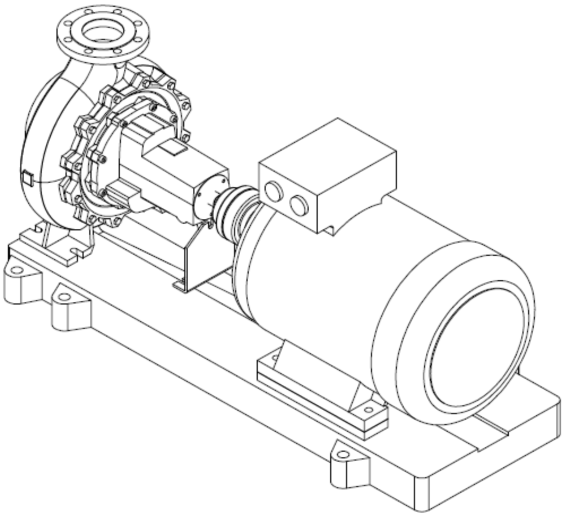
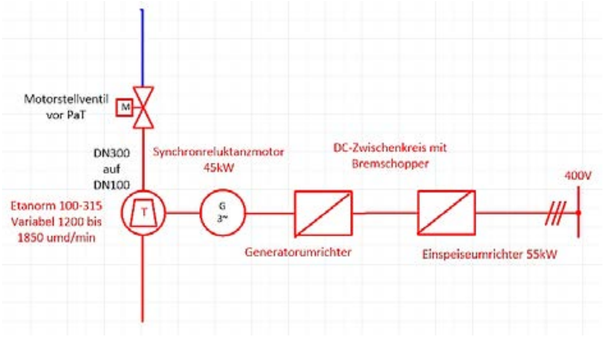
Technical Report

ENERGY GENERATION BY PRESSURE REDUCTION OF DRINKING WATER WITH CENTRIFUGAL PUMP, HIGH-EFFICIENCY GENERATOR, AND GRID CODE-COMPLIANT MAINS SUPPLY

Project:
Drinking water reservoir of the City Wernigerode, Germany





1 Introduction

1.1. Preliminary remarks

The desire to use "normal" off-the-shelf centrifugal pumps as turbines crops up regularly, foremost as an alternative to Francis or Kaplan turbines in connection with alternative energy generation. The significantly lower purchase costs compared to standard water turbines suggest this idea. Pumps are much easier to maintain and handle than "real" turbines.

There are applications, e.g., in the drinking water sector, where pumps are deliberately used as turbines. Often the expected "yield" of the available drinking water volume flow is relatively low and too fluctuating to amortize the acquisition costs of an expensive, "real" water turbine, which, in addition, must be approved for drinking water. Reverse-rotating centrifugal pumps are the obvious choice here. These are available at low-cost thanks to large production quantities. A somewhat less favorable efficiency is accepted in return for the low purchase price. The torque available at the rotating shaft is used to feed the grid by coupling the centrifugal pump and generator. When an inverter feed is used, the speed is not determined by the electrical mains frequency.

The main disadvantage of pumps as turbines (PaT) - in contrast to Francis and Kaplan water turbines - is the absence of a hydraulic control device to adapt to a fluctuating water supply. This problem has been optimized by variable speed operation in the example described below. The inverter feed allows VDE-AR-N 4105 standard-compliant grid operation, but also island operation. A synchronous reluctance motor of efficiency class IE5 was used as the generator.

1.2. Initial Situation

The drinking water network of the city of Wernigerode (Harz, Germany) is fed from various elevated tanks (ET). Further, a self-generation plant with a pump as turbine (PaT) was built at one of the ETs. The supply of the ET is realized via two separate drinking water supply lines and the capacity of the ET is 50,000 m³.
The fluctuation range of flows and pressures are specified below:

<u>Pipeline 1:</u>

- Pipeline DN300
- min. Pressure 6 bar
- max. Pressure 13 bar
- min. Flow rate 0 m³/h
- max. Flow rate 250 m³/h

Pipeline 2:

- Pipeline DN300
- min. pressure 3 bar
- max. pressure 6,5 bar
- min. flow rate 0 m³/h
- max. flow rate 700 m³/h

Furthermore, a surge tank with two connection pipes is connected upstream of the HET as a stilling section. The supply lines feed to port no. 1 via corresponding control valves with motor adjustment provides an emergency feed in the event of a malfunction of the PaT line. Further, connection no. 2 was used for the installation of a PaT. The control is based on the ET's level (classic level control) and after reaching 95%, the system switches over to a feed-off control. This two-fold control structure was put into operation in mid-2020 and is functioning robustly.

1.3. Q- and P- Measured value curves

The following figures 1 and 2 show the monthly graph of the pressure (blue, axis 0-8 bar) before the PaT and the flow discharge (Q, black, in m³/h) for the two drinking water feeders, measured in 15-minute intervals for one month. The daily and weekly fluctuations in drinking water consumption are clearly visible.

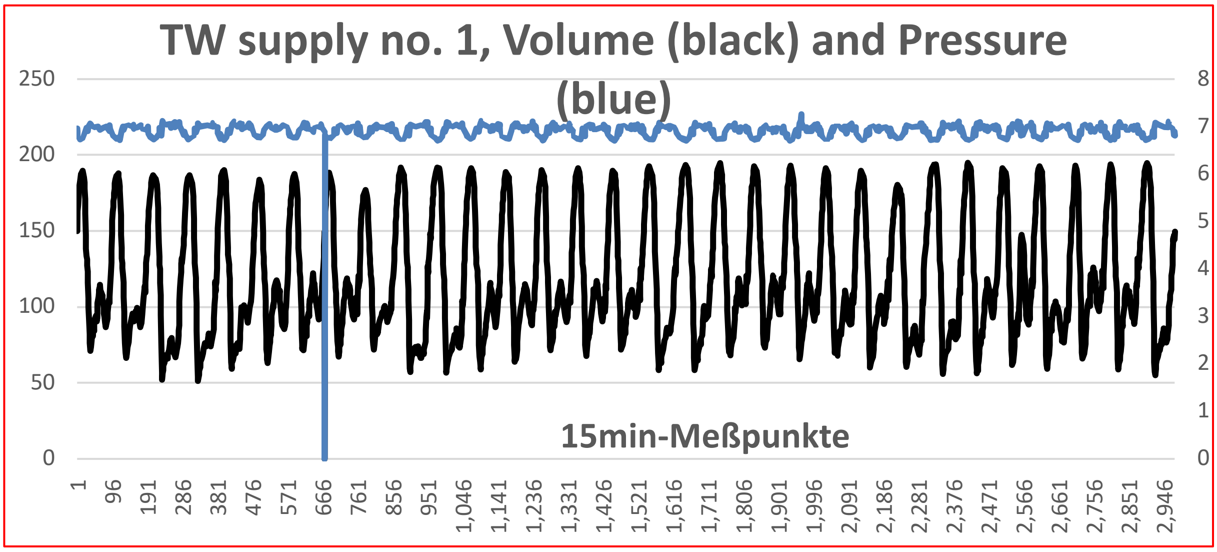


Figure 1:Monthly graph for the drinking water feeder 1

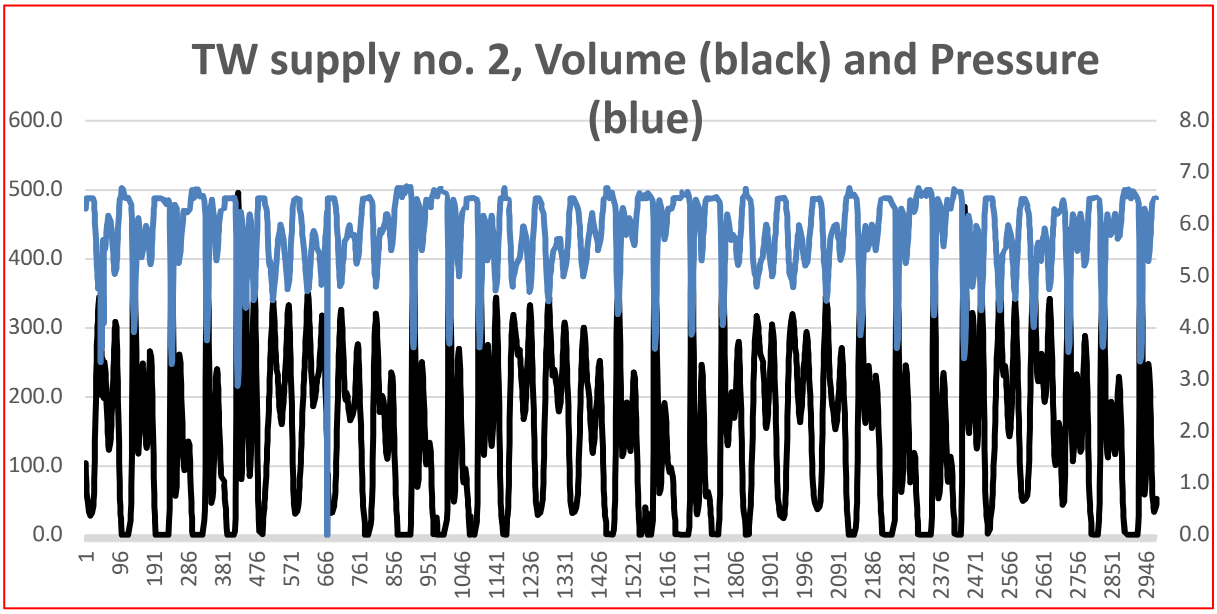


Figure 2: Monthly graph for the drinking water feeder 2

Figure 3 shows the total flow discharge (Q, blue) with an average line (black). In actual operation, the head (P) varies between 1.9 and 5.4 bar depending on the flow rate of 550 and 200 m^3/h. This corresponds to a hydraulic power of 23 kW at an operating point of e.g., 3.3 bar and 410 m^3/h.

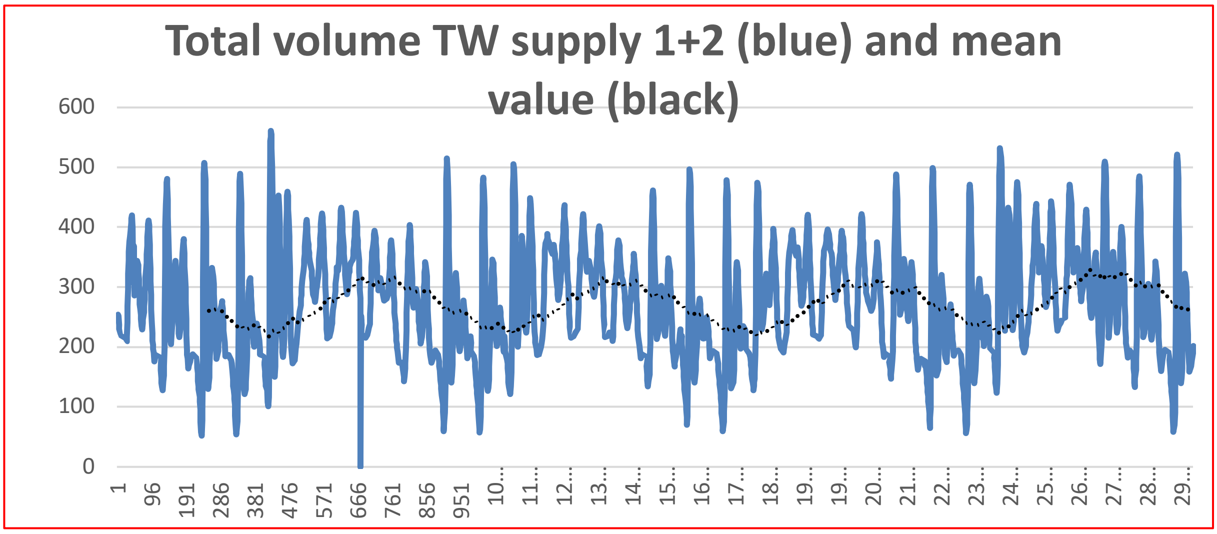


Figure 3: Depicts the total volume of drinking water supply with the average supply line.

2 Basic Technical Data

The technical data of the PaT, the generator, and the inverter unit are summarized below.

1. Off-the-shelf centrifugal pump, make KSB,
    - Type: Etanorm ETB 125-100-315 GBXAV11D303704 B

    Technical data:

    - Flow discharge: 262.00 m³/h
    - Head: 55.00 m
    - Efficiency: 80.1 %
    - Shaft power: 31.46 kW
    - Rated speed:1,520 1/min
    - Max. permissible operating pressure: 16.00 bar
    - Max. permissible torque: 256 Nm

2. Electric generator, make KSB
    - 45 kW synchronous reluctance machine
    - Due to its principle, a reluctance motor has a higher efficiency than an asynchronous motor and meets the efficiency requirements according to IE5.

3. Inverter power supply, make: Siemens
    - Active-Line-Modules and active Interface Modules
        - Input: 3AC 380-480V, 50/60Hz
        - Output: DC 600V, 92A, 55kW

    - Voltage SENSING Modules VSM10 and Control Unit CU320-2 PN

    - Single Motor-Modules
        - Input: DC 600V
        - Output: 3AC 400V, 200A

    - Braking Modules and Brake resistor

3 Centrifugal pump as turbine (PaT)

If a medium flows against the pumping direction from the discharge to the suction port, the direction of rotation of the impeller is reversed. If the pressure energy (head) applied to the discharge nozzle is high enough, this torque can be used to drive a generator. The pump delivers torque to the shaft. In the "3rd quadrant" of its characteristic diagram, the "pump as turbine" (PaT) then differs from the "real" water turbine only in that it usually does not quite achieve the efficiencies possible with classic Francis or Kaplan turbines. For comparison: Kaplan and Francis turbines have an efficiency of 84-90%, a PaT has 80%. In Figure 4, the principal characteristic curves for pump and turbine operation are compared. The curve "M = 0" indicates the no-load characteristic. No torque is taken from the shaft. The PaT rotates freely without braking. The curve "n = 0" is the fixed braking characteristic. Here, the machine is forced to flow through without the shaft rotating. Between these two limit curves, "normal" turbine operation takes place.

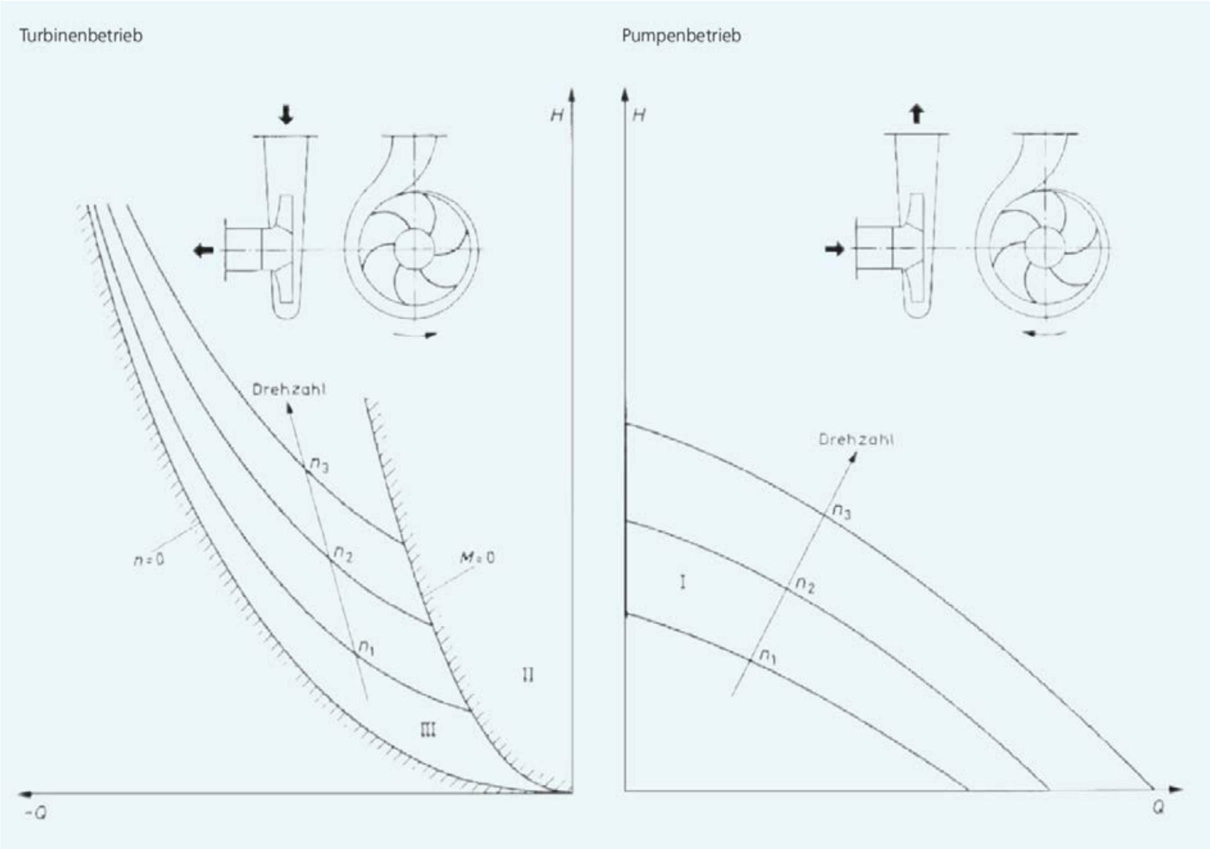


Figure 4:Characteristic curves for pump and turbine operation.

Source: Technik kompakt Nr. 11, Juli 2005 © KSB Aktiengesellschaft

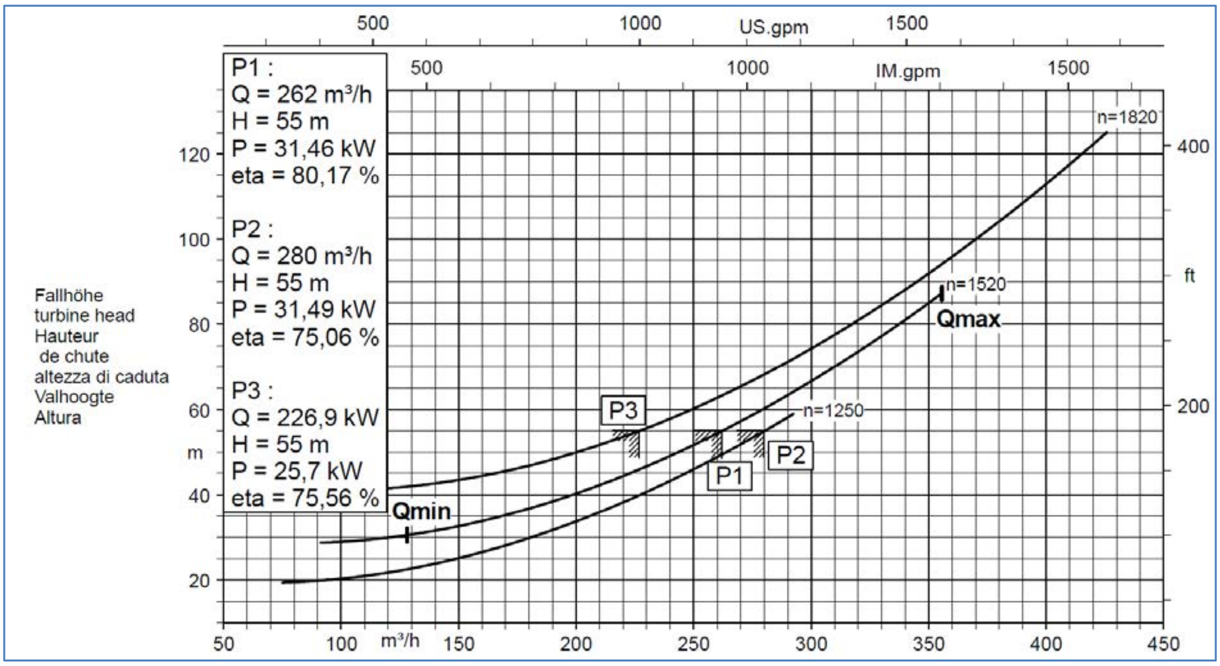


Figure 5: PaT characteristic diagram provided by KSB shows three operating points

The mains voltage is 3x400V/50 Hz, the reluctance machine is operated without a pulse encoder. KSB supplied a ready-to-use unit consisting of PaT and a motor.

Figures 6, 7, and 8 show the local installation conditions at the surge tank before (first picture) and after the conversion. The two feeds are clearly visible.

Figure 6: Before Installation condition at Surge tank

Figure 7:Condition at Surge tank after Installation

Figure 8: Condition at Surge tank after Installation

Optimal working range of the PaT:
The speed operating point of the PaT is specified as a function of the current head. The inverter feed controls the electrical generator to the specified speed and always feeds the mains with 50Hz despite different generator speeds. The specification of the optimum PaT speed is shown in Figure 9.

Figure 9: Optimum PaT speed versus inlet pressure

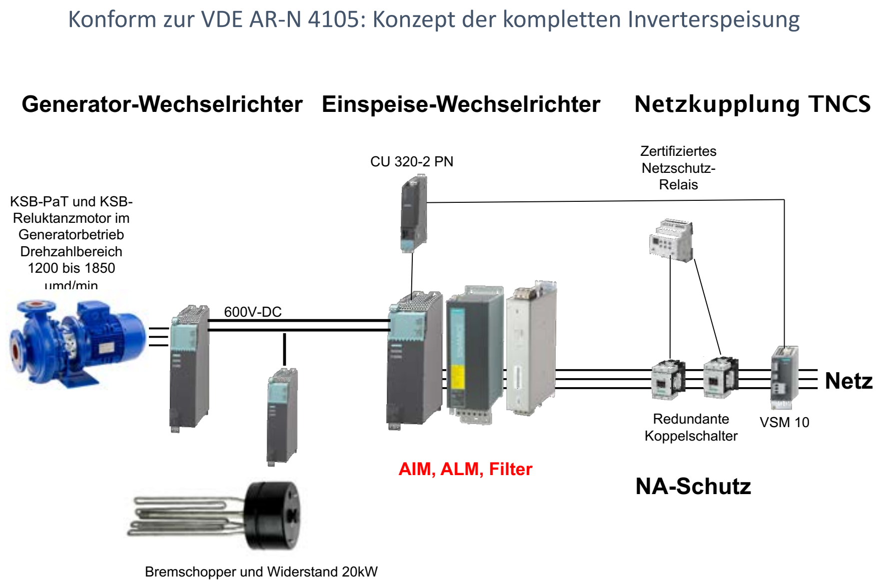


Figure 10: Shows the overall structure of the inverter feed

Error case: Load shedding, e.g., due to power failure

If an electric load is suddenly dropped from the PaT, the flow rate drops within fractions of a second. Figure 11 shows that in the event of a fault, the PaT changes to the no-load characteristic and there is a sudden reduction in the volume flow of approx. 135m³/h. This corresponds to -52% in a very short time. The consequence would be a pressure surge.

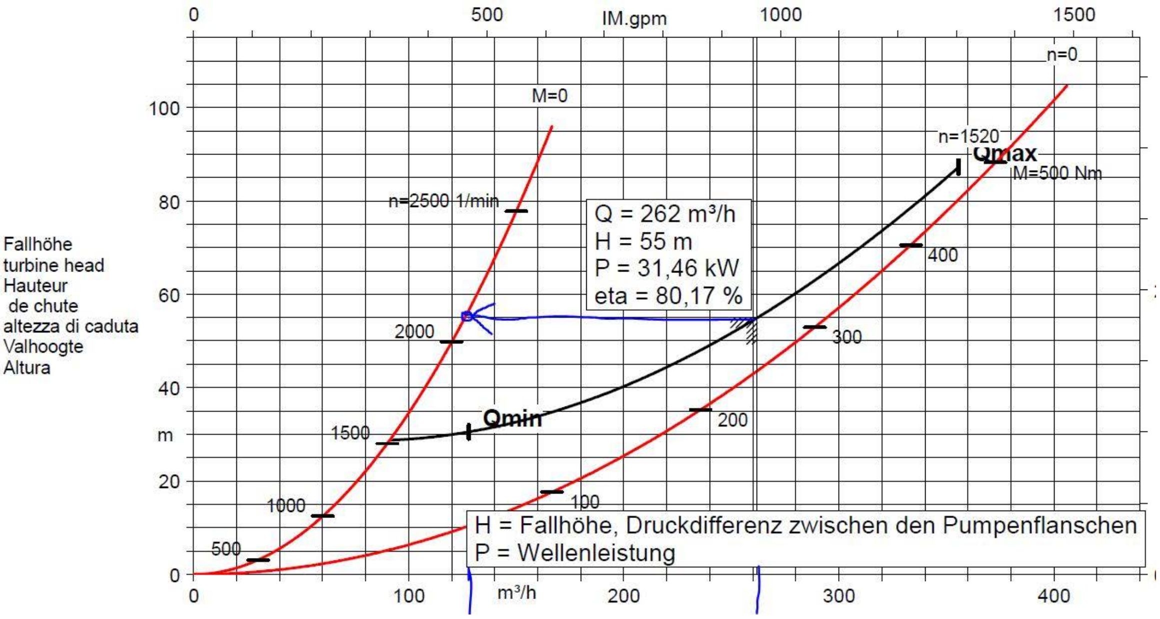


Figure 11:Graph depicting the behavior of PaT during the event of failure

A redundant system was realized to control the situation.

In the event of a power failure, the energy can be dissipated via resistors until the upstream motor valve is closed. This avoids a sudden change in speed and a water hammer effect. As a second measure, a weight-actuated quick-acting butterfly valve was installed upstream of the PaT and a quick-opening butterfly valve was installed in the bypass. The following Figure 12 shows such a flap.

Figure 12: Shows the flap installed at the Surge Tank

The grid protection was implemented in conformity with the feed-in regulations (VDE AR-N 4105).

There is secure communication with the telecontrol center of the public utility company via telecontrol protocol IEC 60870-5-104 via a secure VPN connection.

Conclusion

1) The housing of the synchronous reluctance machine is identical to that of a standard asynchronous machine with the squirrel-cage rotor. This facilitates its use. The price for a reluctance machine of this power is approx. 9% higher than a comparable IE3 asynchronous motor and 3% lower than a comparable IE4 asynchronous motor. The control system of the inverter (Sinamics-S120) with the KSB reluctance machine turned out to be quite smooth. Because of the better efficiency, the reluctance motor is an innovative alternative in generator plants.

2) The electrical power fed into the grid varies between 2.5 kW (bypass operation at 600 rpm and 1.9 bar) to 29.2 kW (normal operation at 1500 rpm and 6 bar).

3) The generator plant has been in operation for more than two years without any problems.

4) The drinking water supply was not affected at any time by the construction of the PaT plant.

5) The control of the PaT system was implemented with a WAGO 8216 controller. There is a secure data connection to the control room of the public utility company via VPN, compliant with 104.

We would like to thank KSB in Halle for their support in realizing the project and Stadtwerke Wernigerode for their kind permission to publish this text.

Image sources:

Image 1 to 12: Dr. Ecklebe Engineering GmbH