Safety in a New Dimension

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Fig. 1 Three Gorges of Yangtse River

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Fig. 2 Expansion stage of the dam Vast energy reserves

SIPROTEC 4 ensures safe operation of the Three Gorges hydroelectric power plant

■ *The project*

In 1992, the Chinese National People's Congress decided to build the Three Gorges Dam on the Yangtse, Asia's longest river. Work on the project began five years later in the province of Hubei near the cities of Sandouping and Yichang, located close to the Three Gorges, with the construction of the dam and hydroelectric power plant.

In its final stage, the dam will be 185 meters high and 2305 meters wide. The resulting lake will stretch for about 660 kilometers to form the world's largest reservoir. The first, partial filling of the reservoir began in June 2003, and final completion is planned in 2009.

China intends to meet three objectives with this project:

- Generating electric power
- Increasing navigability of the Yangtse (previously limited to only 2,800 kilometers).
- Providing flood control for the entire region

The world's largest hydroelectric power plant

The final expansion of the Three Gorges power plant will be designed to supply about 9% of China's entire electric power. 26 turbines and generators with an output of 18,200 MW will be feeding power into the nation's power system. Each of the turbines has been designed for an output of 700 MW. By the completion of the first section late in 2004, 14 generators were connected to the power system.

Siemens PTD has supplied many of the primary systems components. This included for instance 14 generator transformers with a nominal capacity of 840 MVA and high-voltage of 550 kV. PTD High Voltage Division is also supplying 550-kV HVDC systems for the reliable transmission of the electric power.

■ *The starting situation*

The construction of a hydroelectric power plant is a continuous technical and logistical challenge since a host of variables must be included in the planning. The enormous dimensions of this hydroelectric power plant and the enormous forces to be liberated called for solutions that were tailored to this project, especially with regard to safety. The Francis turbine has a diameter of 9.4 meters, and water flows through it at a rate of 996 cubic meters per second. An entire orchestra could be seated within the generator stator (having an inner diameter of 18.5 meters). See Figs. 3 to 5.

On the other hand, there were also requirements for extremely compact designs, for instance of the generator transformers. For the Three Gorges project, these were produced in Nuremberg and transported to the construction site by ship.

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Fig. 3
Turbine shaft

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Fig. 4 Turbine wheel

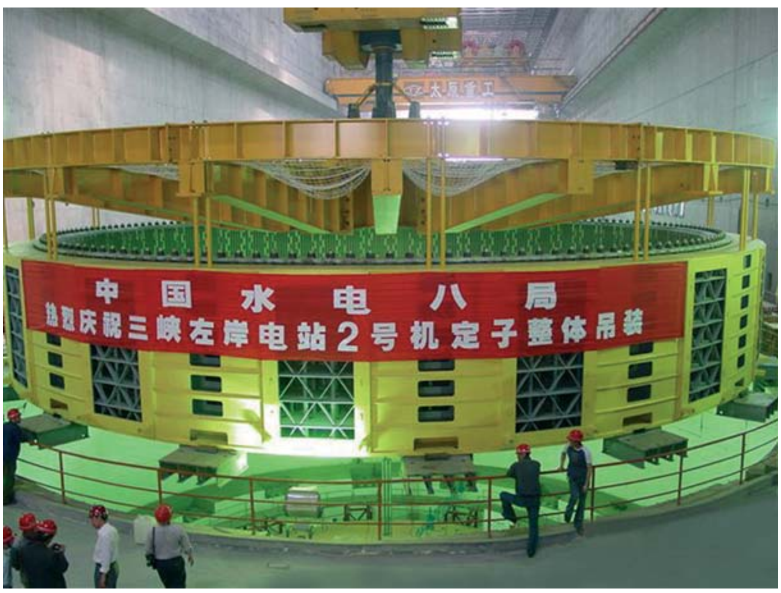

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Fig. 5 The generator stator is lowered into position

■ *The concept*

SIPROTEC 4 provided the latest in protection systems. These systems protect both the generator and the generator transformer including the power system connection. As usual, Power Automation Division supplied the protection cubicles, extensive documentation and the protection settings report. The initial shipment for 6 generators included 12 protection cubicles.

The use of high-performance protection relays from Siemens made it possible to achieve a uniform redundancy concept and to apply the n-1 principle with few relays (2 x 7UM622, 5 x 7UT612 and 2 x 7SJ611). Fig. 6 illustrates the basic design of the protection concept. The two 7UM622s protect the generator and provide backup protection for the generator transformer or the power system (impedance protection or high-voltage side overcurrent protection). The maximum functionality was selected from the available range of functions, and the great majority of functions were activated. As a result, events that are reliably detected by the relays include stator earth (ground) faults (90 % and 100 % with the 20 Hz principle), rotor earth (ground) faults (1-3 Hz measuring principle), short-circuits (differential, impedance and overcurrent protection), excessive loads (overload and negative-sequence protection) and excitation or regulation faults (underexcitation, overexcitation and frequency protection). To prevent damage to the power station unit resulting from effective power swings, out-of-step protection is also provided.

Two 7UT612 relays provide the main protection for the generator transformer and one each 7UT612 provides the main protection for the 15 MVA station service transformer and for the 6.6 MVA excitation current transformer. In the relays for the generator transformer, not only differential protection but also overcurrent protection is provided at the transformer star-point to deal with high-voltage-side earth faults.

The fifth 7UT612 was additionally provided as transverse differential protection at the generator to detect winding faults. This protection principle is a special requirement in hydro power generators. To handle the large rated currents (approx. 24,000 A) the stator winding for each phase is composed of several phase windings. As a result, several rods per phase are located in a single slot. Insulation faults between the rods represent a winding fault, which can cause large circulating currents resulting in enormous damage to the generator. Transverse differential protection provides the required sensitivity, speed and stability to guard against this hazard.

An alternative, simpler solution is to detect the equalizing current between the two star points of the subdivided stator winding. This is provided by the sensitive earth current function in the 7UM62. This function provides redundancy to the transverse differential protection.

Another unique feature of the protection for the power station unit is the processing of external signals, e.g. from the Buchholz relay, oil monitor, SF_6 pressure monitor at the bushings, and other signals related to the machinery. To provide this functionality, these signals were routed directly to the binary inputs of the 7UM relays.

The integrated logic functions (CFC) made it possible to provide the required interlocks and logic connections. An additional benefit of this approach was a reduction in circuitry and elimination of external auxiliary relays.

The different switches must be actuated in accordance with encountered fault conditions. The logical coordination and required tripping programs are provided through the programmable software matrix. As a result, the circuit-breakers can be triggered directly by the binary outputs.

Communications are not included in the illustration. The protection settings and the data readouts in a fault incident are performed by protection experts using DIGSI directly at the relayss. Messages and measured values with relevance to the operating personnel are transmitted via PROFIBUS DP to the power plant control system, where they are displayed.

Sales and marketing

The protection concept is defined, the required protection relays selected and the entire proposal generated to correspond to the customer's bid invitation. The feature that sets hydroelectric power plants and especially the Three Gorges project apart is the long implementation time.

As a result, even product development must be included in the project duration to ensure that the technology remains up-to-date. As a case in point, at the outset of the Three Gorges project, SIPROTEC 4 protection relays had just been introduced, and the advantages of this technology were unfamiliar even in expert circles. It was therefore critically important to meet development schedules and product quality requirements.

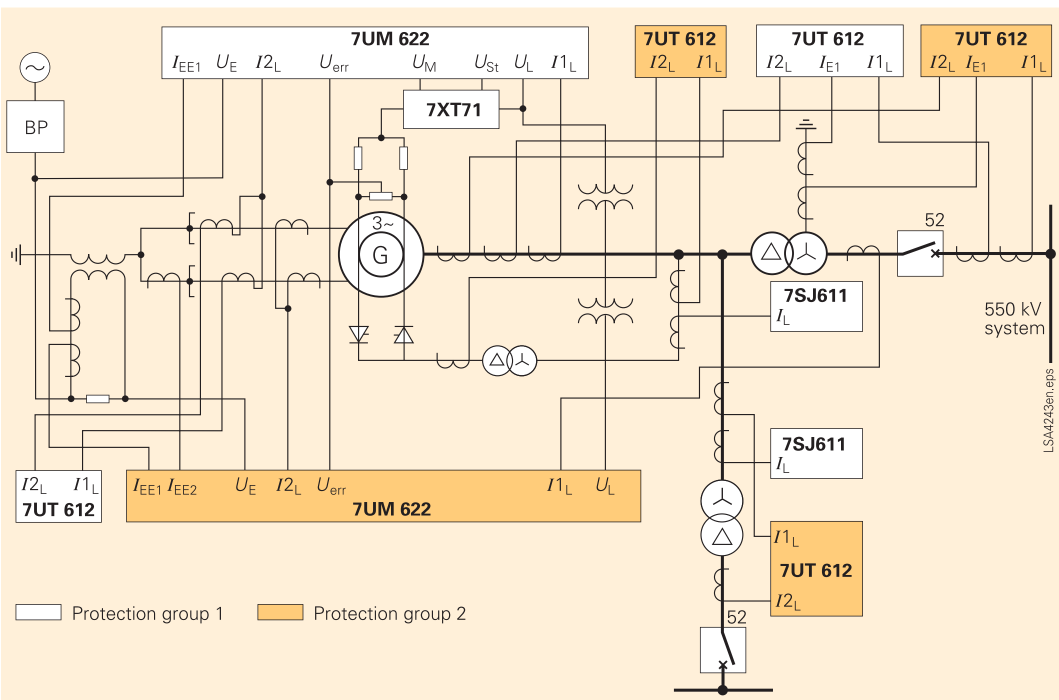


Fig. 6 Protection concept, single-line diagram

The special advantages

Systems business is teamwork

Systems business means delivering systems to the customer on time and at the required quality level. This often means that the effort has to be coordinated among many different companies, subprojects and individuals. Within Siemens, the main effort is divided among the following corporate functions:

Engineering

Detail work begins after the order has been awarded. Obviously this includes detailed specifications for the product design and systems configurations of the components that make up the order. One detail that had to be confirmed for the Three Gorges project was the design of the current transformers. The specific conditions of this project required an optimum balance in meeting economy requirements, space constraints for the current transformer, and dynamic specifications (non-saturated time). The current transformer on the output side for instance has a transformation ratio of 30,000 A to 1 A. To achieve this, 30,000 turns had to be accommodated on several cores without interfering with the transmission characteristics. This challenge was met by designing two linearized TPY cores in addition to a 5P100 10 VA closed core.

Defining the settings was another important part of the engineering project. All setting parameters must be clearly documented in a settings report.

Given the special features of hydroelectric power plants and the dimensional constraints of the primary system (for instance in the case of the generator transformers), the accurate detection of all operational conditions as well as potential hazards called for abundant experience. In addition, the required CFC logic modules needed to be developed and of course tested.

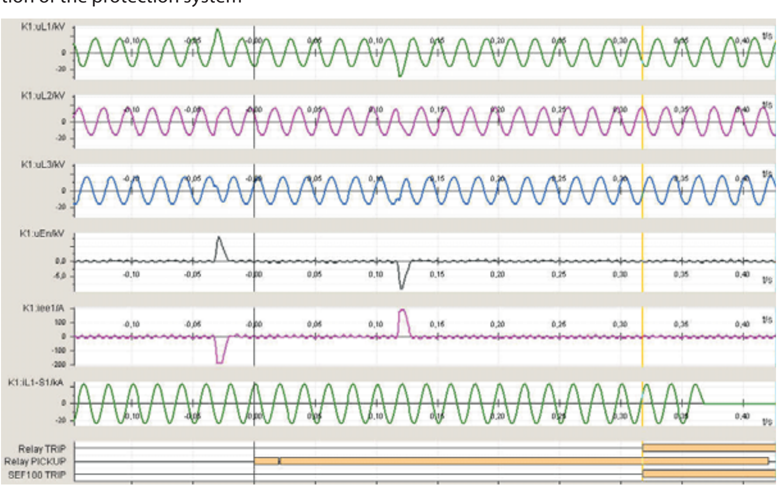
These efforts result in a parameter set generated in DIGSI. The required connection changes (BI, BO, LED, CFC and serial interfaces) must also be implemented in accordance with the circuit manual.

Project implementation

In this sphere, the focus is on coordinating all the tasks and resolving any open questions. Specifically, this includes ordering the equipment and coordinating the delivery schedule with the plant, coordinating the assembly of the cubicles, resolving interfaces, all the controlling, and of course customer support (e.g. during the cubicle acceptance testing). Project-specific training must also be provided for the intended operators to ensure a trouble-free commissioning process.

Since the power station control and protection systems as well as the communications solutions were supplied by different manufacturers, representative devices were used in the integration tests. What's more, a comprehensive test of the entire protection system was performed at the Siemens location in Fürth (see Fig. 8). As a result, the integration of the individual components with the overall system at the construction site proceeded smoothly.

Fig. 7
SIGRA printout of the actuation of the protection system



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From practical experience

To the amazement of all participants, during trial operation the first actuation of a protection relay was caused by the 100% stator earth-fault protection. What had happened? During operation of the generator another protection relay was active, which was designed to monitor the insulation resistance of the stator under operating conditions. This relay caused an earth fault, which was reliably detected and deactivated by the 100% protection function in accordance with the 20 Hz measuring principle.

The tripping on fault provided an opportunity to demonstrate to the customer the effectiveness of the protection scheme provided by Siemens, as well as the benefits of numerical technology. The information stored in the protection made it easy to analyze the fault. Every response of the protection function is logged with milliseconds-accuracy in the fault event buffer, and the momentary values of the analog input values and associated binary tracings are oscillographically recorded in the fault record. The powerful SIGRA tool is used to evaluate the fault record. Fig. 7 illustrates the processed fault record. Clearly visible are the two spikes in the displacement voltage and in the earth current, as well as a phase-angle shift in the conductor-earth voltages. The binary tracings reveal the response of the protection function, showing both the relay pickup and tripping.

Fig. 8 Testing the generator protection cubicles

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Conclusion

Despite the vast scope of this project and the challenges of integrating components by many diverse manufacturers, there was no delay in the construction or commissioning phase. One reason was certainly the unique flexibility of Siemens technology for electric power unit protection; another the excellent teamwork of all participants, such as sales and marketing, engineering, project implementation, production and development, as well as close collaboration with the construction project.