Manual of a 27.6 V, 200 W battery charge controller

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1 Introduction

In this manual a 27.6 V, 200 W battery charge controller is described. The battery charge controller has a separate voltage controller and a separate dump load and is meant to be used in combination with the VIRYA-1.25 or the VIRYA-1.8 windmill if both are provided with a modified 115/200 V winding. For the VIRYA-1.25 and the VIRYA-1.8, the 3-phase rectifier is standard incorporated in the generator. The generators are made from asynchronous motors. The rectifier is connected in delta for the VIRYA-1.25 and in star for the VIRYA-1.8. The VIRYA-1.25 and the VIRYA-1.8 are both windmills for which a licence is required.

The battery charger can also be used in combination with the VIRYA-2.2 windmill if it is provided with a winding meant for 24 V battery charging. No licence is required for the rotor and the generator of the VIRYA-2.2 windmill (for details see folder of the VIRYA windmills with a free licence). The VIRYA-2.2 has an 8-pole, 3-phase axial flux PM-generator with circular magnets and coils. The rectifier is incorporated in the generator.

The battery charge controller is designed by Kragten Design. The printed circuit board of the voltage controller is designed by Arnold Schoffelmeer from the one man office Asquin. Unfortunately Mr. Schoffelmeer has passed away and therefore the voltage controller can no longer be ordered at Asquin. However, the required information for manufacture of the voltage controller is given is this manual, so every specialist in electronics can make it.

Normally, only those who have obtained a licence for a certain wind turbine have the permission to manufacture the battery charge controller belonging to that wind turbine. However, this 27.6 V, 200 W battery charge controller can be used without a licence and it is even allowed to use the principle for bigger battery charge controllers which are built up from several 200 W modules connected in parallel.

The dump load is given on drawing 0604-01. This drawing is made by drawing pen on format A1 polyester film and therefore it is difficult to make it digital and to add the drawing to this manual. But I will describe the dump load in chapter 5 and this description may be enough to make it. A photo of the drawing is given in appendix 1. A print of this photo may be too vague to read the measures but it can be enlarged on the screen of the computer. The drawing also contains a list with standard parts.

Although the battery charge controller has been designed carefully, no responsibility is assumed by Kragten Design for the operation of it, nor for any of its separate parts.

2 Description of the battery charge controller (see figure 1, 3 and drawing 0604-01)

It is supposed that all the components of the battery charge controller are incorporated in a box situated near the battery and the dump load. The box will not be drawn by Kragten Design. The battery charge controller has the following functions and components:

1 Stopping the windmill rotor if necessary, by making short circuit in the DC-wiring. This is done by a short circuit switch situated on the front side of the box.
2 Protecting the batteries against over-charging. This is done by the voltage controller situated on the bottom of the box in combination with the two resistors and the one Darlington transistor situated on the cooling plate of the dump load. The voltage controller limits the charging voltage of a 24 V battery up to about 27.6 V.
3 Dissipation of the surplus energy if the maximum charging voltage is reached. This is done by the cooling plate of the dump load. The maximum total power to be dissipated is about 200 W which is just enough for the VIRYA-1.8 and the VIRYA-2.2 as these windmills have a maximum power of respectively 190 W and 200 W. The cooling plate has to be positioned such that it is never sunlit.
4 Preventing too large currents if short circuit is made in the wiring of the battery load. This is done by a min. 10 A fuse and fuse holder situated on the front side of the box.

5 Showing the charge current of the windmill generator (and a possible solar panel for the VIRYA-1.25). This is done by a 10 A ammeter situated on the front side of the box.
6 Showing the battery voltage. This is done by a 30 V Voltmeter situated on the front side of the box. Discharge of the batteries must be stopped if the open battery voltage is less than 22 V for a 24 V battery.
7 Functioning as a point where the external wires to generator, dump load, battery and load can be connected. This is done by a terminal block situated on the front side of the box.
8 Functioning as a mounting base and protection for all the components. This is done by the box. The box is meant to be connected to the wall of a room. An aluminium box is probably not watertight so it should not be mounted outside.

It is advised to place the battery on the ground, to mount the controller box above the batteries and to mount the dump load on the wall above the controller box. The distance in between the cooling plate and the wall must be about 4 cm. The dump load must be placed such that sun light can not fall on it. If two 12 V batteries are placed in series they must be identical. Each battery must have a capacity of at least 30 Ah for the VIRYA-1.25 and at least 60 Ah for the VIRYA-1.8 and the VIRYA-2.2. However, bigger is better as this makes that a larger wind less period can be bridged for a certain power use and that less energy will be dissipated in the dump load at large currents.

3 Description of the voltage controller

The simplest way to protect the batteries against over-charging is to limit the battery charge voltage to 2.3 V per cell. This corresponds with 27.6 V for a 24 V battery. Regulation of the field, like in a car generator, is not possible because of the permanent magnet armature. Disconnection of power source and battery, like it is done in certain controllers of solar panels, is not allowed, because this will result in an unloaded rotor having an increased noise level. Certain controllers for solar panels are making short-circuit if the maximum voltage is reached but this is also not acceptable for a windmill because it will stop the rotor.

The voltage controller is seen as a standard part in the drawing of the battery charge controller and the required components are therefore not specified on this drawing. One can manufacture it using the given wire diagram of figure 1 and the drawing of the printed circuit board of figure 2.

The voltage controller can be used for 12 V or 24 V lead sulphuric acid batteries. The required maximum charge voltage is adjusted by potentiometer P1. P1 is adjusted in such a way that the OpAmp U1 starts conducting at 27.6 V for a 24 V battery and at 13.8 V for a 12 V battery. One needs an accurate digital Voltmeter and a DC power supply. If a power supply is not available one may use the windmill but the battery has to be removed during the adjustment procedure.

Point 2 of the OpAmp has a reference voltage of 6.2 V caused by the zener diode D1. The OpAmp starts conducting as soon as the voltage at point 3 becomes equal or larger than the voltage at point 2. The voltage at point 3 depends on R1, R2, the adjustment of P1 and the battery voltage.

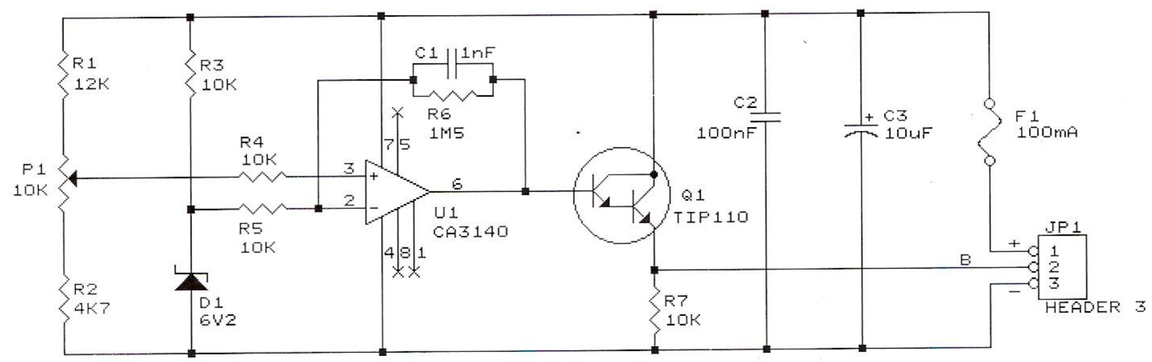
The battery voltage is available between + and –, corresponding with point 1 and 3 of the header JP1. The values for R1 and R2 have been chosen such that a voltage of 6.2 V can be realised at point 3 of U1 for both charge voltages remaining within the range of P1. The calculation of the resistors R1 and R2 and the potentiometer P1 is given in a Dutch note of A. Kragten dated 8-2-1998 (ref. 1).

The base current for the Darlington transistor Q1 is supplied by point 6 of the OpAmp. This transistor Q1 supplies the base current for the Darlington transistor item 01N mounted on the cooling plate item 01 given on the drawing 0604-01. The wire diagram of the whole system is given in figure 3.

The sensibility of the OpAmp is determined by capacitor C1 and resistor R6. The values for C1 and R6 have been chosen such that only a minimal rise of the charge voltage occurs at increasing charge current.

Capacitors C2 and C3 are necessary to prevent oscillation caused by the wires in between the voltage controller and the transistor on the cooling plate.

The battery charge controller of the VIRYA-1.25, the VIRYA-1.8 and the VIRYA-2.2 windmills differs from the controllers of other small VIRYA windmills. It has no heat sinks and only one Darlington transistor on a cooling plate and most of the energy is dissipated in the resistors. Therefore the system is somewhat cheaper and the transistor is less sensible to damage. The maximum power in the transistor is generated at half of the maximum battery voltage which has a favourable influence on the lifetime of the transistor.



C1, C2 and C3 are 63 V. P1 is 0.15 W. All resistors are 0.25 W

figure 1 Wire diagram of voltage controller for battery charge controller

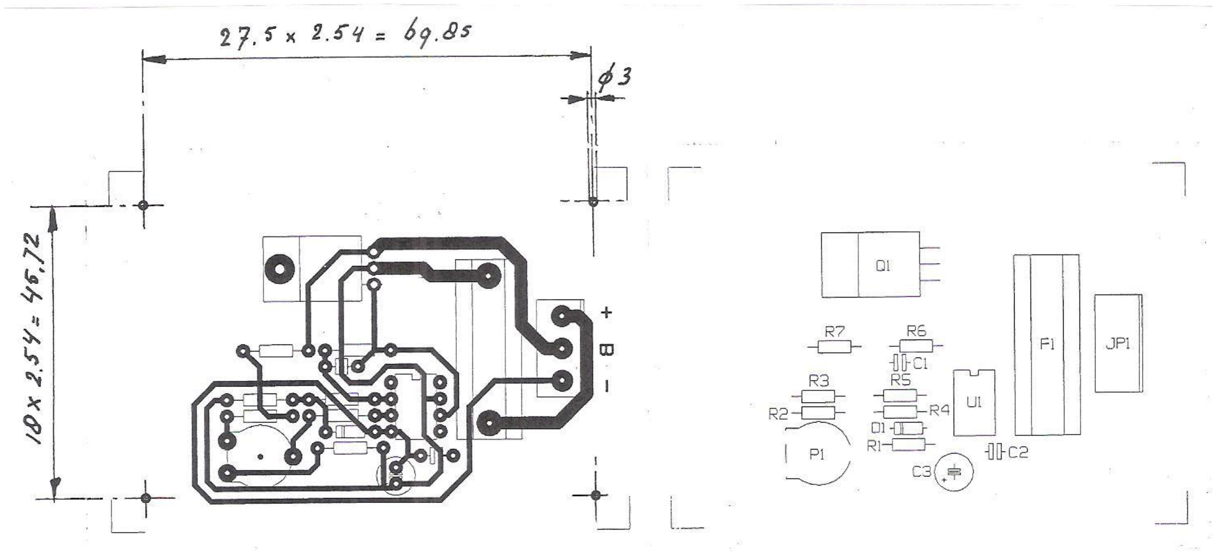


figure 2 Printed circuit board of voltage controller

Be alert that the left picture of figure 2 isn't the mirror image of the right picture but that it is what you see for a transparent circuit board.

4 Wire diagram of the whole system

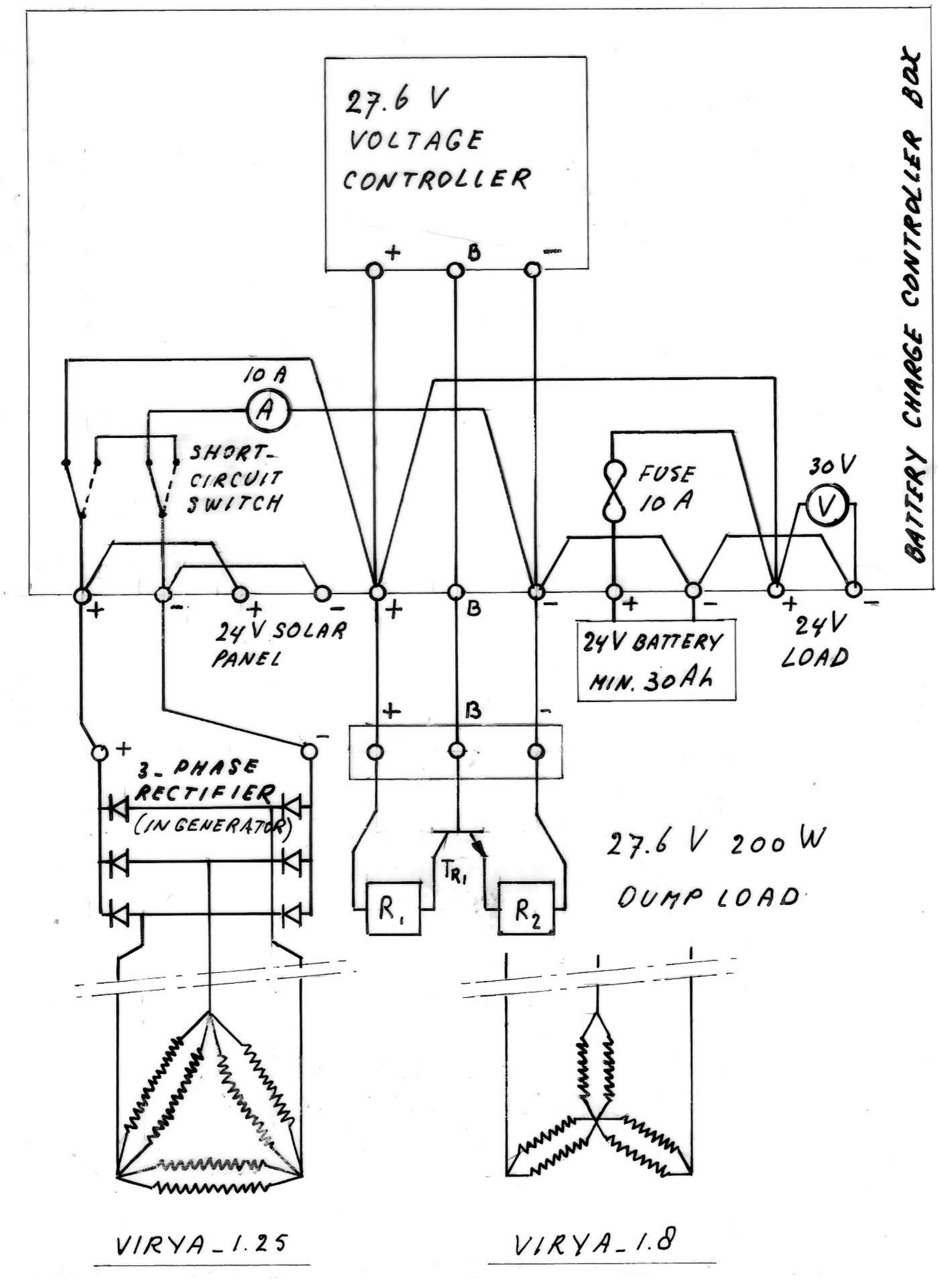


fig. 3 Wire diagram of the whole system for the VIRYA-1.25, the VIRYA-1.8 and the VIRYA-2.2

5 Manufacture of the parts

Manufacture of the cooling plate item 01 and the sheet item 02 of drawing 0604-01

The aluminium sheet of the cooling plate item 01 has dimensions 3 * 250 * 500 mm with rounded edges. The two resistors type HSC 100 1R5 are each mounted at the centre of half the plate using four bolts and nuts M4. The hole pattern is copied from the resistors such that the long side of the resistor is vertical. The cooling plate is mounted with the long side horizontal to the wall of a room by four M6 bolts and four expanding shells. The four 6.5 mm holes for these bolts are lying at the corners of the cooling plate at a distance of 50 mm from the edges. A 16 A, panel mount terminal block with three terminals is mounted to the back side of the cooling plate at the bottom centre. The wires to the resistors, the transistor and the battery charge controller are guided to this terminal block.

The aluminium sheet item 02 has dimensions 5 * 80 * 80 mm. This sheet is mounted at the centre of the cooling plate. The aluminium sheet is mounted to the cooling plate by four M4 bolts and nuts which lie at a square with a pitch of 50 mm. The transistor is mounted in the centre of the aluminium sheet by two bolts and nuts M4. A 6.5 mm hole is made around each transistor wire. The hole pattern for these holes is copied from the Darlington transistor MJ11032. Heat sink compound has to be used in between the aluminium sheet and the cooling plate and in between the transistor and the aluminium sheet. The holes in the aluminium sheets are pre-drilled with a 2.5 mm drill. After mounting everything has to be painted black with heat resistance paint.

6 Heat dissipation in the transistor and the resistors

6.1 Description of the functioning of the 200 W dump load

In the older VIRYA dump loads almost all energy is dissipated in transistors. As transistors are rather expensive, a cheaper system was developed for the VIRYA-1.25, the VIRYA-1.8 and the VIRYA-2.2 which uses only one power transistor and two resistors. The transistor is placed in the hart of the aluminium cooling plate item 01 of drawing 0604-01. To increase the ability of heat transport from the transistor to the cooling plate, an aluminium sheet item 02 is placed in between the transistor and the cooling plate. The wire diagram is given in figure 3 of chapter 4.

Each resistor has a value of 1.5 Ω. One resistor R_1 is placed in the collector line of the transistor Tr_1 and resistor R_2 is placed in the emitter line. The total resistance of the two resistors is 3 Ω.

In earlier prototypes all resistors were placed in the emitter line but this has the following disadvantage. The minimum base-emitter voltage of the transistor Tr_1 is about 2 V. The base current of Tr_1 is supplied by the transistor Q_1 of the voltage controller and this transistor has also a minimum base-emitter voltage of about 2 V. This means that the minimum collector-emitter voltage of Tr_1 is about 4 V. If one of the resistors is placed in the collector line of Tr_1, the voltage drop over this resistor will be more than 4 V at high currents. In this case the collector-emitter voltage of Tr_1 will become about 1.1 V. This means that more power can be dissipated before Tr_1 is opened maximally.

The voltage controller is adjusted at a voltage of U = 27.6 V for a 24 V battery. As soon as this voltage is reached, point B of the controller header will get voltage and this voltage supplies the base current for Tr_1. Therefore Tr_1 starts conducting and a certain current will flow through the emitter and through the collector. The base current is very low because Tr_1 is a Darlington transistor and therefore the emitter current of Tr_1 can be taken the same as the collector current. The voltage controller is so sensible that the maximum battery voltage is maintained within 0.1 V independent of the emitter current. So the maximum battery voltage is taken as a constant value of 27.6 V.

The maximum battery voltage is called U_{batt}. The collector-emitter voltage of Tr_1 is called U_{tr}. The two resistors are identical and have a resistance R = 1.5 Ω and a nominal maximum power of 100 W. Both resistors have the same voltage and the voltage over each resistor is called U_r. The total voltage over both resistors is called $U_{r\,tot}$. It is valid that:

$U_{r\,tot} = 2\ U_r$ (V) (1)

It is also valid that:

$U_{batt} = U_{tr} + U_{r\,tot}$ (V) (2)

(1) + (2) gives:

$U_{batt} = U_{tr} + 2\ U_r$ (V) (3)

According to the law of Ohm it is valid for U_r that:

$U_r = I * R$ (4)

I is the current through one resistor which is the same as the total module current.

(3) + (4) gives:

$U_{tr} = U_{batt} – 2 * I * R$ (V) (5)

Substitution of U_{batt} = 27.6 V and R = 1.5 Ω in formula 5 gives:

$U_{tr} = 27.6 – 3 * I$ (V) (6)

So U_{tr} decreases with increasing current which is favourable because transistors normally fail at a combination of a large current and a large voltage. For the heat dissipation in one resistor P_r it is valid that:

$P_r = I^2 * R$ (W) (7)

Substitution of R = 1.5 Ω in formula 7 gives:

$P_r = 1.5\ I^2$ (W) (8)

For the total heat dissipation in the two resistors together $P_{r\,tot}$ it is valid that:

$P_{r\,tot} = 2 * I^2 * R$ (W) (9)

Substitution of R = 1.5 Ω in formula 9 gives:

$P_{r\,tot} = 3\ I^2$ (W) (10)

For the heat dissipation in the transistor P_{tr} it is valid that:

$P_{tr} = U_{tr} * I$ (W) (11)

(5) + (11) gives:

$P_{tr} = U_{batt} * I – 2 * I^2 * R$ (W) (12)

Substitution of U_{batt} = 27.6 V and R = 1.5 Ω in formula 12 gives:

$P_{tr} = 27.6 * I – 3 I^2$ (W) (13)

This function has a maximum for dI / dP = 0. dI /dP is given by:

$dI / dP = 27.6 – 6 I$ (14)

Substitution of dI / dP = 0 in formula 14 gives I = 4.6 A

For the total heat dissipation in the transistor and the two resistors P_{tot} it is valid that:

$P_{tot} = P_{r\ tot} + P_{tr}$ (W) (15)

(9) + (12) + (15) gives:

$P_{tot} = 2 * I^2 * R + U_{batt} * I – 2 * I^2 * R = U_{batt} * I$ (W) (16)

Substitution of U_{batt} = 27.6 V in formula 16 gives:

$P_{tot} = 27.6 * I$ (W) (17)

The minimum voltage over the transistor U_{tr} is 1.1 V. Formula 6 can be written as:

$I = (27.6 – U_{tr}) / 3$ (A) (18)

Substitution of U_{tr} = 1.1 V in formula 18 gives I = 8.8333 A.

Using formula 8, 10, 13 and 17, P_r, $P_{r\ tot}$, P_{tr} and P_{tot} are calculated for values of I from 0 A up to 9 A increasing with 1 A (including I = 4.6 A, I = 7.3 A, I = 8.8333 A and I = 9.2 A). The calculated values are given in table 1. Using formula 6, U_{tr} has been calculated too and the calculated values are also given in table1.

I (A)	P_r (W)	$P_{r\ tot}$ (W)	P_{tr} (W)	P_{tot} (W)	U_{tr} (V)
0	0	0	0	0	27.6
1	1.5	3	24.6	27.6	24.6
2	6	12	43.2	55.2	21.6
3	13.5	27	55.8	82.8	18.6
4	24	48	62.4	110.4	15.6
4.6	31.74	63.48	63.48	126.96	13.8
5	37.5	75	63	138	12.6
6	54	108	57.6	165.6	9.6
7	73.5	147	46.2	193.2	6.6
7.3	79.935	159.87	41.61	201.48	5.7
8	96	192	28.8	220.8	3.6
8.8333	117.0408	234.0816	9.7175	243.7991	1.1
9	121.5	243	5.4	248.4	0.6
9.2	126.96	253.92	0	253.92	0

table 1 Variation in P_r, $P_{r\ tot}$, P_{tr}, P_{tot} and U_{tr} as a function of I for U_{batt} = 27.6 V and R = 1.5 Ω

The variation of P_r, $P_{r\ tot}$, P_{tr} and P_{tot} as a function of I is given in figure 4

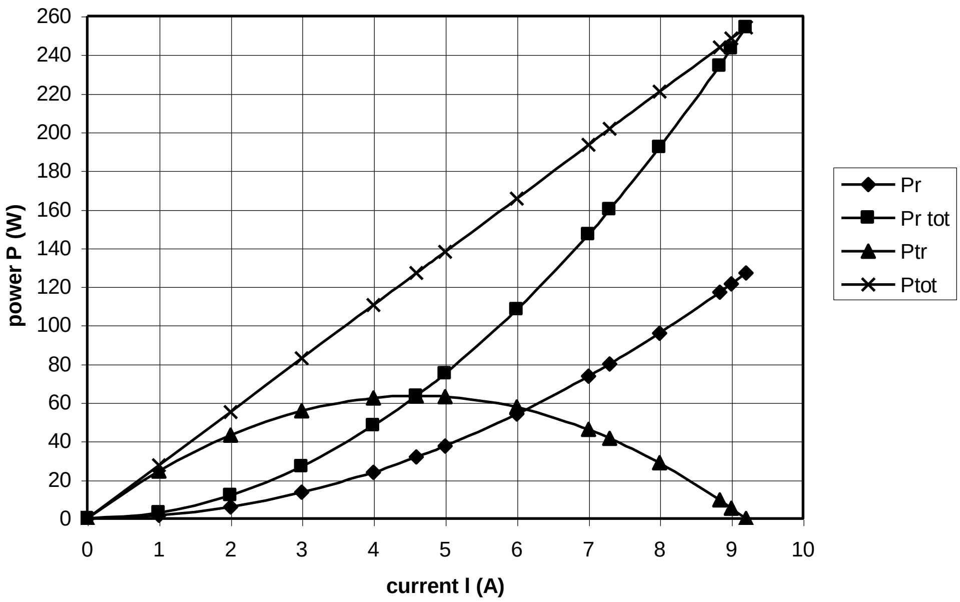


fig. 4 Variation of P_r, $P_{r\ tot}$, P_{tr} and P_{tot} as a function of I for U_{batt} = 27.6 V and R = 1.5 Ω

The P_r-I, $P_{r\ tot}$-I and P_{tr}-I curves from figure 4 are parabolas. The P_{tr}-I curve is cutting the x-axis at I = 0 A and I = 9.2 A and has a maximum at I = 4.6 A.

The minimum collector-emitter voltage is 1.1 V and using formula 18 it was calculated that this voltage is valid for I is 8.8333 A. So as this voltage is reached, the transistor is completely open and from this point the charge voltage will become more than 27.6 V if I increases more. In table 1 it can be seen that P_{tot} = 243.7991 W for U_{tr} = 1.1 V. However, this power is much too high for P_r. It is assumed that a maximum current of I = 7.3 A is acceptable. In figure 4 it can be seen that this gives a power of each resistor of about 80 W, a power of the transistor of about 40 W and a total power of the dump load of about 200 W. The VIRYA-1.25 windmill has a maximum power of 100 W so the dump load has a reserve for a 100 W solar panel. The VIRYA-1.8 and the VIRYA-2.2 have a maximum power of respectively 190 W and 200 W so the dump load has no reserve for a solar panel.

6.2 Calculation of the allowable transistor temperature

In table 1 it can be seen that the maximum power which the transistor has to dissipate is about 63.5 W at a voltage of 13.8 V. A voltage of 13.8 V is much lower than the so called "second break down" voltage of 30 V above which not only the power but the voltage itself starts to have an influence on the maximum power.

The nominal power of the transistor type MJ11032 is 300 W, however, at a casing temperature of 25 °C or less and at a voltage less than 30 V. The junction temperature is 200 °C and the maximum power decreases linear in between 25 °C and 200 °C. It can be proven that the maximum temperature T_{max} is given by:

$$T_{max} = 200 - 175\ P / 300 \qquad (°\ C) \qquad (19)$$

Substitution of P = 63.5 W in formula 19 gives T_{max} = 163 °C. It is expected that this very high temperature will not be reached for the chosen geometry of the cooling plate.

However, in practice it has been found that the real maximum power for a certain temperature for a long lifetime of the transistor must be a lot lower than the values given by the manufacturer. It is supposed that the large cooling plate and the thick auxiliary plate in between the transistor and the cooling plate will keep the transistor at a sufficiently low temperature. The transistor and the resistors can be supplied by Farnell.

6.3 Calculation of the allowable resistor temperature

It is assumed that the VIRYA-2.2 windmill can generate a maximum current of about 7.3 A at a voltage of 27.6 A during wind gusts. In figure 4 it can be seen that P_r = 80 W for I = 7.3 A.

The nominal power of the resistor is 100 W at a temperature of 25 °C if a 3 mm thick heat sink is used with an area of 995 cm^2. The real area is 2 * 25 * 25 = 1250 cm^2, so somewhat more which is favourable. However, a part of this area is also used for the transistor and therefore it is assumed that the requirement of the heat sink area is just fulfilled. The allowable power decreases linearly from 100 W at 25 °C to zero at 250 °C.

It can be proven that the maximum temperature T_{max} is given by

$$T_{max} = 250 – 225 P / 100 \qquad (° C) \qquad (22)$$

Substitution of P = 80 W in formula 22 gives T_{max} = 70 °C. It is expected that this temperature will not be reached, even not at a room temperature of 35 °C.

The maximum theoretical temperature of the transistor was calculated to be 163 °C so the first impression is that the resistor is more sensible to damage than the transistor. However, the allowable maximum temperature for the transistor appears to be much lower than the theoretical value if the transistor must have a long life time. Another aspect is that a resistor doesn’t contain critical components like it is the case for a transistor and that the manufacturer of the resistor says that it can be overloaded by a factor 2 during three minutes.

In figure 4 it can be seen that P_{tot} = 127 W for I = 4.6 A and that the power in the transistor is maximal and 63.5 W for this current. In figure 4 it can also be seen that P_{tot} = 200 W for I = 7.3 A. In the P_{el}-V curve of the VIRYA-2.2 windmill it can be seen that a power of 127 W is generated for a wind speed of about 6.2 m/s. A power of 200 W will be generated only for wind speeds of 9 m/s and higher. So for moderate wind speeds, the transistor will be used very often on the maximum power. However, the resistors will be used on the maximum power only during high wind speeds. Therefore it is expected that the transistor is the most critical component and that it must be protected as much as possible by reducing the maximum power which it can dissipate. This is realised by the chosen value of the resistor of R = 1.5 Ω.

The 27.6 V, 200 W dump load can be seen as a module and several modules can be placed in parallel to create a dump load of higher power. As the dump load transistors are Darlington transistors, the required base current is very low. So the voltage controller is able to supply the base current of at least six 200 W modules in parallel with a total power of 1200 W. One needs an aluminium sheet size 3 * 500 * 1500 mm for such a 1200 W dump load. The same principle can also be used for a 13.8 V battery charge controller except that one must use 100 W resistors with a resistance which is a factor 4 lower, so 1.5 / 4 = 0.375 Ω. However, this is a non existing value. If a resistance of 0.47 Ω is used, the maximum power which can be dissipated without over loading the transistor, will be about 180 W.

7 References

1 Kragten A. Bepaling van de weerstanden R1 en R2 en de potmeter P1 uit de VIRYA-1.65 regelaar, in Dutch, KD-note 8-2-1998, engineering office Kragten Design, Populierenlaan 51, 5492 SG Sint-Oedenrode, The Netherlands.

Appendix 1 Photo drawing dump load drawing number 0604-01