Use of the VIRYA-1 or the VIRYA-1.25AF for pumping of drinking water using a 12 V battery and a pump with a 12 V, DC motor

ing. A. Kragten

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Engineering office Kragten Design
Populierenlaan 51
5492 SG Sint-Oedenrode
The Netherlands
telephone: +31 413 475770
e-mail: info@kdwindturbines.nl
website: www.kdwindturbines.nl

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1 Introduction

The VIRYA-1 and the VIRYA-1.25AF windmills are described in a folder which can be copied from my website: www.kdwindturbines.nl at the menu VIRYA-folders. The folder is available in English and in Dutch.

Design calculations of the VIRYA-1 rotor and description of the PM-generator are given in report KD 608 (ref. 1). This report also contains drawings of the rotor and the generator. The VIRYA-1 makes use of the same head as used for the VIRYA-1.04 windmill. The drawings of the head are given in the manual of the VIRYA-1.04 (ref. 2).

Design calculations of the VIRYA-1.25AF rotor and description of the PM-generator are given in report KD 626 (ref. 3). This report also contains a drawing of the rotor and the armature sheet. The VIRYA-1.25AF makes use of a slightly modified head of the VIRYA-1.36. The drawings of the head are given in the manual of the VIRYA-1.36 (ref. 4). All mentioned reports and manuals can be found on my website at the menu KD-reports.

Both windmills are meant for 12 V battery charging. Both windmills are provided with an 8-pole axial flux PM-generator. The housing of this generator is made from the front wheel hub of a mountain bike. The VIRYA-1 generator has a stator sheet which is made from 4 mm phenolic fabric and therefore no eddy currents are generated in this sheet. This makes that the generator has a very low sticking torque which is only caused by the bearing friction. The VIRYA-1.25AF generator has a stator sheet which is made from 3 mm galvanised steel sheet and therefore the maximum torque level is higher but eddy currents are generated in the stator sheet. However, measurements given in chapter 9.4 of report KD 626 show that the increase of the sticking torque due to the eddy currents is acceptably low and that the rise of the stator temperature is only about 6° at the maximum rotational speed which happens in the windmill.

Only some preliminary tests have been performed for the generators of the VIRYA-1 and the VIRYA-1.25AF. A complete generator has not yet been measured and the P_{mech}-n and P_{el}-n curves which are used to check the matching in between rotor and generator are estimated. This means that the given P_{el}-V curves as given in the folder are estimated too.

To get more certainty about the P_{el}-V curves it is necessary to build a complete generator and measure it on a test rig for a 12 V battery load. I have such a test rig available. The test rig was originally designed to test a Chinese axial flux generator. The test rig is described in report KD 595 (ref. 5). The test rig has a reducing chain transmission from the driving motor to the generator. As the torque level of the VIRYA-1 or the VIRYA-1.25AF generator is much lower than for the tested Chinese generator, the VIRYA-1 or the VIRYA-1.25AF generator can be tested directly mounted to the shaft of the driving motor of the test rig. A coupling to connect the flange of the generator to the shaft of the driving motor has already been made, so testing is rather easy if the generator is available.

The generated power is stored in a 12 V battery. It is specified that this battery should have a capacity of at least 30 Ah for the VIRYA-1 and 60 Ah for the VIRYA-1.25AF. It is assumed that the maximum charging current is that low that no battery charge controller with dump load is needed to prevent over charging when the battery is full. However, it has to be checked in practice if this is really true. If the maximum charging voltage becomes higher than about 14 V, one must use a bigger battery or a battery charge controller is needed. A 200 W battery charge controller for a 24 V battery is described in a public manual (ref. 6). This battery charge controller can be modified for a 12 V battery. Then the maximum power which can be dissipated is only 180 W but this is certainly enough for the VIRYA-1.25AF. This modification is described in the end of chapter 6 of the manual.

The stored energy can be used to power small LED lamps or other small 12 V equipment. It might also be possible to power a small water pump if this pump is equipped with a 12 V, DC motor. Such pumps are manufactured by for instance the company Flojet. Selection of the correct pump is out of the scope of this report. Even a pump with the smallest motor will require an electrical power which is much larger than the power which can be supplied by the windmill at low wind speeds. So a battery will certainly be necessary.

So pumping takes place only during a short period and the energy generated by the windmill in the remaining hours is stored in the battery. To verify if the VIRYA-1 or the VIRYA-1.25 is large enough for water pumping, first the required daily pumping energy has to be determined.

2 Determination of the required daily pumping energy

The idea to use one of the small VIRYA-windmills for water pumping was initiated by a teacher of a Dutch technical school who wants to stimulate people in Gambia to pump drinking water by locally manufactured small wind turbines. He told me that the water was pumped from hand dug open wells for which the average water level is about 10 m deep. But the maximum water level is about 15 m deep. I assume that the water is pumped in a reservoir which is positioned about 2 m above ground level so the maximum total height H = 17 m.

I have no idea of the amount of drinking water which is required per person per day in Gambia so first I have investigated what is used in The Netherlands and compared that with my own use. I live together with my wife so we have a 2-persons household. The Dutch average use for a 2-persons household is 93 m^3 per year. Our use is about 48 m^3 per year so far below the average. We use the water for drinking, washing and cooking of food, washing of clothes, showering, toilet flushing and during dry periods for the vegetable garden. Our rather low water use is mainly realised by minimising the use of toilet water and short showering periods. 48 m^3 per year for a 2-persons household means about 66 litre per day per person.

If there is shortage of water or of energy to pump water, one must be more economical with water than we are. I think that if 40 litre water is available per person per day one still can have a comfortable life. Assume a family in Gambia has about five members so one needs about 200 litres of water per day per family. It doesn’t mean that the reservoir must have a capacity of 200 litres. May be 20 litres is enough. It might even be possible to cancel the whole reservoir if the flow of the pump is large enough. Assume that 200 litres per day has to be pumped by one wind turbine per family. The required hydraulic power P_{hyd} to pump a certain flow of water q upwards against a height H is given by the formula:

$$P_{hyd} = \rho_w * g * H * q \quad \text{(W)} \qquad (1)$$

In this formula, the hydraulic power P_{hyd} is the potential power which the water has gained after lifting up to the height H. So P_{hyd} is not the electrical power needed to drive the pump motor. ρ_w is the density of water which is 1000 kg/m^3. g is the acceleration of gravity which is 9.81 m/s^2. H is the static height and it was chosen that H = 17 m. q is the flow in m^3/s. It was estimated that one needs 200 litres of water per day so 0.2 m^3 per day. A day has 3600 * 24 = 86400 seconds. So the flow q = 0.2 / 86400 = 0.000002315 m^3/s. Substitution of these values in formula 1 gives that P_{hyd} = 0.386 W. This is a very low hydraulic power.

The hydraulic energy E_{hyd} which the amount of water has gained during a certain time t is given by:

$$E_{hyd} = P_{hyd} * t \quad \text{(Joule or Ws)} \qquad (2)$$

In the formula t is the time in seconds. Assume that the pumping time is one day so t = 3600 * 24 = 86400 s. Substitution of P_{hyd} = 0.386 W and t = 86400 s in formula 2 gives that E_{hyd} = 33350 Joule.

The average electrical power P_{el} which has to be produced by the windmill is much higher than P_{hyd} because of the pump efficiency η_p, the pump motor efficiency η_m and the battery efficiency η_b. The efficiencies are taken as a factor of 1, so not as a percentage. It is assumed that the pump is pumping only during some minutes a day. So almost all the needed energy is extracted from the battery.

The energy which is directly supplied by the windmill and not stored in the battery, is neglected. P_{el} is given by:

$$P_{el} = P_{hyd} / (\eta_p * \eta_m * \eta_b) \qquad (3)$$

If a small pump of manufacture Flojet is chosen, this pump will be equipped with three diaphragms. Such a pump will have an efficiency of about 0.6. Assume that the pump motor has an efficiency of 0.7. Assume the battery has also an efficiency of 0.7. The cable losses are neglected. Substitution of these values and P_{hyd} = 0.386 W in formula 3 gives that P_{el} = 1.31 W. This is still a very low power. The electrical energy E_{el} which is needed during a certain time t is given by:

$$E_{el} = P_{el} * t \qquad \text{(Joule)} \qquad (4)$$

In the formula t is the time in seconds. Assume the pumping time is one day so t = 3600 * 24 = 86400 s. Substitution of P_{el} = 1.31 W and t = 86400 s in formula 4 gives that E_{el} = 113184 Joule. This is a low amount of energy and it can be expected that even the VIRYA-1 can generate this energy in one day at low wind speeds.

3 Determination of the generated daily windmill energy

The P_{el}-V curves of the VIRYA-1, the VIRYA-1.04 and the VIRYA-1.25AF are given on the left graph at the first page of the folder. This graph is copied as figure 1.

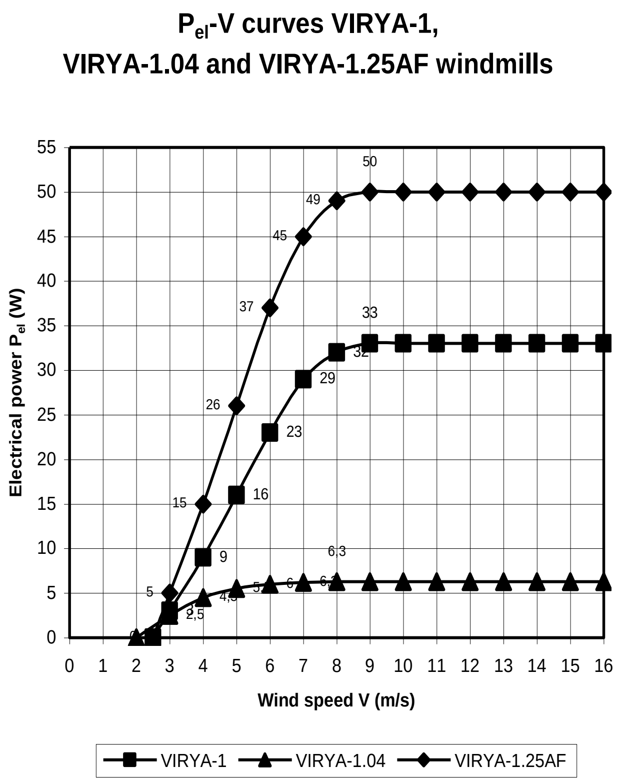

fig. 1 P_{el}-V curves of the VIRYA-1, the VIRYA-1.04 and the VIRYA-1.25AF

In figure 1 it can be seen that the P_{el}-V curve of the VIRYA-1.04 starts already at a cut-in wind speed of 2 m/s. The P_{el}-V curves of the VIRYA-1 and the VIRYA-1.25AF have a cut-in wind speed of 2.5 m/s. The maximum power of the VIRYA-1.04 is 6.3 W at a rated wind speed of 8 m/s. The maximum power of the VIRYA-1 is 33 W at a rated wind speed of 9 m/s. The maximum power of the VIRYA-1.25 is 50 W at a rated wind speed of 9 m/s.

The electrical power P_{el} at a certain constant wind speed V can be read in the graph for every wind speed. The wind speed at a certain place will vary continuously and depends on the season and the day but also on the height of the tower. Sometimes the average wind speed is known for a certain season. As water is a basic need, one has to choose the season with the lowest average wind speed for the calculation of the windmill power. The generated energy in a certain time for a certain average wind speed is higher than for the same constant wind speed because the P_{el}-V curve isn't a straight line through the origin. The difference depends on the fluctuation of the wind speed and on the difference in between the average wind speed and the cut-in wind speed. This effect is explained using the P_{el}-V curve of the VIRYA-1.

Assume we have a constant wind speed of 4 m/s. In figure 1 it can be read that P_{el} = 9 W. Assume we have an average wind speed of 4 m/s and the wind speed is 3 m/s for half the time and 5 m/s for half the time. P_{el} = 3 W for V = 3 m/s and P_{el} = 16 W for V = 5 m/s. So the average value of P_{el} = (3 + 16) / 2 = 9.5 W. This is 0.5 W higher than for a constant wind speed of 4 m/s. Assume we have an average wind speed of 4 m/s and the wind speed is 2 m/s for half the time and 6 m/s for half the time. P_{el} = 0 W for V = 2 m/s and P_{el} = 23 W for V = 6 m/s. So the average value of P_{el} = (0 + 23) / 2 = 11.5 W. This is 2.5 W higher than for a constant wind speed of 4 m/s.

Assume we have a constant wind speed of 3 m/s. In figure 1 it can be read that P_{el} = 3 W. Assume we have an average wind speed of 3 m/s and the wind speed is 2 m/s for half the time and 4 m/s for half the time. P_{el} = 0 W for V = 2 m/s and P_{el} = 9 W for V = 4 m/s. So the average value of P_{el} = (0 + 9) / 2 = 4.5 W. This is 1.5 W higher than for a constant wind speed of 3 m/s. Assume we have an average wind speed of 3 m/s and the wind speed is 1 m/s for half the time and 5 m/s for half the time. P_{el} = 0 W for V = 1 m/s and P_{el} = 16 W for V = 5 m/s. So the average value of P_{el} = (0 + 16) / 2 = 8 W. This is 5 W higher than for a constant wind speed of 3 m/s.

Assume we have a constant wind speed of 2 m/s. In figure 1 it can be read that P_{el} = 0 W. Assume we have an average wind speed of 2 m/s and the wind speed is 1 m/s for half the time and 3 m/s for half the time. P_{el} = 0 W for V = 1 m/s and P_{el} = 9 W for V = 3 m/s. So the average value of P_{el} = (0 + 9) / 2 = 4.5 W. This is 4.5 W higher than for a constant wind speed of 2 m/s and even 1.5 W higher than for a constant wind speed of 3 m/s. Assume we have an average wind speed of 2 m/s and the wind speed is 0 m/s for half the time and 4 m/s for half the time. P_{el} = 0 W for V = 0 m/s and P_{el} = 16 W for V = 4 m/s. So the average value of P_{el} = (0 + 16) / 2 = 8 W. This is 8 W higher than for a constant wind speed of 2 m/s and even 5 W higher than for a constant wind speed of 3 m/s. So even if the average wind speed is lower than the cut-in wind speed, some power will be generated because of the fluctuation of the wind speed!

The values of P_{el} are now read in figure 1 for the VIRYA-1, the VIRYA-1.04 and the VIRYA-1.25 windmills and for constant wind speeds V of 3, 4 and 5 m/s. The electrical energy E_{el} is calculated using formula 4 for a period of one day, so for t = 86400 s. The result of the calculations is given in table 1.

	V = 3 m/s		V = 4 m/s		V = 5 m/s	
	P_{el} (W)	E_{el} (Joule/day)	P_{el} (W)	E_{el} (Joule/day)	P_{el} (W)	E_{el} (Joule/day)
VIRYA-1	3	259200	9	777600	16	1382400
VIRYA-1.04	2.5	216000	4.5	388800	5.5	475200
VIRYA-1.25AF	5	432000	15	1296000	26	2246400

Table 1 Read values of P_{el} (W) and calculated values of E_{el} (Joule/day) for three different windmills and three different constant wind speeds

In chapter 2 it was calculated that the required electrical energy E_{el} = 113184 Joule/day. So even the VIRYA-1.04 is able to generate this energy easily at a constant wind speed of only 3 m/s so at an average wind speed which may be lower than 2 m/s. But I advise to build at least the VIRYA-1 because for this windmill, a lot of energy is left for other goals than water pumping or one can pump the required amount of water from deeper wells.

4 Determination of the battery capacity

Information about lead sulphuric acid batteries is given in chapter 3 of report KD 378 (ref. 7). The capacity of a 12 V battery is normally given in Ah for a discharge time of 10 hours. This means that a 60 Ah battery is discharged with a current I = 6 A during 10 hours and that the minimum discharge voltage of about 10.6 V is reached at the end of the discharge time. The capacity is larger if the battery is discharged with a smaller current during a longer time and smaller if the battery is discharged with a larger current during a shorter time. The average discharge voltage U_{av} for a discharge time of 10 hours is about 11.3 V. The available energy E_a in Joule or Ws is given by formula 11 of KD 378 which is copied as formula 5.

$$E_a = I * U_{av} * 36000 \quad \text{(Joule)} \qquad (5)$$

The battery must be chosen as large as possible for three reasons. The first reason is that one must be able to bridge a long windless period. The second reason is that the charging voltage may not become too high if the battery is full and if no battery charge controller is used. The VIRYA-1 has a maximum power of about 33 W. This means that the maximum charging current is about 2.75 A for a charging voltage of 14 V. The bigger the battery, the lower the charging voltage will be for a full battery for this charging current. The third reason is that the discharge current must be not too high otherwise the battery efficiency becomes too low. The discharge current depends on the chosen pump and pump motor and on the height H for which it is used.

Assume a 60 Ah battery is chosen which is discharged in 10 hours, so I = 6 A. Substitution of I = 6 A and U_{av} = 11.3 V gives that E_a = 2440800 Joule. In chapter 2 it was calculated that the required hydraulic energy E_{hyd} = 33350 Joule. The electric energy which is needed by the pump motor E_{elpm} is given by:

$$E_{elpm} = E_{hyd} / (\eta_p * \eta_m) \quad \text{(Joule)} \qquad (6)$$

Substitution of E_{hyd} = 33350 Joule, η_p = 0.6 and η_m = 0.7 in formula 6 gives that E_{elpm} = 79405 Joule. So this is lower than the energy E_{el} = 113184 Joule which has to be supplied daily by the generator but that’s because the battery efficiency is not taken into account if the battery capacity is taken. The available energy in a full 60 Ah battery is a factor 2440800 / 79405 = 30.7 larger than the required daily energy for water pumping. So a 60 Ah battery can bridge a period of 30.7 days if no other energy is taken from the battery than for water pumping and if the battery has no self discharge. This is a very long period and it might be allowed to take a smaller battery if bridging a wind still period was the only criterion to select the battery capacity. However, a smaller battery may require a battery charge controller and the extra costs of this device may completely neutralise the lower costs of a smaller battery. As the windmill won’t be used only for pumping water, it is nice to have a big battery which allows the use of other equipment during windless periods.

5 References

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