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Specialized in designing small electricity generating windmills and PM-generators

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Modification of the winding of the PM-generator type FP-640

The company WindGenKids supplies a 36-pole PM-generator type FP-640. A YouTube video about this generator can be found on the website of the company: www.windgenkids.com at the menu “About us”. In this video it is told that the armature has 36 poles so it has 18 north poles and 18 south poles. The magnets are glued inside the armature and the armature is turning around a stator with 27 coils. The stator has a 3-phase winding so it has nine coils for each phase. The coils are wound around a laminated stator stamping so the stator has 27 poles. It is assumed that all coils have the same winding direction and wire thickness and the same number of turns per coil and that all nine coils of one phase are connected in series. The winding is connected in star and the star point is hidden somewhere in the winding. The free end of each phase is connected to a terminal at the generator housing. I call the three phases U, V and W and the corresponding terminal is given the same name.

It might be possible to use this generator for a small horizontal axis wind turbine for 12 V or 24 V battery charging if the current is rectified using a 3-phase rectifier. However, my conclusion is that the original winding has to be modified otherwise the generated DC voltage will be much too high.

A PM-generator with iron in the coils will have a preference position for the clogging torque when an armature pole is just opposite a stator pole. If the armature has 4 poles and if the stator has 3 poles, there will be 3 * 4 = 12 preference positions per revolution. If the armature has 9 * 4 = 36 poles and if the stator has 9 * 3 = 27 poles, there will be 9 * 12 = 108 preference positions per revolution. At this moment I don’t know the peak in the clogging torque measured from stand still position but it will be rather high as nine armature poles will be opposed to nine stator poles at the same time. This peak determines at what wind speed a certain wind turbine rotor with a certain starting torque coefficient will start rotating.

In the video it is told that the open or unloaded AC voltage is 60.8 V for a rotational speed n = 100 rpm. As the star point is hidden somewhere in the winding, it is assumed that this is the AC voltage measured in between two of the three terminals at the generator housing. If all coils are identical, the voltage measured in between whatever two terminals will be the same.

Star rectification of a 3-phase winding is explained in chapter 3.2.1 of my public report KD 340 which can be copied for free from my website: www.kdwindturbines.nl. The effective DC voltage U_{DCeff} is given by formula 13 if the voltage drop over the rectifier is neglected. This formula is copied as formula 1.

$$U_{DCeff} = 0.955 * \sqrt{2} * \sqrt{3} * U_{eff} \quad \text{(V)} \quad \text{(star rectification)} \qquad (1)$$

In this formula, U_{eff} is the effective AC voltage of one phase. Although the voltage in one phase varies sinusoidal, one measures the effective value if a normal volt meter is used. If a 3-phase winding is connected is star, U_{eff} is the AC voltage measured in between the star point and the free end of a phase. So the measured AC voltage of 60.8 V is not equal to U_{eff}! The AC voltage in between the free ends of two different phases is a factor √3 higher than U_{eff}. So U_{eff} = 60.8 / √3 = 35.1 V for n = 100 rpm. Substitution of U_{eff} = 35.1 V in formula 1 gives that U_{DCeff} = 82.1 V for n = 100 rpm.

Even for 24 V battery charging, this voltage is much too high. As the open voltage is proportional to the rotational speed, it means that a DC voltage of 24 V will be generated already at a rotational speed of 100 * 24 / 82.1 = 29.2 rpm which is extremely low.

It might be possible to solve this problem by modification of the standard winding, so it isn't required to rewind the generator with thicker wire and a lower number of turns per coil. I have experience with modification of the standard 230/400 V winding of an asynchronous motor into a 115/200 V winding by connecting the first and the second layer of the winding in parallel in stead of in series. This is explained in chapter 4 and figure 2 of my public report KD 341. If bundles of coils are connected in parallel which are originally connected in series, this is only allowed if the bundles of coils are identical. If the bundles of coils aren't identical, different voltages will be generated in each bundle and this will result is large internal circulating currents.

If one phase has nine coils which are originally connected in series, there are only two options to connect bundles of coils in parallel. One option is to connect all nine coils in parallel but this is a lot of work and the voltage is reduced by a factor nine which is probably not necessary. The other option is to make three bundles of three coils. The modified winding can be rectified in star or in delta resulting in two different DC voltages for n = 100 rpm. If the modified winding is rectified is star, the DC voltage drops by a factor 3 so it becomes 82.1 / 3 = 27.37 V at n = 100 rpm.

Delta rectification of a 3-phase winding is explained in chapter 3.2.2 of report KD 340. The effective DC voltage for delta rectification is given by formula 15 of KD 340 if the voltage drop over the rectifier isn't neglected. If the voltage drop over the rectifier is neglected, the term – 1.4 is cancelled. So in this case the effective DC voltage is given by:

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

So U_{DCeff} for delta rectification is a factor √3 lower than for star rectification. So if the modified winding is rectified in delta, the effective DC voltage drops by a factor 3 * √3 = 5.2 and becomes 82.1 / 5.2 = 15.79 V at n = 100 rpm.

It depends on the windmill rotor which is used in combination with the modified generator, if the matching in between rotor and generator is acceptable. Matching is explained in chapter 8 of my public report KD 35. However this chapter can only be understood if the other chapters are studied first. Correct matching means that the P_{mech}-n curve of the generator for the average charging voltage is lying close to the optimum cubic line of the rotor. The optimum cubic line of the rotor is given by formula 8.1 of KD 35. The P_{mech}-n curve of the generator for a certain voltage has to be measured on a test rig for which it is possible to measure the torque and the rotational speed. Measured curves of PM-generators for different load conditions are given in for instance my public reports KD 78, KD 200 and KD 595.

If the generator is used for 12 V battery charging, the real charging voltage depends on the current and on the charging state of the battery. It normally varies in between 12 V and 14 V so the average charging voltage is about 13 V. So if the modified generator is used for 12 V battery charging, it should be measured for a constant voltage of 13 V, rectified in star and in delta. For my generator measurements, I have used no real battery but a battery charge controller which can be adjusted at a certain constant voltage. But one can also use a real almost empty battery of the correct voltage and of enough capacity. For 24 V battery charging, the modified generator has to be measured for 26 V, rectified in star and in delta.

Modification of the winding is a tricky procedure and one must know very well what one is doing. The first thing to do is to look at the original winding and find out how the coils are connected. One also has to find the star point. At the star point, three wires are soldered together and probably covered with some isolation tube. I have only seen the video and I haven't observed the real generator. So my idea about how the winding looks like is based on my knowledge about other PM-generators and on logic reasoning.

The coils are mounted in a certain sequence of the three phases. The nine coils of the phase U are called U1, U2, U3, U4, U5, U6, U7, U8 and U9 starting at the star point. The coils of phase V and W are numbered in the same way. The sequence of all 27 stator coils is: U1, V1, W1, U2, V2, W2, U3, V3, W3, U4, V4, W4, U5, V5, W5, U6, V6, W6, U7, V7, W7, U8, V8, W8, U9, V9 and W9.

Every single coil has a coil end which starts at the inside of the coil and a coil end which ends at the outside of the coil. Assume that the star point corresponds to the inside coil end. After finding of the star point, the isolation tube is removed and the wires are cut just after the soldering connection. A new isolated wire has to be soldered at each of the new inside coil ends. I advise to use wires with the three different colours red, yellow and blue for the outside coil ends of the three phases U, V and W and to use black wires for all inside coil ends. The procedure is now described for phase U but is the same for the other two phases.

A black wire is soldered to the inside coil end of coil U1. From the original star point one counts three coils for phase U and cuts the connecting wire in between coil U3 and coil U4. One solders a red wire to the outside coil end of coil U3 and a black wire to the inside coil end of coil U4. Next one counts three more coils and cuts the wire in between coil U6 and coil U7. Again one solders a red wire to the outside coil end of coil U6 and a black wire to the inside coil end of coil U7. Next one counts three more coils and if one has made no mistakes, one arrives at the terminal. The outside coil end of coil U9 is removed from the terminal and a red wire is soldered to the outside coil end of coil U9. All three black wires of phase U are now soldered together. All three red wires of phase U are also soldered together. The same procedure but now with the colours yellow and blue for the outside coil ends, is used for the phases V and W. So now one has three bundles of three coils for each phase.

Next one has to make a choice if the generator will be rectified in star or in delta and if one wants to use the three original terminals. As an alternative one may use a terminal block with six terminals as also used for asynchronous 3-phase motors. This has the advantage that one can change in between star and delta connection by changing the position of three brass connecting strips. But let’s assume that one wants to use the three original terminals.

For star rectification, all black coil ends are soldered together, isolated and positioned somewhere in or outside the winding. The red coil ends are connected to terminal U, the yellow coil ends are connected to terminal V and the blue coil ends are connected to terminal W. An advantage of bringing the star point outside the winding is that now it can be short-circuited with the three coloured coil ends and so one gets the same high maximum breaking torque as for short-circuit in delta. However, this requires an extra wire in between the star point and the short-circuit switch.

For delta connection, three black coloured coil ends of one phase and three coloured coil ends of another phase are connected to one terminal. One should not connect black and coloured coil ends of the same phase to one terminal because this results in short-circuit of that phase! For black and coloured coil ends of the same phase one will measure a certain low resistance R in between a black and a coloured coil end. A disadvantage of delta connection is that higher harmonic currents can circulate in the winding and this gives some reduction of the generator efficiency. An advantage is that the peak torque for short-circuit in delta is larger than for short-circuit in star, so the generator is better suited to be used as a brake.

To get a DC current with only a little fluctuation of the rectified voltage, one needs a 3-phase bridge rectifier which can guide a sufficiently large current. Such a rectifier contains six diodes. A diode is symbolised by a triangle and a short line perpendicular to the wire line. The current can only flow in the direction of the triangle point. The wire diagram is now given in figure 1 for the original winding for rectification in star and in figure 2 for the modified winding for rectification in star and in delta.

It might be that delta rectification of the modified winding can be used for 12 V battery charging and that star rectification can be used for 24 V battery charging if the correct wind turbine rotor is designed.

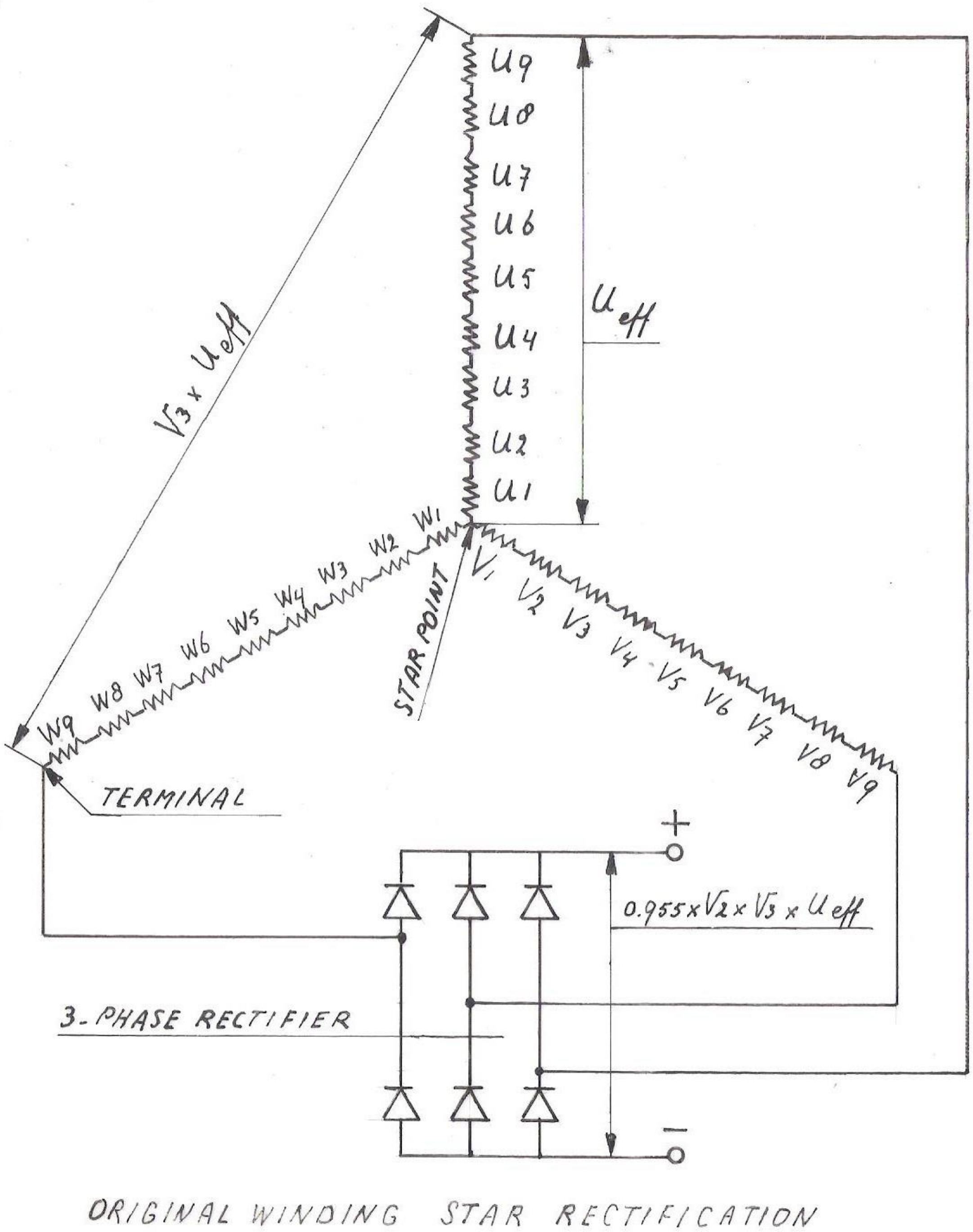

fig. 1 Original winding

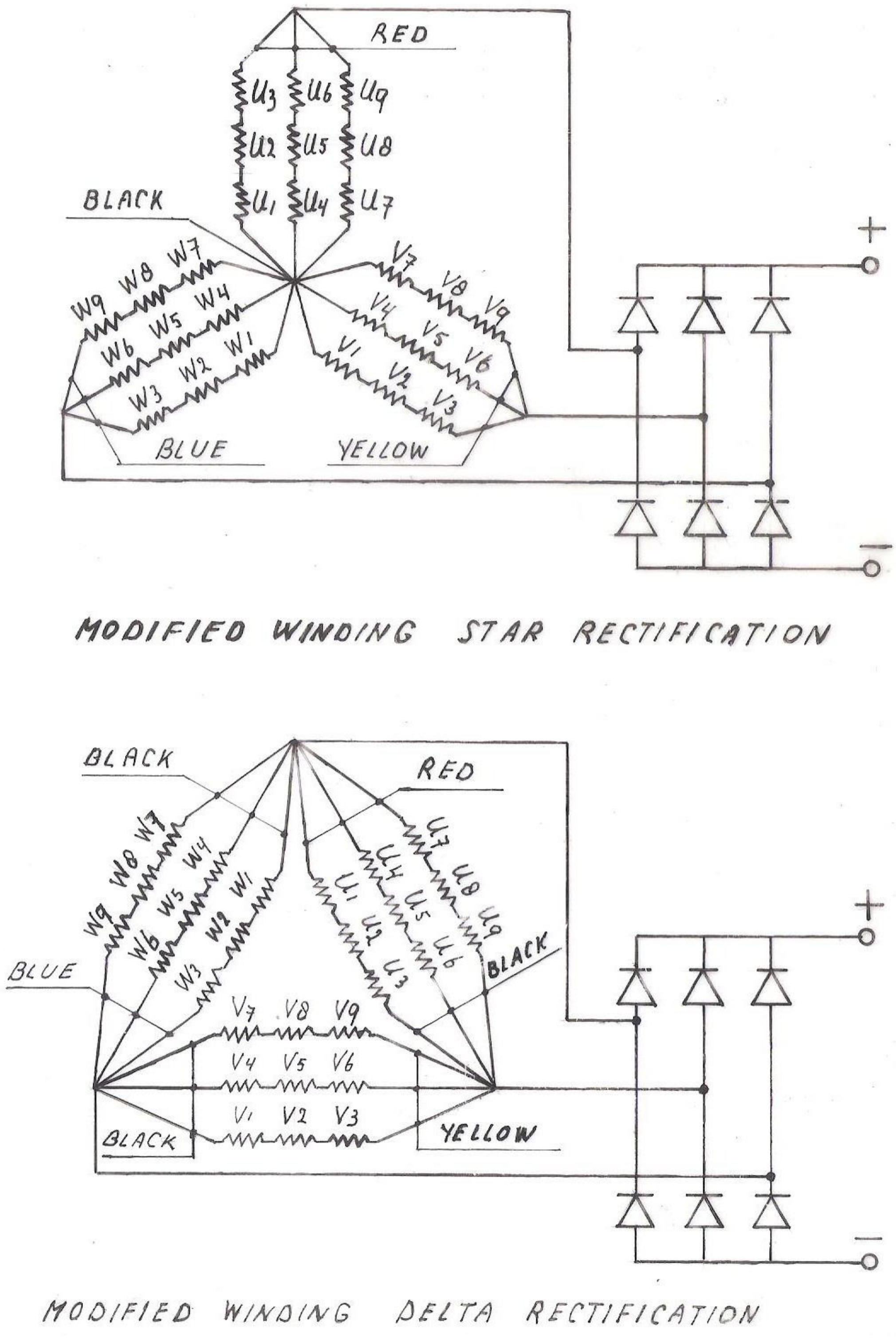

fig. 2 Modified winding