Ideas about an 18-pole, 2-phase permanent magnet generator using the housing of a 6-pole asynchronous motor frame size 100 for driving a 0.55 kW motor of a centrifugal pump

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KD 723

 The generator has not yet been built and tested.

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1 Introduction

One of the most critical parts of a small wind turbine is the generator. For my older range of VIRYA windmills, I 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 (and several others types) are described in my public report KD 341 (ref. 1). These generators are very strong and have good characteristics. The sticking torque isn't fluctuating because the armature poles are making a certain angle with the axis. This facilitates starting of the rotor at low wind speeds.

The original shaft and armature is thrown away and a new stainless steel shaft and a new mild steel armature have to be made. Deep, inclined grooves have to be milled in the armature which needs special tools and is rather complicated and time consuming. 10 mm thick neodymium magnets have to be glued in the grooves. The whole generator is therefore rather difficult to manufacture and rather expensive.

I did several attempts to design a PM-generator which is simpler or cheaper and wrote KD-reports about every new idea. I have described radial flux and axial flux generators and generators with and without iron in the coils. The main disadvantage of a generator without iron in the coils is that this results in a big air gap. A big air gap reduces the magnetic flux flowing through the coils and therefore many thick and expensive magnets have to be used. The main disadvantage of a generator with iron in the coils is that this iron results in eddy currents and that the generator may have a strong peak on the sticking torque if the armature isn't designed properly. A large peak on the sticking torque results in a high starting wind speed if a fast running windmill rotor with a low starting torque coefficient is used.

There are several ways to reduce the peak on the sticking torque. I way to realise this for a 16-pole generator made from an asynchronous motor frame size 100 using 24 magnets size 40 * 15 * 5 mm, is described in report KD 718 (ref. 2). Mechanically this generator has sixteen poles but physically it has four poles and therefore the original stator of a 4-pole, 3-phase motor can be used. In this report KD 723 it is researched if an about similar armature construction, using the same size of magnets, can be used for an 18-pole generator but now with a 2-phase winding. This generator is meant to be connected directly to a 0.55 kW, 1-phase motor of a centrifugal pump. The frequency f is 50 Hz for n = 333.33 rpm.

A starting point for this generator is that it can be made from the housing and shaft of a standard 6-pole asynchronous motor frame size 100. This has as advantage that the housing and the bearing covers are rather cheap because they are already manufactured in large quantities. Another important advantage is that a housing of an asynchronous motor is water tight if the shaft is provided by an IP-55 seal. A generator of frame size 100 has a shaft diameter at the front bearing of 30 mm and a shaft end with a diameter of 28 mm, a length of 60 mm and an 8 mm wide key groove. It is meant to be used in combination with the 3-bladed VIRYA-3B3 rotor which has a rotor diameter of 3 m. A PM-generator made from an asynchronous motor has a magnetic flux which is radial at the air gap in between the armature and the stator stamping, so this generator will be of the type "radial flux".

2 Description of the 18-pole PM-generator

2.1 General

It is chosen to take an asynchronous motor in which a stator stamping of the German manufacture Kienle & Spiess is used. Information about dimension of stator stampings of this manufacture are given on the website: www.kienle-spiess.de. The chosen stator stamping has the code: IEC 100/6-8.103. The outside diameter is 150 mm, the inside diameter is 103 mm. This stamping is used for a 1.5 kW, 6-pole motor and the length of the stator stamping is 120 mm for this motor. The stamping has 36 slots, so 36 stator poles.

The stamping has six 4.07 mm holes at a pitch circle of 144 mm. The manufacturer which uses this stamping of Kienle & Spiess for its 1.5 kW, 6-pole motor has not yet been selected.

It is chosen to use this stamping for an armature with eighteen magnetic poles, so nine north and nine south poles. The angle in between the heart of a north pole and the heart of a south pole is 20° for an 18-pole generator. This means that the optimum angle in between two legs of a stator coil is 20° too. This is possible for a stator with 36 slots as the angle in between the slots is 10°. So a coil uses slots which are lying at an angle of 20° from each other.

2.2 Description of the armature

This new generator has an armature which is made from three 40 mm long mild steel bushes which have a diameter of 103 mm. The bushes are pressed on the original motor shaft such that the distance in between the bushes is 10 mm and that the middle bush is positioned at the final place. The bushes are turned to a diameter of 102.4 mm after pressing.

A groove pattern is made in each bush such that there is an angle of 3° 20’ in between the groove patterns. This shift of the groove patterns makes that the armature will get 108 preference positions in stead of 36 preference positions when all grooves patterns would be in line. If the groove pattern is made in all three bushes, both outer bushes are pressed against the middle one. So after pressing, the total length of the armature becomes 120 mm which is the same as the length of the stator.

Next the groove pattern in one bush is described. It is chosen that the magnets are positioned in nine 15 mm wide and 5.6 mm deep grooves with the magnet area radial and that the grooves are made in parallel to the armature axis. The angle in between the heart of the grooves is 40°. So a short and stiff 15 mm diameter cutter can be used. One magnet size 40 * 15 * 5 mm is glued in each groove with epoxy or anaerobe glue such that the north pole of all magnets faces to the outside of the armature. So 9 magnets are used for one bush and totally 27 magnets are needed for one armature. In between the magnets, nine south poles are formed by the remaining material of the armature. So the armature has totally nine north poles N1-N9 and nine south poles S1-S9.

At each side of a 15 mm wide magnet groove there is a 2.5 mm wide and 3.6 mm deep groove to make that the south poles also have a width of about 15 mm and to prevent magnetic short-circuit in between a north and a south pole at the sides of a magnet. These grooves can be made with an 20 mm cutter.

The stator has 36 slots so it has 36 poles and so the stator pole angle is 10°. The stator slots are numbered 1 – 36. In figure 1, the armature is drawn such that the heart of north pole N1 of the middle bush is just opposite the heart of coil U1 lying in slots 1 and 3.

The two stator poles in between slots 1 and 3 are just opposite to armature pole N1. The armature will therefore have a preference position for the drawn position of the magnets in the middle bush. However, it will have a preference position for the magnets in the left bush if the armature has rotated 3° 20’ right hand. It will have a preference position for the magnets in the right bush if the armature has rotated 3° 20’ left hand. This means that the armature will have a preference position every 3° 20’ and so it will have 108 preference positions per revolution. This seems enough to flatten the peak on the sticking torque up to an acceptable low value.

The six 4.07 mm holes at a pitch circle of 144 mm in the stamping IEC 100/6-8.103 of Kienle and Spiess may cause eighteen small extra preference positions per revolution. These preference positions can be prevented by placing of a mild steel rod with a diameter of 4 mm and a length of 120 mm in each hole.

The neodymium magnets are supplied by the Polish company Enes Magnets website: www.enesmagnets.pl. The magnets of this company are rather cheap if compared to magnets with the same volume of other magnet suppliers. The magnets size 40 * 15 * 5 mm have quality N38.

The current price for one magnet is € 1.61 including VAT but excluding transport if small quantities are ordered. 27 magnets are needed for one generator, so the magnet costs for one generator are about € 45 which is rather cheap for this generator size.

So the armature is made of three 40 mm long mild steel bushes with an outer diameter of 103 mm. The middle bush has to be positioned such that the outer sides of the two outer bushes coincide with the sides of the stator stamping after pressing both outer bushes against the middle bush. The bearings and the original short-circuit armature have to be removed first from the shaft if an original motor shaft is used.

The original short-circuit armature has an inner diameter of 36 mm. The original motor shaft is provided with small grooves in the direction of the axis to guarantee a strong press fitting. As the original stator stamping is made of very soft steel, it might be required to give the bushes of this new armature an inside diameter which is a little larger than 36 mm, so for instance 36.1 mm, otherwise the required pressing force may be too high. The bushes are turned to a diameter of 102.4 mm after pressing them on the shaft. This must be done such that the outside is exactly concentric to the two bearing seats. So the air gap in between the south poles becomes (103 – 102.4) / 2 = 0.3 mm.

The 15 mm wide grooves for the magnets are made that deep that the distance in between the bottom of the groove and the axis of the shaft is 45.6 mm. This means that the depth of the groove measured from the outside of the armature is 51.2 – 45.6 = 5.6 mm. The magnets are not jutting out of the armature for this groove depth. The average air gap at the magnets is somewhat larger than the air gap at the south poles but this is no problem.

The front bearing cover at the shaft side has an oil seal. No fan is needed and so the back bearing cover is closed and the back bearing cover therefore has no seal. The shaft has to be shortened if the back bearing cover is closed. The bearings have an internal rubber seal at both sides. The space in between the front bearing and the shaft seal is filled with grease to create an extra barrier against the entrance of water and dust. So the original motor shaft can be used and stainless steel isn't needed for its anti magnetic qualities as it is the case for the older VIRYA generators with inclined magnet grooves. A cross section and a side view of the generator armature are given in figure 1 at chapter 2.3.

2.3 Description of the stator

The stator stamping is pressed in the aluminium generator housing. The stator stamping has 36 slots in which the coils are laid. The stator slots are numbered 1 – 36. The slots with odd numbers contain two nine coils of phase U. The slots with even numbers contain the nine coils of phase V.

The nine coils U are lying in the first layer. The coil heads of these coils are bent to the outside to make place for the coils of phase V which are lying in the second layer. Coil U1 makes use of slots 1 and 3. Coil U2 makes use of slots 5 and 7 and so on. The nine coils V are lying in the second layer. Coil V1 makes use of slots 2 and 4. Coil V2 makes use of slots 4 and 6 and so on.

An 18-pole armature has the same magnetic position if the armature has rotated over an angle $\beta = 40°$. So a rotational angle $\beta = 40°$ corresponds to a phase angle $\alpha = 360°$. So a rotational angle $\beta = 1°$ corresponds to a phase angle $\alpha = 9°$.

The armature is drawn in the position for which there is no angle in between the heart of coil U1 and the heart of magnet N1 lying in the middle bush. It is assumed that the voltage generated in a coil is varying sinusoidal and that it is zero if the heart of the magnet in the middle bush is coinciding with the heart of the coil. So the voltage generated in coil U1 is zero for the drawn position. In figure 1 it can be seen that there is an angle of 10° in between the heart of the north pole N1 and the heart of coil V1. So there is a phase angle of 9 * 10° = 90° in between the voltage generated in coil U1 and coil V2. This phase angle is found for all coils with the same coil number so the phase angle in between phase U and phase V is 90°. This is standard for a 2-phase grid.

In figure 1 it can be seen that in one magnetic north pole is opposite a coil of phase U all other coils of phase U are also opposite a north pole. So all nine coils of phase U can have the same winding direction. All nine coils of phase V can also have the same winding direction.

At this moment it is assumed that all nine coils of one phase are wound together at a winding thorn outside the generator and that all nine coils are wound right hand. The beginning of coil U1 is labelled U_A and the end of coil U8 is labelled U_B. The begin of coil V1 is labelled V_A and the end of coil V8 is labelled V_B. Elastic isolated wires with different colours are soldered to the ends of the enamelled copper wires and guided to the terminal block of the generator in a way as this is normally also done for a 3-phase winding but two tags aren't used. A brass connecting strip is only used if the two phases are connected in series. The determination of the number of turns per coil and the wire thickness will be explained in chapter 5.

A prototype of the generator has to be measured and a windmill rotor with the correct rotor diameter and design tip speed ratio has to be chosen for correct matching (see chapter 5).

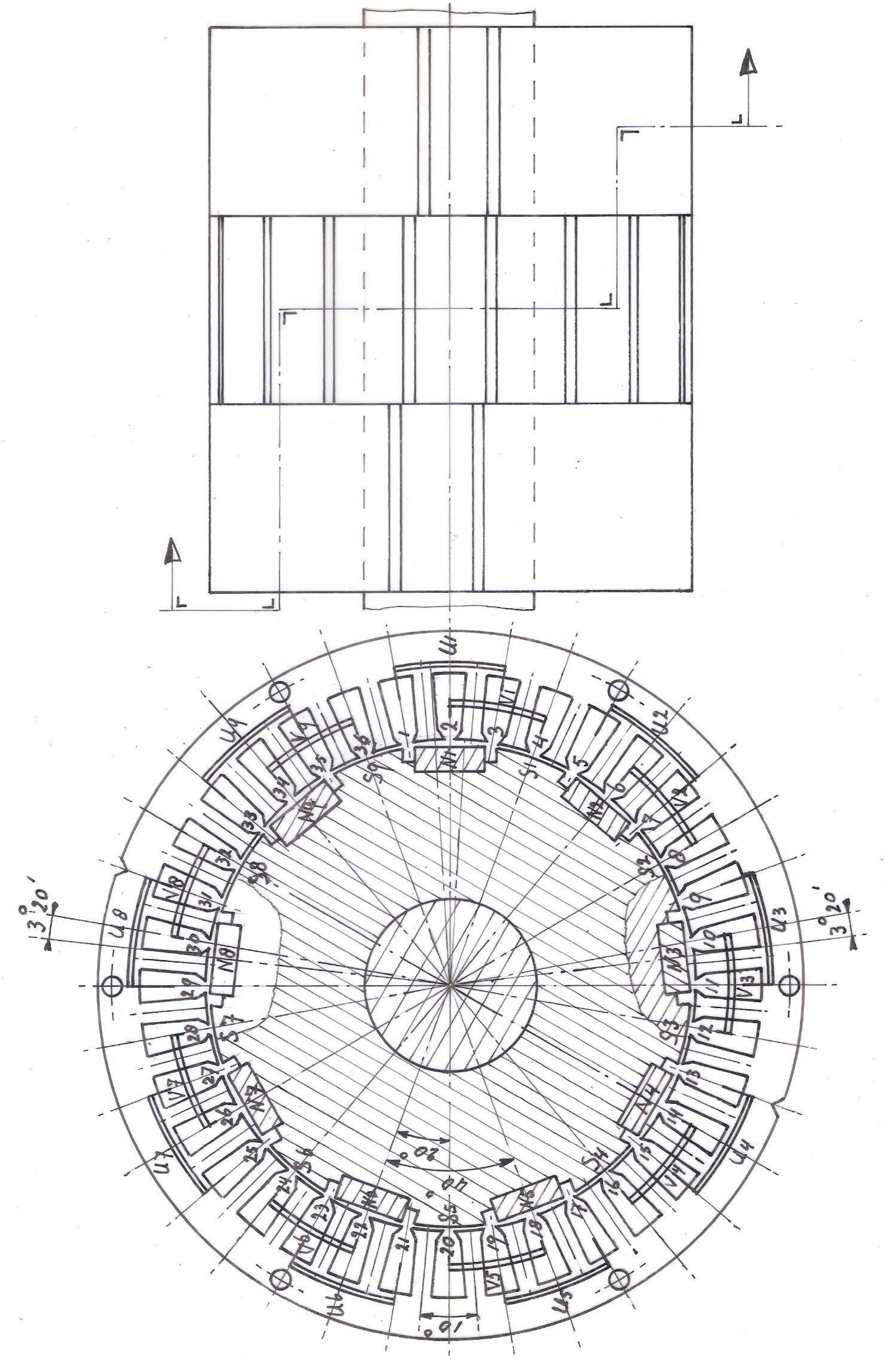

fig. 1 18-pole generator with a 2-layers, 2-phase winding

3 Determination of the flux density in the air gap

A part of a magnetic loop is flowing inside the armature and a part is flowing inside the stator. Eighteen magnetic loops are coming out of a 18-pole armature. Nine loops are turning left hand and nine loops are turning right hand. The right hand magnet loop coming out of magnet N1 will be followed.

This magnetic loop comes out of the right halve of magnet N1 and flows through the large air gap t_3 into the stator stamping. Next it flows in the stator and makes a right hand bend of 200°. Next it flows through the small air gap t_2 and enters the left halve of south pole S1. Next it flows into the steel armature bush and makes a right hand bend of 160° and enters the magnet of the north pole N1 at the bottom side. So this magnetic loop flows through one magnet and the two air gaps t_2 and t_3.

A magnet has a thickness t_1 = 5 mm. As the glue layer is very thin, it is assumed that there is no air gap in between the inside of the magnet and the bottom of the groove.

The stator stamping has an inside diameter of 103 mm. It is assumed that the armature is turned at a diameter of 102.4 mm at the south poles. So for the air gap t_2 at the south poles it is valid that t_2 = 0.3 mm. The air gap opposed to the magnets is maximal at the heart of the magnet and minimal at both sides. The groove depth is chosen such that there is a distance of 45.6 mm from the bottom of the groove up to the shaft axis. This means that the air gap at the heart of the 5 mm thick magnet is 51.5 – (45.6 + 5) = 0.9 mm. The air gap at the sides of the magnet is about 0.35 mm so the magnets don't jut out of the armature. The average air gap is more than half the mathematical average because the air gap is moon shaped. Assume that the average air gap at the north poles t_3 = 0.7 mm.

The flux density in the air gap is calculated by formula 5 from report KD 341 for a PM-generator with tangential orientation of the magnets. A simpler formula can be derived for this PM-generator with radial orientation of the magnets if the magnetic resistance of the iron is neglected and if it is assumed that the magnetic resistance of the magnets is the same as for air. Formula 1 of KD 341 changes into:

$$B_{r\ eff} = B_r * t_1 / (t_1 + t_2 + t_3) \quad \text{T} \qquad (1)$$

For radial positioning of the magnets, the pole area is the same as the magnet area. So it isn't necessary to compare the magnet area with the pole area as it is required for tangential positioning of the magnets. So formula 1 can be used directly to calculate the flux density in the air gap. The used magnets with quality N38 have a remanence B_r of about 1.24 T. Substitution of B_r = 1.24 T, t_1 = 5 mm, t_2 = 0.3 mm and t_3 = 0.7 mm in formula 1 gives that $B_{r\ eff}$ = 1.03 T.

In KD 341 it is assumed that the stator stamping is saturated if the calculated flux density in the air gap is larger than 0.9 T. So it can be expected that the generator is saturated and so the maximum possible torque level is gained. The stator stamping can be saturated at the spokes in between the slots or at the bridge in between the bottom of the slots and the outside of the stamping. The stamping is designed for a 6-pole motor and it is used for a generator with an 18-pole armature. The magnetic flux which is flowing through the bridge is very low for an 18-pole winding as only half of the magnetic flux coming out of a magnet is flowing through this bridge. So if the stator stamping is saturated, it will be saturated only at the spokes.

4 Determination of the voltage variation for different coil combinations

A 2-phase winding can be rectified but the rectified DC-current has a large fluctuation. This is explained in chapter 6 of report KD 340 (ref. 3). So if a DC current is wanted, one can better use the 16-pole generator as described in report KD 718 (ref. 2). A 2-phase winding is only a realistic option if the generator is connected to a centrifugal pump with a 1-phase motor.

Large centrifugal pumps generally have a 3-phase asynchronous motor but small centrifugal pumps generally have an asynchronous motor meant for one phase of the grid. This motor called a 1-phase motor but it isn't a real 1-phase motor as a real 1-phase motor has no starting torque. In reality, the motor has a 2-phase winding with one main winding and one auxiliary winding. The main winding has a low resistance. The auxiliary winding has a high resistance. The second phase is created by a big capacitor. The auxiliary winding is only needed to start the motor. If the motor runs at it nominal rotational speed, only very little power is generated by the auxiliary winding.

Some 1-phase motors have a stronger auxiliary winding and a centrifugal switch which disconnects the second phase above a certain rotational speed. But this is only required if the motor must have a large starting torque. Centrifugal pumps have a low starting torque and so asynchronous motors used in those pumps normally have no centrifugal switch. There are several options of how a small centrifugal pump with a low motor power can be used in combination with a 2-phase PM-generator.

The first option is that one uses only 1-phase of the generator and one uses a pump motor with a big capacitor to create a small second phase to give the motor a certain rather low starting torque. So as only one phase of the generator is used, the other phase can be used to power a second pump motor or another load. But in this case only a very small pump motor can be used.

The second option is that the capacitor of the pump motor is cancelled and that the second phase is supplied by the second phase of the generator. This seems the most logic solution but it has as problem that the second phase of the pump motor isn't meant to supply power when the pump motor is running at its nominal rotational speed. So if both generator phase windings are the same, the second phase may supply a too high current which may burn the second winding of the pump motor. So this can only work if the winding of the second phase of the generator has a much higher resistance than the winding of the first phase. The generated voltage must be the same and so the second winding must have the same number of turns per coil but a much thinner wire thickness. This means that the slots of the second winding are only partially filled with copper. It also means that one must be sure which winding is the main winding and which winding is the auxiliary winding if the generator is connected to the pump motor. This are reasons why I don't like this second option.

The third option is that one uses a pump motor which is designed for a 2-phase grid. So this is a pump motor with two identical windings. In this case, the generator can have two identical windings too. But this requires a special pump motor and those motors aren't generally available.

The fourth option is that the two phases of the generator are connected in series and so finally the generator supplies only one phase. This phase is used for a pump motor with a big capacitor. Provisionally this fourth option is chosen.

In figure 1 it can be seen that all coils have the same geometry. If all coils have the same number of turns per coil, every coil will generated the same open voltage at a certain rotational speed. It is assumed that the voltage varies sinusoidal and that the peak voltage is U_{max}. However, there is a phase shift of 90° in between the voltages generated in the coils of phase U and the coils of phase V. In chapter 2 it was assumed that the voltage for coil U1 is zero for the given position of the armature. This armature position is called the zero position.

The voltage fluctuation of the two coils U1 and V1 is given by the following two formulas if the maximum voltage is U_{max}.

$$U1 = U_{max} \sin\alpha \quad (V) \qquad (2)$$

$$V1 = U_{max} \sin(\alpha - 90°) \quad (V) \qquad (3)$$

The following formula is valid if both voltages are added.

$$U1 + V1 = U_{max} \{\sin\alpha + \sin(\alpha - 90°)\} \quad (V) \qquad (4)$$

It can be proven that this function has a maximum for $\alpha = 135°$. The maximum of U1 + V1 is 1.4142 * U_{max}. If the voltages generated in U1 and V1 would be exactly in phase to each other, the total voltage would be 2 * U_{max}. So the 90° phase shift results in a decrease of the voltage by a factor 1.4142 / 2 = 0.7071 which is a rather large reduction. However, I see no other way to make that the generator is finally supplying a 1-phase current which can be used for a standard 1-phase motor with a starting capacitor.

The voltage fluctuations of these three functions are given in figure 2 for the assumption that U_{max} = 1 V.

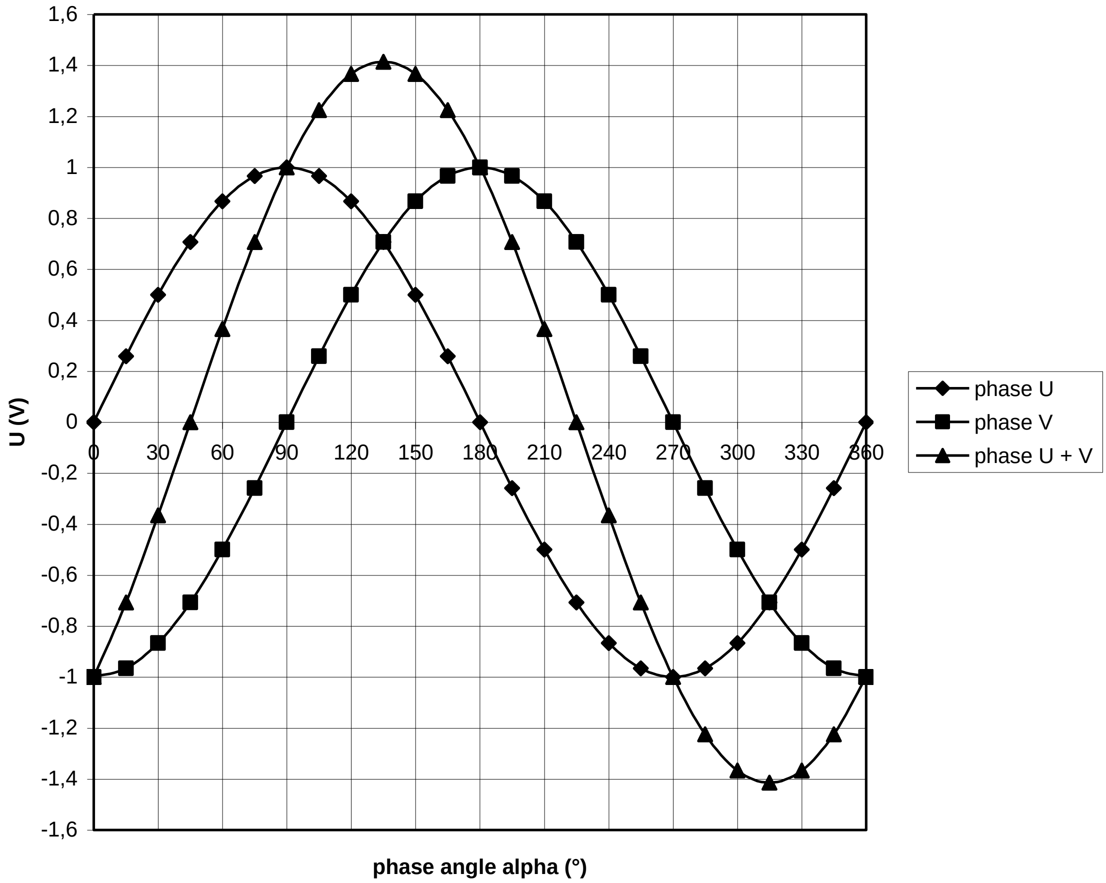

fig. 2 Voltage fluctuation according to formulas 2 – 4 for U_{max} = 1 V.

5 Determination of the number of turns per coil and the wire thickness

The generator is meant to be used in combination with the VIRYA-3B3 rotor. The design calculations for this rotor are given in report 484 (ref. 4). The P-n curves of the rotor for different wind speeds are given in figure 4 of KD 484. This figure is copied as figure 3 but the P_{mech}-n curve, the P_{el}-n curve and the P-n curve for short-circuit in star and delta of the original VIRYA-3B3 generator are removed.

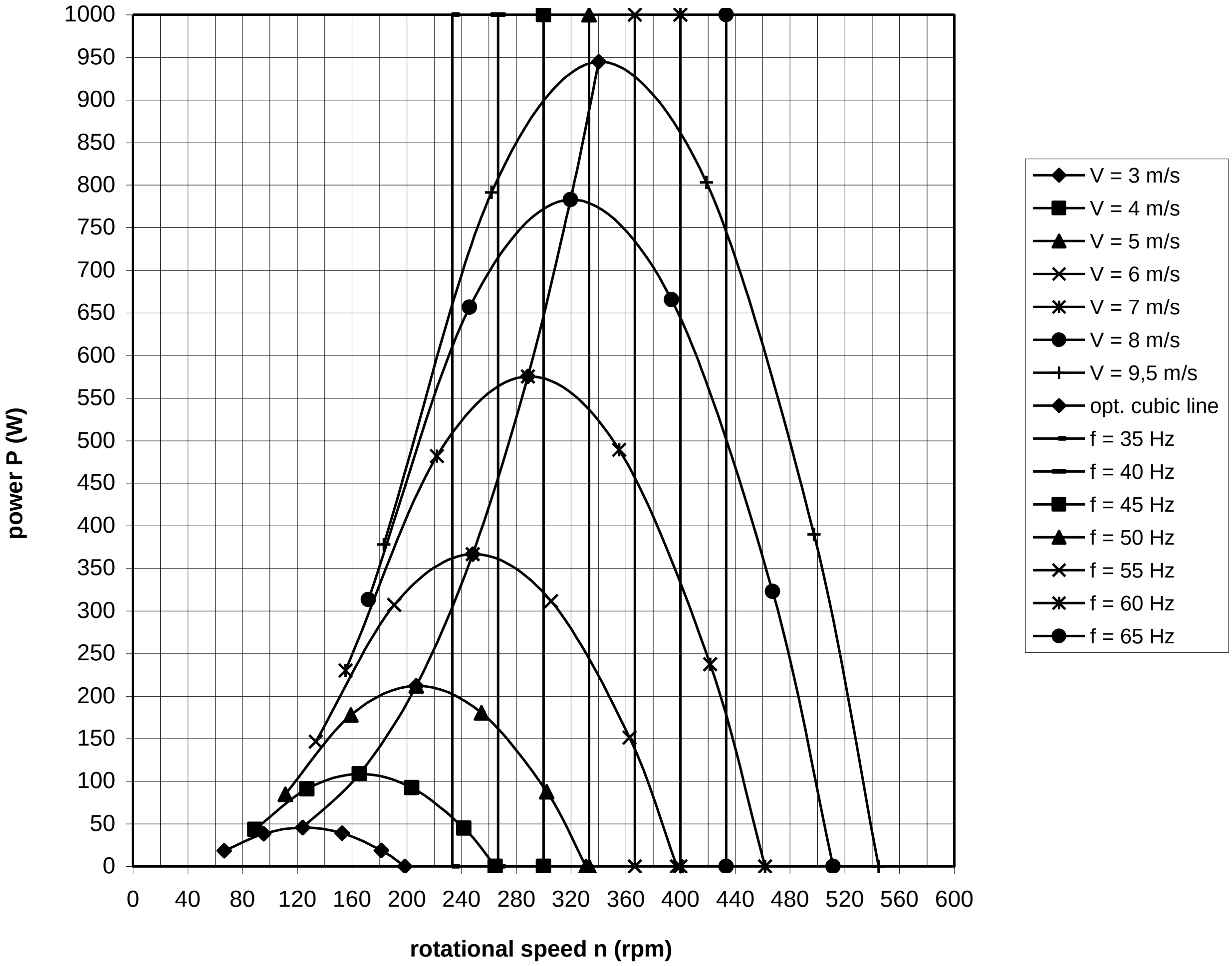

fig. 3 P-n curves of the VIRYA-3B3 rotor for V_{rated} = 9.5 m/s and optimum cubic line

An 18-pole PM-generator has a frequency f = 50 Hz for a rotational speed of n = 333.33 rpm. The frequency is proportional to the rotational speed, so the rotational speed for other frequencies can be determined easily. The lines for constant frequencies of 35 Hz, 40 Hz, 45 Hz, 50 Hz, 55 Hz, 60 Hz and 65 Hz are also given in figure 3.

The pump and the pump motor are designed for a frequency of 50 Hz but can also work at lower or higher frequencies. However, the maximum static head reduces with the square of the rotational speed and therefore it is assumed that the static head can no longer be supplied if the frequency is lower than 35 Hz. The maximum allowable frequency may be limited by the pump or by the pump motor. It is assumed that the maximum frequency is 65 Hz.

First it will be investigated how much power can be supplied by the windmill generator at f = 50 Hz. In figure 3 it can be seen that the line for f = 50 Hz intersects the optimum cubic line of the rotor at a power of about 890 W. This is the mechanical power which the rotor can supply at a wind speed of about 9 m/s. The wind speed for which the line for f = 50 Hz is intersecting with the optimum cubic line is called the design wind speed V_d. So V_d = 9 m/s.

It is assumed that the generator is strong enough to absorb this mechanical power at n = 333.33 rpm. The electrical power depends on the generator efficiency η_{gen}. The generator is used at a high voltage and so the efficiency will be rather high. Assume η_{gen} = 0.8 (-). This means that P_{el} = 0.8 * 890 = 712 W. It is assumed that the centrifugal pump is equipped with a pump motor with a nominal mechanical power of 0.55 kW = 550 W. The real mechanical power depends on the pump load and this depends on the real static water head and on the dynamic head which is caused by pipe losses. A certain pump is meant for a certain head but the real head depends on the water level in the well and this water level may vary. So the pump motor is generally not loaded up its maximal level. Assume it is loaded up to 460 W. A small 1-phase asynchronous motor has a rather low efficiency. Assume that the motor efficiency is 0.65. So the required electrical power is 460 / 0.65 = 708 W. This is about the same as the 712 W which can be supplied by the generator at a rotational speed of 333.33 rpm. So a pump with a 0.55 kW motor seems a good choice.

A design wind speed of 9 m/s belonging to a frequency of 50 Hz is rather high but the pump will also work at lower frequencies. It is assumed that there is a switch in between the generator and the pump motor which is steered by the frequency. It is assumed that this switch is adjusted such that the pump motor is connected at a frequency of 50 Hz and disconnected at a frequency of 35 Hz. In figure 2 it can be seen that a frequency of 50 Hz is gained for a wind speed of 5 m/s if the rotor is running unloaded. The maximum power which can be generated at V is 5 m/s is much lower than the design power of 890 W. So the needed power is extracted from the kinetic energy of the rotor and this means that the rotor slows down. If the rotor has slowed down that far that the frequency is 35 Hz, the connection will be broken and the rotor will speed up again. So some water will be pumped if the wind speed is slightly higher than 5 m/s. There is a wind speed for which the required motor power is that low that the frequency stays above 35 Hz and so above that wind speed, the connection in between the generator and the pump motor will not be broken.

The pump motor is designed for a nominal phase voltage of 230 V. A normal grid has a voltage which is maintained rather stable at this voltage. But the loaded voltage of a PM-generator depends very much on the supplied current. The higher the current, the lower the loaded voltage and the smaller the ratio in between the loaded voltage and the unloaded voltage. It is assumed that the unloaded voltage must be at least 300 V AC to get a loaded voltage of 230 V at n = 333.33 rpm if a 0.55 kW pump motor is used. But if this assumption is right must be checked for a prototype.

The winding is determined as follows. First one test coil is laid with a wire thickness of for instance 1 mm enamelled copper wire and for this wire thickness the maximum possible number of turns per coil are laid. Assume that 50 turns can be laid in the available space. The open AC voltage of this one coil is measured for a rotational speed of 333.33 rpm. Assume that the open voltage is 15 V AC. So the open voltage of all nine coils of one phase will be 135 V. In chapter 4 it was found that the voltage of the two phases U and V connected in series is a factor 1.4142 higher than the voltage of one phase. So the voltage of the complete winding will be 1.4142 * 135 = 190.92 V. The open voltage must be 300 V. So the number of turns per coil has to be increased by a factor 300 / 190.92 = 1.571 and becomes 1.571 * 50 = 78.6 rounded to 79. The wire thickness has to be reduced by a factor $\sqrt{}$ (190.92 / 300) = 0.798 and so it becomes 0.798 * 1 = 0.8 mm. In this case the winding contains the same amount of copper as for the test winding.

Next a complete winding is laid with 0.8 mm enamelled copper wire with 79 turns per coil. Next both phases are connected in series and the generator is measured for a resistance load which is made that strong that the loaded voltage is 230 V at n = 333,33 rpm. Next it is checked if the generated electrical power is about 700 W. If not, one has to change the resistance and see if 700 W can be generated for a lower voltage. If 700 W can be generated at a voltage of for instance 200 V it means that the number of turns per coil was chosen too low.

So the number of turns per coil has to be increased by a factor 230 / 200 = 1.15 and becomes 1.15 * 79 = 91. The wire thickness has to be reduced by a factor √ (1 / 1.15) = 0.9325 and becomes 0.9325 * 0.8 = 0.75 mm. So now the final winding is known. Next the generator has to be loaded by a 1-phase pump motor such that the loaded electrical power is about 700 W.

If it isn't possible to find a resistance for which the electrical power is about 700 W at n = 333.33 rpm it is an indication that the generator is too light for the selected pump motor.

6 Alternative 6-pole armature and original 6-pole winding

It is possible to use the same armature construction with three bushes and a 3° 20' shifted groove pattern for an armature which has physically six poles. This is now called the 6-pole armature although mechanically it still has eighteen poles. The original 6-pole, 230/400 V, 3-phase winding can be used for a 6-pole armature. The winding is rectified and the generated DC voltage will be about a factor 1.5 higher than for the 16-pole generator with a 4-pole winding as described in report KD 718 (ref. 2). This means that the nominal battery voltage must be chosen higher. I expect 72 V for star rectification and 36 V for delta rectification.

To get a 6-pole armature, the magnet orientation must be different as used for the 18-pole armature. This is realized by positioning the magnets such that there are two rows of magnets with the north pole to the outside followed by one row of magnets with the south pole to the outside. The first impression may be that now the north poles will be stronger but that isn't the case because two iron south poles are created at each side of a south magnet and one iron north pole is created in between two north magnets. The magnetic flow pattern is given in figure 4. The inner magnetic loop flows through a whole magnet. The outer magnetic loop flows through a halve magnet but has the same direction.

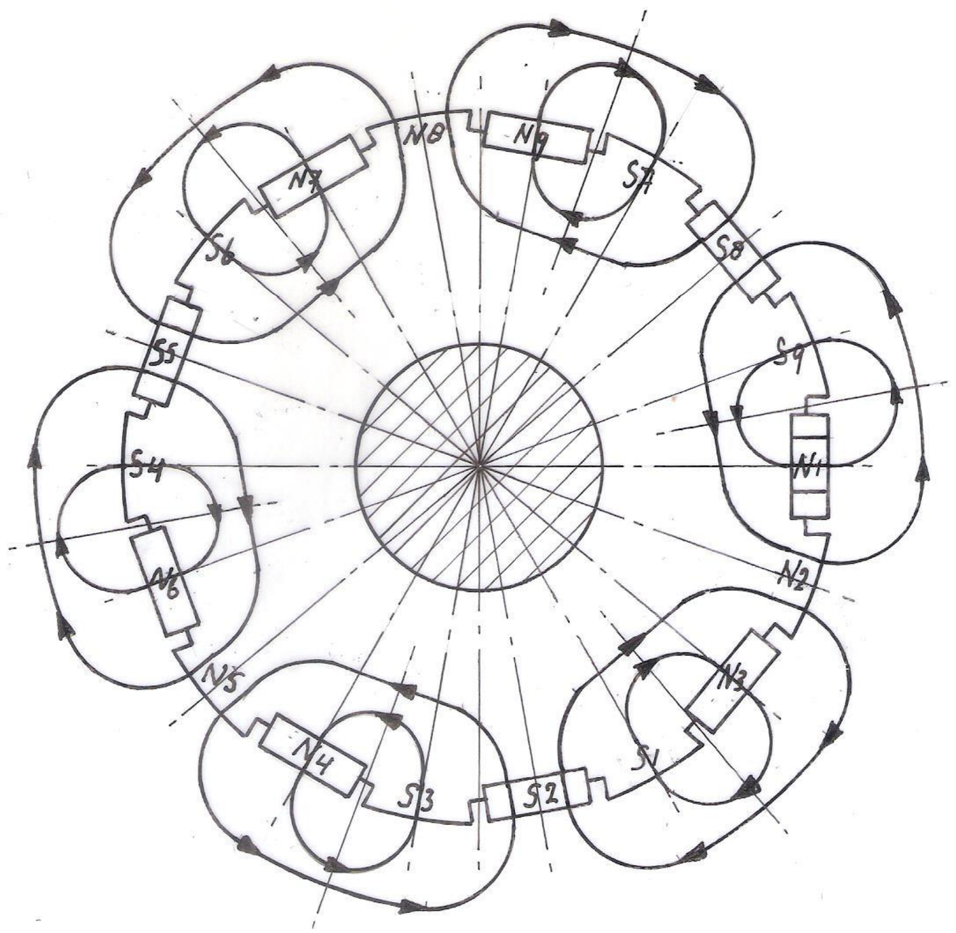

fig. 4 Alternative 6-pole armature combined with the original 6-pole winding

This 6-pole generator (with mechanically eighteen poles) can be compared with the 4-pole generator (with mechanically sixteen poles) as described in report KD 718 (ref. 2) (in this report it is called a 16-pole generator). Both generators are using a housing frame size 100 and the length of the stator and the armature is 120 mm. The armature diameter of the 4-pole generator is 89.4 mm and of the 6-pole generator is 102.4 mm. So the armature volume of the 6-pole generator is a factor $(102.4 / 89.4)^2 = 1.31$ larger. The maximum torque level is proportional to the armature volume if the flux density in the air gap is the same. This is about the case and so the maximum torque level and therefore also the maximum power of this 6-pole generator, is about a factor 1.3 higher than that of the 4-pole generator.

However, this 6-pole generator is more expensive because manufacture of an armature with three armature bushes and a shifting groove pattern is more difficult, a larger iron bar is needed to make the armature bushes and six more magnets are needed. If a standard motor is used to make a prototype, it might be easier to find a 4-pole motor than a 6-pole motor as 4-pole motors are more standard. But if it would appear that the 4-pole generator is not strong enough for the VIRYA-3B3, this 6-pole generator might be an alternative if one wants to use the windmill for battery charging.

As the voltage of a 6-pole generator is about a factor 1.5 higher than that of a 4-pole one, it is expected that standard 230/400 V winding can be used for 72 V battery charging for star rectification and for 36 V battery charging for delta rectification but this are unusual voltages. In chapter 4 of KD 341 (ref. 1) it is explained how a 230/400 V winding can be modified into a 115/200 V winding. But this is only possible for a 2-layers winding. A 6-pole generator can’t have a 2-layers winding. This can be explained as follows.

The armature pole angle of a 6-pole armature is 60°. This means that the optimum angle in between the left and the right leg of a stator coil is 60° too. But this is only possible for all coils if the stator has 18 slots. If the stator has 36 slots, two coils are laid around each other. The inner coil has an angle of 50° and the outer coil has an angle of 70° in between the legs.

So every phase contains three coil bundles and each coil bundle contains two coils. Three coil bundles can’t be divided in two layers, so a 6-pole motor always has a 3-layers winding. The three coil bundles are normally connected in series. What can be done is to connect the three coil bundles in parallel. This reduces the voltage by a factor three and increases the current by a factor three. The standard 230/400 V winding is now transformed into a 76.7/133.3 V winding and it is expected that this winding can be used for 24 V battery charging for star rectification and for 12 V battery charging for delta rectification.

7 References

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2 Kragten A. Ideas about a 16-pole, 3-phase permanent magnet generator using the housing and winding of a 4-pole asynchronous motor frame size 100, May 2021, free public report KD 718, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

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