Ideas about a small 34-pole permanent magnet generator for a small windmill or for human power, using the stator stamping of a 6-pole asynchronous motor frame size 80 and 17 neodymium magnets size 40 * 7 * 3 mm

ing. A. Kragten

March 2015

KD 580

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

Contains page

1 Introduction

One of the most critical parts of a small wind turbine is the generator. As far as I know, simple and cheap direct drive 3-phase permanent magnet (PM) generators with a low clogging torque are not available on the market. For my current range of VIRYA windmills I therefore have developed a range of PM-generators. These generators are derived from standard asynchronous 4-pole, 3-phase motors by replacing the original shaft and short-circuit armature by a stainless steel shaft and a mild steel armature which is provided by neodymium magnets. These generators are described in report KD 341 (ref. 1). These generators are very strong and have good characteristics. The clogging torque is not fluctuating because the armature poles are making a certain angle with the axis. This facilitates starting of the rotor at low wind speeds. However, these generators are rather difficult to manufacture and rather expensive, especially if a western motor housing is used.

Strong fluctuation of the clogging torque can also be prevented by choosing a large pole number and if the number of stator poles differs only 2 from the number of armature poles. A 34-pole PM-generator of this kind is described in general in chapter 6 of KD 341 (ref. 1) and in detail in report KD 560 (ref. 2). A high armature pole number is needed if the generator is meant to generate a high voltage and frequency which is directly used to power an asynchronous motor. This 34-pole generator is designed for the VIRYA-3.3S windmill which is primary meant to be coupled to a 0.55 kW, 3-phase motor of a centrifugal pump. However, the generator can also be used for battery charging if it is provided with a low voltage winding. A prototype of this generator is built at this moment by an Indian company but the generator has not yet been tested.

A 22-pole PM-generator using the same principle, is designed for the VIRYA-1.46 windmill. This generator is described in report KD 553 (ref. 3). A prototype of this generator has been built. This generator has 264 preference positions per revolution and some fluctuation of the clogging torque can still be felt.

A small PM-generator can also be driven by human power to charge a 12 V battery. A 12-pole hand wheel generator meant for this goal is described in report KD 404 (ref. 4). A prototype of this generator has been built already in 2008 using an Indian stator stamping. This generator has 36 strong preference positions per revolution on the clogging torque. Preference positions are very unfavourable for a windmill generator because the peak torque results in a high starting wind speed. It was thought that a high peak torque was no problem if the generator is hand driven and in fact the large peak torque could easily be supplied. However, the strong fluctuation of the torque resulted in a strong vibration and in noise and therefore it was unpleasant to drive the generator by hand. This was the reason why the idea was cancelled.

The 34-pole PM-generator as described in report KD 560 has 612 preference positions per revolution and for these many preference positions, the fluctuation on the clogging torque will be almost flattened. So the idea is to develop a small 34-pole PM-generator which can be used for a small windmill for 12 V or 24 V battery charging but which can also be used as hand wheel generator for 12 V battery charging. It may be even be used on 230 V, 50 Hz with a high voltage winding and driven by an accelerating chain transmission and pedal power.

2 Description of the generator

For the stator stamping it is chosen to select a stamping from the catalogue of the German manufacturer Kienle & Spiess. The catalogue can be found on the website: www.kienle-spiess.de following the path motoren/generatoren - induction machines - link zum catalogue. It is chosen to use a IEC stamping of a 6-pole motor frame size 80. This stamping is available in two versions IEC 80/6-8.80 with 30 armature grooves and IEC 80/61.80 with 26 armature grooves.

The stator stampings of both versions are identical and have 36 stator grooves so 36 stator poles. As only the stator stamping is used for the PM-generator, both versions can be used. This stamping has an outside diameter of 120 mm and an inside diameter of 80 mm. The stamping is provided with six 3.05 mm holes at 60° and at a pitch circle of 115 mm. Six 3 mm threaded pins and 12 Nuts M3 will be used to clamp all laminations together and to connect the stator to the front and the back bearing cover. As the outside of the stamping is in direct contact with the open air, it is covered by epoxy to prevent rust.

The stamping is normally used for a 6-pole asynchronous motor frame size 80 with a nominal power of 0.37 or 0.55 kW. The stator length for a 0.37 kW motor is 70 mm and for a 0.55 kW motor is 90 mm. For the PM-generator it is chosen to use a stator length of 40 mm. It is expected that a stator with a length of 40 mm can be supplied by the manufacturer if the ordered quantity is large enough. For a prototype it might be needed to use a 70 mm or 90 mm long standard stamping and to cut a 40 mm long piece from it.

The stator winding is a so called 1-layers winding. This means that the winding has no crossing coil heads. A coil is laid around one stator spoke and the coil heads are therefore very small. The width of the bearing covers can therefore be only 20 mm. The 3-phase winding is given in figure 1. For every phase there are two bundles of three coils. The coil configuration over 360° is: 3 coils U, 3 coils W, 3 coils V, 3 coils U, 3 coils W and 3 coils V.

The armature is made out of a 80 mm mild steel bush which is pressed to a steel or stainless steel shaft. For the normal VIRYA-generators, stainless steel is required to prevent magnetic short-circuit in between the armature poles. For this new 34-pole generator, stainless steel isn’t required to prevent magnetic short-circuit but it is advised because rust of the shaft may destroy the shaft seal and because the rotor hub can’t rust to a stainless steel shaft. The shaft has a diameter of 15 mm at the bearings. The bearings have size 15 * 35 * 11 mm and two rubber seals. An extra oil seal size 15 * 30 * 6 mm is mounted at the shaft side to prevent entrance of water. The generator shaft has a tapered shaft end at the front side for connection of the rotor hub or for connection of the hand wheel.

The outside of the armature is turned to a diameter of 79.5 mm and so the air gap in between armature and stator is 0.25 mm. 17 shallow grooves are milled in the armature in parallel to the armature axis. The grooves have a depth of 3.2 mm and a width of 7.1 mm. A 2.2 mm deep and 0.7 mm wide groove is made at each side of the 7 mm main groove. These grooves prevent magnetic short-circuit in between the sides of the magnets. A neodymium magnet size 40 * 7 * 5 mm is glued in each groove forming 17 north poles. The 17 south poles are formed by the remaining material left en between the grooves. The width of a south pole is also about 7 mm. The magnets are supplied by the Polish Internet company www.enesmagnets.pl. The magnet quality is N38SH. In March 2014, I have ordered 70 of these magnets for the VIRYA-1.46 generator and I paid € 64.30 including mailing costs and excluding VAT. So the magnet costs for one generator are about € 15.60 which is certainly acceptable.

The stator pole angle for 36 stator poles is 360° / 36 = 10°. The angle in between the coils is the double value so 360 / 18 = 20°. The armature pole angle for 34 armature poles is 360° / 34 = 10.5882°. The angle between two north poles is the double value so 360 / 17 = 21.1765°. The difference in between the stator pole angle and the armature pole angle is 10.5882° - 10° = 0.5882°. Assume a preference position is created if an armature pole is just opposite a stator pole. This means that the number of preference positions per revolution is 360° / 0.5882 = 612. This is a very large number so it can be expected that the fluctuation of the clogging torque can be neglected. The number of preference positions can also be found by multiplying the number of armature poles and stator poles and divide it by two as 34 * 36 / 2 = 612.

The 17 north poles are called N1 – N17. The 17 south poles are called S1 – S17. A picture of armature and stator is given in figure 1. The position of the armature in figure 1 is drawn such that north pole N1 is just opposite coil U2.

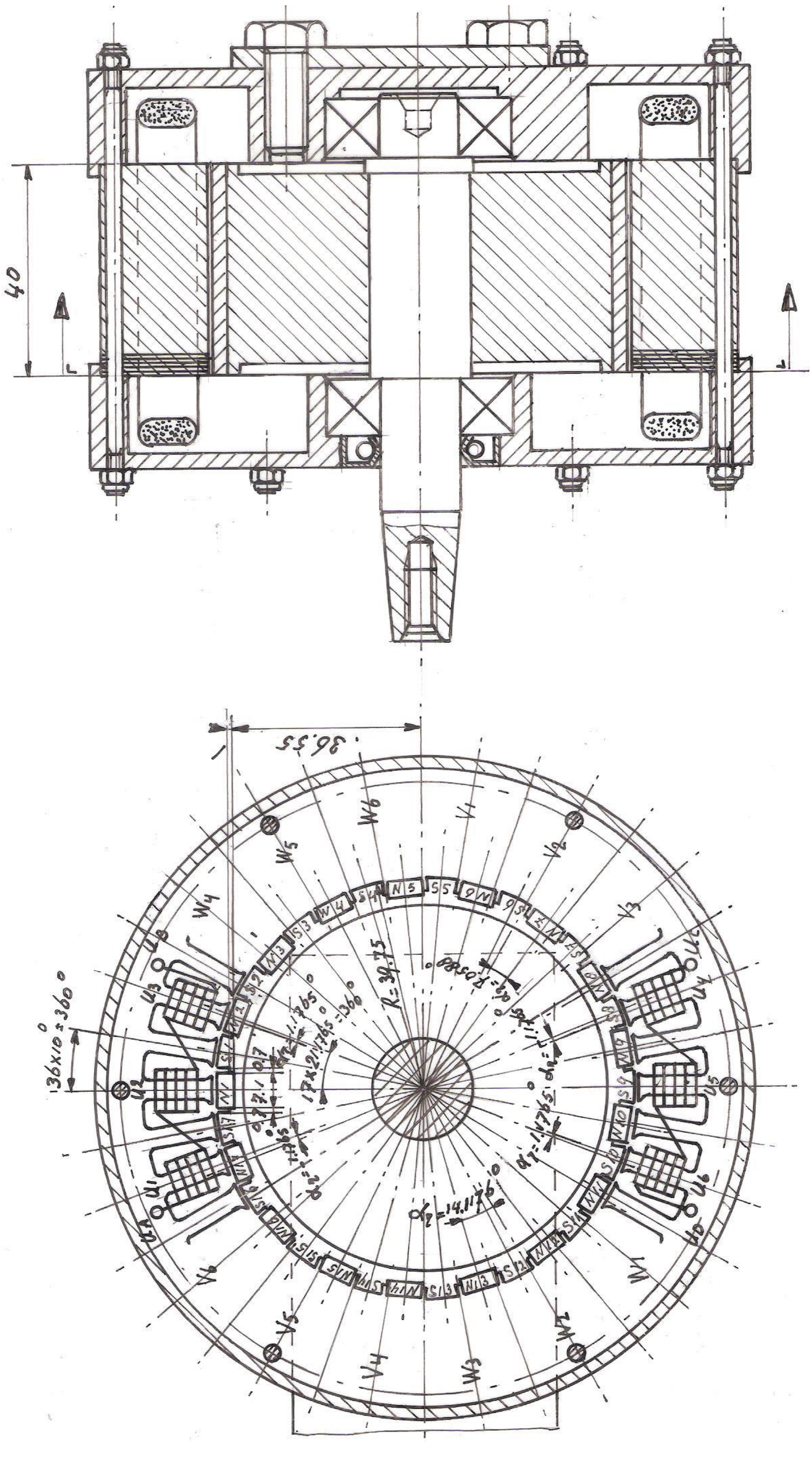


figure 1 34-pole armature and 36-pole stator for housing size 80F-6, 120 * 80 mm

The bearing covers are made out of aluminium bar with a diameter of 125 mm. For serial production it might be cheaper if the bearing covers are cast. A terminal box is mounted to the back side of the back bearing cover. This terminal box contains a terminal with nine contacts and a 3-phase rectifier. The back bearing cover is provided with four M8 mm threaded holes at a pitch circle of 50 mm for connection of the generator to the generator bracket of the windmill. These threaded holes can also be used for a bracket with which the generator can be connected to the wall of a house in case it is used as hand wheel generator.

A terminal box with nine contacts and five brass strips makes it possible to connect the two bundles of three coils of one phase in parallel or in series and therefore the generator can be used for 12 V or for 24 V battery charging (see chapter 5). The rotational speed as hand wheel generator is much lower than for use as windmill generator and connection of the bundles in series is then used for 12 V battery charging.

3 Checking if a 3-phase current is generated

A 3-phase current has three phases called U, V and W. Normally the voltage U of each phase varies sinusoidal and the angle α in between the phases is 120°. The formulas for the voltage of each phase are:

$U_u = U_{max} * \sin\alpha$ (V) (1)

$U_v = U_{max} * \sin(\alpha - 120°)$ (V) (2)

$U_w = U_{max} * \sin(\alpha - 240°)$ (V) (3)

The three curves are shown in figure 2.

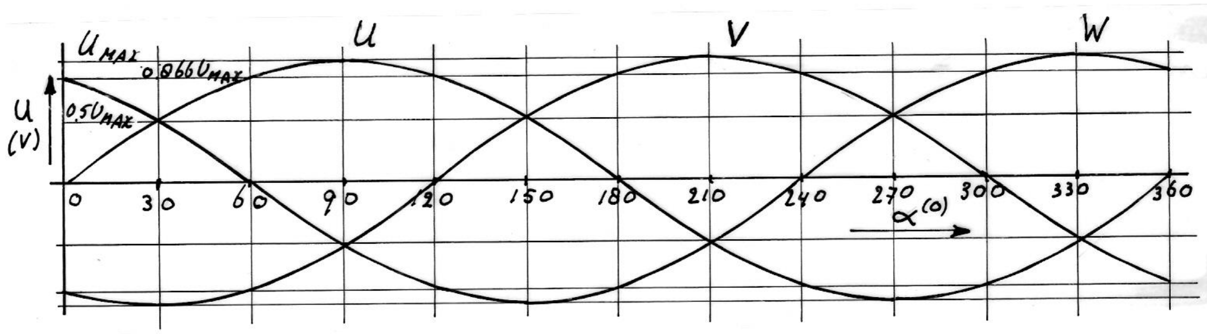


fig. 2 Three phases U, V and W

A pure sine wave is generated if a coil is rotating in a constant magnetic field because the magnetic field through the coil varies sinusoidal. If a permanent magnet is moving along a coil, the generated voltage may not be a pure sine wave, especially if the distance in between the magnets is large. But for the chosen generator configuration it is assumed that the generated voltage varies about sinusoidal.

If the rotor has two poles, the position of the rotor with respect to the stator will be the same if the rotor has rotated 360°. So the phase angle α is the same as the rotational angle α_r of the rotor. If the rotor has 34 poles this will be the case for 360 * 2 / 34 = 21.1765° rotation of the rotor. This results in the formula:

$\alpha = \alpha_r * p_r / 2$ (-) (4)

α is the phase angle, α_r is rotational angle of the rotor and p_r is the number of rotor poles.

In figure 1 it can be seen that $\alpha_r = 0°$ in between N1 and U2, that $\alpha_r = 7.0588°$ in between N7 and V2 and that $\alpha_r = 14.1176°$ in between N13 and W2. Substitution of $\alpha_r = 0°$ and $p_r = 34$ in formula 4 gives $\alpha = 0°$. Substitution of $\alpha_r = 7.0588°$ and $p_r = 34$ in formula 4 gives $\alpha = 120°$. Substitution of $\alpha_r = 14.1176°$ and $p_r = 34$ in formula 4 gives $\alpha = 240°$. The difference in between the phase angles is 120° and so a 3-phase voltage is created in between the coils U2, V2 and W2.

In figure 1 it can be seen that $\alpha_r = -1.1765°$ in between N17 and U1 and that $\alpha_r = 1.1765°$ in between N2 and U3. So this means that the voltages generated in U1 and U3 are not in phase with the voltage generated in U2.

In figure 1 it can be seen that the coils U4, U5 and U6 are not about opposite to north poles but that they are about opposite to the south poles S8, S9 and S10. This means that the generated voltage in this bundle of coils will be opposite to the voltage as generated in the bundle of coils U1, U2 and U3 if the coils have the same winding direction. It is decided to give all 18 coils the same winding direction and to connect all six coils of one phase in series for 24 V battery charging. The coil ends of the bundle of the three coils U1, U2 and U3 are called U_A and U_B. The coil ends of the bundle of the three coils U4, U5 and U6 are called U_C and U_D. The first bundle of 3 coils of phase U has to be connected such to the second bundle of 3 coils, that the generated voltages in both bundles are strengthening each other. This is realised if coil end U_B is connected to U_D. For 12 V battery charging both bundles have to be connected in parallel and for this situation coil end U_A is connected to U_D. It is allowed to connect U_B to U_C but this isn’t done for a terminal with 9 contacts (see chapter 5).

The generator winding is very simple if compared to the winding of a normal 6-pole asynchronous motor. This is because all coils have the same shape and because there are no crossing coil heads. The strength of the magnetic field flowing through a coil will be the same for each coil and the generated voltage in each coil will therefore be the same too. This is not the case for a normal 6-pole winding as some coils have a different pitch. The coil heads are very small if compared to the length of the part of the coil lying in the grooves. A minimum amount of copper will therefore be used and the winding will have a relatively low resistance resulting in a high generator efficiency.

The angles in between the coils U4 – U6 and the poles S8 – S10 are the same as the angles in between the coils U1 – U3 and the poles N17 – N2.

Coil U1 and U4. Substitution of $\alpha_r = -1.1765°$ and $p_r = 34$ in formula 4 gives $\alpha = -20°$.
Coil U3 and U6. Substitution of $\alpha_r = 1.1765°$ and $p_r = 34$ in formula 4 gives $\alpha = 20°$.

Addition of sinusoidal voltages which are out of phase but which have the same frequency results in a voltage which is also sinusoidal. The total voltage U_{tot} for the six coils U1 – U6 is given by:

$$U_{tot} = U_{max} * 2 * \{\sin(\alpha - 20°) + \sin\alpha + \sin(\alpha + 20°)\} \quad \text{(V)} \qquad (5)$$

It can be proven that this function has a maximum value for $\alpha = 90°$. Substitution of $\alpha = 90°$ in formula 5 gives:
$U_{tot\ max} = U_{max} * 2 * (\sin 70° + \sin 90° + \sin 110°) = 5.7588 * U_{max}$.

If the voltages U1 - U6 would be exactly in phase, the resulting maximum voltage would be 6 * U_{max}. So the difference in phase angle gives a small reduction of the total voltage by a factor 5.7588 / 6 = 0.960 and therefore also a small reduction of the generated power. A factor 0.960 is certainly acceptable, so the given shift of the phase angles in between the three coils of a bundle U is allowed. The same counts for the coils V and W.

Rectification in star will give the lowest clogging torque because higher harmonic currents can’t circulate in the winding. If the generator is used as a brake, the highest short-circuit is created for rectification in delta or if the star point is short-circuited too. However, this means that an extra wire is required from the star point to the short-circuit switch and as this makes the wiring more complicated. So braking is done for rectification in star without short-circuiting of the star point. Because the frequency is high, it might be required to make short-circuit over a resistor to create a torque which is high enough at normal rotational speeds.

4 Calculation of the flux density in the air gap

A calculation of the flux density in the air gap for the current VIRYA generators is given in chapter 5 of KD 341 (ref. 1).

A PM-generator is normally designed such that the magnetic field in the stator is saturated or almost saturated. For this condition, the generator has its maximum torque level and this means that it can supply the maximum electrical power for a certain rotational speed. The stator can be saturated at the narrowest cross section of the spokes in between the stator slots but it can also be saturated at the bridge in between the bottom of the stator slots and the outside of the stator stamping. The stator stamping is originally designed for a 6-pole motor and for a 6-pole motor there is a large magnetic flux in the bridge. The magnetic flux in the bridge for a 34-pole PM-generator is very low because only half the flux coming out of one a stator pole is flowing through the bridge. So only the magnetic flux in the spokes is critical. The stator is about saturated if the calculated flux density in the air gap is 0.9 T or higher.

The remanence B_r (magnetic flux) in a neodymium magnet size 40 * 7 * 3 mm supplied by Enes with quality N38SH is in between 1.22 T and 1.26 T, if the magnet is short-circuited with a mild steel arc which is not saturated. Assume it is 1.24 T. However, an air gap in the arc reduces the magnetic flux because it has a certain magnetic resistance. The resistance to a magnetic flux for the magnet itself is about the same as for air. The magnet thickness is called t_1. The magnetic resistance of the iron of the armature can probably be neglected. The magnetic resistance of the iron in the stator can’t be neglected if the stator is close to saturation. However, this is complicating the calculation a lot and so the magnetic resistance of the iron in the stator is also neglected. So the total magnetic resistance is only caused by the magnet itself and by the air gaps.

The air gap t_2 in between a south pole and the stator is 0.25 mm. The average air gap t_3 in between a north pole and the stator is somewhat larger because the magnet is flat and because the depth of a magnet groove is chosen 3.2 mm. It is assumed that t_3 = 0.4 mm. So the magnetic resistance is increased by a factor $(t_1 + t_2 + t_3) / t_1$ because of the two air gaps. This means that the remanence in the air gap is reduced by a factor $t_1 / (t_1 + t_2 + t_3)$. The effective remanence in the air gap $B_{r\,eff}$ is given by:

$$B_{r\,eff} = B_r * t_1 / (t_1 + t_2 + t_3) \quad \text{(T)} \qquad (6)$$

Substitution of B_r = 1.24 T, t_1 = 3 mm, t_2 = 0.25 mm and t_3 = 0.4 mm in formula 6 results in $B_{r\,eff}$ = 1.02 T. This is higher than 0.9 T so the stator will probably be saturated. The flux density in a spoke can be calculated if the spoke width is known. The spoke width is about 3.7 mm. As a magnet has a width of 7 mm, the magnetic flux is concentrated by a concentration factor k = 7 / 3.7 = 1.89. So the magnetic flux in a spoke can be calculated to be 1.89 * 1.02 = 1.93 T. This is higher than 1.6 T so the spokes are saturated and the maximum possible torque level will be realised.

I think that it is worth wile to make a prototype of a stator and an armature according to the geometry as given in figure 1 and chapter 2 and to test if the generator will have acceptable characteristics.

5 Switching from 12 V to 24 V

The European grid is connected in star and has a voltage of 230 V in between the star point and a phase and a voltage of about 400 V in between the phases. 3-phase motors of 4 kW and larger are normally started in star and then switched to delta to prevent high starting currents. There are countries where the grid is connected in delta and for those countries star-delta switching isn't possible. Large motors used in those countries have a 2-layers winding in star and the windings can be connected in series during starting and in parallel once the nominal rotational speed is reached. To realise this one uses a terminal with nine contacts and five strips. Such terminal can also be used for the 34-pole generator to switch from 12 V to 24 V.

The terminal has nine contacts situated in three vertical rows. The distance of adjacent contacts in a row is identical to the distance in between the rows. The contacts of the left row are called U_1, U_3 and U_2 from bottom to top. The contacts of the middle row are called V_1, V_3 and V_2 from bottom to top. The contacts of the right row are called W_1, W_3 and W_2 from bottom to top (see figure 3). A contact name differs from a coil name because the number of a contact name is given as indices. Five brass strips are available to make certain connections in between certain terminal contacts. The contacts U_1, V_1 and W_1 are connected to the AC points of the 3-phase rectifier.

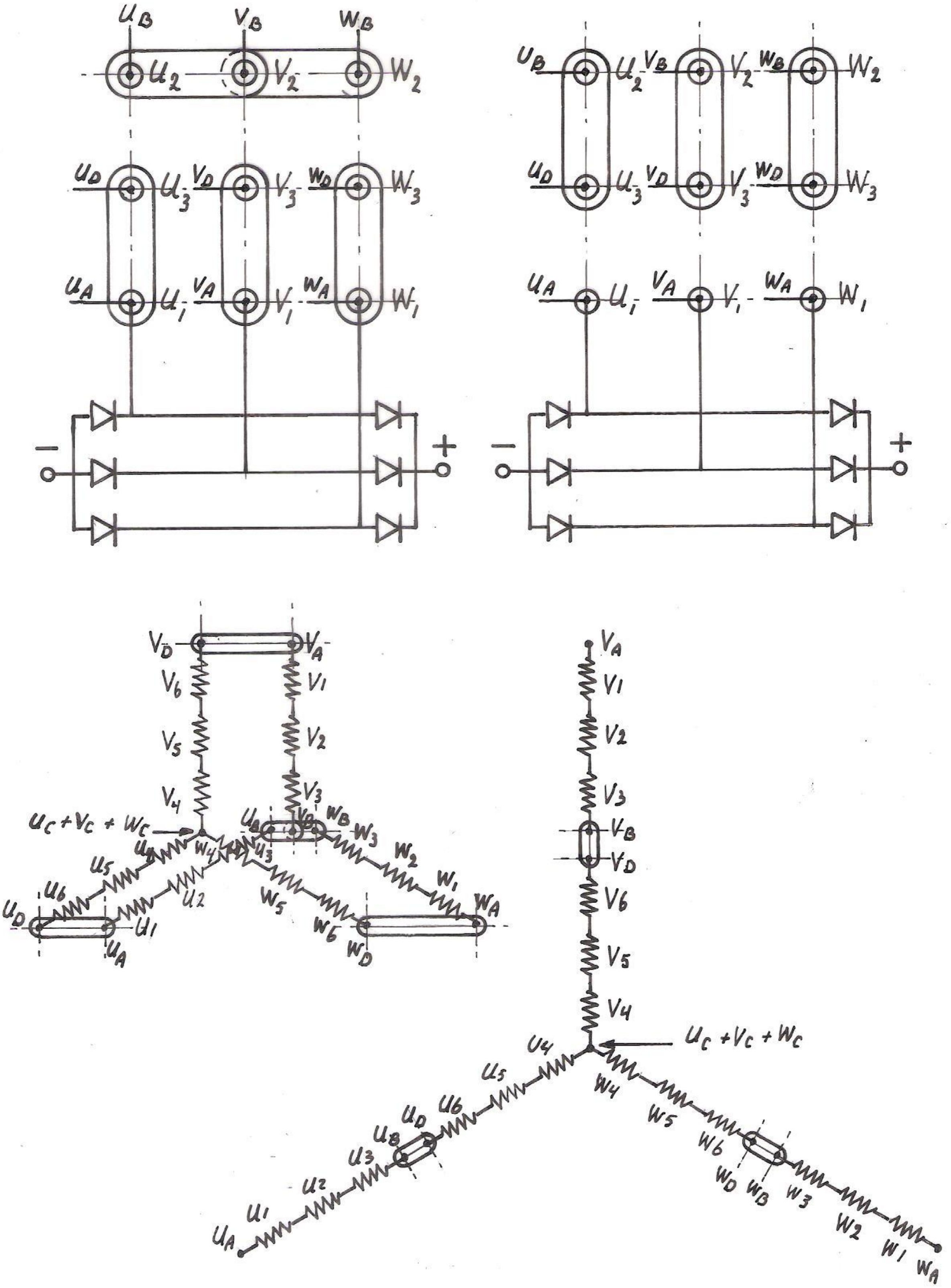
The coil ends U_C, V_C and W_C are connected to each other and are forming a star point which is situated at the outside of the winding. The coil end U_D is connected to point U_3 of the terminal. The coil end V_D is connected to point V_3 of the terminal. The coil end W_D is connected to point W_3 of the terminal (see figure 3).

The coil end U_A is connected to point U_1 of the terminal. The coil end V_A is connected to point V_1 of the terminal. The coil end W_A is connected to point W_1 of the terminal. The coil end U_B is connected to point U_2 of the terminal. The coil end V_B is connected to point V_2 of the terminal. The coil end W_B is connected to point W_2 of the terminal (see figure 3).

Five strips are used for 12 V battery charging. U_2 is connected to V_2 and V_2 is connected to W_2. U_1 is connected to U_3, V_1 is connected to V_3 and W_1 is connected to W_3. Three strips are used for 24 V battery charging (or for 12 V battery charging as hand wheel generator). U_2 is connected to U_3, V_2 is connected to V_3 and W_2 is connected to W_3 (see figure 3).

In figure 3 it can be seen that for 12 V battery charging, both star points aren't connected to each other. This connection is therefore called 12 V double star or 12 V / 2 Y. If all coils are identical, there is no voltage difference in between both star points. So it is allowed to connect both star points together. However, this isn't possible with a terminal with only nine contacts. For 24 V battery charging there is only one star point and this connection is therefore called 24 V star or 24 V / Y.

The terminal with nine contacts can be cancelled if one accepts that the generator has only one nominal voltage for one rotational speed. So one has a 12 V version and a 24 V version. In this case the connections in between both bundles of three coils have to be made on the outside of the winding according to the left picture of figure 3 for the 12 V version and according to the right picture of figure 3 for the 24 V version. In this case both star points can be connected for the 12 V version. The terminal box contains only a 3-phase rectifier and the free coil ends are directly connected to the three AC contacts of the rectifier. The disadvantage of this option is that two different generators have to be hold on stock and that the user and the supplier have to be sure what version is needed.



12 V / 2Y 24 V / Y

fig. 3 Connection of the winding in double star for 12 V and in star for 24 V battery charging

6 Use of the generator in combination with the VIRYA-1.5 rotor

It is assumed that the generator will be used in combination with the VIRYA-1.5 rotor which has a design tip speed ratio λ_d = 4.5. This rotor is made from one stainless steel strip size 166.6 * 1500 * 2 mm. The rotor calculations are given in report KD 465 (ref. 5). The rotor drawing has drawing number 1103-01. However, the hub of this rotor is originally meant to be used in combination with the 22-pole PM-generator which has a cylindrical shaft of 14 mm and a 5 mm wide key. So the hub has to be changed such that it fits to a tapered shaft. The windmill head will be derived from the head of the VIRYA-1.46 windmill. The generator bracket has to be changed such that it is in parallel to the generator back bearing cover.

The P-n curves of the rotor for a 1 mm stainless steel vane blade are given in figure 4 of KD 465. This figure is copied as figure 4. Figure 4 of KD 465 gives also the estimated P_{mech}-n and P_{el}-n curves for the 4-pole PM-generator which was chosen at the time writing report KD 465. In figure 4, these curves are replaced by the estimated P_{mech}-n and P_{el}-n curves of the 34-pole PM-generator for 26 V star. 26 V is the average charging voltage for a 24 V battery. The two bundles of three coils of one phase are connected in series for 24 V battery charging.

The point of intersection of the P_{mech}-n curve for 26 V star of the generator with the P-n curve of the rotor for a certain wind speed, gives the working point for that wind speed. The electrical power P_{el} for that wind speed is found by going down vertically from the working point up to the point of intersection with the P_{el}-n curve. The values of P_{el} found this way for all wind speeds, are plotted in the P_{el}-V curve (see figure 5). For high powers, the voltage is higher than 26 V and therefore the generator efficiency will be higher too. This results in a little higher electrical power. The P_{el}-V curve is corrected for this effect.

The matching of rotor and generator is good for wind speeds in between 4 and 9 m/s because the P_{mech}-n curve of the generator is lying close to the optimum cubic line. The supply of power starts already at a wind speed of 2.7 m/s ($V_{cut\ in}$ = 2.7 m/s). This is low and therefore the windmill can be used in regions with low wind speeds. The maximum power is about 150 W which is good for a rotor with 1.5 m diameter.

For calculation of the starting wind speed of the rotor it is required to know the clogging torque of the generator at stand still position. But this can only be measured if a prototype has been built.

In figure 4 it can be seen that the P_{el}-n curve starts at a rotational speed of 220 rpm. This means that the unloaded voltage is equal to the battery voltage at that rotational speed. It is assumed that the open battery voltage is 25 V for a 24 battery if the battery is about half full. So the winding has to be chosen such that the open DC voltage is 25 V for a rotational speed of 220 rpm. The required number of turns per coil to realise this, is determined as follows.

The relation in between the effective rectified DC voltage U_{DCeff} and the effective AC phase voltage U_{eff} for star rectification is given by formula 13 of KD 340 (ref. 6) if the voltage drop over the rectifier is neglected. The voltage drop can be neglected for the very low current which is flowing through a digital volt meter if the open voltage is measured. Formula 13 of KD 340 is copied as formula 7.

$$U_{DCeff} = 0.955 * \sqrt{2} * \sqrt{3} * U_{eff} \quad \text{(V)} \qquad (7)$$

Next a test winding with a thin wire is laid for the six coils of phase U. Assume this test winding has 50 turns per coil. The open effective AC voltage is measured for n = 220 rpm. Assume it is measured that U_{eff} = 6 V. Substitution of U_{eff} = 6 V in formula 7 gives that U_{DCeff} = 14.04 V. The voltage must be 25 V, so the number of turns per coil has to be increased by a factor 25 / 14.04 = 1.781 and becomes 1.781 * 50 = 89. Next the maximum wire diameter has to be chosen for which it is possible to lie 89 turns in the available space of a stator groove.

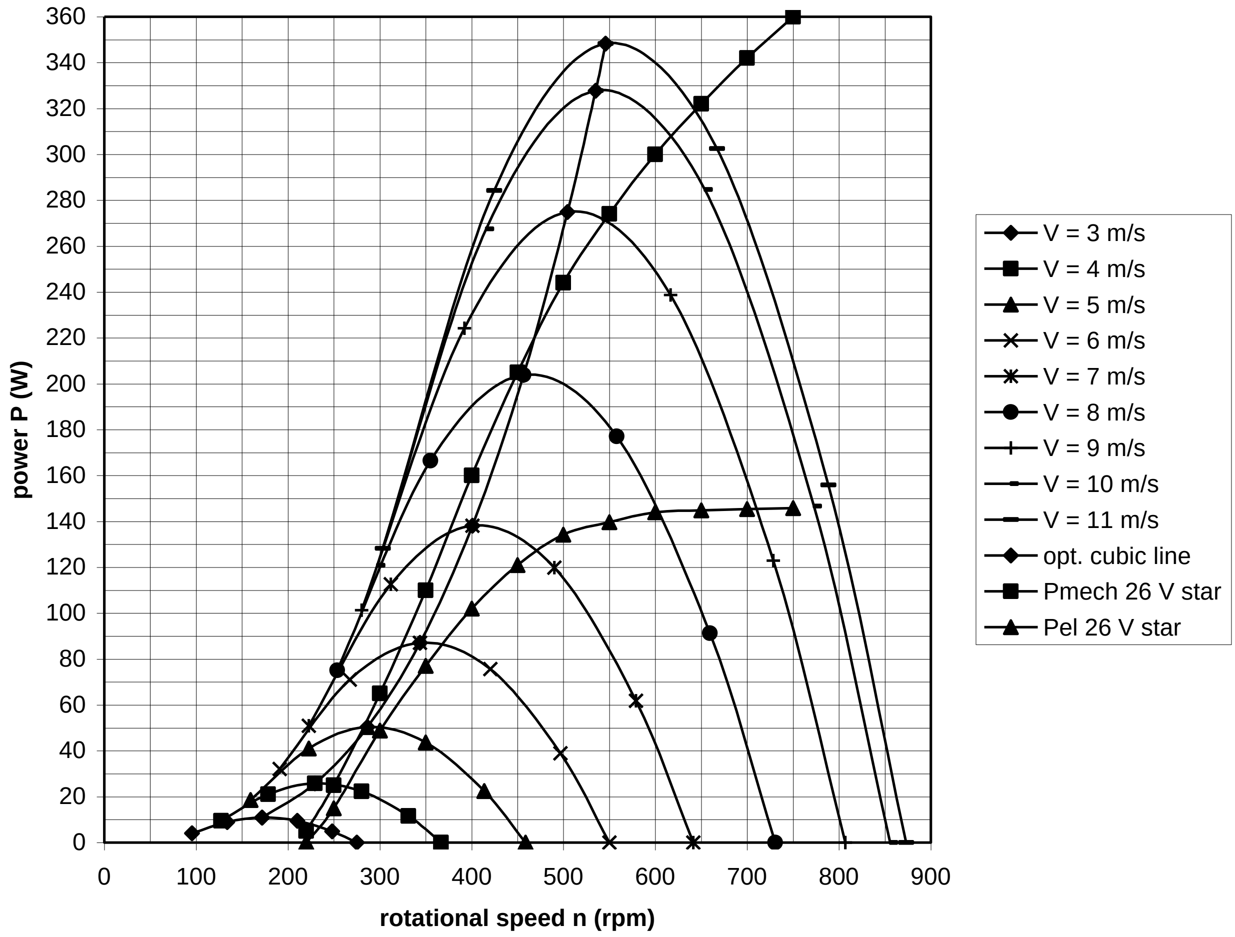


fig. 4 P-n curves of the VIRYA-1.5 rotor, optimum cubic line, estimated P_{mech}-n and P_{el}-n curves for 34-pole generator for 26 V star

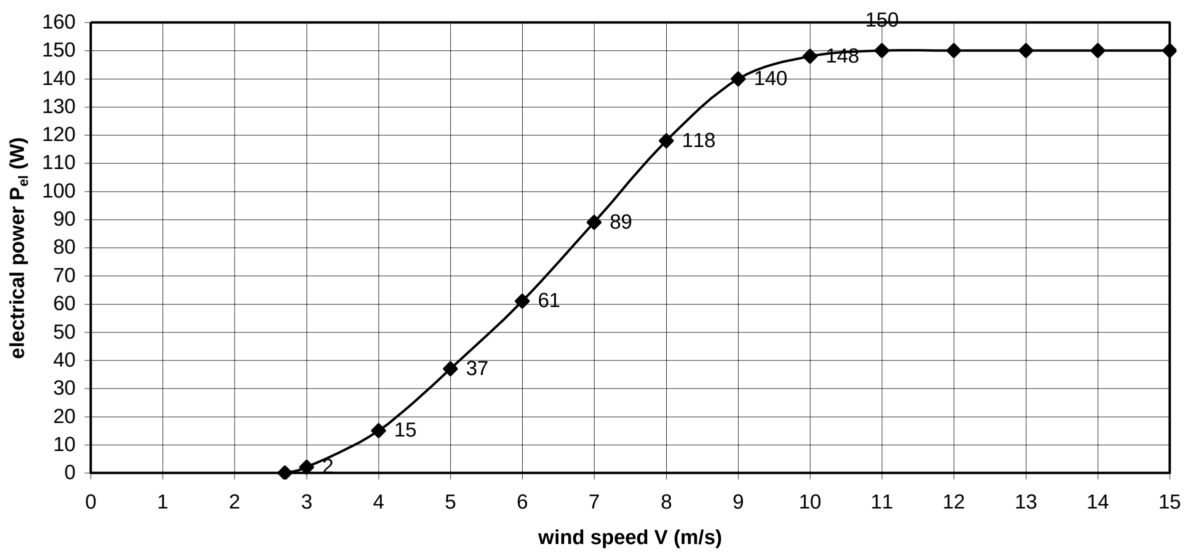


fig. 5 P_{el}-V curve of the VIRYA-1.5 windmill with V_{rated} = 11 m/s for 24 V battery charging and rectification in star

Next the final winding can be laid for this wire thickness. Next the generator has to be measured for a constant DC voltage of 26 V and it has to be checked if the measured P_{mech}-n and P_{el}-n curves are about the same as the estimated curves as given in figure 4. For measuring of the P_{mech}-n curve it is required to measure the torque Q and the rotational speed n and this requires a special test rig.

If the generator is used as hand wheel generator for 12 V battery charging, the winding will be used in the same configuration as for 24 V battery charging with a windmill. So both bundles of three coils of one phase have to be connected in series. It is assumed that the open battery voltage of a 12 V battery is 12.5 V if the battery is half full. An open DC voltage of 12.5 V will be reached at half the rotational speed as the rotational speed for 25 V, so at 110 rpm or 1.83 rev/s. So at this rotational speed charging starts. For a substantial current one has to turn faster. The maximum comfortable rotational speed is about 3 rev/s so it seems possible to use the generator as hand wheel generator for 12 V battery charging. The maximum power and the efficiency will be much lower for 12 V than for 24 V battery charging if the two bundles of one phase are connected in series.

It might also be possible to create a mini 50 Hz, 230 V, 3-phase grid if the generator is provided with a high voltage winding. A 34-pole generator has frequency of 50 Hz for a rotational speed of 3000 * 2 / 34 = 176.47 rpm. Assume that the generator is driven by pedal power and by an accelerating chain transmission. If the peddling speed is about one rev/s, so about 60 rpm, an accelerating gear ratio of about 176.47 / 60 = 2.94 is needed. This can be realised with a 1-step chain transmission.

7 Alternatives

7.1 Cancelling of the 0.7 mm wide side grooves

At both sides of the 7.1 mm mean groove there is a 0.7 mm wide and 2.2 mm deep side groove. These grooves prevent magnetic short-circuit at the sides of a magnet through the iron of the armature and they make that a south pole has about a width of 7 mm. In chapter 4 it was calculated that the flux density in a stator spoke is 1.93 T, so far above the value of 1.6 T at which the stator iron is saturated. So this indicates that it might be allowed to accept some magnetic short-circuit at the sides of the magnets if the side grooves are cancelled. Manufacture of the grooves will then be simpler and cheaper.

To test if cancelling of side grooves is allowed, one should make two armatures, one with and one without side grooves and measure the open voltage for a certain stator winding at a certain rotational speed. If the open voltage without side grooves is the same as with side grooves it means that the stator spokes are still saturated and in this case it is allowed to cancel the side grooves.

7.2 Increasing the width of the stator to 45 mm

If the stator width is increased to 45 mm it has just the width of half the stator width of a standard 0.55 kW, 6-pole motor. If the width of the armature is maintained at 40 mm it means that the stator juts 2.5 mm out of the armature at each side. A stator spoke is widened at the inner side because this allows the use of caps which prevent that the coils come out of the grooves. Because of this widened ends, the spokes are not or less saturated at these points. So the magnetic flux can spread a little at these widened spoke ends and the magnetic flux lines in the narrow part of the spokes will be almost parallel. The calculated magnetic flux in the stator will then decrease with a factor 40 / 45 = 0.889 and will be 0.889 * 1.93 = 1.72 T. This is still higher than 1.6 T so the stator spokes are still saturated. This means that a larger total magnetic flux will flow through the stator and that a large maximum power can be generated.

The aluminium bearing covers have a 2 mm wide collar at the outside for centring of the stator stamping. The width of the bearing coves at the bearings is 18 mm which is just enough for a 6 mm wide seal, an 11 mm wide bearing and a 1 mm wide centring cone. If both the armature and the stator have a width of 40 mm, a chamber has to be made at both sides of the armature to prevent that the armature touches the bearing covers. If the stator has a width of 45 mm, these chambers can be less deep or can may be even cancelled.

It is expected that the stator will no longer be saturated if option 7.1 and option 7.2 are combined, so the 0.7 mm wide sides grooves can’t be cancelled for a 45 mm wide stator.

7.3 Using a stator width of 90 mm and 34 magnets

If a standard 90 mm wide stator stamping is used and if the number of magnets is doubled, the torque and power level will be doubled too if compared to the configuration of option 7.2. The armature will have two rows of magnets separated by a 5 mm wide groove. However, doubling of the torque level with a factor 2 means that the VIRYA-1.5 m rotor will be much too small. As the torque level of a rotor increase with R^3, a new rotor has to be designed with a diameter of about 1.9 m. A rotor shaft with a diameter of 15 mm is too small for a rotor with a diameter of 1.9 m, so a 20 mm shaft has to be used. But this also requires bigger bearings size 20 * 47 * 14 mm and so wider bearing covers are needed. In case of a 90 mm wide stator it might be better to use a standard motor housing and standard bearing covers of a 0.55 kW, 6-pole motor. In this case it is also possible to use the original motor shaft which has a 19 mm shaft end and a 6 mm key groove. In this case the rotor can have a hub which is clamped around the shaft just the way as it was done for the original hub of the VIRYA-1.5 rotor.

Extra advantages of using a standard motor housing are that this housing is provided with cooling fins, that the outside of the stator isn’t in direct contact with the open air and that a terminal box is already corporated in the housing.

7.4 Using a stator stamping frame size 90

In stead of using a stator stamping of a 6-pole motor frame size 80, it seems possible to use a stator stamping of a 6-pole motor frame size 90. This stamping has an inside diameter of 90 mm and an outside diameter of 135 mm. The width of a stator spoke is about 4 mm in stead of 3.7 mm. So the magnetic flux in a stator spoke will be concentrated by a factor 7 / 4 = 1.75 and the magnetic flux in a stator spoke will be 1.02 * 1.75 = 1.78 T. This is still higher than 1.6 T so the stator stamping will also be saturated if the stator stamping of a motor with frame size 90 is used. A larger stator stamping has larger grooves and more copper can be used in these grooves, so the maximum torque and power level will increase. But also the sticking torque will increase and it has to be investigated if the VIRYA-1.5 rotor is still strong enough for this larger stator stamping. A larger stator stamping requires an outside diameter of the bearing covers of 140 mm.

Standard stator stampings of a 6-pole motor frame size 90 have a length of 75 mm for a 0.75 kW motor and a length of 100 mm for a 1.1 kW motor. So it isn’t possible to make a 40 mm or 45 mm wide stator from a standard stamping without creating some waste material.

8 References

1 Kragten A. Development of the permanent magnet (PM) generators of the VIRYA windmills, May 2007, free public report KD 341, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

2 Kragten A. Ideas about a direct drive 34-pole permanent magnet generator for the VIRYA-3.3S windmill using the stator stamping of an Indian 6-pole, 3-phase, 2.2 kW asynchronous motor frame size 112 and 51 neodymium magnets size 10 * 10 * 5 mm, May 2014, reviewed December 2014, free public report KD 560, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

3 Kragten A. Development of a simple 22-pole permanent magnet generator for a small windmill using the housing of an Indian 4-pole, 3-phase, 0.37 kW asynchronous motor frame size 71 and 22 neodymium magnets size 40 * 7 * 3 mm, April 2014, report KD 553, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

4 Kragten A. Development of the Handwheel Generator, a direct drive, 12-pole, manually operated 12 V battery charger, December 2008, report KD 404, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode.

5 Kragten A. Calculations executed for the 2-blade rotor of the VIRYA-1.5 windmill (λ_d = 4.5, steel blades) with generator frame size 71 and original motor shaft, August 2011, report KD 465, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode.

6 Kragten A. Rectification of 3-phase VIRYA windmill generators, May 2007, reviewed October 2014, free public report KD 340, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode.