with six air-water cooler sets (2 coolers per set) for each machine, had to be replaced together with all the cooling-water and oil lines.

Table 1: Technical specifications of the seven generators

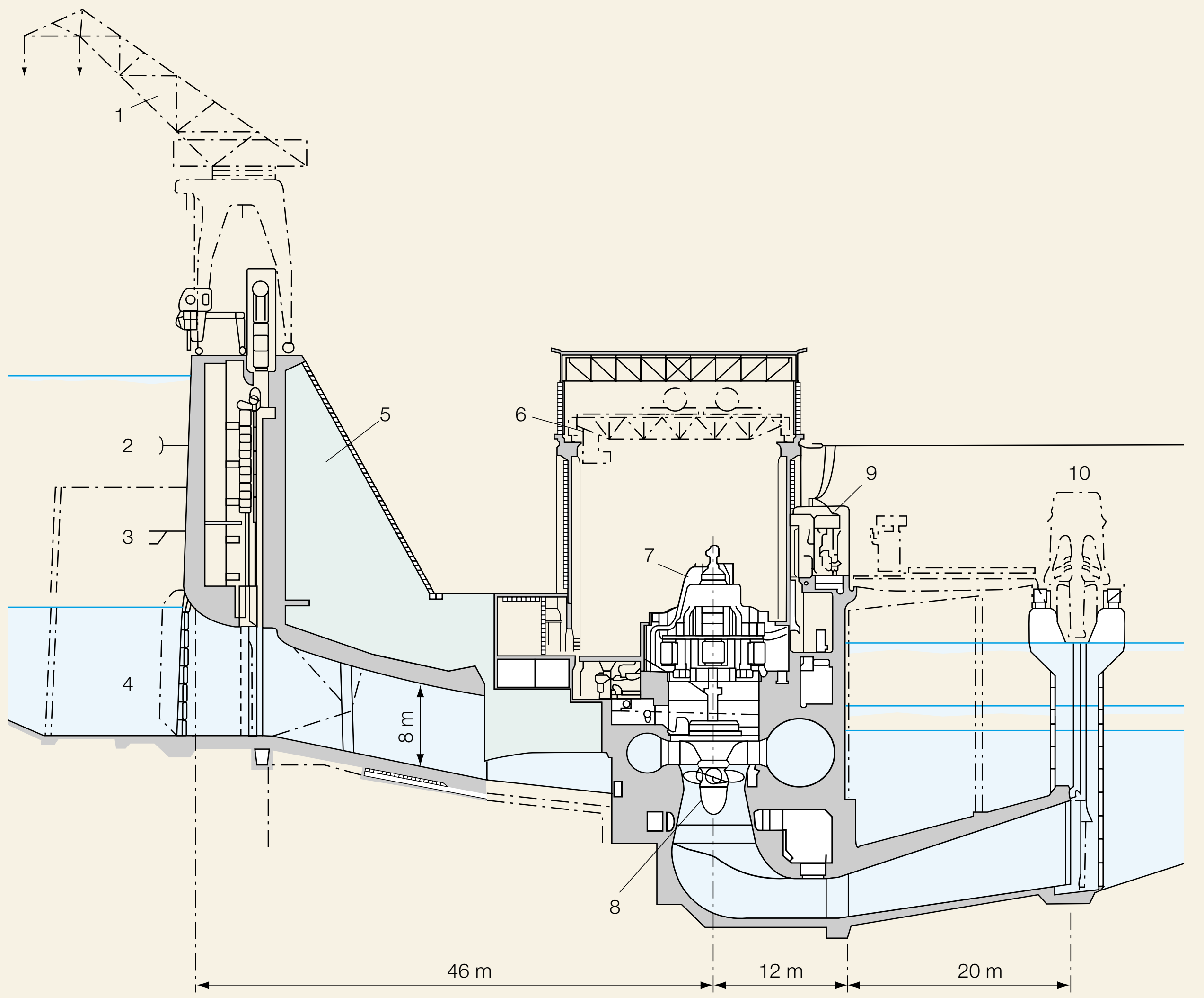
Power rating	49.5	MVA
Rated voltage	11	kV
Rated power factor	0.95	
Rated frequency	50	Hz
Rated speed	100	rev/min
Runaway speed	345	rev/min
Flywheel effect (GD^2)	15,000	tm^2
Stator bore	7,500	mm
Rotor weight	485	t

Table 2: Technical specifications of the unit transformers

Power rating	51/51/30	MVA
Rated voltage	132/11/11	kV
Vector diagram	Ynd11 d5	
Rated frequency	50	Hz

Section through the Aswan 1 hydroelectric scheme **3**

1 *Intake dam crane*
2 *Intake gate*
3 *Concrete*
4 *Trash rack*
5 *Granite rubble masonry*
6 *265-t crane*
7 *47-MW generator*
8 *Kaplan turbine*
9 *Unit transformer*
10 *Draft tube bridge*



Stator

Only the frame of the stator was re-used during the rehabilitation. The steel sections for mounting the laminations were re-measured and aligned. To ensure maximum frictional engagement, the stator laminations were restacked one by one on site. The employed true-running check device allowed immediate, high-precision checking of the work performed, so that the value for the air gap could easily be complied with. The laminated core of the stator consists of low-loss steel sheets with thicknesses of 0.5 to 0.35 mm, covered with a special insulating enamel. Cooling sheets were inserted at precisely calculated distances. These guide the cooling air through the stator. The laminated core is compressed by means of stator bolts and compression plates, with clamp nuts and cup springs fitted at the ends to ensure lamination compression over the operating time of the machine.

The stator windings are designed as two-layer Roebel bar windings with class F Micadur insulation. As mentioned, the windings were inserted in the stator slots using ABB's tried and tested round-packing technique, and fixed permanently in place with springs and double wedges. The end windings have been reinforced with impregnated glass-fiber cord to ensure the mechanical strength needed to withstand the forces that could be caused by disturbances in the power network. A special corona protection varnish was applied to the windings bars over their entire lengths, including the end windings, to achieve uniform potential distribution.

The air coolers are attached to the stator. Expansion bellows were fitted to the cooling-water pipes to ensure freedom of movement in the event of expansion during operation.

Rotor

The rotors consist of a flange shaft with a through-bore of 400 mm, a length of 9 m and a weight of 40 t **6**. Two ten-armed wheel centers for supporting the gear rims were shrunk onto the shaft. The brake ring is attached to the bottom wheel center, which is also the point where the hoists for lifting and fixing the rotor are attached. Most of these features were replaced. The 60 rotor poles, made of solid cast steel, are fitted into the gear rims with their T-shaped pole claws and secured in position with pole wedges and bolts. The flat copper coils of the poles were re-insulated with NOMEX-strengthened synthetic resin. This guarantees insulation class F with high insulation resistances and excellent dielectric values.

Bearings

The generator bearings were fitted with new white-metal-coated pads. An automatic high-pressure oil-lift system for the lube oil was installed, and the monitoring instruments replaced.

In the case of machines 3 to 7 the guide bearing is fitted beneath the rotor, at the bottom bearing bracket and at the turbine shaft. The combined thrust and guide bearing for the turbine and generator is located above the rotor. Machines 8 and 9 each have a guide bearing above the rotor and at the turbine, plus a combined thrust and guide bearing beneath the rotor at the bottom bearing bracket.

The thrust bearing has to carry the entire weight of the rotating parts of the generator and the turbine, ie approx 650 t, plus the water force of approx 950 t.

The self-lubricating pad-type thrust bearing consists of 18 pads, with a total carrying capacity of 1,600 t. Each pad can be individually adjusted. Each of the pads of machines 8 and 9 rests on 58 spring

Power house of the Aswan Dam hydroelectric plant **4**

elements. All the machines received new thrust bearings and were fitted with a high-pressure oil-lifting system, which is activated automatically when the machine starts up to ensure the required film of lubricant between the bearing surfaces.

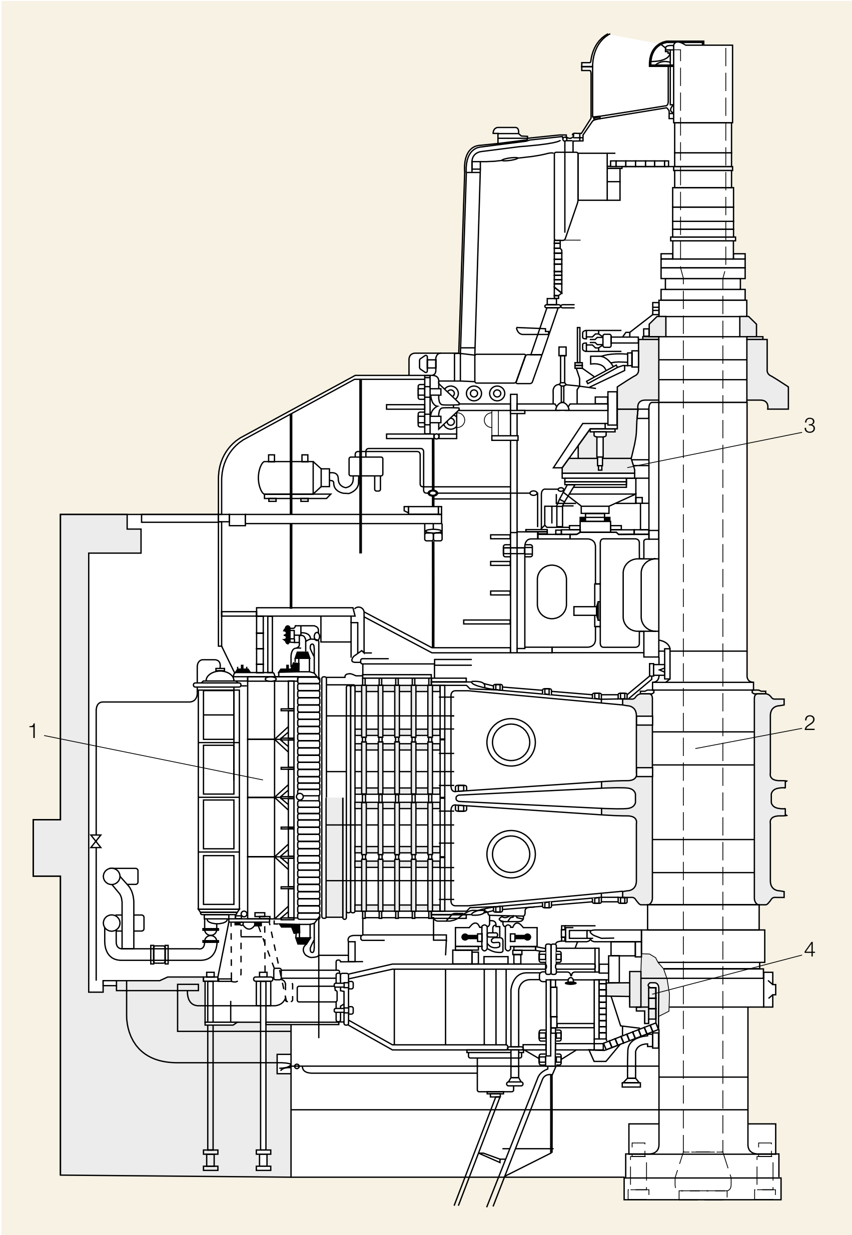
The bottom guide bearing is likewise self-lubricating, but has an oil supply which is independent of the thrust bearing.

Excitation system

The original excitation machine, which was flanged onto the generator shaft, was removed and replaced by a static excitation system with three-phase excitation transformer. The static rectifier features modern thyristor technology and consists of three three-phase thyristor bridges connected in parallel. If one bridge fails, the remaining two will supply the excitation current required for full-load operation of the generator. The voltage is controlled automatically, but there is also the option of manual control, eg for test purposes. The rotor current, stator current and load angle are also controlled fully automatically.

Generator busduct

The generators are linked to the unit transformer by three-phase metal-enclosed generator busducts and flexible connection strands at the generator terminals. The busducts are dimensioned for the full rated current of the generators and are air-cooled. Feeders lead to the field-circuit transformer. In the case of machines 4 and 6, which were fitted with new three-winding unit transformers (*Table 2*), additional generator circuit-breakers were installed to enable the station-service power supply to be maintained should the network or power plant fail completely.



Sectional view of a vertical-shaft generator **5**

1 *Stator* 3 *Combined thrust and guide bearing*
2 *Rotor* 4 *Lower guide bearing*

Solution of specific turbine problems

During a routine inspection of the spiral of the first recommissioned machine, cracks were discovered in the corrosion protection and, after further inspections, at the last support blade. More detailed investigations revealed a large number of hairline cracks at the top and bottom ends of the support blade, and a massive crack in the middle of the blade. Support blade cracks had never been encountered in this kind of turbine anywhere in the world before, and were thus completely unforseeable. Metallurgical analyses dated the inception of these cracks, which could be rendered visible only by means of special procedures using contrast media and UV light, to several decades ago. Detailed examinations of the phenomenon revealed that the cracks had probably originated after initial commissioning during the early years of operation, and had been triggered by Karman vortexes.

The blades were repaired using appropriate heat-treatment processes. In addition, the shaping of the end edges of all the support blades was optimized.

All the rehabilitated machines had to prove their operational reliability in a precisely specified, seven-day trial run before being handed over to the customer. Index measurements also had to be carried out before and after rehabilitation. They all showed a significant improvement in the efficiency of the machines after rehabilitation.

Power plant instrumentation and control

The entire power plant process is monitored and controlled by the ABB Master hydropower plant process control system **7**. This system has a hierarchical structure and controls the operation of the power plant on three process levels:

- *Level 1:* Individual control cubicles for the operation of individual drives and apparatus, eg for maintenance and testing.
- *Level 2:* Machine control cubicles of the seven turbine-generator units, in which all of the incoming and outgoing information is monitored and processed.
- *Level 3:* Central control room, from which the entire power plant is controlled.

Each machine has its own process station which acquires and processes the incoming signals and data and also sends commands to the peripherals **7**. The process visualization is provided by a local monitor. All the individual process stations are linked over the station data bus to the central control room of the power plant, where the ongoing process can be viewed and controlled at an operator station.

Lowering the rotor of generator no 4 into the stator **6**

Besides this fixed operator station (MMC station), there is also a mobile operator station (a so-called trolley version). The mobile version can be connected when required to any local process computer in a machine control cubicle using plug-type connectors. This arrangement had already proved to be an advantage for rehabilitating machines while the other machines were still running.

The functions of the operator stations are as follows:

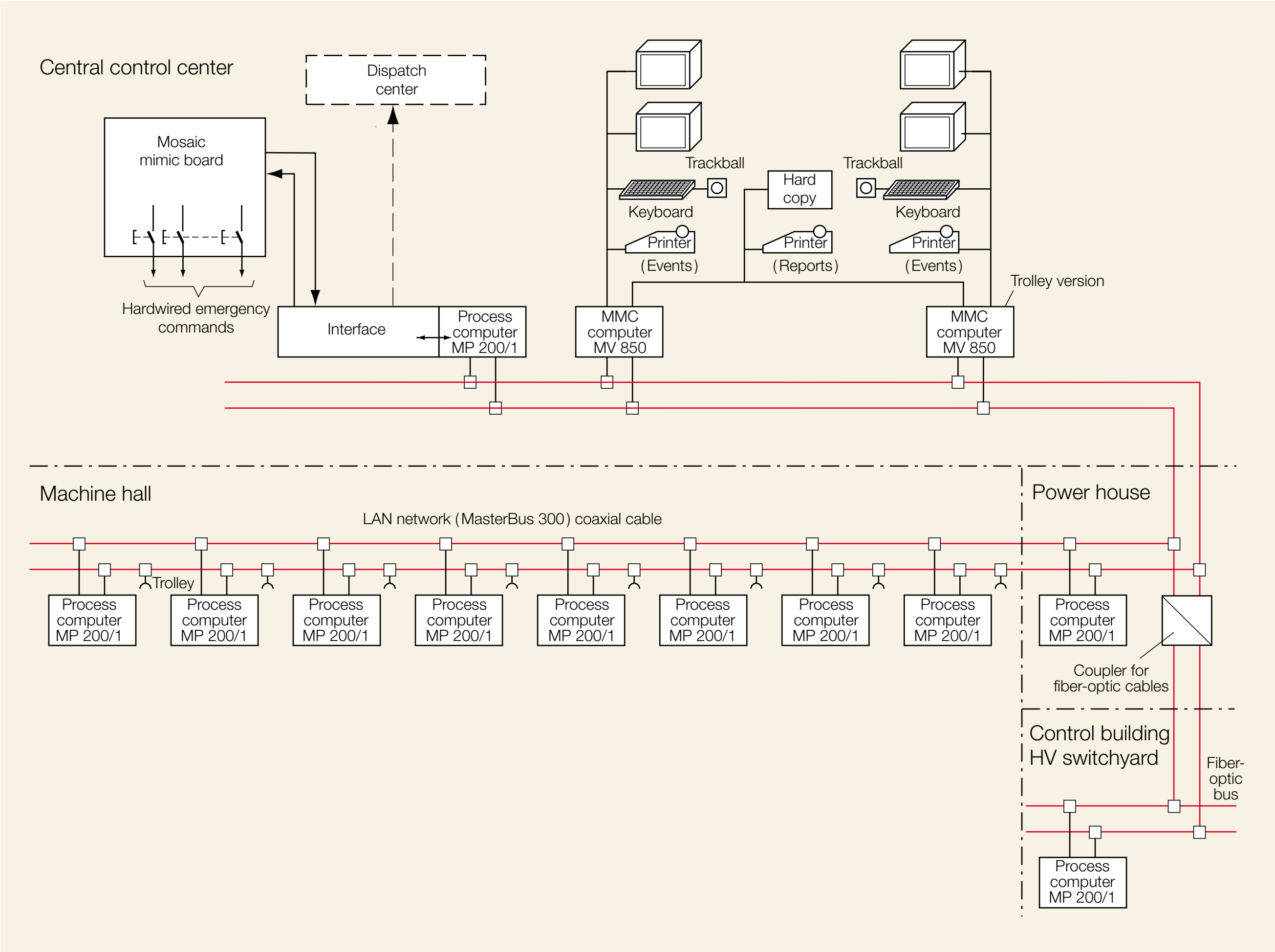
- Displaying information in the form of mimic diagrams, group displays and trend curves
- Acquiring and listing events and disturbance messages
- Dialogue functions involving the process, eg specification of setpoint values, commands for switching circuit-breakers
- Creating event logs

The process is observed by means of both a mosaic-type display board and a redundant MMC (man-machine communication) system **7**. Future expansion is provided for, the highest level envisaged being management by a regional and/or national load dispatching center which would receive the relevant information from the power plant and control the individual machines as required.

The backbone, so to speak, through which all the system's 'nerve paths' run, is the redundant databus (LAN network), consisting of two coaxial cables with a data transmission rate of 10 Mbit/s inside the hydroelectric power plant and two glass-fiber cables to the 132-kV outdoor substation. This databus links all the process computer systems to each other and to the MMC systems.

System functions

The functions of the control system are as follows:



Basic diagram of the computer-based ABB Master control system **7**

MP 200/1 *MasterPiece 200/1 process control station*
MV 850 *MasterView 850 process operator station*
Trolley *Terminal for connecting mobile process operator station*

- Automatic starting and stopping of the machines with sequence control
- Acquisition of information from the process, such as digital and analogue measured values, breaker positions, etc
- Output of signals, commands, setpoint values, etc
- Display of information in the form of mimic diagrams, static displays, group status displays and trend curves
- Acquisition and listing of events and disturbance messages
- Generation of event logs and trend curves
- Dialogue between man and machine

Central control room

The central control room was designed by ABB to state-of-the-art human engineering principles, and was successfully executed by EEA with help from local contractors.

The operating staff can conveniently monitor the ongoing power plant process from the control room console, video displays and a mosaic-type display board. enabling them to intervene manually if necessary.

Switchgear and transformers

For the power plant auxiliaries, ABB Arab installed a new 11-kV substation in place of the old installation, which had oil circuit-breakers. The new metal-enclosed substation is fitted with withdrawable SF_6 circuit-breakers. It is fed by the two station-service turbines, each rated at 11.5 MW, and by machines 4 and 6. In addition, the station-services transformers and a part of the 132-kV outdoor substation were replaced.

All the 400-V substations were replaced by modern substations in MNS withdrawable-module design (supplied and installed by ABB Arab). Also replaced were the DC systems (ie, accumulators, rectifiers and DC substations) and the public address system.

Goods and services supplied for the rehabilitation of the Aswan 1 hydroelectric power plant

Cranes

- Complete overhaul of the two 265-t main cranes in the machine house
- Supply of two new 10-t cranes for the machine house
- Complete overhaul of the 150-t dam crane
- Complete overhaul of the cranes used to move the locking elements for the waterways

Hydraulic steel structures (hydromechanical equipment)

- Complete rehabilitation by means of sandblasting and corrosion protection:
  – Downstream stoplogs
  – Upstream stoplogs
  – Upstream operation logs
  – Upstream inlet gates
  – Pressure tunnels up to spiral casings
- Rehabilitation of hydraulic drives of the upstream logs

Kaplan turbines and governors

- Complete rehabilitation by means of sandblasting and corrosion protection:
  – Spiral casing
  – Supporting vanes
  – Suction tube
- Complete mechanical overhaul plus renewal of parts subject to wear:
  – Servomotors of guide vanes and runner blades
  – Bearings
  – Shaft seals
  – Runner blades
  – Guide vanes
- Supply of new oil-hydraulic turbine governors with digital control device

Vertical three-phase AC synchronous generators

- Supply and installation of new generator parts and auxiliary equipment
  – Laminated stator core
  – Roebel bar windings
  – New insulated pole coils
  – Thrust bearing segments
  – Instrumentation
  – Cooling-water system
  – Static excitation equipment

Electrical equipment

- Supply and installation of new auxiliary equipment:
  – 11-kV switchgear
  – 0.4-kV and DC switchgear
  – Batteries, chargers
  – Auxiliary transformers
  – 11-kV and LV cabling, trays, installation
- Supply and installation of new unit-related equipment:
  – 0.4-kV and DC motor control center
  – Generator protection
  – Machine control board, controlled by process computer
  – Generator busduct
  – Cabling
  – Unit transformer, 51/51/30 MVA, 11/132 kV (units 4 and 6 only)
  – Parts of the 132-kV switchyard

Supply and installation of new instrumentation and control equipment, including:

- Process computer equipment for all station service and auxiliary equipment as well as for the 132-kV switchyard
- Equipment for central control room with 2 MMC systems, with connection to all existing process computers via the databus

Other supplies and services

- 80-t mobile crane
- Machines and tools for power plant workshop
- New compressed air supply for power plant
- New cooling-water supply system
- New drainage system
- Oil treatment plant
- Comprehensive training of owner's personnel in Europe and Egypt, in two phases

Performance tests

Before being handed over to the customer, all the rehabilitated machines were put through a seven-day, predefined trial run to prove their operational efficiency. Index measurements were also taken before and after the rehabilitation. These showed a significant improvement in efficiency for all the machines.

In August 1996 ABB Kraftwerke AG concluded what was the biggest rehabilitation project so far in the history of Egypt's hydroelectric industry, on schedule and to the entire satisfaction of the owner. The work lasted 58 months. On conclusion of the project, the Aswan 1 hydroelectric power plant became once again one of the most advanced facilities for power generation in Egypt, and will be supplying electricity to an energy-hungry nation for another thirty years to come.

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