

# **Application-oriented Planning Documents for Pumps as Turbines**

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## 1 Generation of Planning Documents

For more than 35 years now, KSB has been receiving queries about, and orders for, reverse-running pumps. According to a recent market study, policy decisions like the Kyoto Protocol, in combination with the increasing cost of energy, are generating increasing demand for alternative, renewable sources of energy in all market segments. In Germany alone, there is a posited potential for pumps as turbines (PaTs) on the order of 100 - 250 MW installed electric generating capacity. Most of that potential is still being wasted in water handling systems and industrial facilities equipped with throttling elements, even though it would be very easy and extremely economical to harness that potential with PaTs.

What makes PaTs so worthwhile?

- Short payback period thanks to:
  - Series production and accordingly minimal initial investment costs
  - Very good optimum point efficiency and, hence, revenues from the power yield.
- Low life cycle costs thanks to:
  - Very low maintenance and repair costs.

Obviously, a growing sense of ecological responsibility and the fact that this kind of power generation can be very profitable have helped enkindle a waxing general interest in renewable energy.

## 2 Economic Efficiency

The following, very simplified equation is useful for estimating how much power (P in kW) can be captured with the aid of a PaT system:

$$P \approx 7 \cdot Q \cdot H$$

with: P [kW]            power  
      Q [m<sup>3</sup>/s]        flow rate  
      H [m]             head

Process efficiency (approx. 70 %), gravitational acceleration and density are already factored in.

The power yield can either be used to reduce the internal consumption of expensive grid electricity, hence distinctly reducing expenditures for purchased line power, or it can be fed into the local grid in return for feed-in compensation.

To calculate the achievable annual revenues, the specific output merely has to be multiplied by the number of annual operating hours and the feed-in tariff, which in many countries is already regulated by law (see section 7).

$$\text{Annual revenues} = P \cdot \text{operating hours} \cdot \text{feed-in tariff}$$

with: annual revenues [€/a]  
      P [kW]                            power  
      operating hours [h/a]        no. of annual operating hours  
      feed-in tariff [€/kWh]

Owing to the low initial investment costs and high energy prices, it takes only a few short years for a PaT system to pay for itself.

### 3 Applications for Pumps as Turbines

Pumps as turbine (PaTs) are called for wherever differences in pressure (e.g., system head) and flow quantities can be exploited in a plant or system. Our pumps make it both easy and very inexpensive to generate and recover additional energy. Consequently, PaTs can be used wherever the high cost of investment would make it diseconomical to generate power with a conventional turbine.

Thanks to the broad range of series pumps available from KSB, PaT systems occupy a nearly universal range of application:

- Industrial facilities (where they supplant practically all kinds of throttling devices)
- Water handling systems (upstream of water tank feed-in points)
- Small hydropower systems
- River locks with little head and high flow rates
- Chemical and petrochemical processes (e.g., gas scrubbing systems)
- Bottom outlets of impounding reservoirs
- Oil supply systems
- Reverse osmosis

The power yield can be fed into the public grid (mains mode) and/or provided to internal consumers (island mode). It is also possible to directly couple a PaT and a drive machine to either lessen the load on the drive or to replace it completely.

The use of PaTs is therefore particularly worthwhile wherever machines still have to be driven with expensive grid power, while a PaT could supply the required energy by replacing, say, a throttling element. That way, power consumption costs can be significantly reduced.

## 4 Planning a PaT System

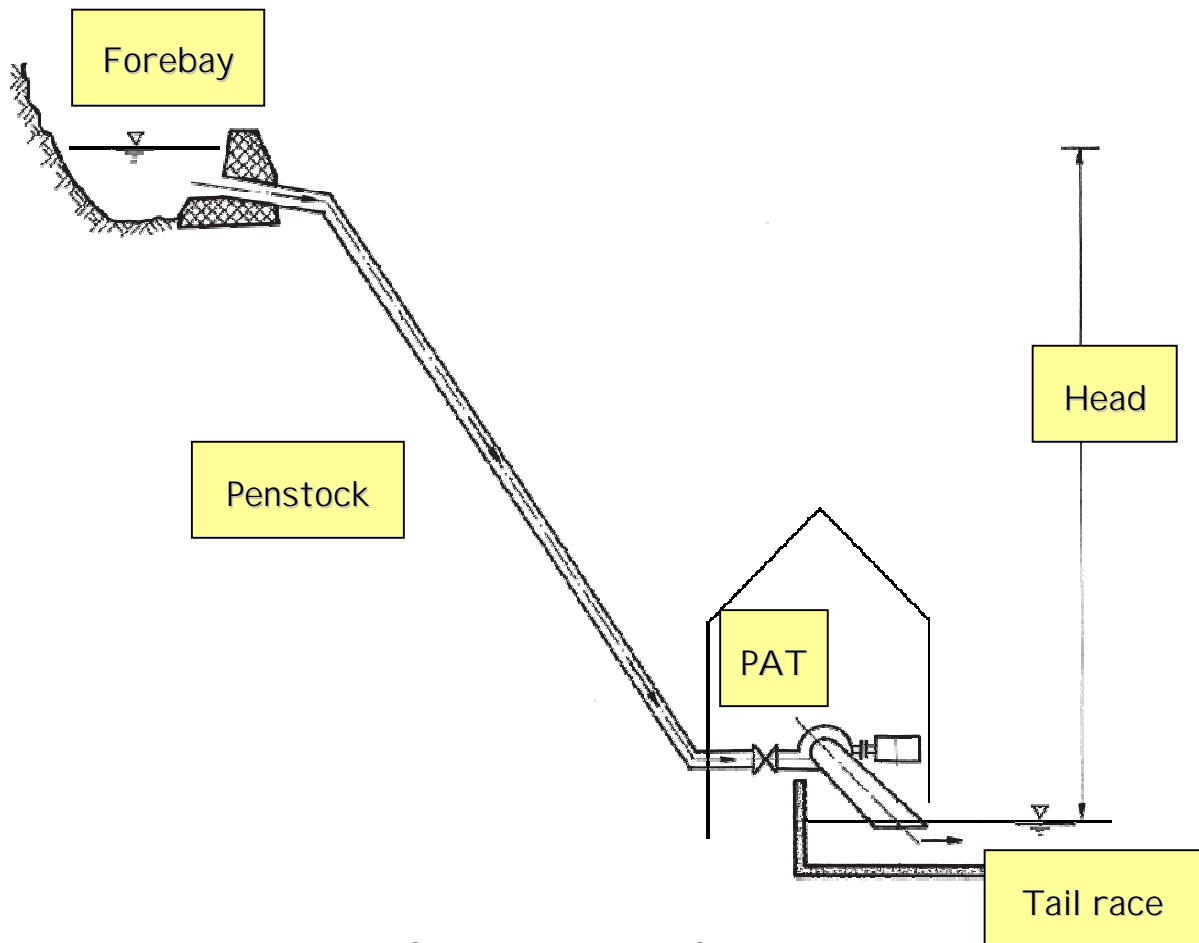


Figure 1 Conceptual sketch of a PaT system

Before the planning for a PaT system like that sketched out in Figure 1 begins, both the temporal distribution of flow and the head should be known. With those data, the most effective, most economical size of PaT system can be found. The following pointers should be adhered to for PaT system planning:

- Layout of the PaT by your KSB contact partner
- Elaboration of a plant concept (electric/electronic and mechanical systems)
- Electronic and mechanical integration of the PaT into the plant concept

For PaT systems, due attention also must be paid to the importance of operational reliability! In that connection, please refer to section 4.2.

### 4.1 Products

Considering the nearly seamless spectrum of pumps to be found for practically all conceivable pumping situations and types of installation, an optimal type of set can also be found for turbine service operation in most power generation applications. To help narrow down the choice, Figure 2, below, presents a pump-as-turbine range chart.

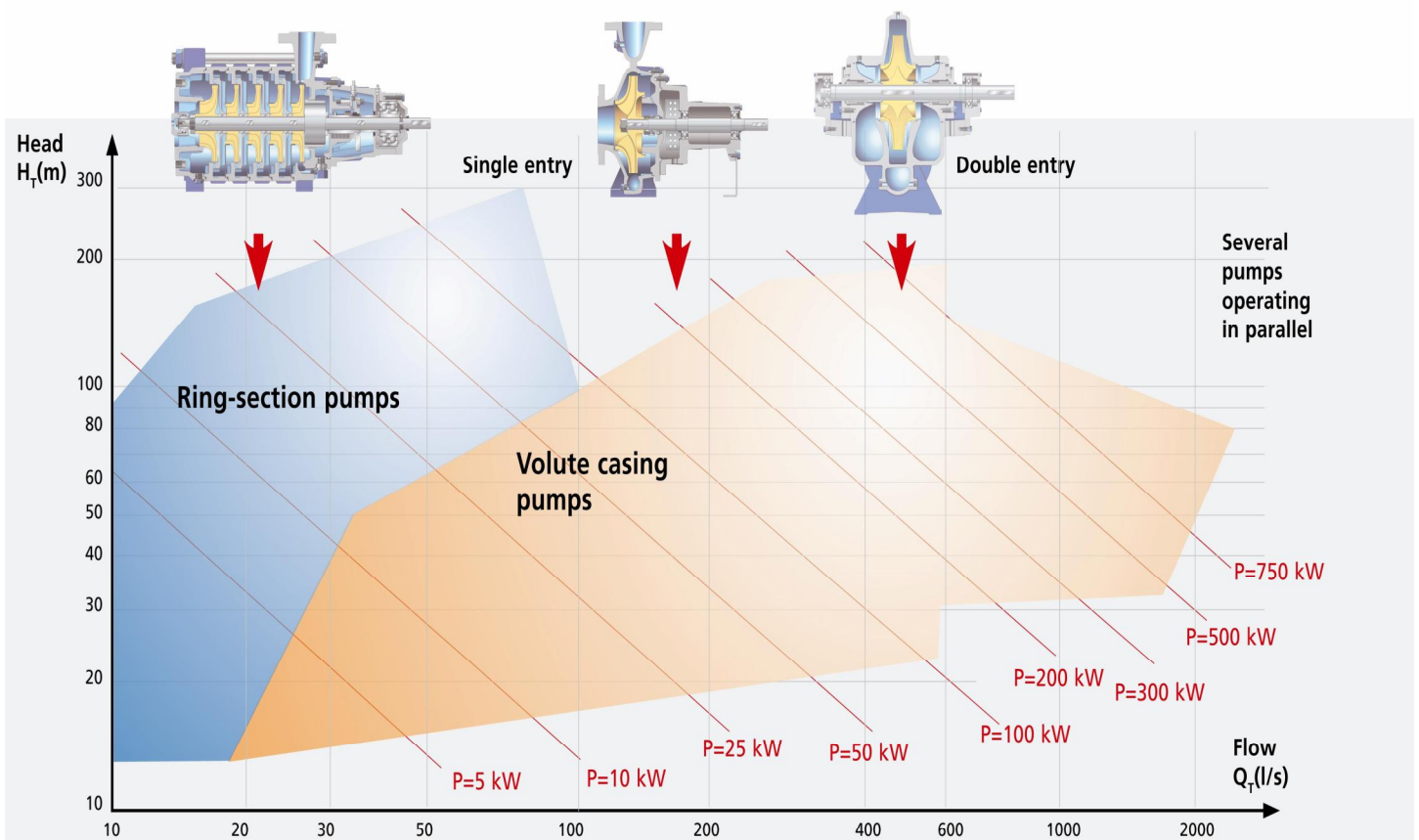


Figure 2 Pump-as-turbine range chart

## **4.2 Safety relevance**

Care must be taken to ensure that the PaT system always remains safely within its reliable range of operation. To ensure this, the chosen pump must be certain to withstand the elevated turbine-service stress levels, and all rotating parts must be reversible.

In case of load rejection (e.g., power outage during mains operation), the "turbine" would accelerate to runaway speed. It is therefore important that appropriate safety measures be taken to ensure that such systems are not exposed to excessive loads.

Other plant-specific factors such as resistance to pressure surge (water hammer) and susceptibility to cavitation also must be clarified in advance.

A system pressure surge must always be anticipated, when the conditions of flow are altered, for instance by closure of a valve or when the impeller/rotor accelerates due to a power outage. We therefore recommend that the pressure surge susceptibility be calculated in advance.

The formation of steam bubbles when the system pressure drops below the vapour pressure of the fluid is called cavitation. While cavitation rarely occurs in PaT systems, it is nevertheless important to investigate the system pressure conditions in order to completely rule out any chance of cavitation. Such aspects as the chemical composition and temperature of the medium are important both in that connection and for the selection of a PaT.

Please consult our experts on this point.



## 5 PaT System Control

With a view to making a PaT system as economical as possible for any and all combinations and fluctuations of flow rate and head, there are three ways to adjust the PaT to its duty point. First, however, it must be clear whether the PaT system will be operating on a mains mode or an island mode. In the mains mode, the generated power is fed into an existing power grid, while the electricity generated on the island mode must be directly available to consumers at a frequency of 50 or 60 Hz.

### 5.1 Constant speed (e.g., with asynchronous motor as generator)

If constant-speed operation is assumed, the PaT can only be designed for one particular volumetric flow rate and one particular head. All other conditions have to be accommodated by means of throttling elements and/or a bypass. This, of course, causes part of the energy potential to be lost. On the other hand, such systems are technically uncomplicated, easily controllable and, above all, very inexpensive. The speed is maintained by way of the existing power grid, so this option is unsuitable for island operation. Figure 3 shows the system's hydraulic arrangement, and Figure 4 illustrates its electrical layout - both for a postulated constant speed.

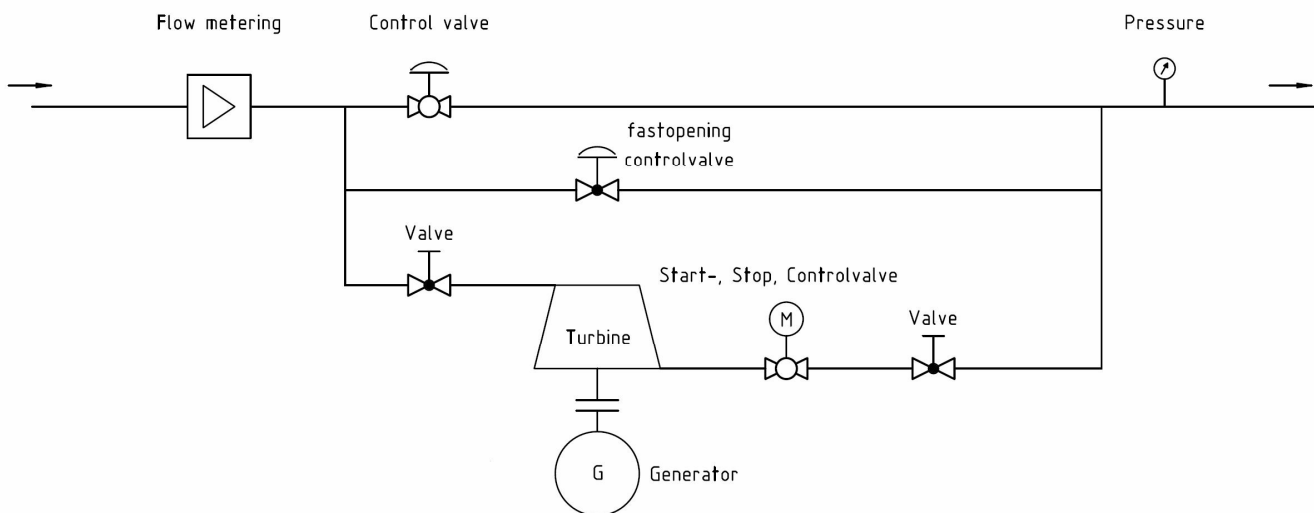


Figure 3 Hydraulic diagram of a PaT system

Table 1 below lists the components required for a PaT system:

Table 1 Required PaT system components:

Flow measurement	Inductive flow meter Ultrasonic flow meter	
Control valve	Annular piston valve, diaphragm valve	
Quick-opening control valve	Annular piston valve, diaphragm valve	
Shut-off valve	Butterfly valve, ball valve, gate valve	e.g., Isoria (KSB product)
Start/stop valve	Butterfly valve, ball valve, gate valve	e.g., Isoria, Boa (KSB products)
Pressure measurement	Pressure pickup	

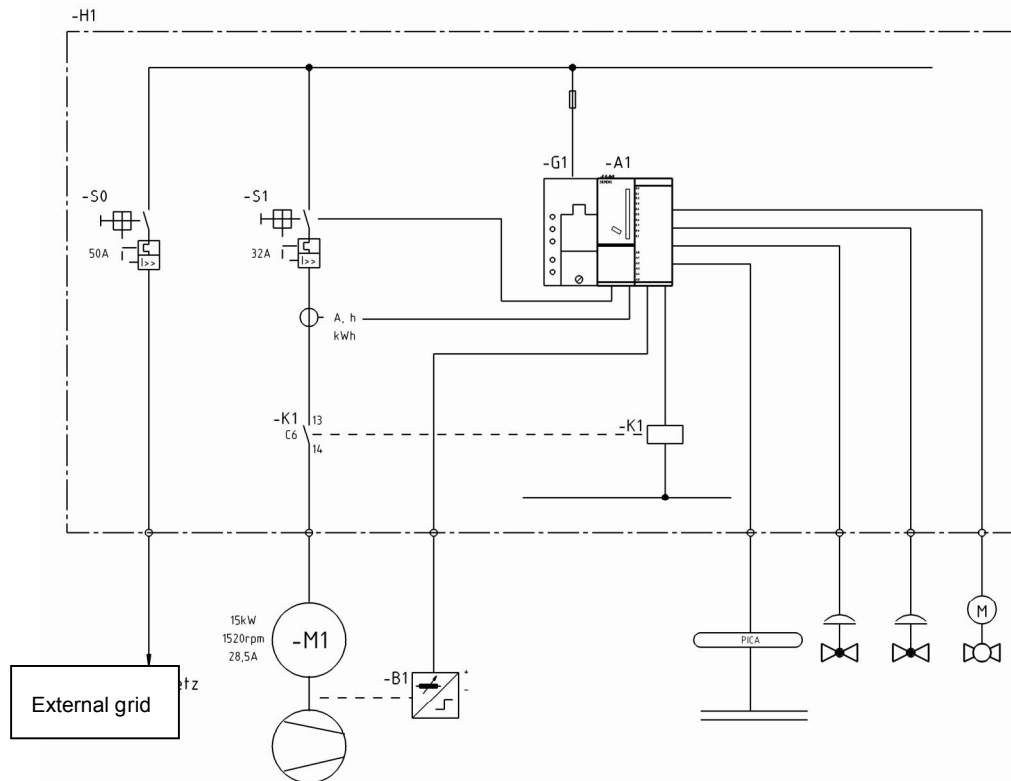


Figure 4 Electric system diagram of a constant-speed PaT

It is also possible to use a synchronous generator in place of an asynchronous motor, depending on the outcome of a cost efficiency analysis. For island operation, the use of a synchronous generator is frequently more expedient.

## **5.2 Variable speed**

The basic idea behind the variable speed approach is to exploit, if possible, the entire available energy potential with no further throttling. The following options are available:

### 1) Negative-feedback frequency converter

One possibility is to install a negative-feedback frequency converter. In combination with standard three-phase motors, this cost-effective solution enables the use of other speed ranges for the PaT and the plant. It should be noted that frequency converters can not be operated on an island mode.

### 2) Variable speed gear

Speed adjustment can also be enabled by a variable speed gear - an option that calls for an advanced cost efficiency analysis.

## **5.3 Control with several constant-speed PaTs in parallel**

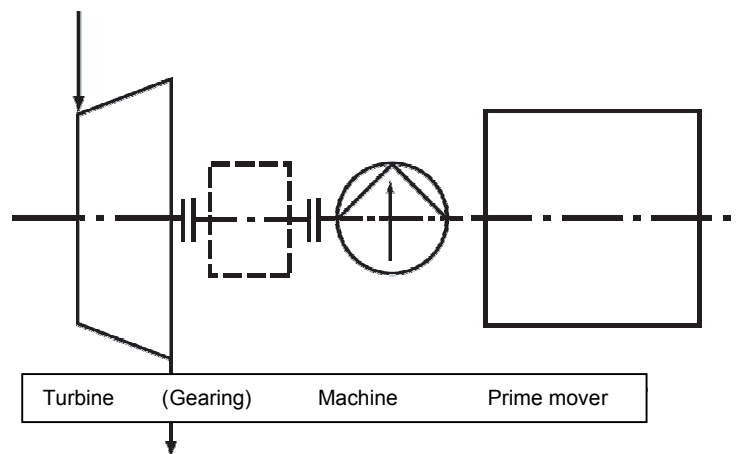
One good way to make optimal use of the energy potentials affected by pronouncedly fluctuating flow rates is to split the volumetric flow among several PaTs, as in the cascade arrangement shown in Figure 5.



Figure 5 Four of eight parallel PaTs in service at the water utility authority (Zweckverband Landeswasserversorgung, Stuttgart, Germany) in Stuttgart

#### 5.4 Direct coupling with a machine

If the idea is to either drive a machine directly or disburden its prime mover, a PaT can be connected up to the machine by means of a continuous shaft or gearing.



Finally, hybrid forms of the aforementioned configuration can be employed to achieve the targeted results.

## 6 Subsidies

### 6.1 Germany

At the end of 2008 Germany's *Bundestag* (Parliament) enacted the Renewable Energy Sources Act (EEG) 2009, which entered into force on 1 January 2009. According to that directive, new facilities commissioned from 2009 onwards are entitled to the guaranteed feed-in tariffs, in cent/kWh, shown in Table 2. The extent to which the potential yield satisfies the renewable energy criteria established in the EEG must be determined on a case-by-case basis.

Table 2 Feed-in tariffs for new facilities up to 5 MW:

Power share	EEG 2009 (Bundestag Resolution, 6 June 2008) [cent/kWh]
< 500 kW	12.67
500 kW - 2 MW	8.65
2 MW - 5 MW	7.65

A full comparison of EEG feed-in compensation instruments for 2009 (in German only) can be found at:

[http://www.umweltministerium.de/files/pdfs/allgemein/application/pdf/eeg\\_verguetungsregelungen.pdf](http://www.umweltministerium.de/files/pdfs/allgemein/application/pdf/eeg_verguetungsregelungen.pdf)

For more information on the Renewable Energy Sources Act, please consult the website of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety at:

<http://www.umweltministerium.de>

## 6.2 Austria

In Austria, the feed-in tariff is determined by way of the 2009 *Ökostromverordnung* (~ green electricity regulation) according to which, since 1 January 2009, new or revitalised facilities in which the average annual output has been increased by more than 50 % are eligible for the feed-in tariffs listed in Table 3, below.

Table 3 Feed-in tariffs acc. to the 2009 green electricity regulation (*Ökostromverordnung*) for revitalised Austrian facilities with average annual output increases of at least 50 %:

	Tariff [cent/kWh]
For the 1 <sup>st</sup> GWh	6.23
For the next 4 GWh	4.99
For the next 10 GWh	4.15
For the next 10 GWh	3.92
For any quantity of exceeding 25 GWh	3.76

For revitalised facilities in which the average annual output is increased by at least 15 %, the 2009 *Ökostromverordnung* describes the somewhat lower tariffs listed in Table 4 below:

Table 4 Feed-in tariffs acc. to the 2009 green electricity regulation (*Ökostromverordnung*) for revitalised Austrian facilities with average annual output increases of at least 15 %:

	Tariff [cent/kWh]
For the 1 <sup>st</sup> GWh	5.94
For the next 4 GWh	4.56
For the next 10 GWh	3.79
For the next 10 GWh	3.42
For any quantity exceeding 25 GWh	3.29

According to the *Ökostromverordnung*, these tariffs are subject to the condition that the facility be commissioned on or before 31 December 2009, and that the increase in average annual output be documented by the expert's opinion of a certified engineer.

For more information on the Austrian provisions, please go to:

<http://www.oem-ag.at>

### 6.3 Switzerland

Switzerland's revised Energy Act includes a package of measures for promoting renewable energy sources and electric efficiency. The main pillar of that act is the break-even feed-in tariffs table for electricity generated from renewable energy sources.

Constructed according to the Swiss Federal Council's energy regulation (EnV), the anticipated feed-in tariffs will basically consist of three elements. For information beyond that contained in the following brief overview, please consult the quoted sources.

- 1.) Base rate: The applicable output for determining the feed-in tariff is the equivalent output, i.e., the quotient of the amount of electricity, in kWh, measured at the feed-in point in the course of the year in question, divided by the total number of hours of the year in question less the number of elapsed hours prior to the facility's commissioning and/or subsequent to its shutdown. The equivalent-output-dependent base rate is calculated proportionally for the power classes listed in Table 4:

Table 5 Base-rate feed-in tariff in Switzerland acc. to power class:

Power class	Base rate [Rp./kWh]
≤ 10 kW	26.0
≤ 50 kW	20.0
≤ 300 kW	14.5
≤ 1 MW	11.0
≤ 10 MW	7.5

- 2.) Pressure class bonus: The pressure class bonus is prorated according to the gross head of the system relative to the head categories shown in Table 5 below:

Table 6 Pressure class bonus in Switzerland acc. to head category:

Head category [m]	Pressure class bonus [Rp./kWh]
≤ 5	4.5
≤ 10	2.7
≤ 20	2.0
≤ 50	1.5
> 50	1.0

3.) Hydraulic engineering bonus: If the implemented, state-of-the-art hydraulic engineering (incl. discharge lines) accounts for less than 20 % of the overall first cost of the project, no hydraulic engineering bonus is granted. For shares in excess of 50 %, the full bonus is granted. Shares ranging from 20 % to 50 % are linearly interpolated. The bonus is prorated according to the facility's equivalent output in line with the power classes listed in Table 6. "Dotierwasserkraftwerke" ("remuneration" hydropower stations) are excluded from this bonus.

Table 7 Hydraulic engineering bonus in Switzerland acc. to power class

Power class [kW]	Hydraulic engineering bonus [Rp./kWh]
≤ 10	5.5
≤ 50	4.0
≤ 300	3.0
> 300	2.5

The source of the above information and additional data can be found at:

Energy Act: [http://www.admin.ch/ch/d/sr/c730\\_0.html](http://www.admin.ch/ch/d/sr/c730_0.html)

Energy Regulation: [http://www.admin.ch/ch/d/sr/c730\\_01.html](http://www.admin.ch/ch/d/sr/c730_01.html)

General information: <http://www.admin.ch>



## 8 References

Pertinent references are listed at:

<http://www.ksb.com/pat>

## 9 Query Sheet

At [http://www.ksb.de/ksb/web/COM/en/segmente/water/Kontakt/Wasser\\_inquiry.txt](http://www.ksb.de/ksb/web/COM/en/segmente/water/Kontakt/Wasser_inquiry.txt), you will find a query sheet (look for "Contact form") that you can fill out to request relevant information. Just fill it in and send it back to us, or e-mail the pertinent data to us.