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VARIABLE SPEED OPERATION OF LARGE HYDRO POWER PLANTS

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Motivation for variable speed operation of large hydro power plants

The presence of a high amount of renewable energies in the grid has changed the requirements for power plants drastically. These fluctuating energy sources lead to a faster and more unpredictable change in energy production. The residual load must be produced by conventional power plants, like pumped storage power plants.

Especially for pumped storage power plants (PSPPs) the use of a variable rotating speed represents a reasonable approach. The main advantages are as follows:

- Variable speed operation and therefore active power control in pumping mode
- Turbine efficiency optimization and extended operating range
- Improved operation of pump-turbines (optimal rotational speed differs for these two modes)

Today, a few large PSPPs with converter-fed generators have been installed, demonstrating the additional value of the added flexibility.

Variable speed operation of pumped storage power plants

Conventional pumped storage power plants

One of the two main arrangements of PSPPs consists of three machines (ternary machine set): turbine, motor-generator and pump (Fig. 1, left). These three machines are linked by a common shaft. The rotating direction for this configuration is the same for both turbine and pumping mode. In turbine mode, the generated active power can be regulated by controlling the water flow rate across the turbine. For pumping mode, the pumped power is constant, because of the fixed operating frequency of the line-connected motor-generator. The only option to control the power absorbed is a hydraulic short circuit.

The second arrangement consists of a pump-turbine and a motor-generator (Fig. 1, right). In this case, the turbine mode and the pumping mode have different directions of rotation. Therefore, additional equipment is needed to synchronize the motor-generator in pumping mode. The power absorbed in pumping mode cannot be controlled.

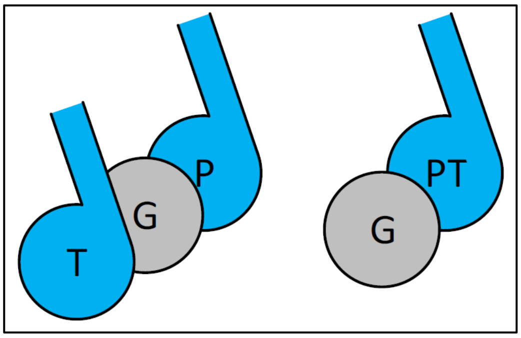

Figure 1: Ternary machine set (left) and pump-turbine arrangement (right)

Start-up converter

First, frequency converters used in PSPPs were used as start-up converters especially for operation in pumping mode, whereby the generator is accelerated to nominal speed with the frequency converter and then synchronized to the grid. Then, the converter is bypassed so as to continue operation without the additional loss of the frequency converter. When compared with today's technologies, these converters had indeed much lower efficiencies and higher harmonics, what imposed additional stress on the motor-generator. However, such was acceptable for the short durations of the start-ups.

Converter for pumping mode only

Then, frequency converters started to be used for start-up and pumping mode only. Today, several of such systems are in operation. In this case, the power in pumping mode can be widely regulated by simply adjusting the feeding frequency of the motor-generator. Also, the pump-turbine can be operated in both rotational directions. For turbine mode, the converter is bypassed and the motor-generator is operating directly from the line.

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Doubly-fed induction machine

The doubly-fed induction machine (DFIM) can be considered as the current state-of-the-art of variable speed PSPPs. It has a relatively high efficiency and the lower additional cost than a full-size frequency converter (FSC), since the frequency converter only needs to be rated to provide power a fraction of the rated power, depending on the desired speed-range. However, such systems do not allow starting the pump directly in water (requiring additional time to de-water the pump). Furthermore, achieving compliance with the latest grid requirements for low voltage ride through (LVRT) is often challenging and hence costly.

Motivation for full-size converter integration in large hydro power plants

The main drawbacks of the use of an FSC are the additional cost, losses, and complexity, as well as increased space requirements. These need to be compensated by the added flexibility of operation. Especially when compared with the DFIM, the FSC operated synchronous generator offers the following advantages:

- Reactive power capability of the FSC even at standstill
- Fault tolerance (submodule bypass or additional submodules for redundancy)
- Compliance with the latest grid requirements (LVRT)
- Large speed range
- Pump start-up directly in water (fast response)

Other problems of FSC operation are additional voltage stress of the winding insulation as well as additional loss in the machine due to the harmonic content of the phase voltages. However, when compared with earlier techniques, these can be kept relatively small with today's modular multi-level converter (MMC) technology (e.g., Fig. 2).

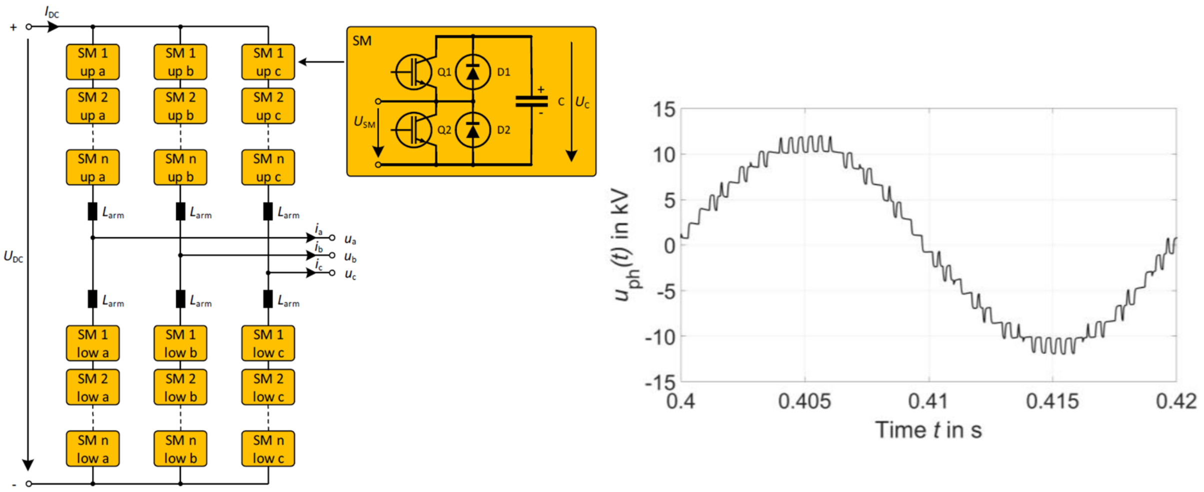

Figure 2: Block diagram of an MMC (left) and simulated waveform of a 15-level PWM phase voltage (right)

The simulated waveform of the MMC's phase voltage is very smooth and sinusoidal due to the high number of voltage steps (15-level MMC). Therefore, the additional loss in the synchronous generator is quite low and there is low additional voltage stress for the winding insulation as well.

Today's requirements in energy generation can only be fulfilled with more dynamic solutions than the line-operated synchronous motor-generator offers. The FSC operated synchronous generator in large hydro power plants is a promising technology for supporting further implementation of renewable energies.