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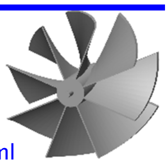

# Project "Generbine"

Underwater turbine, where one and the same part
forms the permanent magnetic rotor of a *gener*ator
and the hydraulically active blade wheel of a tur*bine*

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# Content

# Abstract

An underwater turbine is proposed of which the blade wheel is made of hard-magnetic material and takes up the function as rotor of a permanent-excited generator. This documentation shows a conceptual draft of a prototype. It provides an analysis of its hydraulic, electrodynamic and electric properties on a theoretical basis. A prospect for the detailed analysis and the further steps of development is given as well.

### *Patent application*

The basic principle of combining runner blades and permanent-magnetic rotor branches in one constructional part has been put in a European Patent Application [1]. However, it turned out that such a combination has been proposed before in a different way [2]. For that reason, the patent application of the generbine has been stopped, but of course it is now granted that no future patents will be able to obstruct the development of the generbine.

# 1. General concept

## 1.1 Principle design

The principle idea of the generbine is the use of one and the same construction element both as the blade wheel of a turbine and as the rotor of a generator. In concrete terms, this idea led on the hydraulic side to a propeller turbine with fixed blades, but running at variable speed. On the electric side, the generbine principally constitutes a permanent-magnetically excited synchronous generator. But, as we will see more detailed in section 1.2, the output frequency varies with speed and thus it has been preferred to rectify the produced electricity and use it as a direct voltage.

Figure 1 shows the construction principle in two sectional views from the front and from the side.

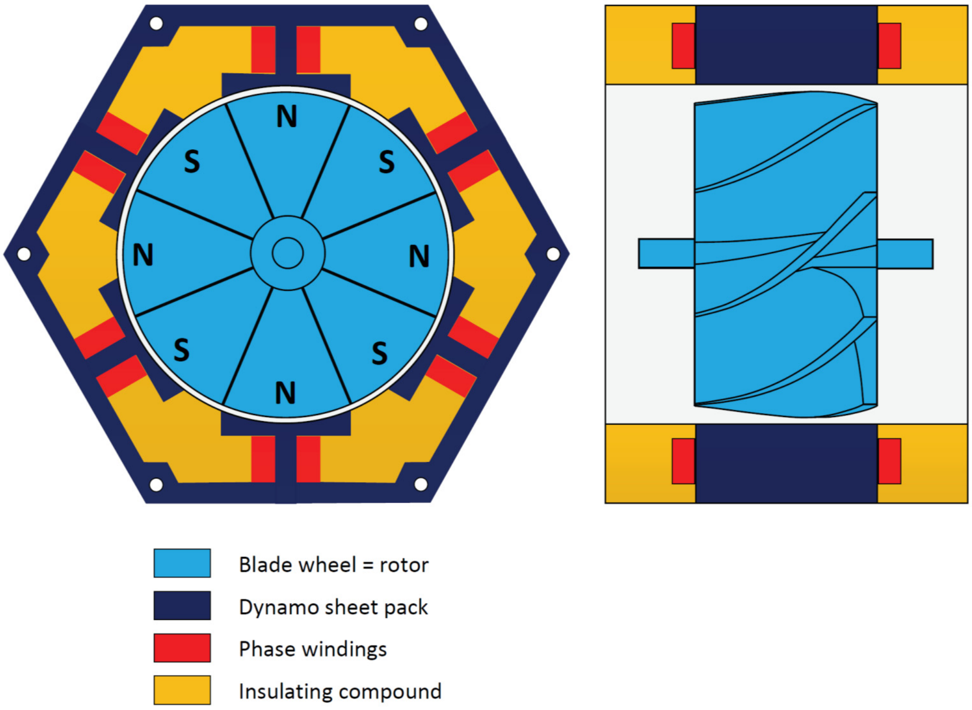


**Figure 1: Construction principle of stator and rotor**

The stator of the generbine consists, as usual in generator construction, of a packet of punched soft-magnetic dynamo sheets that are insulated against each other to minimize eddy-current losses. The windings are slipped on the stator pole branches.

The rotor, however, is manufactured of hard-magnetic material, which can in principle be done by casting, sintering, or injection molding processes (the latter in the case of plastic bonded materials). The discrete segments serve on the one hand as turbine blades, for which purpose their shape is optimized, e.g. following the shapes of fixed propeller turbine blades. On the other hand, they constitute the magnetic poles, which means that their number must be even and they have to be adapted to the requirements of an optimal magnetic circuit as well.

Evaluations have been made concerning the material of the rotor blades as well as the number of blades and the number of stator branches. The necessary compromise between hydraulic and electric performance led to the proposal of using $z_{Rot}$ = 8 rotor blades made of a (Fe-)Al-Ni-Co cast alloy. It may be necessary to coat the blades by an adequate material in order to achieve a sufficient corrosion resistance. – The proposed number of $z_{Stat}$ = 6 stator branches differs from the number of runner blades, which turns out to improve the quality of the produced electric power (see section 1.2 for more detail).

## *1.2 Electric circuit*

According to the theory of synchronous generators, each of the stator windings provides an alternating voltage. The amplitude as well as the frequency of this voltage increases proportionally to the speed of the rotor.

As already mentioned, the output will preferably be rectified. This is done by using one bridge rectifier for each winding. The rectifier outputs are then serially interconnected as shown in figure 2.

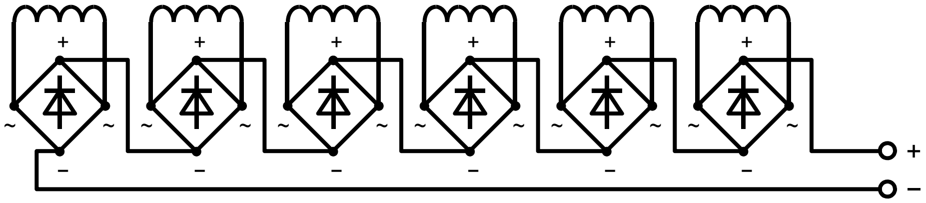


**Figure 2: Electric circuit of the stator windings**

Figure 3 shows first, in red, the timing function of the induced voltage in winding 1. It has the shape of trapezoidal pulses. The voltages on the other windings are not shown; they would be shifted by a phase angle of ($k$-1)·360°/$z_{Stat}$ ($k$ being the winding number) with regard to winding 1.

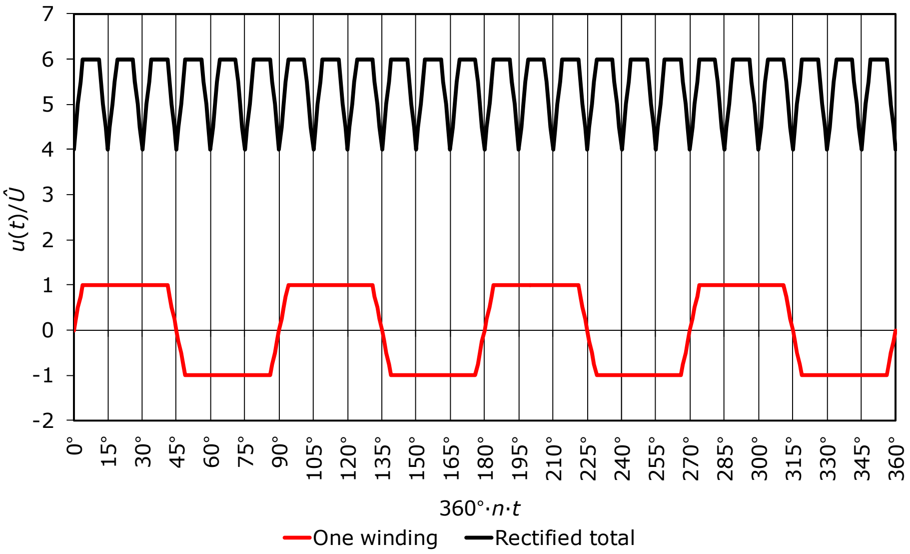


**Figure 3: Timing function of the induced voltage**

Behind the serially connected rectifiers, the total direct voltage shown in black results. It contains a component that pulsates with a frequency corresponding to the rotational speed, multiplied with the least common multiple of $z_{Stat}$ and $z_{Rot}$. Thus, differing numbers of rotor blades and stator branches increase the frequency of this ripple, which makes it easier to be reduced by a filter connected to the output of the generbine. Furthermore, a cleverly designed shape of the stator poles may even intrinsically reduce the ripple to almost zero.

## 1.3 Hydraulic behavior

As mentioned in section 1.1, the generbine is in fact a propeller turbine, but running at variable speed. Expressed in a simplified manner, the volume flow of the water determines the speed. When electric power is drawn, the runner is slowed down below the idle speed; the generbine opposes the volume flow by building up a pressure difference between inlet and outlet. This pressure difference can be covered as usual by a barrage providing the necessary head, or just by the dynamic pressure of the free flowing water as known from wind turbines.

Each of the known types of turbines is adapted to varying water flow by one or two adjustable parameters: the Pelton turbine by the throughput of the jet nozzles; the Francis, propeller, and Kaplan turbines by the angle of incidence of the guide vanes. The Kaplan turbine additionally provides adjustable runner blades in order to prevent the shock losses occurring at part-load operation of Francis and propeller turbines.

And the generbine? It is adapted to part-load operation by the varying speed. As mentioned, the runner blades are not adjustable, and section 1.4.1 will show that the use of guide vanes is recommended, but also in a non-adjustable design. However, theory shows that shock losses can perfectly well be avoided by solely adapting the speed to the water flow. Thus the generbine should theoretically provide a part-load performance that is nearly as good as the one of a fully adjustable Kaplan turbine. (Of course, the hydraulic efficiency will on the whole be poorer because of the partly contradictory hydraulic and electrodynamic requirements to be met by the blade shape. This is the price paid for the multiple use of the blades.)

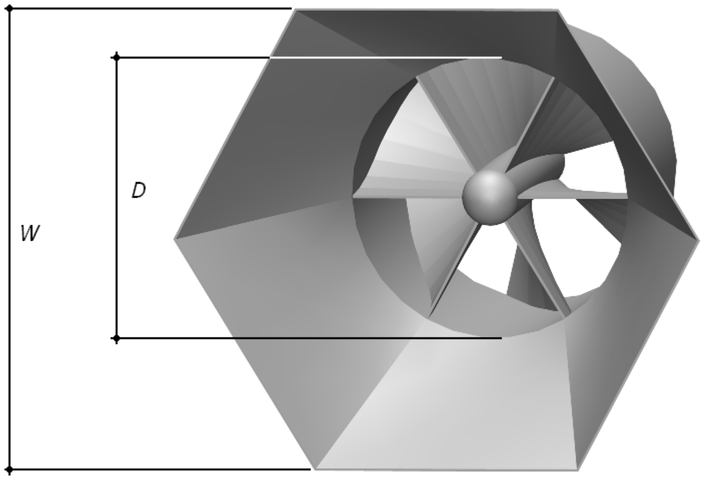
But how is the correct adaptation of the speed to a varying volume flow ensured? This is proposed to be done by a maximum-power-point tracking unit similar to that of a photovoltaic power plant: The electric load of the generbine (and thus its hydraulic resistance) is adapted such that the maximum of electric power is obtained.

It must be mentioned, however, that a generbine should never, ever be regulated to a certain volume flow or to a certain upstream water level. This can be done when using Kaplan turbines, because their guide vanes can be closed to a significant amount while the turbines still provide an acceptable efficiency. A generbine, however, could be slowed down to zero (which leads to zero power production) and would still let pass a great fraction of the nominal volume flow. – The generbine is not a regulation valve, but a device gathering energy, and as such has to be regulated to maximum power!

## 1.4 Balance of system

### 1.4.1 Inflow and outflow

An inflow nozzle provided with guide vanes will be used to improve hydraulic efficiency. The conic narrowing of the nozzle raises the flow velocity from the inlet to the generbine by the factor $r$ (see figure 4).



$$r = \frac{\frac{\sqrt{3}}{2}\cdot W^2}{\frac{\pi}{4}\cdot D^2} = \frac{2\cdot\sqrt{3}}{\pi}\cdot\left(\frac{W}{D}\right)^2$$

**Figure 4: Shape of the inflow nozzle including fixed guide vanes**

A corresponding diffuser, but without guide vanes, is used at the outflow side. The size of the outer hexagon is at least the size of the generbine itself, but may be chosen larger. By choosing a large factor *r*, meaning a large ratio *W*/*D*, inflow nozzle and outflow diffuser can adapt the generbine to slowly flowing waters. This is especially important in free circumfluent water, in order to gather sufficient volume flow to run the generbine in its optimum operating range.

At least on the inlet side, a grille should be provided that on the one hand protects the generbine from damage by solids floating in the water, and on the other hand prevents animals, especially fishes, from swimming in. This is also recommended on the outlet side. – Figure 5 shows the completely assembled device.

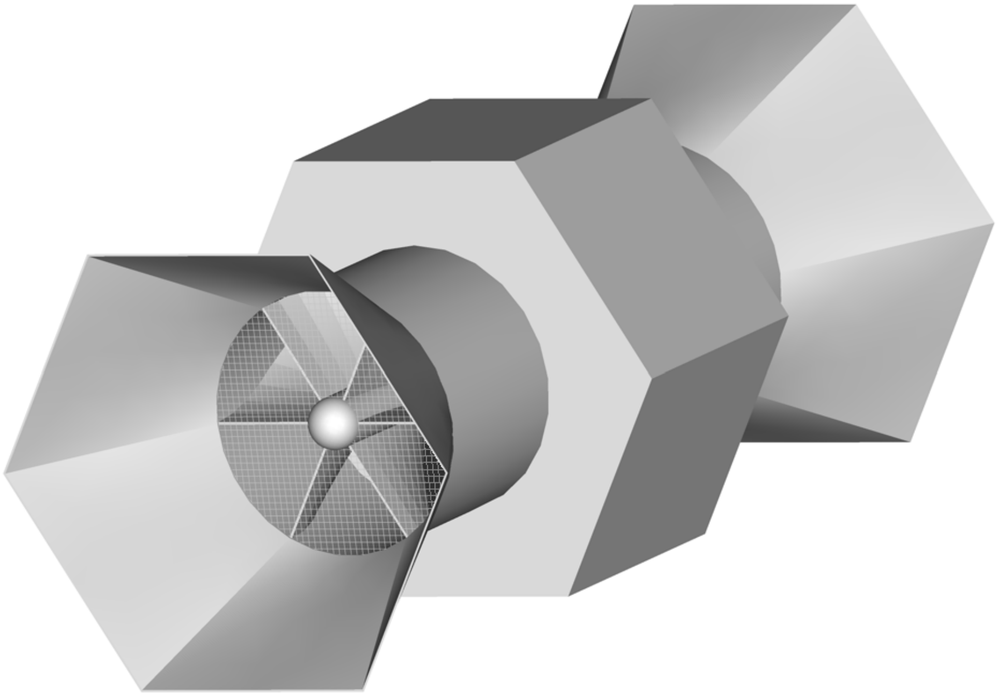


**Figure 5 Complete device consisting of: inflow nozzle with grille and guide vanes, the generbine itself, and the outflow diffuser**

### *1.4.2 Lining-up and electric interconnection of generbines*

According to the concept, larger hydroelectric plants are constructed in a modular way by lining up several generbines as shown in figure 6. As a result of the hexagonal shape, this is possible without gaps.

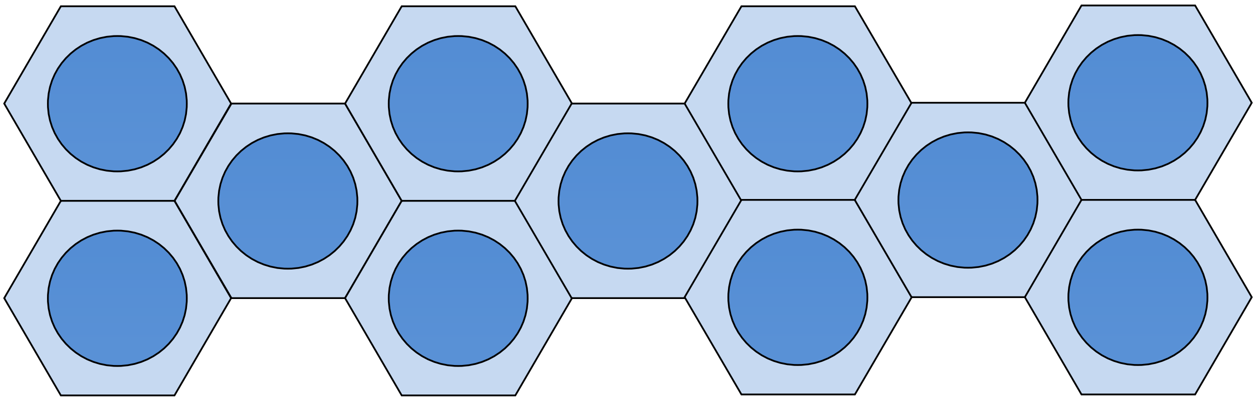


**Figure 6: Lining-up of generbines**

Concerning the electric interconnection, the best solution is to use one DC-DC converter per generbine or per group of generbines, which performs a maximum-power-point tracking as it is mentioned in section 1.3. The output is supplied to a DC bus, from which a further conversion to grid alternating voltage can take place. A corresponding concept is proposed in [3].

# *2. Dimensioning a first prototype*

## *2.1 Parameters of the generbine and their interdependences*

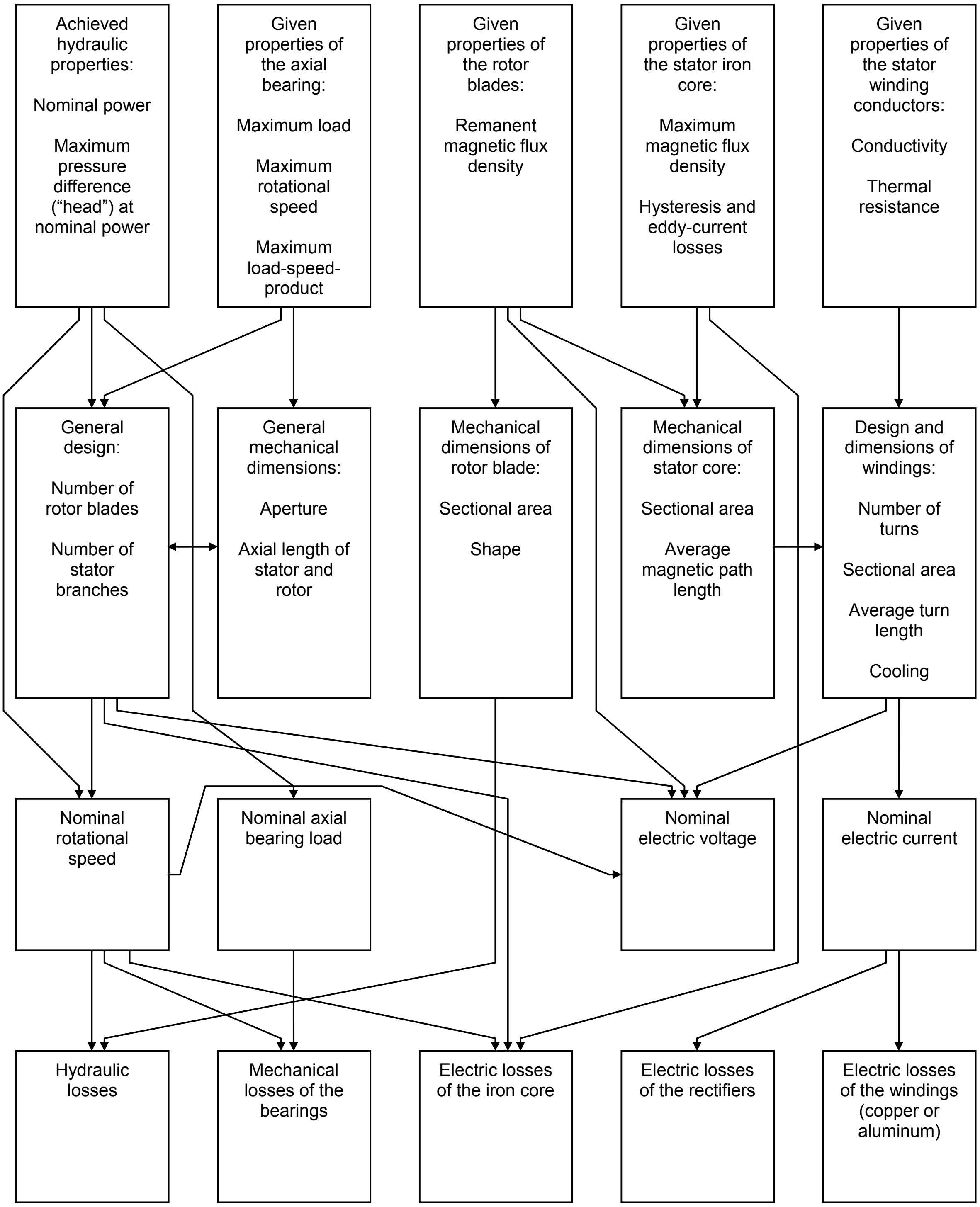


**Figure 7: Simplified interdependences between target or given properties (uppermost row), design or dimensioning quantities (middle rows), and resulting performance (lowest row)**

Figure 7 gives a first general idea of the complex interdependences between the different parameters of the generbine.

For the design and the dimensioning, several iterative calculation runs have been made in order to optimize the proposed prototype as far as it seemed possible on a merely theoretical basis.

The following design points were fixed at a certain stage of evaluation:

- The prototype will have an aperture diameter of 0.5 m. This will probably be the only size of the generbine in a series production, too, although the concept may principally be scaled to different sizes. (In fact, the evaluation has quite long been focused on an aperture of 1 m. However, a size of 0.5 m turned out to have a better mass-to-power ratio – in spite of a lower electric efficiency – probably leading to a better cost-to-benefit ratio, too.)
- As material for the runner blades, an Al-Ni-Co cast alloy is proposed, as already mentioned in section 1.1. It provides a remanent magnetic flux density of more than 1 Tesla, and is at the same time much more corrosion-resistant than rare-earth magnetic materials. The casting process allows to give the blades the twisted shape that is necessary for their hydraulic function.
- A number of $z_{Rot}$ = 8 runner blades and $z_{Stat}$ = 6 stator branches has been found to enable a quite simple and straight-forward construction of the magnetic circuits. Although a turbine optimized for the working area of the generbine (see section 2.2) would probably be equipped with fewer blades, the chosen number has been maintained as a good compromise between hydraulic and electrodynamic requirements.
- The construction of the stator core has also been fixed from the beginning; as mentioned in section 1.1, commercial-grade dynamo sheets will be used.

## 2.2 Shape and dimensions of the runner blades

Once the above mentioned parameters have been fixed, the dimension and shape of the single runner blade remain to be determined.

In order to get a sufficient magnetic flux in the air gap between rotor and stator, which determines the obtained electric power, a minimum cross-sectional area has to be maintained. This requires a minimum thickness, which should at that be constant (measured in axial direction) over the breadth of the blade in order to achieve a regular distribution of the flux. However, if the blade is made too thick, this will deteriorate the hydraulic efficiency.

The axial length and the overall shape of the blade can be determined according to hydraulic requirements. However, during the calculation runs, a further aspect came into sight: There emerged the possibility to use maintenance-free plastic plain bearings for the blade wheel, but only if the resulting axial load and especially the load-speed-product was not too high. So, certain requirements concerning pressure difference and rotational speed at full load had to be met in addition.

This led (at an aperture diameter of 0.5 m) to a runner blade of $L$ = 350 mm axial length, about $A_{Rot} \approx 5000$ mm² cross-sectional area, and a parabolic shape providing (at the perimeter) a blade exit angle of about $\beta_1$ = 47° (see figure 8, left).

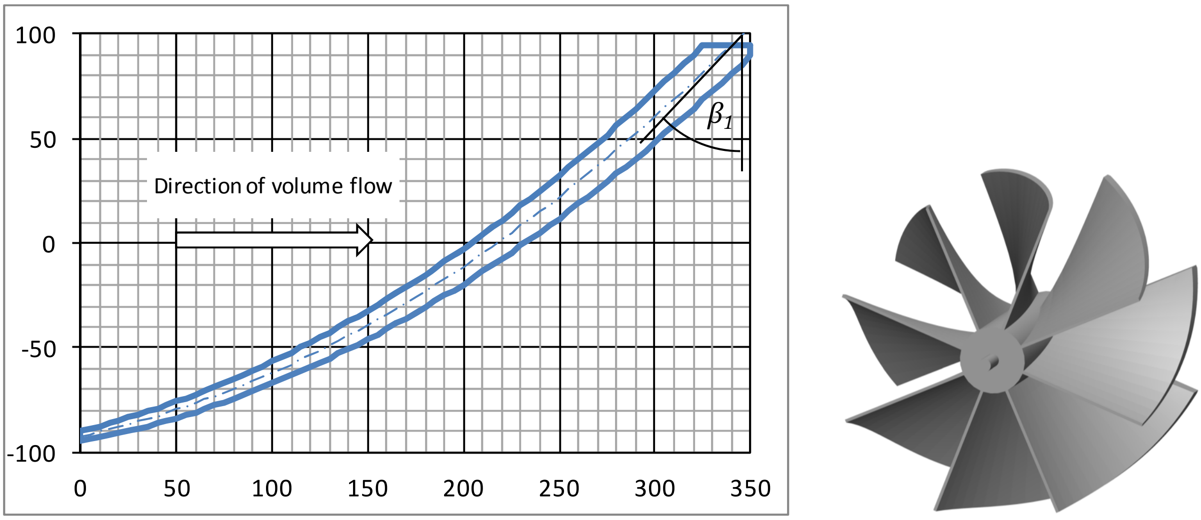


**Figure 8:** **Shape of the runner blades (left: shape of the blade perimeter; right: 3D-view of the blade wheel)**

The next figure shows the theoretical volume-flow/pressure-difference and volume-flow/power diagram, resulting for the so dimensioned and shaped blade wheel.

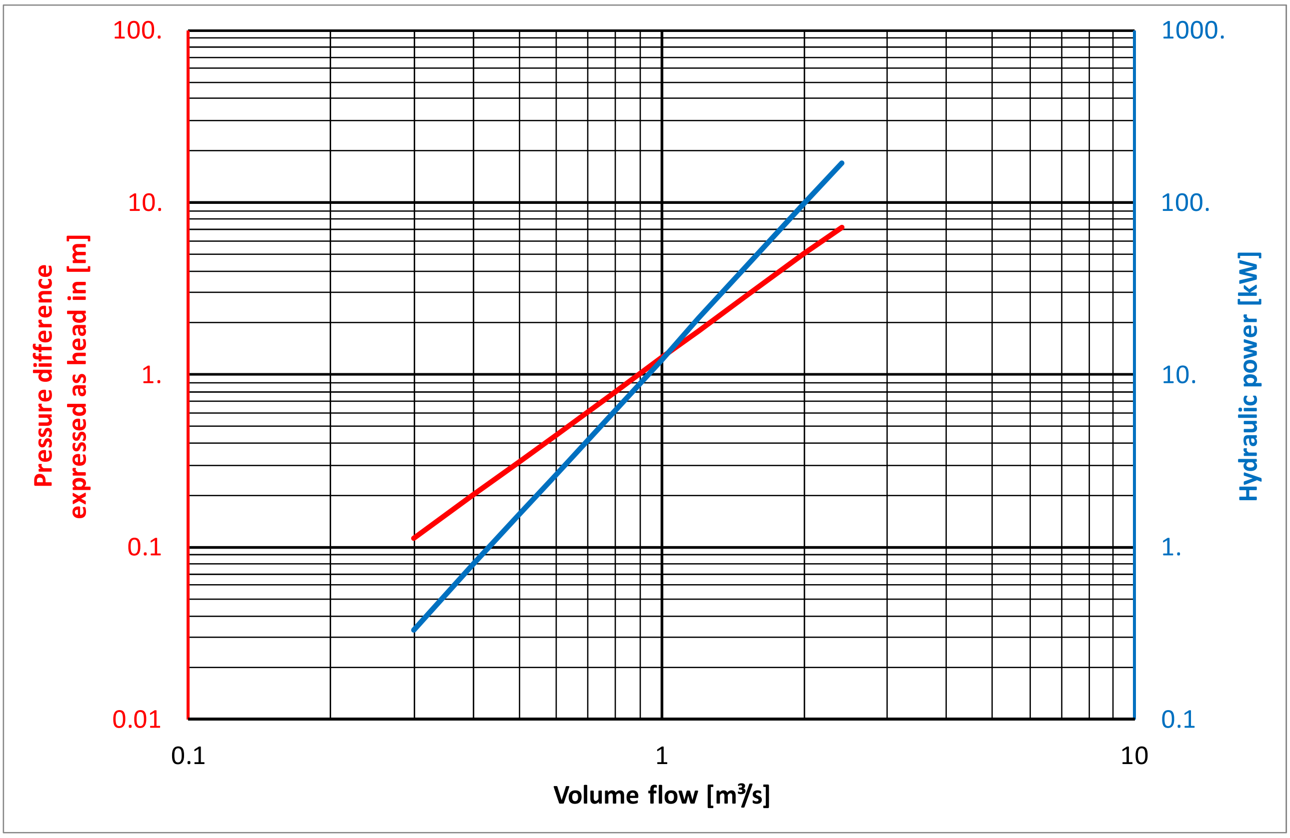


**Figure 9:** **Theoretical operating characteristic of the generbine in the volume flow / pressure difference diagram and the volume flow / power diagram**

According to figure 9, the generbine prototype will cover a volume flow range of about 0.3 to 2.4 m³/s. The corresponding head in this range is as low as 11 cm up to 7.2 m; maximum hydraulic power will theoretically be about 170 kW.

## 2.3 Calculation sheet

Generbine

Dimensioning

| ***Quantity*** | ***Symbol*** | ***Unit*** | ***Operating point*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* |
| Aperture diameter | $D$ | m | 0.50 | | | | | | | | | |
| Hub diameter | $D_{(i)}$ | m | 0.10 | | | | | | | | | |
| Axial length of stator and rotor | $L$ | m | 0.35 | | | | | | | | | |
| Blade exit angle | $\beta_1$ | ° | 47.5 | | | | | | | | | |
| Fixed guide exit angle | $\beta_5$ | ° | -47.5 | | | | | | | | | |
| Volume flow | $Q$ | $m^3s^{-1}$ | 2.40 | 2.00 | 1.50 | 1.20 | 1.00 | 0.80 | 0.60 | 0.50 | 0.40 | 0.30 |
| Flow area | $A$ | $m^2$ | 0.1885 | | | | | | | | | |
| Axial flow velocity | $c_m$ | $ms^{-1}$ | 12.7 | 10.6 | 8.0 | 6.4 | 5.3 | 4.2 | 3.2 | 2.7 | 2.1 | 1.6 |
| Operational speed @ irrotational flow off | $n$ | $s^{-1}$ | 7.4 | 6.2 | 4.6 | 3.7 | 3.1 | 2.5 | 1.9 | 1.5 | 1.2 | 0.9 |
| Runaway speed | $n_{max}$ | $s^{-1}$ | 14.9 | 12.4 | 9.3 | 7.4 | 6.2 | 5.0 | 3.7 | 3.1 | 2.5 | 1.9 |
| Density of water | $\rho_{H2O}$ | $kgm^{-3}$ | 1000 | | | | | | | | | |
| **Theoretical hydraulic Power** | $P_{th}$ | **kW** | **170.2** | **98.5** | **41.5** | **21.3** | **12.3** | **6.3** | **2.7** | **1.5** | **0.8** | **0.3** |
| Theoretical pressure difference | $\Delta p_{th}$ | kPa | 70.9 | 49.2 | 27.7 | 17.7 | 12.3 | 7.9 | 4.4 | 3.1 | 2.0 | 1.1 |
| Expected axial load | $F_{ax}$ | kN | 13.4 | 9.3 | 5.2 | 3.3 | 2.3 | 1.5 | 0.8 | 0.6 | 0.4 | 0.2 |
| **Bearing-friction loss (spec. work sheet)** | $P_{D,Bearing}$ | **kW** | **15.7** | **9.1** | **3.8** | **2.0** | **1.1** | **0.6** | **0.2** | **0.1** | **0.1** | **0.0** |
| **Mechanical efficiency** | $\eta_{Mech}$ | **1** | **0.91** | **0.91** | **0.91** | **0.91** | **0.91** | **0.91** | **0.91** | **0.91** | **0.91** | **0.91** |
| Number of runner blades | $z_{Rot}$ | 1 | 8 | | | | | | | | | |
| Cross section of rotor = air gap area | $A_{Rot}$ | $m^2$ | 0.0050 | | | | | | | | | |
| Magnetic pathlength in the rotor | $\ell_{Rot}$ | m | 0.250 | | | | | | | | | |
| Effective volume of the rotor | $V_{Rot}$ | $m^3$ | 0.0100 | | | | | | | | | |
| Density of the rotor material | $\rho_{Rot}$ | $kgm^{-3}$ | 7200 | | | | | | | | | |
| Effective mass of the rotor material | $m_{Rot}$ | kg | 72 | | | | | | | | | |
| Flux density in the air gap | $B_{Gap}$ | T | 1.25 | | | | | | | | | |
| Number of stator poles | $z_{Stat}$ | 1 | 6 | | | | | | | | | |
| Flux density in the stator dynamo sheets | $B_{Fe}$ | T | 1.50 | | | | | | | | | |
| Sectional area of the stator iron | $A_{Fe}$ | $m^2$ | 0.0042 | | | | | | | | | |
| Iron filling factor | $k_{Fe}$ | 1 | 0.90 | | | | | | | | | |
| Specif. loss of dynamo sheet (1.5 T / 50 Hz) | $p_{Fe1.5/50}$ | W/kg | 6.0 | | | | | | | | | |
| Stator branch width (yoke width = 1/2) | $b_{Fe}$ | m | 0.013 | | | | | | | | | |
| Average magnetic path length in the stator | $\ell_{Fe}$ | m | 0.702 | | | | | | | | | |
| Effective iron volume of the stator | $V_{Fe}$ | $m^3$ | 0.0175 | | | | | | | | | |
| Density of the stator dynamo sheets | $\rho_{Fe}$ | $kgm^{-3}$ | 7600 | | | | | | | | | |
| Effective mass of the stator dynamo sheets | $m_{Fe}$ | kg | 133 | | | | | | | | | |
| Frequency per stator pole | $f_W$ | Hz | 29.71 | 24.76 | 18.57 | 14.86 | 12.38 | 9.90 | 7.43 | 6.19 | 4.95 | 3.71 |
| Resulting pulse frequency | $f_{Puls}$ | Hz | 178.26 | 148.55 | 111.41 | 89.13 | 74.28 | 59.42 | 44.57 | 37.14 | 29.71 | 22.28 |
| **Iron losses** | $P_{D,Fe}$ | **kW** | **0.48** | **0.40** | **0.30** | **0.24** | **0.20** | **0.16** | **0.12** | **0.10** | **0.08** | **0.06** |
| Number of turns per winding | $N_{Cu}$ | 1 | 100 | | | | | | | | | |
| Induced voltage per winding | $\hat{U}_W$ | V | 74 | 62 | 46 | 37 | 31 | 25 | 19 | 15 | 12 | 9 |
| ditto @ runaway speed | $\hat{U}_{W,max}$ | V | 149 | 124 | 93 | 74 | 62 | 50 | 37 | 31 | 25 | 19 |
| Width of the winding | $b_W$ | m | 0.150 | | | | | | | | | |
| Height of the winding | $h_W$ | m | 0.035 | | | | | | | | | |
| Minimum turn length | $w_{Cu,min}$ | m | 0.73 | | | | | | | | | |
| Maximum turn length | $w_{Cu,max}$ | m | 1.01 | | | | | | | | | |
| Average turn length | $w_{Cu}$ | m | 0.87 | | | | | | | | | |
| Copper filling factor | $k_{Cu}$ | 1 | 0.75 | | | | | | | | | |
| Sectional area of copper | $A_{Cu}$ | $m^2$ | 0.0039 | | | | | | | | | |
| Density of copper | $\rho_{Cu}$ | $kgm^{-3}$ | 8900 | | | | | | | | | |
| Copper mass | $m_{Cu}$ | kg | 159 | | | | | | | | | |
| Insulating compound: contact area | $A_{th}$ | $m^2$ | 0.3206 | | | | | | | | | |
| Insulating compound: thickness | $h_{th}$ | m | 0.0020 | | | | | | | | | |
| Thermal conductivity | $\lambda_{th}$ | $Wm^{-1}K^{-1}$ | 0.9600 | | | | | | | | | |
| String current | $I_W$ | A | 381.8 | 265.1 | 149.1 | 95.5 | 66.3 | 42.4 | 23.9 | 16.6 | 10.6 | 6.0 |
| Current density | $J$ | $A/mm^2$ | 9.7 | 6.7 | 3.8 | 2.4 | 1.7 | 1.1 | 0.6 | 0.4 | 0.3 | 0.2 |
| Conductivity of copper, 120°C | $\kappa$ | $Sm^{-1}$ | 4.11E+07 | | | | | | | | | |
| Conductance of one winding | $G_{Cu}$ | S | 1.87E+01 | | | | | | | | | |
| **Winding losses** | $P_{D,Cu}$ | **kW** | **46.79** | **22.56** | **7.14** | **2.92** | **1.41** | **0.58** | **0.18** | **0.09** | **0.04** | **0.01** |
| Temperature increase | $\Delta T$ | K | 50.7 | 24.4 | 7.7 | 3.2 | 1.5 | 0.6 | 0.2 | 0.1 | 0.0 | 0.0 |
| Voltage drop per diode | $U_{F,Diode}$ | V | 1.00 | | | | | | | | | |
| **Rectifier losses** | $P_{D,Rect}$ | **kW** | **4.58** | **3.18** | **1.79** | **1.15** | **0.80** | **0.51** | **0.29** | **0.20** | **0.13** | **0.07** |
| **Electric effiency** | $\eta_{El}$ | **1** | **0.70** | **0.73** | **0.78** | **0.80** | **0.80** | **0.80** | **0.78** | **0.75** | **0.69** | **0.57** |

Operating parameter

Construction parameter

Material or physical constant

Others: Calculated values

**Table 1: Calculation worksheet for the generbine prototype**

Table 1 shows the worksheet used for the calculation runs. Starting from the construction principle shown in figure 1, the interdependences represented by figure 7 have been put into formulae. Thus the worksheet is an excellent tool for trying out several parameters and finding the optimum by a merely theory-based trial-and-error method. Even the worksheet itself has been subject to several improvements during this process.

In the end, one version of the generbine has been selected which will constitute the base of the prototype construction drawings. It has an aperture of 0.5 m (as mentioned before) and uses copper for the stator windings (a version using aluminum windings has also been evaluated). The resulting parameters are shown in table 1.

Hydraulic efficiency can not be calculated on a merely theoretical basis; once the prototype has been built, test runs will have to give information about that. However, the expected electric efficiency is listed in the worksheet. As winding losses dominate, maximum efficiency is reached far below the nominal power. In other words: From an electrodynamic point of view, the generbine will have a very good partial-load efficiency.

## 2.4 Magnetization of the rotor

For the magnetization of the rotor, an equipment must be available that is able to produce inside a sufficiently strong radial magnetic field with eight poles. Such an equipment is shown in figure 10.

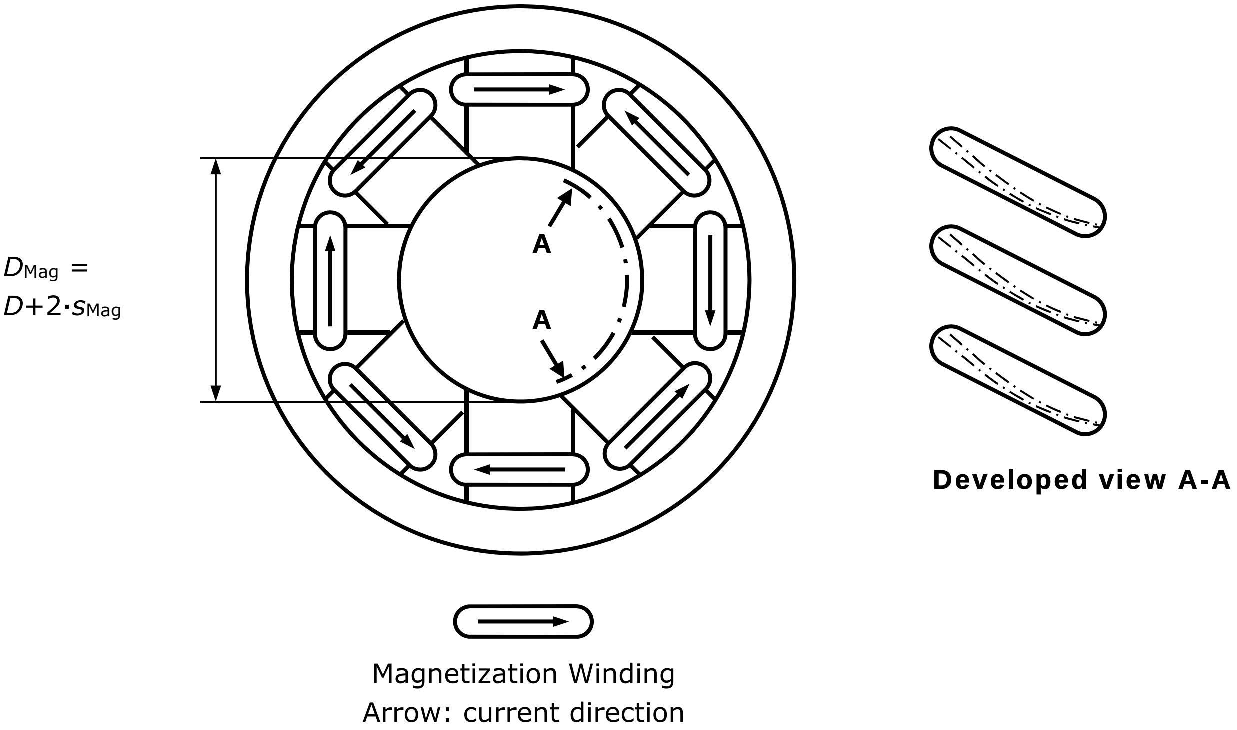


**Figure 10: Equipment for the magnetization of the rotor**

For the dimensioning of the magnetization unit, the following material and design properties of the generbine have to be considered:

- Aperture diameter $D$ of the generbine.
- Saturation flux density $B_s$ of the rotor blade material.
- Coercivity $H_c$ of the rotor blade material.
- Number of rotor poles $z_{Rot}$.
- Magnetic path length in the rotor poles $\ell_{Rot}$.
- Magnetic cross-sectional area of the rotor poles $A_{Rot}$.

From that follow the requirements to be met by the magnetization equipment:

- Shape and sectional area of the magnetization poles:
  The magnetization poles must at least cover the magnetic poles of the rotor (the latter ones shown by dash-dotted lines in the developed view of figure 10). In fact, their sectional area should be sufficiently larger than the one of the rotor poles to make sure that the soft-magnetic material works far enough below the range of saturation.
- Gap between the magnetization poles and the rotor poles, $s_{Mag}$:
  $s_{Mag}$ should not be too large (e.g. about equal to the gap of the generbine), such that the main part of the magnetomotive force becomes active in the rotor poles.
- Magnetomotive force ("ampere turns") in the pole windings of the magnetization equipment, $\theta$:
  $\theta$ should be chosen according to the manufacturer's data of the rotor material. Usually, the field strength in the rotor poles should reach about five times the coercivity. If the influence of the gap width can be neglected, it follows from that:
  $\theta > 5 \cdot H_c \cdot \ell_{Rot}$; at a coercivity of e.g. $H_c = 60$ kA/m and a magnetic path length of $\ell_{Rot} = 0.49$ m, this means $\theta > 147$ kA or about 150 000 ampere turns.

The magnetization can be achieved by a short current pulse.

Depending on the hard-magnetic properties of the rotor material, an open storage of the rotor may no longer be admissible after the magnetization, because the rotor might be partly demagnetized if the magnetic circuit is not closed. It is recommended to move the rotor by a controlled spinning from the magnetization equipment into a magnetic short-circuit collar, such that the rotor poles are continuously enclosed by soft-magnetic material. The rotor can then be stored in the collar for a long time, until it is definitely mounted by shifting it from the collar directly into the stator.

# *3. Questions to be answered by trial runs*

It has already been mentioned repeatedly, that the overall performance of the generbine can not be calculated based on theory alone. Thus, it will be necessary to build and test a prototype. Detailed dimension drawings are in work in order to enable its construction. However, the realization will only be possible as soon as an investor and manufacturer will be found.

In the following, the questions are listed that should be answered by trial runs using this prototype.

## *3.1 Confirmation of theory, go/no-go decision*

Of course, theoretical investigations can always contain faults, or relevant aspects may have been failed to notice. So, the first task will be to confirm the predictions of the theory. Secondly, the test runs have to provide information on the hydraulic efficiency of the prototype.

If there should be fatal errors in the theory, or the hydraulic efficiency seems too poor, this will be the last moment for a no-go decision. One will then have spent several hundred thousand Euro for an experience that hopefully has a scientific value but does not lead to an economically usable product. Of course, such risk is related to all true innovation, and the investor in question should be aware of that.

## *3.2 Material and shape of the runner blades*

### *3.2.1 Persistence of the blade wheel material*

As the blade wheel constitutes at the same time the permanent-magnetic rotor, the material selection is mainly given by the magnetic properties. However, some additional requirements have to be met due to the hydraulic function:

- Resistance against chemical corrosion by the river- or sea-water, respectively.
- Resistance against erosion by suspended particles in the water.
- Resistance against possible erosion by cavitation.

These requirements concern the surface of the material. There may therefore be the necessity of coating the base material that has been selected according to the magnetic properties.

### *3.2.2 Shape of the runner blades*

A special aspect of the generbine is that the blade thickness is fixed according to the second function of the blades as magnetic rotor poles. This makes it impossible to optimize the shape of the runner blades properly according to the hydraulic requirements. The shape proposed for the prototype is a first compromise. The prototype trial runs will show the hydraulic efficiency achieved so far, and build the basis of further improvements as explained in section 3.3.1.

## *3.3 Further optimization*

### *3.3.1 Optimization of performance*

As explained in section 2, the design of the proposed prototype has been optimized as far as it seemed possible on a merely theoretical basis. However, further improvements are very likely to be possible.

The prototype trial runs will provide a basis from where to start. As the construction of several modified prototypes will be quite expensive, their number should be limited. Numerical computer simulations, and/or downscaled model tests may be used instead. This will require cooperation with suited research centers; for that, public financial support is likely to be available.

### *3.3.2 Minimization of production effort*

A second field of optimization is of course the reduction of production effort, in other words minimization of production cost. This process is strongly related to the possibilities, the structure, the equipment, the know-how of the manufacturer in question. The only thing that can be said at this early stage, is that according to the concept, the generbine must become a mass product if it is to be an economical success. The manufacturer should be aware of that from the beginning.

# 4. Reference publications

[1] European Patent Office, 9th March 2011
Patent application EP 2 292 923 A2, Applicant: Blatter, Max
Title (German): Unterwasserturbine

[2] European Patent Office, 2nd February 2000
Patent application EP 0 977 343 A1, Applicant: Fukada, Mitsuhiro
Title: Permanent magnet generator

[3] Max Blatter:
Feeding into the grid of electric energy from distributed sources of variable power over a DC bus
Part 1: General concept for photovoltaic systems and small water and wind turbines of variable speed
Max Blatter, dipl. El.-Ing. ETH, Biel/Bienne, 2009