300 MW
umrichtergespeister drehzahlvariabler Antrieb
für das Pumpspeicherkraftwerk Goldisthal

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Content

- Topology of pump storage station and converter
- Control and operation modes (measurement results)
- New topology to meet the requirements at grid failure
Major benefits of the cyclo-converter driven doubly-fed induction machines
(one of the biggest cyclo-converters in the world)

- Speed optimisation at partial loads
- High efficiency
- Only 30% of total power fed by the converter
- Reduced converter losses
- High dynamic power control
- Grid stabilisation

Single-line diagram of Goldisthal pump-storage station
Machine cavern Goldisthal

Assembly of the rotor of the induction machine, stator completed.
100 MVA cyclo-converter for the doubly-fed induction machine

- 2 anti-parallel 12 pulse thyristor bridges per rotor phase
- Circulating currents
- 3 parallel bridges (1 for redundancy)
- Crow bars for protection
The DC chokes carrying the circulating current improve the protection of the converter.

Rated current: 6365 A
Power flow at constant torque

\[ P_{\text{grid}} = P_{\text{CYC}} \]

\[ P_D = P_s \]

\[ P_{\text{mech}} = \frac{2\pi}{60} n T \]

\[ P_f = P_s \left( \frac{n}{n_s} - 1 \right) \]

\[ T = T_{\text{Nom}} \]

Turbine operation

Subsynchronous

Assumption

\[ T = T_{\text{Nom}} \]

\[ P_f = P_s \left( \frac{n}{n_s} - 1 \right) \]

Subsynchronous

Assumption

\[ T = T_{\text{Nom}} \]

\[ P_f = P_s \left( \frac{n}{n_s} - 1 \right) \]

Oversynchronous
Control structure of the doubly-fed induction machine with cyclo-converter
Torque steps - simulation and measurement

Simulation of a torque step from zero to rated torque

Measurement of a torque step on site
(about 40% of rated torque)

Reachable step response time:
10 ms

2000 kNm/Div
Power control of induction machine at water pressure variation
(300 MW of synchronous machine taken out of operation)

- Delivered power kept constant by changing the speed of the turbine
New topology to drive through grid failure

Requirements:
- No major interruption of the power delivery (grid code requirement)
- Protection assured

\[ \text{Normal operation mode } R = 0 \, \Omega \]
- same as actual topology

\[ \text{During grid failure } R = \text{high value} \]
- limits the mechanical stress of the machine

\[ \text{After grid failure } R = \text{small value} \]
- maintains the drive in its speed range of operation
New topology - Single phase short circuit

<table>
<thead>
<tr>
<th>Cycloconverter</th>
<th>In operation</th>
<th>Pulses off</th>
<th>In operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>0 Ω</td>
<td>1 Ω</td>
<td>0 Ω</td>
</tr>
<tr>
<td>Crow bar</td>
<td>off</td>
<td>triggered</td>
<td>switched off</td>
</tr>
<tr>
<td>Event</td>
<td>Steady state, generator mode</td>
<td>Faulty phase disconnected</td>
<td>Faulty phase reconnected</td>
</tr>
</tbody>
</table>

Simulation of a single phase short circuit (150 ms, following interruption of the faulty phase)
Conclusion

300 MVA doubly-fed cyclo-converter driven induction machine works advantageously in the Pump Storage Plant Goldisthal:

- High efficiency
- Power on demand
- Stabilisation of the grid

Drive can ride through grid failures with new concept (additional variable resistor):

- No major interruption of the power delivery (circuit breakers remain closed)
- Increased availability (restart not necessary)
### Conclusion

Advantages of the cyclo-converter driven induction machine drive compared to a synchronous machine drive

<table>
<thead>
<tr>
<th></th>
<th>Cyclo-converter driven induction machine</th>
<th>Synchronous machine with standard excitement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step response time (P, Q)</td>
<td>150 ms *)</td>
<td>several seconds</td>
</tr>
<tr>
<td>(zero to rated)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Synchronisation time</td>
<td>10 s</td>
<td>20 s or more depending on mechanical load conditions</td>
</tr>
<tr>
<td>Synchronisation transient</td>
<td>damped after 500 ms</td>
<td>damped after several seconds</td>
</tr>
<tr>
<td>reactions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average efficiency of the</td>
<td>80 %</td>
<td>70 %</td>
</tr>
<tr>
<td>whole storage unit (turbine +</td>
<td></td>
<td></td>
</tr>
<tr>
<td>drive)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*) response time of the cyclo-converter control 10 ms
Machine cavern Goldisthal - different phases of the construction
Conclusion

- 300 MVA doubly-fed cyclo-converter driven induction machine successfully commissioned.

- High efficiency due to speed optimisation at partial loads and doubly-fed design (only 30% of total power fed by converter).

- Stabilisation of the grid due to high-dynamic flux oriented control (torque step response time <10 ms).

- Application of drive system beneficial also for pump-storage stations with less power (e.g. 50 to 100 MVA).
Requirements at grid failures and constraints of the topology

**General requirements:**

- No major interruption of the power delivery (grid code requirement)
  - closed stator circuit breaker
  - drive maintained in the operation speed range
- Protection assured
  - limited mechanical stress of the machine

**Constraints of the actual topology:**

- Converter currents not surely switched off (not self commutated)
  - circuit breakers are switched off
  - restart after grid failure necessary
  - reduction of the availability

Grid voltage limits at the grid connection point
(short circuit near to the generator)
(Vattenfall Europe Transmission grid code)
New topology to drive through grid failure

18 kV, 50 Hz

Normal operation mode $R = 0 \, \Omega$
- same as actual topology

During grid failure $R = \text{high value}$
- limits the mechanical stress of the machine

After grid failure $R = \text{small value}$
- maintains the drive in its speed range of operation

Doubly-fed induction motor (generator)

66 Mvar harmonics
- wideband power filter

380 kV, 50 Hz

YNd5

crow bar

New variable resistance $R$
Actual topology - Voltage dip (50%) without switching off the circuit breakers

Result:
- No major interruption of the power delivery
- but
  - too high machine currents
  - too high mechanical stress of the machine
  - drive leaves operating speed range

Simulation of a voltage dip (110 ms, 50% of nominal voltage)
Simulation of a speed variation at constant torque in pump operation

- At steady state operation the rotor flux amplitude and the magnetising current of the stator are constant.

- With constant torque, the rotor current amplitude is constant and independent of the slip of the machine.

- The rotor voltage amplitude varies linearly with the angular velocity of the rotor flux vector related to the rotor angle.
Connection to the grid at 95 % of the rated speed

Reduced start-up time:
- Synchronisation below the synchronous speed
- Fast synchronisation

Measurements at closure of the line breaker:
- Stator phase current [A]
- Rotor phase current [A]
- Reactive power [MVar]
- Active power [MW]
- Torque [kNm]