DEUTSCHES TALSPERRENKOMITEE – ICOLD-ANNUAL MEETING 2001, DRESDEN

# Barrages - Small Hydropower Stations -

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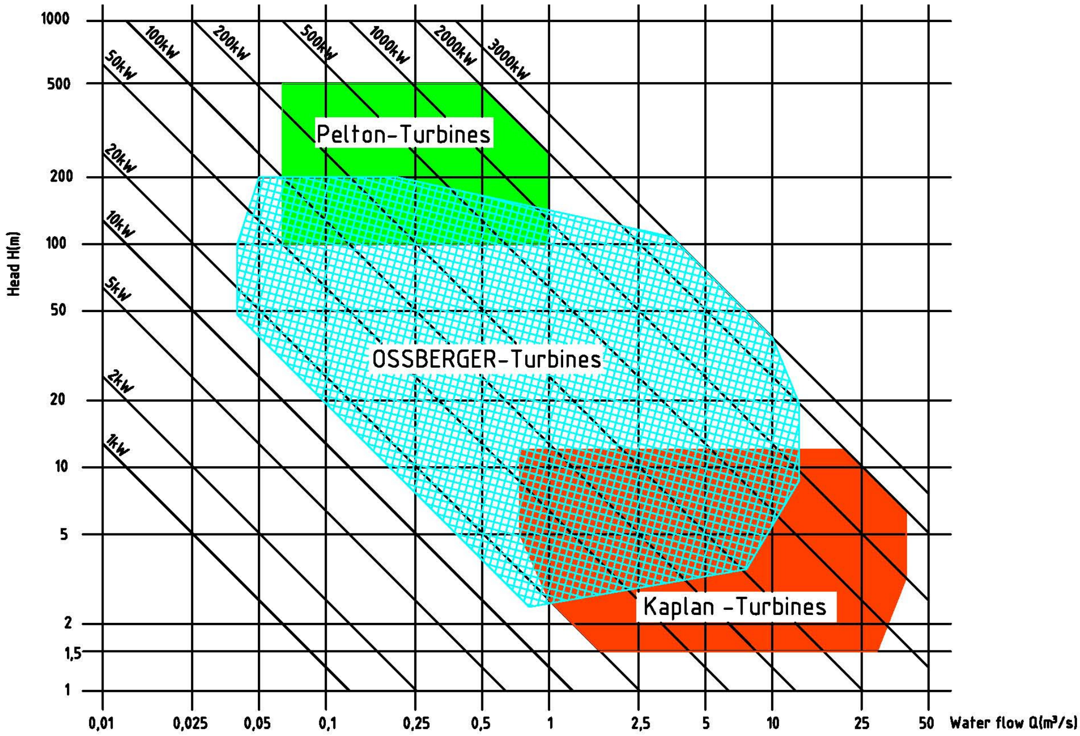
## Introduction

As a schoolboy I visited Frankfurt Airport at the beginning of the 1960s. It was an exciting trip, Lufthansa gave us permission to enter an airplane. Something else remained, however, in my memory: A man on a bicycle pedaling on the airfield. While drafting my paper for today's presentation, I remembered this scene vividly.

Barrages, large-size dams, and small hydro power station. It is like cycling on an airfield. They exist indeed, cyclist on airports. And these also exist, small hydro stations at large dams. My point is: For particular tasks a well-adapted approach could mean the better solution.

## Options:

It is quite easy to select the turbine type. For this purpose the well-known envelopes of various different turbines are available. In principal, conventional turbine types are also suitable for small capacities. If, however, flow variations were mandated by the regulating agency, certain disadvantages would result, if a large-scaled hydro turbine were simply downsized.




*Range of use - Gamme d'utilisation*

High-speed runners have efficiency characteristics with a peak efficiency at approximately ¾ turbine opening, falling below 80 % at half turbine opening. Low speed runners do not reach high peaks; instead, they have a flat efficiency curve from full opening down to a partial opening.

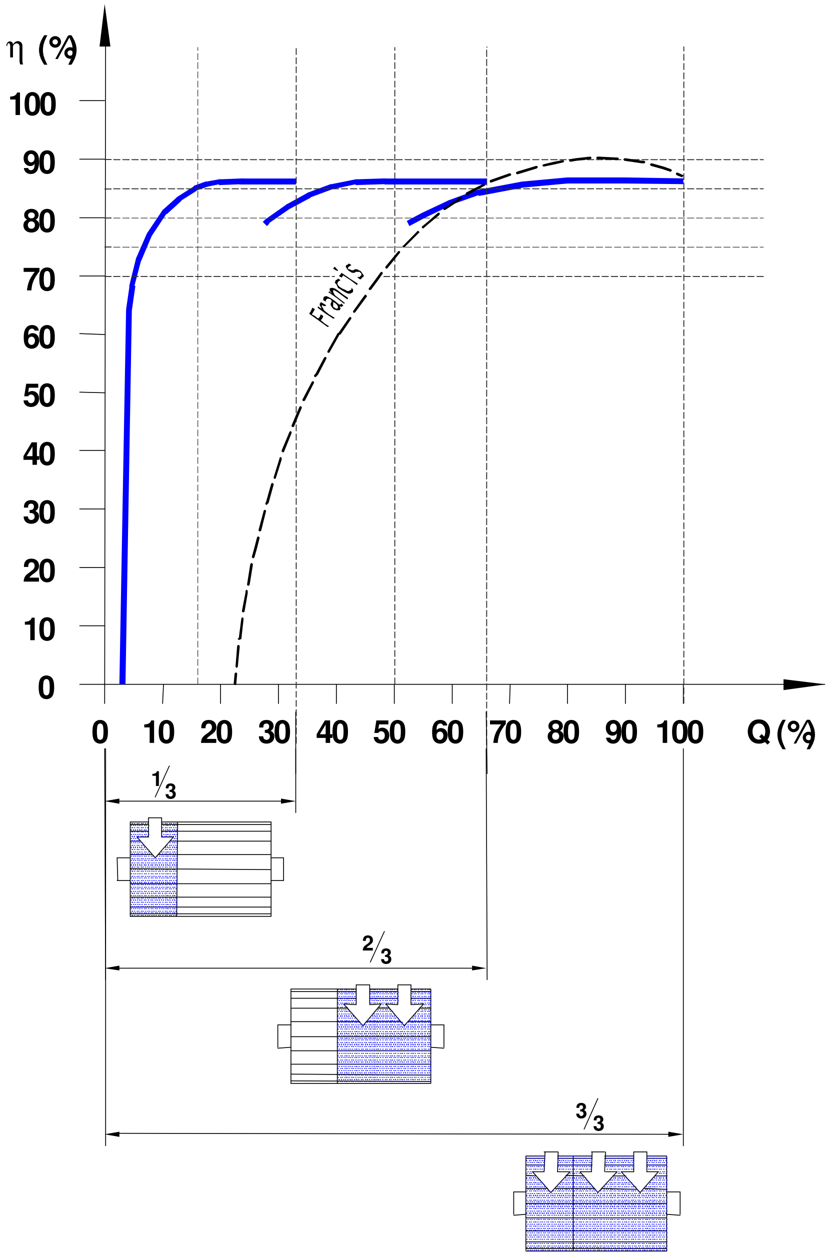
At power stations working economically you might be expect that all turbine manufacturers are trying to improve their equipment to better adapt varying flows through constructive measures. Examples of these efforts include:

- The Francis Turbine is offered with a single or double runner version of medium specific speed, provided the additional costs permit such designs.

- The Kaplan Turbine improves its efficiency by adjusting the blade angel and the wicket gates. Nevertheless, at higher dams, utilization of a Kaplan Turbine may not be practical. As generally known this system has particularly been developed for low heads and high water flows.

- The Ossberger®-Turbine (Cross-Flow- or BANKI- or Michell-Turbine), designed in a two-cell configuration, maintains good efficiency from 1/1 to 1/6 flow. The flat efficiency and the cavitation-free service even at < 1/6 of nominal flow make this system turn out as particularly suitable for hydroeconomic tasks at dams.

- The Pelton Wheel can be built with multi-nozzles to obtain a speed range, where flow variations from 1/1 to approximately 1/6 flow are permissible. Nevertheless the need of several nozzles will result in increased investment costs.




*Efficiency characteristics of an Ossberger®-Turbine developed from the 3 efficiency curves of a 1 : 2 division compared with a Francis turbine.*

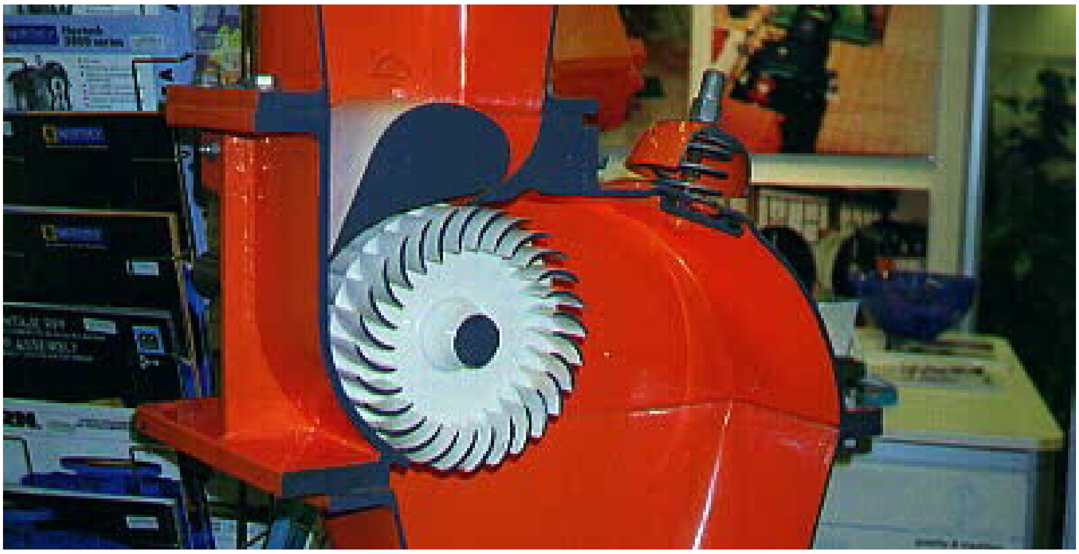
Out of the above reasons the Ossberger® Turbine (other names have already been mentioned, referring to this system in the technical literature) should stand in the foreground of all further considerations.

Originally, the hydraulic turbine invented in 1903 by A. G. M. Michell was the forerunner of the Cross-Flow Turbine. The German Civil Engineer Fritz Ossberger made contact with the Australian genius about whose work he had read. The two men quickly established a strong working relationship and together developed the new water turbine. The new "Free Stream Turbine" designed was granted German Imperial Patent No. 361 593 and the Ossberger® Turbine was born.

The turbine by the Hungarian Prof. Donat Banki received a patent and became more widely known between 1917 and 1919 by a series of publications. This is the reason why this turbine system is called Banki Turbine in some parts of the world.

However, the Ossberger family-run company deserves credit for research and development invested over a period of more than ninety years of production that resulted in such a simple and efficient turbine.

The OSSBERGER turbine is a radial and partial admission free stream turbine. From its specific speed it is classified as a slow-speed turbine. The guide vanes regulate the rectangular cross-section to the water jet, which flows through the blade ring of the cylindrical rotor, first from the outside inward, then after passing through the interior of the rotor from the inside outward.



*Model of Ossberger®-Turbine*

The stipulated by hydro economy are essentially marked by the following:

- Hydro economy makes a signal available, with the background of superior hydroeconomic requirements.
- A constant flow needs to be maintained constant, with changing upstream water level.
- The unit runs at isolated service.

## Examples:

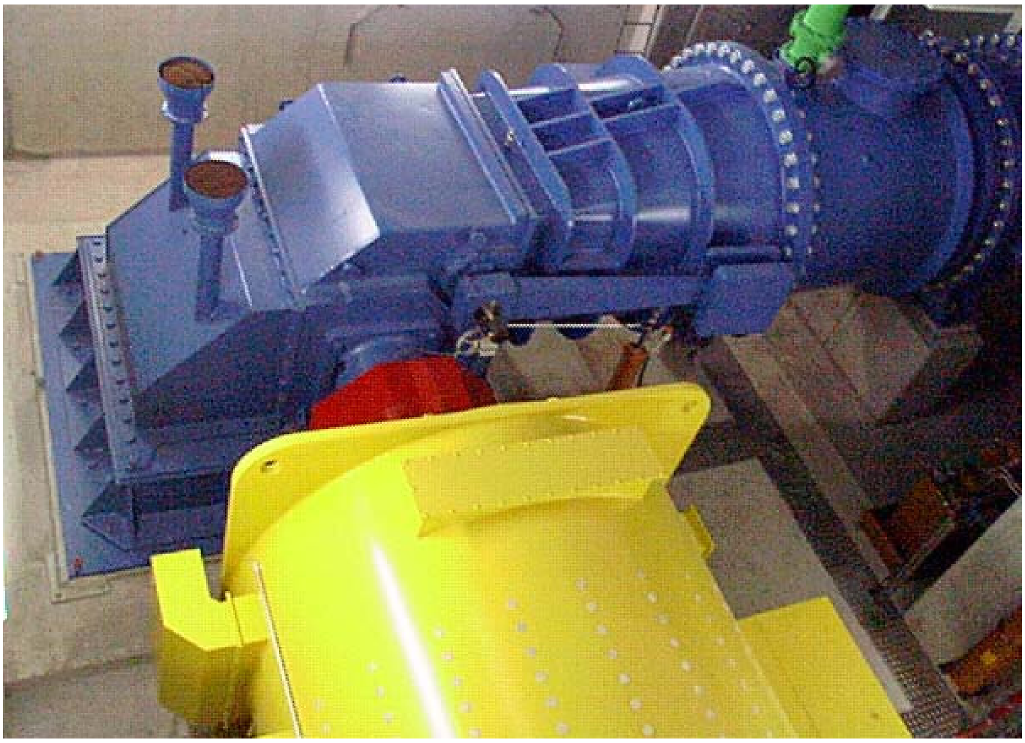
The following are examples, chosen to present the practical use of small hydro power stations at typical project sites with larger dams:

### *Schluchsee:*

Well known as one of the largest pump storage plants in Germany. The task is to redirect flow to the riverbed, arriving in the lower basin at the same time. The water level in the lower basin serves as upstream level for the power station; it is subject to essential variations.

Characteristics:

| | | | |
|---|---|---|---|
| Nominal head: | $H_N$ | = | 30 meters |
| Rated flow | $Q_N$ | = | 4 m³/sec. |
| Min. operating head | $H_{min}$ | = | 16 meters |
| Max. operating head | $H_{max}$ | = | 36 meters |



*With an installed capacity of 1,135 kW it is expected that the mean annual energy production will amount to approx. 3.8 million kWh.*

## Western Dan

This project in the Near-East was equipped with two Ossberger® Turbines. It has been integrated into an irrigation system; the flow rate available for energy production depends on irrigation requirements. Behind the bifurcation towards the powerhouse a pressure monitoring station is located. The desired pressure at this point is defined by the irrigation requirements. The turbine regulator governs the turbine flow to conform the set pressure.

## Markersbach

The natural setting of the Big Mittweida valley serves as the lower basin for another pump storage plant. Here water discharge must correspond exactly to the inflow, with a minimum discharge of 0.2 m³/sec.

Data:

| | | | |
|---|---|---|---|
| Nominal head | $H_N$ | = | 29 meters |
| Rated flow | $Q_N$ | = | 0,6 m³/sec. |
| Flow range | Q | = | 0.2–1.0 m³/sec. |
| Min. operating head | $H_{min}$ | = | 23 meters |

Max. operating head $H_{max}$ = 43 meters

In an article published by the magazine “Hydro Power Unit” the operator reports on turbine efficiency measurements. For a flow range of 0.17 – 1.0 m³/sec. a figure of 85 % turned out as effective.

## *Rothsee*

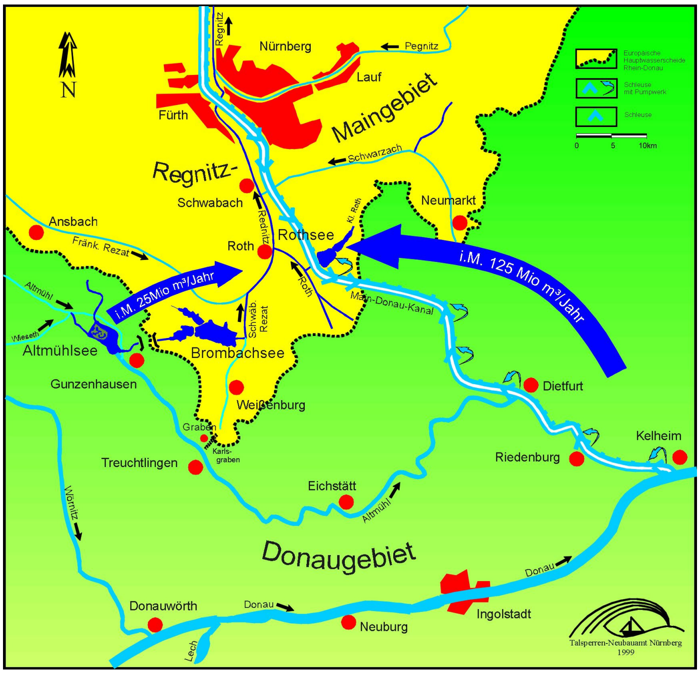
Bavaria is a country abounding in water. Availability of water, however, is subject to strong regional differences.

Southern Bavaria (the Danube region) profits from a large surplus of water. Northern Bavaria, including Franconia (the Regnitz - Main region), has only access to one third of all water reserves of Bavaria. To encourage further development of this part of the country, it was therefore necessary to reduce Franconia’s hydroeconomic obstacles by creating a supraregional water compensation between the Danube and Main areas.

Target of the "Transmission Danube - Main" is to increase the discharge rate of the River Rednitz, downstream of Nuremberg, from approximately 12 m³/sec. during the dry season up to a maximum of 27 m³/sec by the addition of water.

This is achieved by the correlation of two independent systems:

- the canal transmission and
- the Brombach transmission.




The **canal transmission** serves as the "main water conduct" of this hydroeconomic project. Water from the Danube or Altmühl is pumped through the Main-Danube Canal from Kelheim/Dietfurt up to Lake Rothsee near Hilpoltstein. From there it is discharged into the lower lakes and rivers as needed.

To utilize the energy of water conveyance from Lake Rothsee to the lower lakes and rivers, a power station was built.

More than 60 % of the annual discharge of Lake Rothsee can be used for the production of electricity with two turbine sets - a tubular S-type turbine and an Ossberger®-Turbine. Higher water discharges of up to 15 m³/sec., which are required during longer dry periods in the Regnitz-Main area, can be supplemented using additional conical jet valves that are also lodged in the powerhouse.

The main turbine is a so-called tubular S-type turbine, which has been especially desiged, for its operation at Lake Rothsee. The flow regulation requirements mandated a wicket gate controlled turbine. In order to keep civil costs for powerhouse and turbine low, it became necessary to modify the operating point of the turbine without any considerable loss of efficiency. For this reason the "geometry" of the turbine was changed by choosing a turbine wheel with only four vanes, instead of a more costly one with six vanes. The trial run of Lake Rothsee power station took place in November 1994 and fully justified the planning.

*S-Turbine at Lake Rothsee*

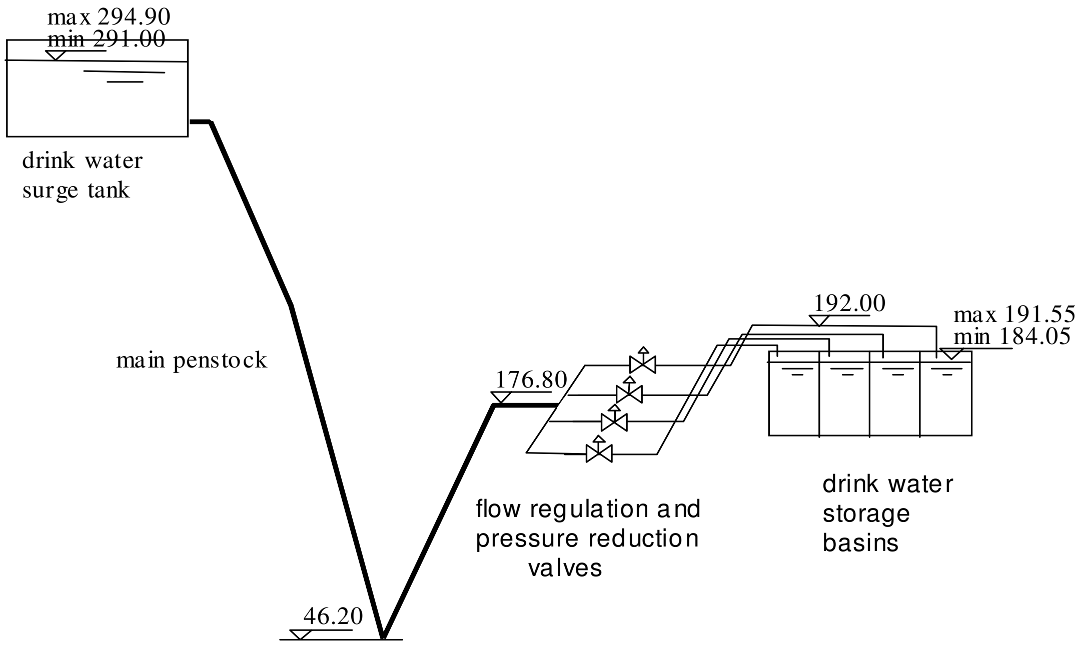
The smaller machine is an OSSBERGER™ Turbine. It mainly serves as energy recovery at minimum discharge rate from Lake Rothsee and is a suitable complementation to the tubular turbine.

| **Turbine data:** | **Tubular S-Type turbine** | **OSSBERGER™ Turbine** |
|---|---|---|
| Maximum flow | 5.0 m³/sec. | 1.0 m³/sec. |
| Maximum power | 628 kW | 122 kW |
| Net head | 14.4 meters | 14.4 meters |
| Average annual performance | 1.6 million kWh | 400 000 kWh |

## *Monte Casale*

The Acquedotto della Romagna is a broad aqueduct system, designed to catch, collect, store and distribute water for drinking and other purposes in more than 40 municipalities located in the Riviera Romagnola (Italy) and the Republic of San Marino. Since the beginning, the conceptual philosophy of the system was to take advantage of the favorable topography and let the water flow only by gravity from the catchment basin all the way to the end user to supply 900,000 residents (and several millions of tourists during the summer) with quality drinking water.

Water is collected from several creeks in the mountainous area between Ravenna and Florence, and stored in the Ridracoli basin (capacity 30 Mm3), created by a concrete arc-gravity dam, 430 m wide and over 100 m high. Since the beginning this dam was built as a multiple-purpose structure, to store water both for aqueduct use and for energy production, as well as cutting peak flows during overflow periods. The first stage making use of the water storage is a hydropower station of 8 MW capacity.




*Hydraulic sketch of existing works*

Almost all the flow is directed towards the Monte Casale site, which is located in the center of the service area. The residual pressure downstream of the penstock mainly depends on the flow rate, due to the prevalent influence of friction losses inside the pipe. Since early test runs, the main penstock has shown to be very sensitive to flow changes, due to intrinsic problems, such as its extreme length and small diameter, minimal wall thickness of the steel pipe and potential sources of deflected pressure waves along the penstock.

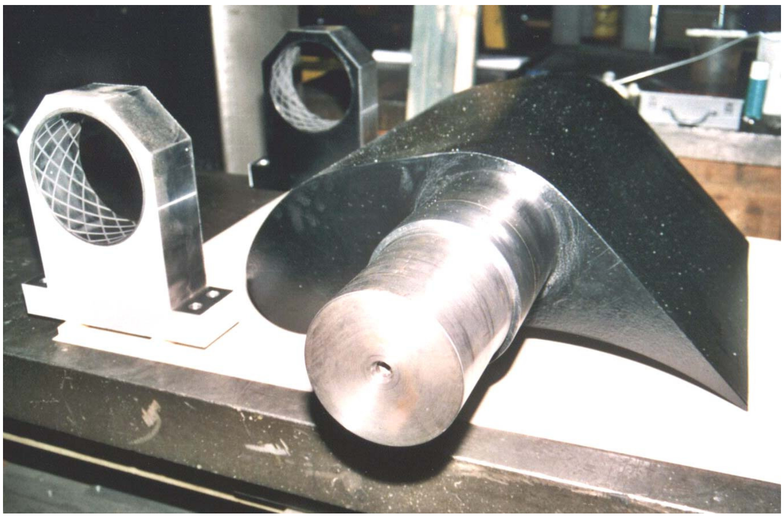
The new hydropower station in Monte Casale was conceived to provide an intrinsically safe, non-dissipative device for flow regulation, to find a reliable and definitive solution to the above mentioned problems. An OSSBERGER™ Turbine was selected.

The turbine is fed by a new by-pass penstock, connected to the main penstock upstream the energy dissipation system. Taking advantage of the local topography, it was possible to place the new powerhouse at a higher level in relation to the storage basins.

*Runner for Monte Casale – witness test*

The selected solution is advantageous with regard to the following:

- Water quality not affected: All parts of the turbine in contact with water are made of stainless steel; all other metal components (tubes, valves etc.) are made of materials certified to comply with potable water regulations and protected by surface coatings with materials of the same certification. Turbine shaft bearings are mounted outside the turbine casing, too far away to come in contact with water. Guide vane bearings are made of maintenance-free self-lubricated materials.



*Guide vane and maintenance-free guide vane bearings*

- No dangerous flow gradient during transient conditions: OSSBERGER GmbH + Co provided a special design for the turbine: Model tests performed at their own test facilities confirmed that the selected geometry granted a flow gradient smaller than 0.2 m3/s per 75 seconds even in the worst case scenario - grid disconnection at maximum output.

- The turbine can exploit the whole range of flows from 0 and 2,5 m3/s.

- The regulation system maintains the flow rate requested by the aqueduct controller at set point. Because power generation is only in parallel with the mains, there is no problem of working in a range where an increased power output results from a flow reduction.

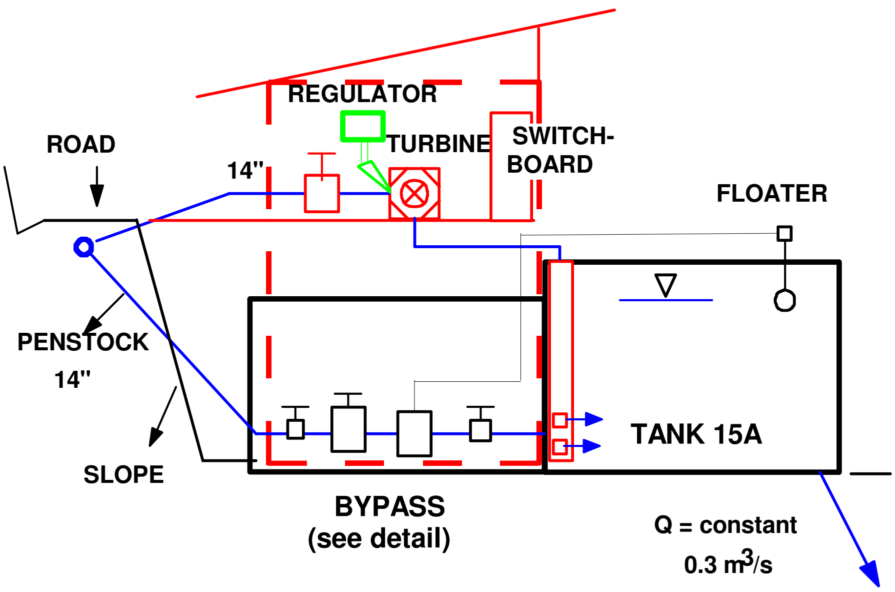
## *La Reforma:*

The water supply system La Reforma, incorporating a water filtrating plant with a capacity of 1 m³/sec., was intended to compliment the existing macro-infrastructure of Santiago de Cali (1,800,000 inhabitants) of Colombia - South America. After completion of the water supply system, the installation of a mini hydro power station was placed directly in front of the intermediate tank # 15A as a pilot project for similar applications.

The max. flow rate of 0.3 m³/sec. which is available for "Línea Nápoles" and the existing net head of 70.4 meters, a power output of 169 kW will be devoloped at the turbine shaft. Since energy demand of the water filtration plant amounts only to 25 kW during daytime and to 30 kW during nighttime, energy transfer was designed to accommodate two different operating modes.

***SMALL HYDRO POWER STATION LA REFORMA***
***SANTIAGO DE CALI - COLOMBIA***

***HYDRAULIC SCHEME***




A. Parallel operation of the mini hydro station with the public mains, i.e. energy feeding into the mains.

B. Isolated, stand-alone operation of the mini hydro station, in case of a power failure of the public grid.

Turbine operation or energy demand during isolated operation must not disrupt the necessary fresh water flow to the town. The water supply has first priority and needs to be assured at all times. In stand-alone mode the flow rate conforms to the energy demand but to guarantee the discharge flow required, a by-pass line is furnished next to the turbine. The task is defined as follows:

$$Q_{set} \text{ minus } Q_{Turbine} = Q_{By\text{-}pass}$$

To comply with this equation an energy-dissipating valve of Erhard Armaturen was installed.

| | |
|---|---|
| Total costs of the project : | US $ 584,000 |
| Costs per installed kW in US $<br>Including : Design, engineering, labor force, materials, equipment, transformer, electrical line, ingoing panel into water conditioning plant, remote control | US $ 3,456 / kW |
| Amortization of investment costs : | 7 - 8 years |

... make electricity flow
even at small streams ...

## Conclusion

Just like building a bicycle. So do not laugh if on your next flight you see a cycler at the airport; think of small hydro stations at big dams. Cases exist, where such things make sense.

OSSBERGER

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