

Control of the line by a pump-storage power generator in the water power station Forbach

At the power station Forbach (Black Forest) of Badenwerke A.G., Karsruhe for the first time in Germany a machine set of a pump-storage utility has participated in the primary and secondary control of the line. For this purpose AEG has developed a frequency inverter in order to make the storage pump controllable

The storage pump driven by a frequency inverter has a pumping level height of 229 m, an output of 20 MW, a pumping volume of 8,8 m³/sec. at a speed between 440 and 500 rpm. The pump has been manufactured and installed in 1991.



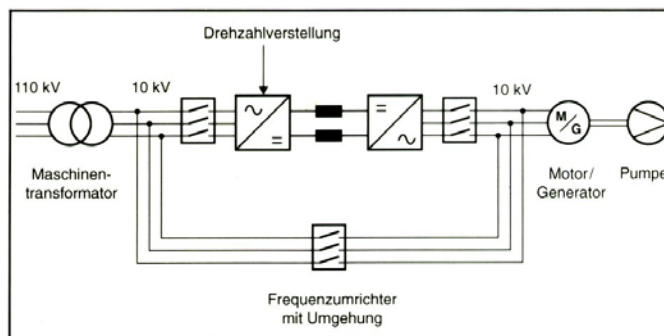
Our picture shows part of the line inverter, particularly the three racks of the power electronic frame work. On the lefthand front side the electronic controls of the thyristors can be seen. On the right side the extrarapid fuse of the DC intermediate circuit can be seen. Befour that two ignition sets for the extrarapid fuses

The European Grid of the Union for coordination of production and transport of electrical energy UCPTE (Union pour la coordinaci3n de la production et du Transport de l'Electricit3, Paris) secures the equilibrium between production and consumption of energy in cooperation between the power stations of all members by primary control¹. Time wise subsequently for the observance of the agreed power interchange and the suppression of frequency deviations serve a secondary control which is also called power-frequency-control or line control.

The company Badenwerke AG Karlsr3he has as early as in the fiftieth put into operation the first-power-frequency-control also called line control. As controlling power station even at that time the pump-storage power station Forbach with two sets of the department Schwarzenbach works with a total power of 43 MW were used. After a while further machines in the Schluchsee works H3usern, Witznau and Waldshut with another 225 MW were included in the control scheme and during the seventieth the pump-storage stations S3ckingen and Wehr in the southern Black Forest region were also included. As of today Badenwerk has 865 MW as control power from hydraulic energy inverters on hand. Up to now mainly water power stations as alternator duty have been used due to the quick availability line control power. During the pumping duty until now a participation in the primary and secondary control service was not possible. By the speed regulation through a frequency inverter the storage pump during primary control can contribute to correct frequency deviations of the line, by reducing the pump power and consequently to discharge the line.

During the secondary control service the pump speed depending on the load factor of the line control is reduced. An additional advantage is produced by the fact, that the frequency inverter may serve as a starting device for the machines and for speed programming in case of changes in the required power service program. Until now the power control range of this pilot plant with only 12 to 20 MW is small, compared to the to the total control volume of the Badenwerke plants. However this plant will contribute to the experience gained in this technology which may be applied to larger pump-storage power stations. For this purpose the existing power station equipments regarding their additional electrical and mechanical capabilities will be checked for frequency inverter duty. In particular speed oscillations of the entire shaft arrangement, temperature rise, noise and the like will be analysed and the results taken into account when dimensioning the inverter.

¹Hoffmann, E.; Sch3ufle, R.: Der Einsatz einer regelbaren Speicherpumpe in der Netzregelung. Elektrizit3tswirtschaft 92 (1993) 25



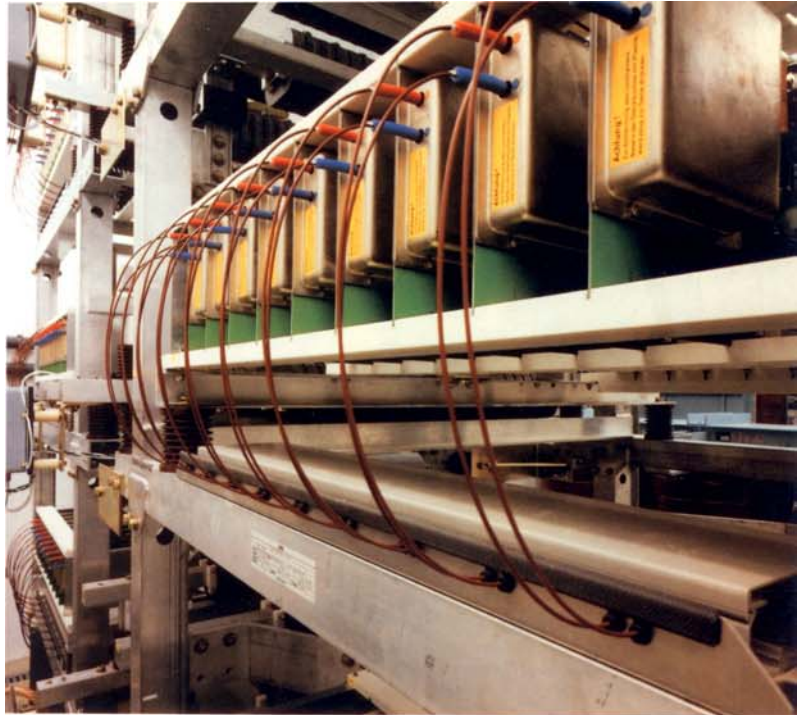
Principle diagram of an inverter fed synchronous machine

The electronic controls of the thyristors are situated on H.V. potential and are connected with the information electronics by way of fibre optic data transmitting the ignition orders. A second optic fibre control the reaction of the thyristors to the ignition order.

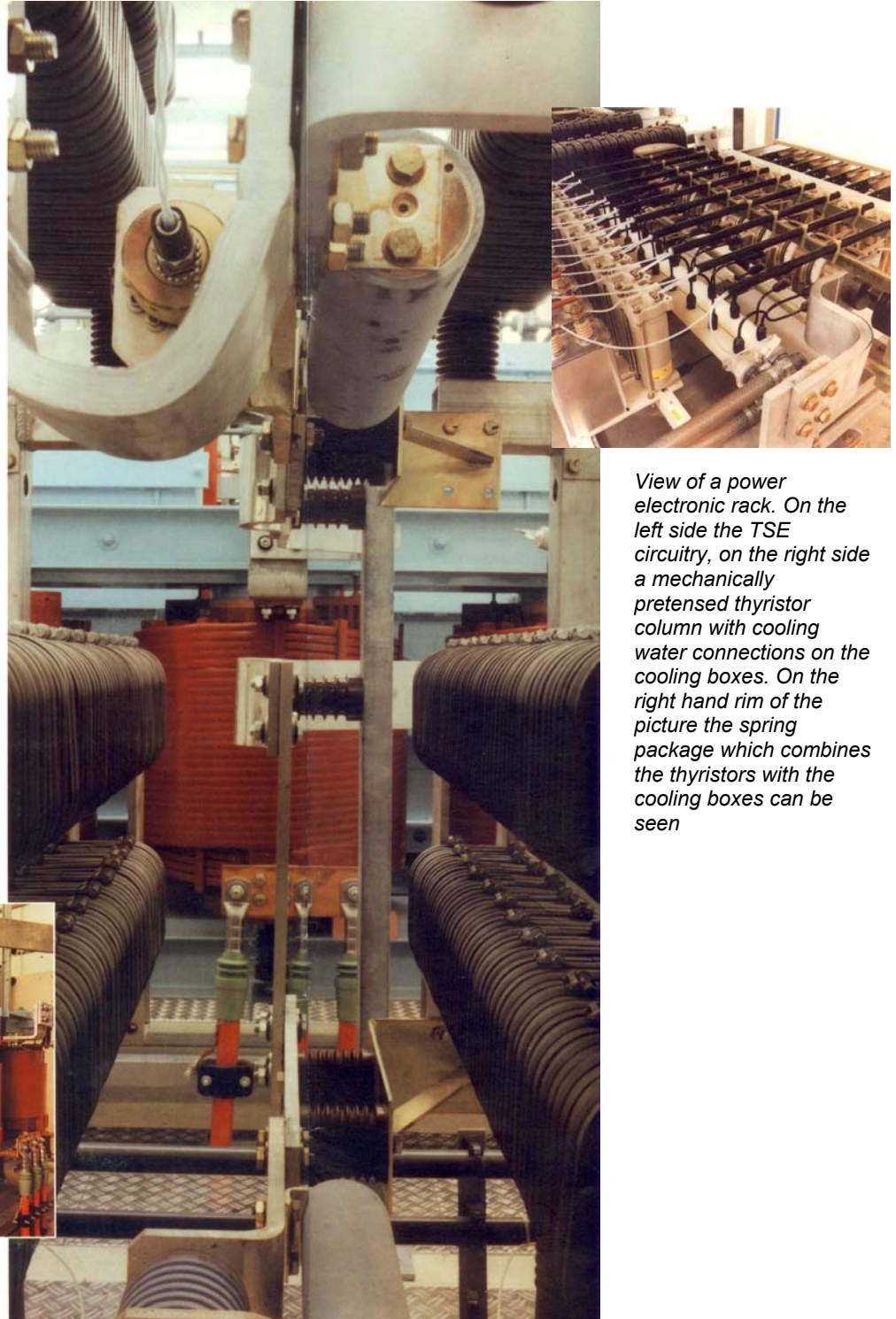
Furthermore it is to be taken into account that the inverter loads the line and the transformer with non-sinusoidal currents, inductive reactive power and commutating over voltages.

Frequency inverters for pumped storage plants have been used before mainly in plants where only a pump turbine, that is a machine for two directions of rotation was installed in order to start it up for pumping. These frequency inverters are serving only for starting up the machine with empty pump to nominal speed and will be switched off after reaching the synchronization of the speed of the alternator with the line. The output of these frequency inverters are therefore much inferior compared to the rated output of the machine. At the pump-storage station Forbach however the frequency inverter is operating continuously. This frequency inverter performs mainly eight different programs

- fromstandstill either into controlled or uncontrolled pump duty or turbine duty
- from controlled pump duty into uncontrolled pump duty (synchronous motor/- alternator direct on line and
- from uncontrolled pump duty back to controlled pump duty on the frequency inverter
- from controlled pump duty into turbine duty and
- from turbine duty into controlled pump duty and
- from this duty back to standstill
- from turbine duty the machine can be brought to standstill by braking duty with the frequency inverter in case the machine is to be put out of service.



Water cooled smoothing reactors in the intermediate DC circuit. The electrical connections are the massive copper bars. The reactors are cooled by water hoses.



The commutation reactor of the line converter is air-cooled, the damping reactors visibly behind of the DC inverter intermediate circuit are water-cooled

View of a power electronic rack. On the left side the TSE circuitry, on the right side a mechanically pretensed thyristor column with cooling water connections on the cooling boxes. On the right hand rim of the picture the spring package which combines the thyristors with the cooling boxes can be seen

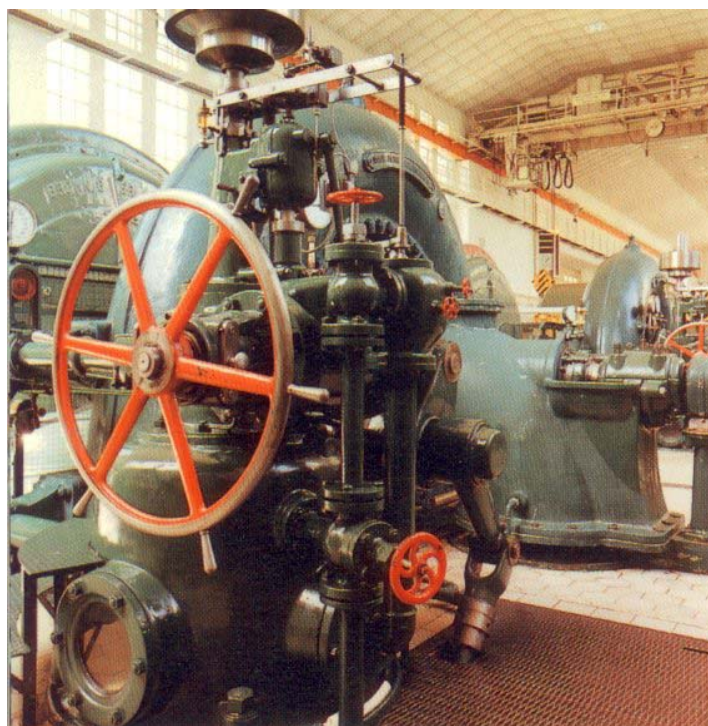
By this view into the line power converter and on both side you can see on both sides the ferrite cores which limit the rate of current rise

Line Control

Special conditions will prevail during changes from turbine duty to pump duty and the reverse operation. In order to go easy on the pump in this case the machine will be reduced in this speed by the frequency inverter; the line converter will be taken into power inverter duty, the machine converter will operate in DC duty. This means, that energy is fed back into the line. The machine will be submitted to braking electrically until the pump reaches full/ empty speed. After filling/ emptying the rated speed will be recovered by acceleration. In this way the machine is submitted to a very soft duty. When passing from the controlled to the uncontrolled duty, that is when connecting the machine to the line, the necessary synchronization is achieved in idle as well as full load duty (motor duty) by the frequency inverter. Controlled by means of a synchronizing equipment, frequency, phase angle and voltage of the synchronous machine are controlled by the frequency inverter and the exciter equipment respectively in accordance with the values of the line and the machine will be coupled directly to the line by a switch. The frequency inverter will be simply bridged and can be put out of service thereafter.

In this way an uninterrupted transition from controlled to uncontrolled duty is possible. Without interruption the process can be reversed and the frequency inverter can take the machine from line duty into inverter duty. For this purpose with connected coupling switch the frequency inverter will be activated and controlled in such a way, that it will take over the active power flow from the coupling switch, so that it can be disconnected without carrying any current.

The operation as controlled pump duty is the main task of the frequency inverter. The speed will be adjusted between 400 and 500 rpm, that is equivalent to a pump output of 12 to 20 MW. The output can be adjusted manually or by way of a fast acting frequency meter within a microprocessor circuit or through the degree of load by the line control.



View of the Murgwerk, the older portion of the Schwarzenbachwerk built between 1914 and 1918. The Francis turbine and the alternators, five pieces with 5 MVA each, are working til today

Design and operation of the inverter

The inverter consists of a line controlled converter connected in series with a machine controlled inverter in a bridge connection of six pluses which depends on the synchronous machine. The line controlled converter operates during motor pump duty as a rectifier. The machine controlled inverter operates then as inverter, taking the reactive commutation power from the overexcited synchronous machine. The rated voltage of the inverter is 10 kV, the frequency range 0-50 cycles, the active power at 50 cycles amounts to 21,3 MW and the voltage of the intermediate circuit is 13 kV. The arrangement of this electronic power inverter in the form of a rack system. A frame combines the constructive racks into a complete inverter ready for operation.

The individual bridges consist of a pile of nine highly isolating thyristors for 1300 A at 85 °C enclosure temperature and 5200 V blocking voltage in both directions. They form thyristor columns where between the disc type thyristors water cooled refrigeration boxes are arranged and are combined to a mechanically pretensed unit. In case of a fault each thyristor can be changed without opening the water circuit, therefore the outage times of the equipment are reduced to a minimum.

Cooling medium is chemically pure water in a closed circuit. This water will be re-cooled in a cooler by raw water. Each thyristor is equipped with an RC circuit and serves as a voltage divider and overvoltage damping device. Separate protective circuits on all thyristors are protecting them by automatic ignition against damages, if supplied in case of a fault with high overvoltages

Summary

The new frequency inverter at the Forbach Power Station of the Badenwerke AG makes it possible not only to start and brake the machine quickly, but it can participate during the pumping duty in the primary and secondary control of the line by variation of the speed. The span of control lies between 20 MW and 12 MW. A future application of this technology in larger pump storage plants is possible when the machine sets are dimensioned according to the experiences gained. AEG has participated in the planning and supply of the electrical equipment. The complete frequency inverter equipment is part thereof with its power electronics, inverter control, speed- and power control and the 10 kV switchgear as well as an exciter equipment dimensioned to this special requirement of the existing synchronous motor/ alternator.



View of a power electronic rack

Netzregelung durch Pumpspeichermaschine

Frequenzumrichter speist Synchronmaschine

Im Kraftwerk Forbach (Schwarzwald) der Badener AG, Karlsruhe, wurde erstmals in der Bundesrepublik Deutschland ein Mischanlass eines Pumpspeicherverses im Pumpbetrieb an der Primär- und Sekundärregelung des Netzes beteiligt. Hierfür entwickelte und installierte die AEG einen Frequenzumrichter, mit dem die Speicherpumpe regelbar wird.

Die mit Hilfe des Frequenzumrichters angetriebene Speicherpumpe hat eine Förderhöhe von 220 m, eine Leistung von 20 MW, eine Fördermenge von 8,8 m³/s bei einer Drehzahl von 440 bis 500 min⁻¹. Die Pumpe wurde im Jahr 1991 hergestellt und installiert.



**AEG Berlin
factory for current rectifier products**

AEG have been developing, projecting, manufacturing and selling power electronics plants and components for more than 60 years. The new production facility in Berlin with more than 46000 square metres of production and office premises, around 1000 employees and modern production equipment has been in service since 1984 to provide the facilities required to consolidate and expand upon the technological lead held by the company. During the last 8 years AEG's propriety factory together with its highly experienced engineers and personell was rented and operated by several different companies. Today it is Convertteam GmbH a daughter of Barclays Bank

Characteristics of the systems, plant and components include innovative technology, high safety and reliability levels and quality assurance with extremely accurate quality control and operational testing facilities. The extensive service provided meets the high quality standards of the products.

The reference list of different power electronics applications are long and not limited.

Products and Services

The division program includes:

- Converter for drive technology
- Motion control systems
- Converter for power plant technology
- Rectifier for high voltage and high current applications.
- Construction of controls and workshop Services
- Wind generation applications
- Converters: 50/60/16 2/3 Hz

These products are being marketed by the specialized departments for plant construction as part of the total plants

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