

Pelton turbine design of Gilgel Gibe II

The Gilgel Gibe II project contains four Pelton turbines, each delivering 107 MW to the Ethiopian grid. Their impressive physical dimensions place these turbines among the world's largest. The design of the turbines is a product of the longstanding correlation of computerized tools by the hydraulic and mechanical experts of Voith Siemens Hydro, making the equipment in Gilgel Gibe II one of the most advanced power units in the world.

A look at history and technology

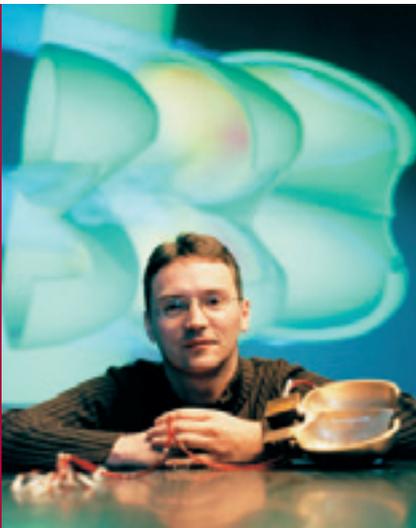
Pelton turbines belong to the family of free jet turbines. Originally invented in 1880 by the gold miner Lester Pelton, design was refined and optimized over the time.

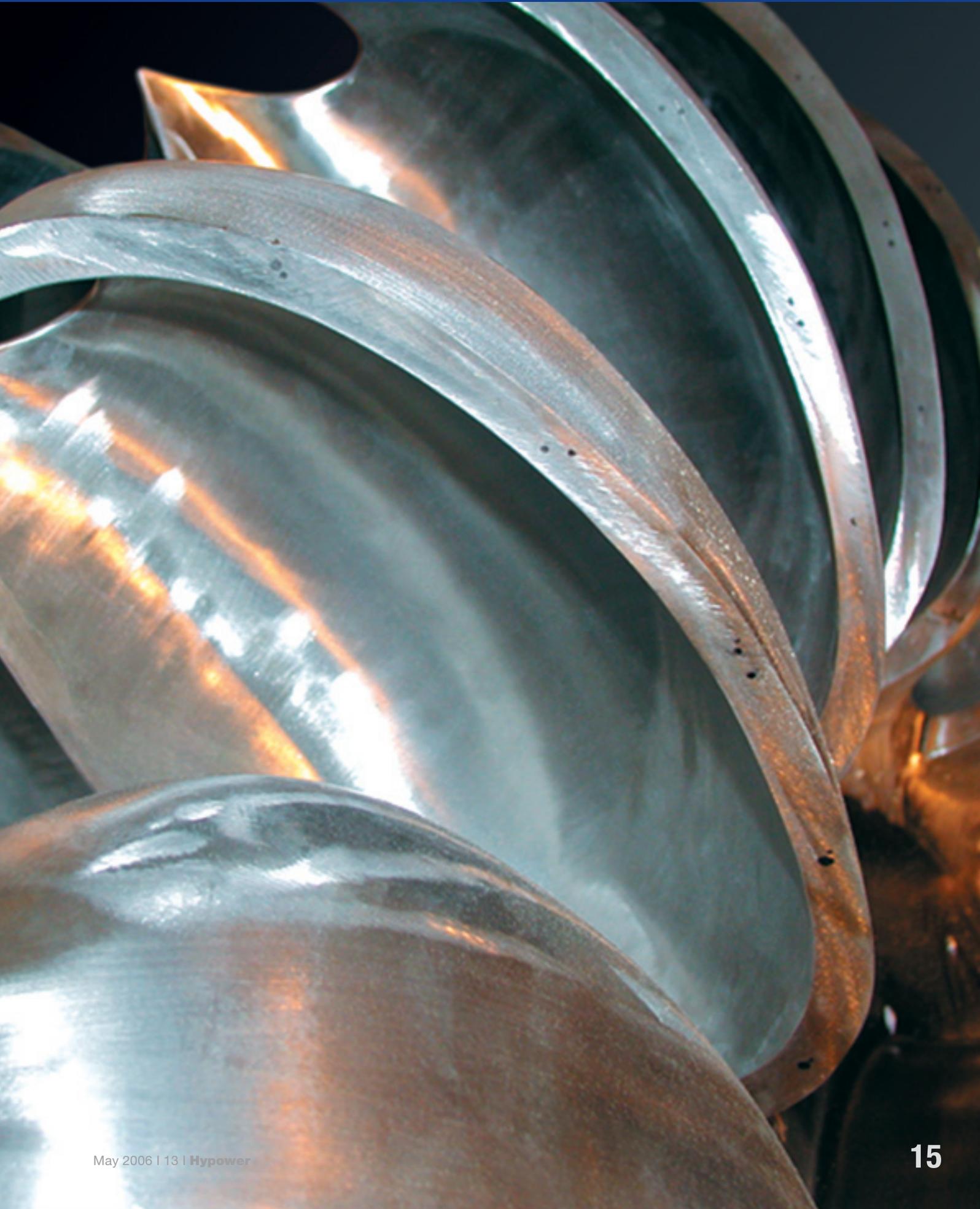
The basic principle, however, is still the same. A nozzle is placed at the end of the pressure line, converting the potential energy of the water into kinetic energy by forming a water jet. The jet is directed to the runner buckets, the hydraulically active parts of the turbine. At the entrance into the symmetrically shaped buckets the water jet is split into two parts, each developing a sheet of water on the bucket's curved surface. At the end of the working cycle, the water leaves the bucket in the opposite direction of the free jet. The rotational energy is then transferred through the shaft to the generator.

At a runner circumferential velocity of around half the jet velocity, the maximum efficiency in the energy conversion is reached because the energy of the discharging water is at its minimum.

A common classification of modern Pelton turbine designs is related to the orientation of the shaft. Pelton turbines with a horizontal shaft are designed with up to three nozzles; turbines with a vertical oriented shaft have three to six nozzles. The typical application of Pelton turbines is in low specific speed conditions, which means the available water flow rate is small compared to the available head. Among the different types of hydraulic machinery, the Pelton turbine shows an impressive part load performance.

The author, Reiner Mack, is Voith Siemens Hydro's Product Responsible for Pelton turbines. Reiner.Mack@vs-hydro.com





The graph bottom left shows a comparison of the efficiencies of a six jet Pelton turbine with a typical Francis turbine. At up to 60 % load the multi-jet Pelton turbine has a clear advantage, which explains why Pelton turbines are very often used for rapid grid regulation.

Pelton turbines have been designed and built at Voith Siemens Hydro for more than 100 years. A large number of turbines have been delivered to our customers ranging from small hydro size up to a unit capacity of almost 300 MW – as reached by the most powerful Pelton turbines in the world. Longstanding experience and continuous development make Voith Siemens Hydro one of the leading suppliers of Pelton technology.

Pelton solution for Gilgel Gibe II

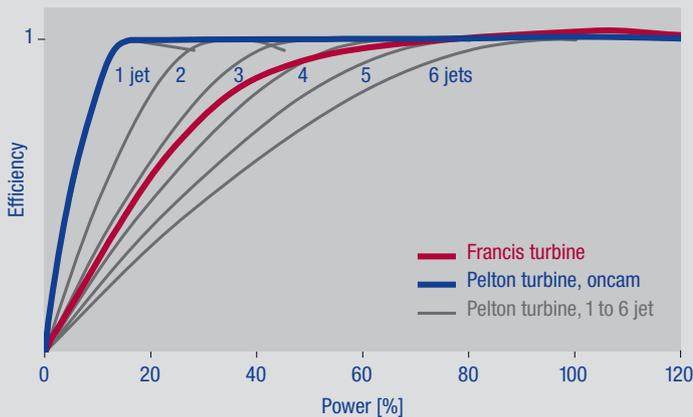
Among past projects, the turbines for Gilgel Gibe II stand out, because the design and layout was strongly supported by computer aided design tools. Some aspects of the hydraulic and structural design of these turbines are presented here.

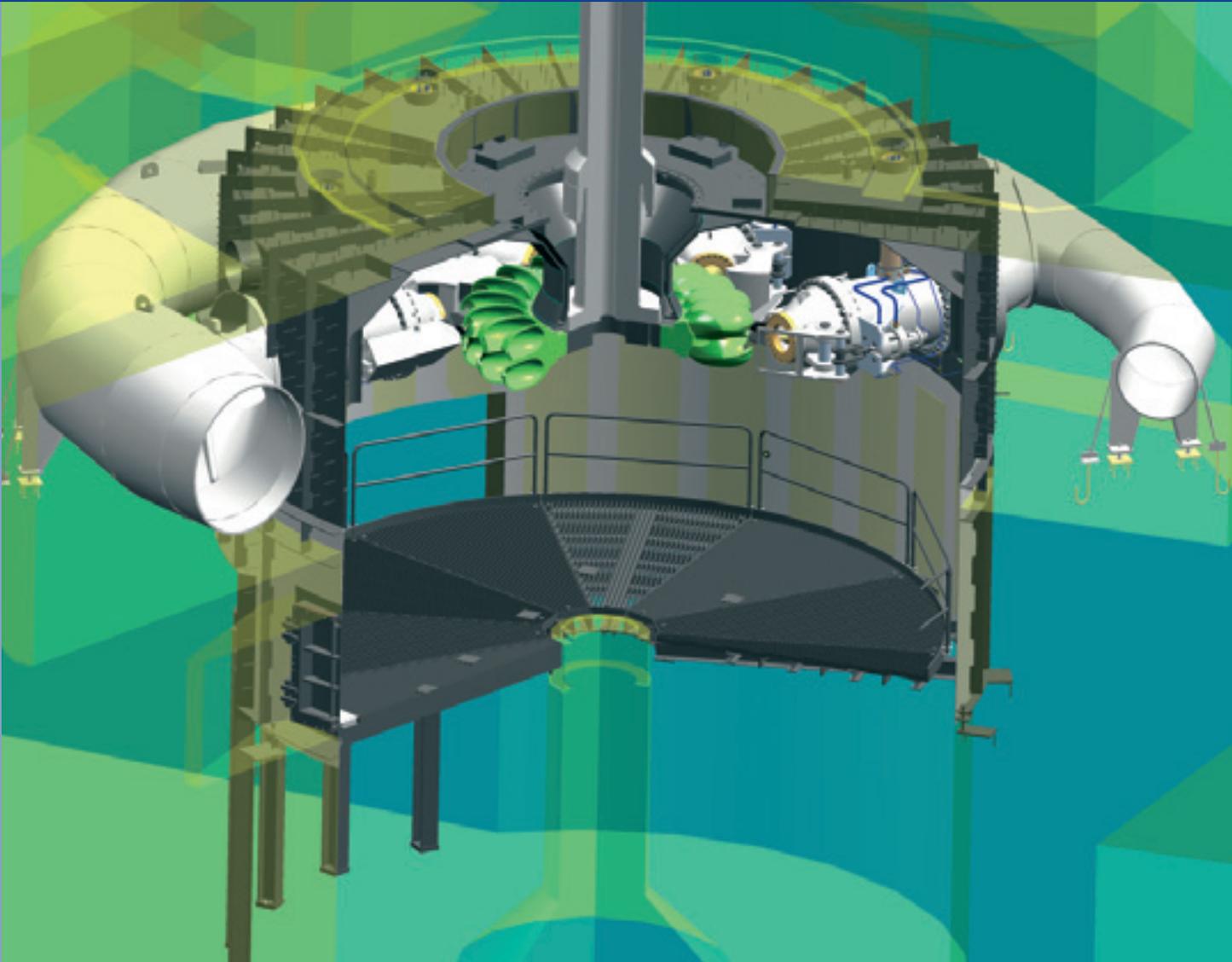
The illustration on the right shows a cutout view onto a 3D CAD model of the turbine. Six nozzles are fed by a distributor line that has a total width of around 14 m.

The Gilgel Gibe II project's four vertical Pelton turbines each deliver 107 MW power at a maximum net head of around 500 m. The photograph below illustrates the large dimension of the distributor line during manufacture. The inlet is nearly two meters in diameter, making it possible to walk through most of the distributor line.

Efficiency comparison of a six jet Pelton turbine with a typical Francis turbine.

Distributor line of Gilgel Gibe II during manufacturing.





Cutout view of the 3D CAD model of the Gilge Gilbe Pelton turbine.

Distributor details

Each distributor line is manufactured in three pieces, which are then welded together at the construction site. A particular hydraulic challenge for these turbines was the high specific speed at which the turbines will run with respect to the typical range of Pelton turbines. Because of this, a detailed optimization of all components had to be performed during the development of the turbine.

The optimization of the distributor line was focused on reducing flow separation zones, which are the main cause for energy loss and for insufficient jet quality at the outlet of the nozzles. The computational fluid dynamics tools (CFD), established at Voith Siemens Hydro for many years, were used for the optimization.

The detailed view into all aspects of the flow field allowed the identification of critical areas and a rapid change in the geometry of the machine. Several development loops were done within a short period of time, leading to a significant improvement. The final geometry shows a very even velocity distribution, illustrated by the streak lines as shown below.

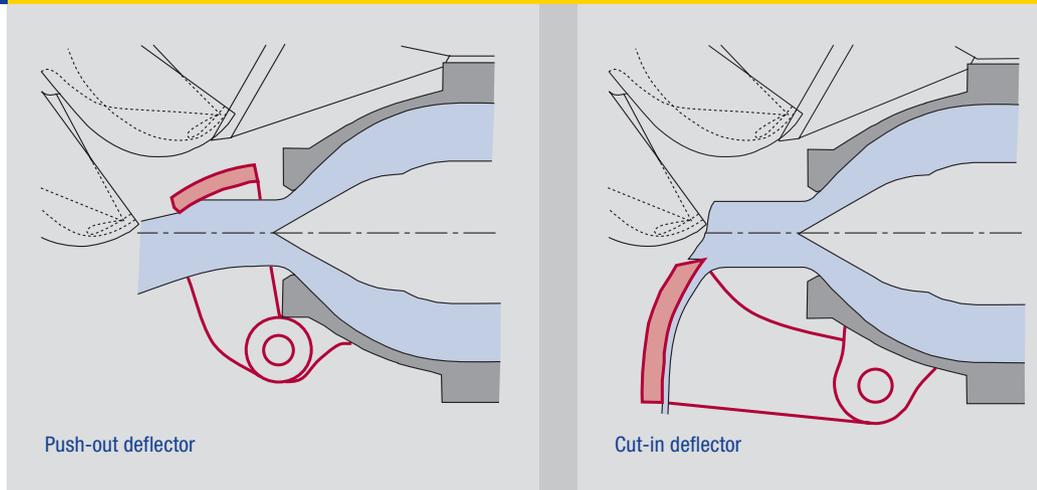


Streak lines of the optimized Gilgel Gibe II distributor line.

Regulation capabilities

Since the power of the Gilgel Gibe II turbines is large, compared to the electrical grid they are connected to, rapid and very frequent regulating capabilities of the units are necessary. Because of this, the typical Voith Siemens Hydro cut-in deflector was used for the turbines. An illustration of the difference between the cut-in deflector and the commonly used push-out deflector is shown in below. While the push-out deflector presses the complete jet to larger jet circle diameters, the cut-in deflector guides only a part of the jet away from the runner.

The push-out deflector bends and deforms the jet right at the side where the bucket touches the jet first. However, the inlet part of the Pelton bucket is very sensitive to changed inlet conditions and poor jet quality. Drop erosion and cavitation damage to the runner often are the result of the use of push-out deflectors for frequent regulating action. The cut-in deflector has very little impact on the jet, especially on the side where the bucket touches the jet first. There is no negative change in the jet surface or shape.



Comparison of the push-out and the cut-in deflectors.

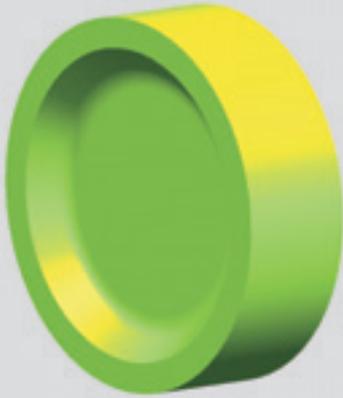


Runner design

The runners for Gilgel Gibe II are almost 3.5 m in diameter and each is manufactured from a forged disc with welded buckets. This technology, patented by Voith Siemens Hydro, ensures the highest possible material quality in between adjacent buckets, the area where the highest stresses typically occur. The first stage of the process is the manufacturing of the forged disc. An intensive check for hidden cracks is performed with ultrasonic testing after the disc is pre-machined. After that, the root area of the buckets is milled out of the disc.

Parallel to the milling of the forged disc, the bucket heads are cast and machined. The buckets are then welded onto the machined disc. In order to ensure the highest quality of the weld seams, ultrasonic, magnetic particle and liquid penetration testing is performed. Balancing and polishing of the hydraulic surfaces finalize the manufacturing. For the reliable and safe operation of the runner, a complete geometrical check of the hydraulic surfaces and the high stressed regions is performed after the manufacturing of the runner is completed.

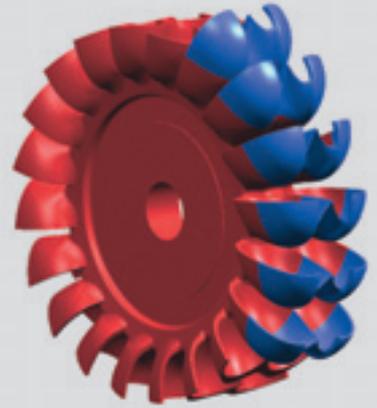
Stress distribution of the Gilgel Gibe II runner.



Forged disc



Milled root area



Bucket head welded

Runner manufacturing process used in Gilgel Gibe II.

Jet bucket interaction

Similar to the hydraulic design of the distributor line, the optimization of the jet bucket interaction was also developed using CFD tools. A typical bucket flow sequence, taken by high speed camera, is shown below. The time dependent working cycle can be observed very well by looking at the discharging water. As the buckets move, the water starts to discharge in the root area.

Further into the working cycle, the discharging water covers more and more of the bucket rim. Though the high speed camera gives a good impression of the bucket flow, the insight is limited to only certain viewpoints on the moving buckets. In order to have a more detailed view of the flow behavior, instationary simulation of the bucket flow was used. In particular, the multijet configuration was investigated in more detail.

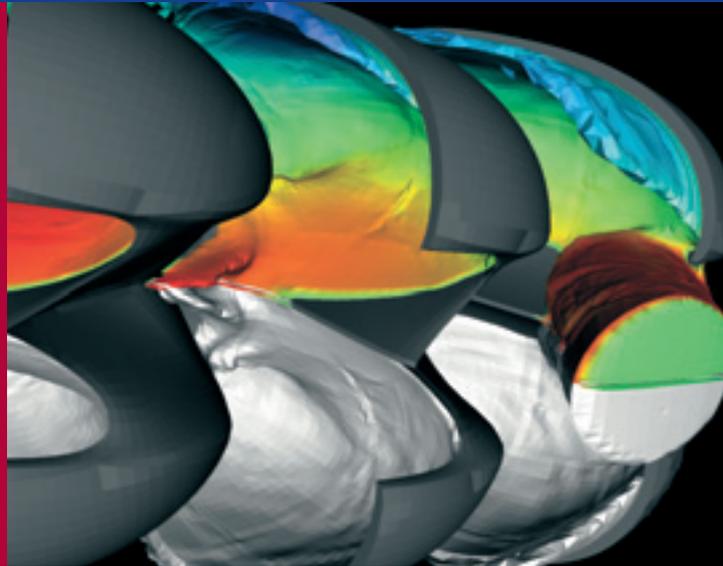
A snapshot of the water sheet development during the cut in sequence of an adjacent jet is shown on page 21 top right. As illustrated, the incoming jet touches the already established water sheet of the previous jet. Because of this, detailed simulations with one and two jets had to be performed in order to optimize the multijet configuration for the Gilgel Gibe II design.

Time dependent flow visualization, taken by a high speed camera in a typical model Pelton turbine.





Finished runner



Snapshot of the multijet bucket flow simulation during the entry of the second jet.

The addition of the Pelton turbines at Gilgel Gibe II will improve the Ethiopian electrical grid. Not only will the available power increase, but also the fast regulating capabilities and the high efficiency over the whole power range will substantially improve the stability of the grid and consequently will increase the reliability of the energy supply. Optimized with modern computer aided tools that were correlated with the longstanding experience of the Voith Siemens Hydro experts, the Gilgel Gibe II turbines will be one of the most advanced power units operated worldwide.

Technical summary

- Scope of supply includes:
 - Four 107 MW vertical Pelton-turbines, frequency governor and inlet valves
 - Four 125 MVA generators and excitation equipment
 - Protection, control and monitoring system
 - Main step-up transformers
 - Switchyard 400 kV including overhead lines
 - Powerhouse cranes
 - Ventilation and air conditioning
 - Cooling water system
 - Auxiliary electrical equipment
 - Telecommunication and control systems
 - Fire protection
 - Lighting and small power systems
 - Cabling systems
 - Earthing and lightning protection system
 - Emergency power supply

