Analog card
by

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Contents

Figures

1 Introduction

Currently a digital card is used that was described before [1] together with the ELC. Here the analog card used before is described. It is a simplification of the control by Jan Portegijs [2]. The other parts of the ELC are the same so they are not described again.

The analog controller regulates the frequency. Trying to regulate voltage gives either a very complicated control or it become unstable in special situations.

For a single phase system does one have one of the cards in Figure 19 and for a three phase system does one also have the card in Figure 20.

2 Signal flow, describing of the different parts of the ELC

A circuit diagram of the different parts is shown in Figure 21 and a block diagram is shown in Figure 22. Figure 19 and Figure 20 shows the layout on the cards.

2.1 Signals

Figure 10 to Figure 16 shows the signal measured at the oscilloscope for some of the points A to ZZ in Figure 21. It is the picture taken from the screen on the oscilloscope and inverted to black and white. All the pictures have the 220V AC signal. On left side of the figures is the voltage shown and zero volt (0 220V) for the 220V signal.

2.2 Voltage from generator

Figure 8 show the voltage from the alternator with no ELC connected to the alternator. Figure 9 shows the voltage from the alternator when the entire load goes through the ELC. The voltage goes all the way down to zero when the triac turns on the load to the heater.

2.3 Power supply

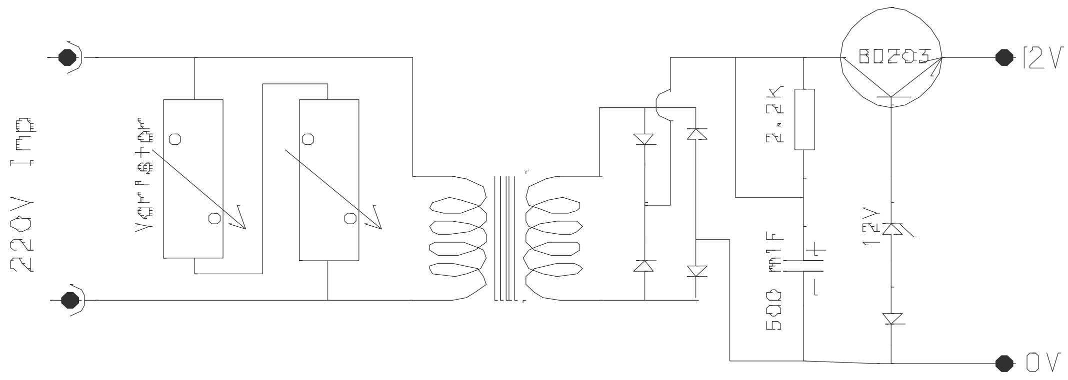

Figure 1 Power supply

Figure 1 shows the power supply. Here a simple circuit is used. Two varistors are connected in series at the inlet to protect again voltage spikes. It should operate up to 500 V which is the runaway voltage of the alternator. To avoid that the varistors start to conduct at that voltage, two varistors is connected in series. Here the varistors type 14K471U are used, because they where available with highest voltage.

A 500 mA or 1000 mA transformer is used depending on the size of the projects. The transformer must give from 17 V to 14 V at 220 V input voltage. Many types of transistors are used, and a fail safe transformer is not found.

The output voltage (U^+) varies between 11.6 and 12.6 V depending mainly on the 12V zener diode that is used. The AC component of the outlet voltage is 2 mV. Also the DC outlet voltage varies +/- 2 mV depending on power usage, without creating any feedback on the controller. The 500 miF condenser should not be larger than necessary. A condenser that is too big can slow down the startup of the system which causes the voltage to increase considerably higher than 220 V at startup, so a 500 microfarad capacitor is used.

The noise condenser with resistor described by Jan Portegijs [1] is not used.

2.4 Input resistor

The components between the input phase and neutral and the input point J in Figure 21 is shown simplified in Figure 2. It gives voltage $U^+/2.0$ when phase voltage is zero volts, but delayed 0.2 ms because of the 1nF capacitor. The 8 V zener diode reduces the max voltage to 8 Volt. Without the zener diode, the input voltage to the OPAMP at point J can go above 12 V. The OPAMP (OPeration AMPlifier) LM324 that we use does only work when the input voltage is below U^+. Tests show that the output signal went down to zero volts when one of the inputs to the OPAMP was close to U^+. The signal at point J is shown in Figure 10 together with the input voltage from the alternator.

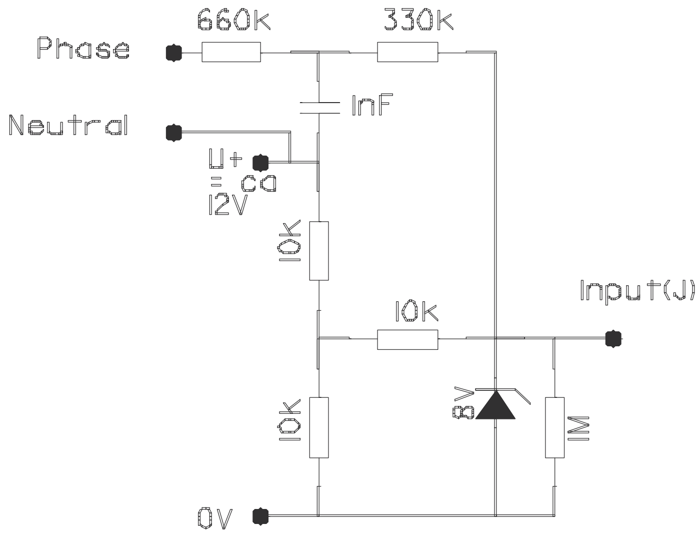

Figure 2 Simplified drawing of the components between the generator voltage and the input J.

2.5 Zero volt sensor

The zero volt sensor consist of OPAMP 5 and 6 in Figure 21. It takes the input signal from J and gives out a signal to P every time the alternator voltage changes sign. When the voltages go from positive to negative it give a signal 0.2 ms after the voltage reaches ï 20V. When it goes from positive to negative it gives a signal 0.2 mS after the voltage reaches 20V. The 1 MΩ resistors gives a positive feed back that makes the change when the voltage becomes ï 20V or + 20V. OPAMP 6 gives opposite signal than OPAMP 5. When one of OPAMP 5 or 6 changes value one get a signal at output P. Figure 11 shows the signal at P. Without the 1nF capacitor and the 1 MΩ resistors an output signal at P would occur when the triacs switches on and the phase voltages goes down to zero.

2.6 Saw tooth generator

The saw toot generator (Figure 22) consist of OPAMP 8 in Figure 21. An input signal at P resets the saw toot generator and is shown in Figure 11.

The 100 nF capacitors, the 3.3 kΩ, 47kΩ, 5kΩ and 10 kΩ resistors make the saw toot generator. The top voltage and also the average voltage become proportional to the period (1/frequence). It is also proportional to U^+, something that is wanted. Figure 13 shows the signal out of the saw toot generator.

2.7 Forbidden zone generator

The forbidden zone generator consists of OPAMP 7 in Figure 21 with the components surrounding it. The output is low when input voltage is between ï 78 and + 78 V but delayed 0.2 ms.

When the voltage goes to zero after the triacs switch on, the forbidden zone generator also goes low, but it is delayed 0.25 mS. Figure 12 show the signal at point U out of the forbidden zone generator.

The forbidden zone generator is connected to point X. It ensures that the triac does not try to start when the voltage is close to zero. The reason is that the triac will not start when the voltage over the triac is low.

Without the 1 nF capacitor, the forbidden zone generator can give a signal immediately after the triac starts to conduct when the generator voltage goes down to zero. That stops the signal to the gate which can then be very short, possibly causing the Triac to not start.

2.8 Smoother

The smoother in Figure 22 takes the signal from the Saw tooth generator at C and smoothes it to get the average value. The average value reduces with frequency and then gives the frequency. The smoothing is done by three capacitors, two 4.7 µF and one 1 µF after the PI regulator. The value of the capacitors is chosen to get a fast response and reduce as much of the AC part of the voltage that is necessary. If potentiometer P2 is in center position the AC part is 0.02V at output E and 0.06V at ñU Regò in Figure 21..

2.9 PI Regulator

The regulator consists of OPAMPs 1 and 2 that makes an PI (Proportional Integral) regulator. OPAMP 1 is the proportional part and OPAMP 2 is the integral part. They are connected to the 10 kohm and 22 kohm resistors and compared with the saw tooth generator. The load is a function of output from the proportional part and the integral part is shown in Figure 3. The integral part of the regulator can be slow, so we want the load to be able to turn off when the voltage suddenly decreases or to turn on when the voltage suddenly increases. After a long time the integral part of the regulator will set the voltage at a given level independent of the load. The output of the proportional voltage (Point P in Figure 21) then becomes 4.6 V (if U^+ =12V) when the system is stable.

Potentiometers below 5 kohm were not available, so a 5 kohm potentiometer is connected in parallel to a 470 ohm resistor. The system for a single phase system consists of four potentiometers P1, P2, P3 and P4. For a three phase system it has six potentiometers, P1, P2, P3 and 3 pieces of P4.

Do the adjustment in the following way for a 3 phase system:
1: Let P1, P2 and P3 be in center position
2 Adjust P4 to wanted alternator voltage on the single phase card.
3: Eventually adjust P4 for the two other phases so the voltage at point C in Figure 19, Figure 20 and Figure 21 become the same for all three phases.
4: Fine adjust the voltage by adjusting P1.
5: Put glue on the potentiometers P4 so the village people do not mess it up

If voltage oscillates, try to reduce it by turning P3 and P2.

Figure 17 and Figure 18 shows the response of the ELC. A test is done with a generator giving 1.6 kW, where the load controller is connected to a heating element of 4 kW. The village load is simulated by putting on and off heating elements. Figure

17 shows the frequency response when an external load of 1200 W is turned off, and Figure 18 shows the effect that is used on the 4 kW heating element.

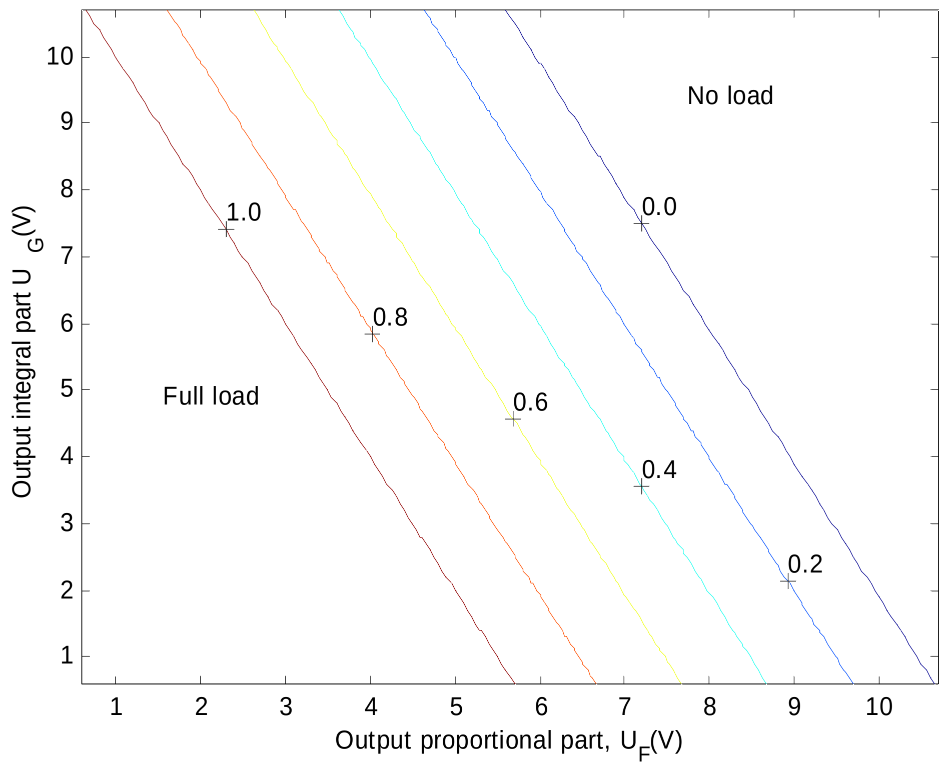

Figure 3 Load as function of output voltage from proportional part and integral part of the regulator

2.10 Frequency sensor

A rough frequency measurement is put on the control; it is assumed the voltage increase with frequency. It consist of OPAMP 3 and 4 in Figure 21 and 3 light diodes. One light diode turns on at high voltage, one at low voltage and one at normal voltage. The signal is fed from the proportional regulator, and the voltage deviation before one of the diodes lights depend on the setting of the proportional potentiometer P3.

The upper diode lights when the voltage is low and the lower light diode lights when the voltage is high. In addition the powerhouse has a light bulb, connected before the controller. The green light diode light when everything is fine.

These diodes will reveal most error situations in the controller.

2.11 Comparator

The signal from the saw toot generator at point C in Figure 13 then goes through some resistors and fed with the signal from the forbidden zone generator at point U to point X in Figure 21. The signal at point X is shown in Figure 14. That signal is compared with the output of the regulator. When the signal at X goes higher than the signal from the regulator, the signal at point Y goes high. This is fed to a light diode. That light diode is lightning depending one the load. At full load it is lighting 100% at half load 50% and no lightning at zero load. At full load the signal at point Y is shown at Figure 15. All the capacity of the of the heating element can not be used.

Figure 4 shows the comparator for a single step process and a two-step process. The two-step process requires two TRIAC drivers. Currently only the single step process is used,

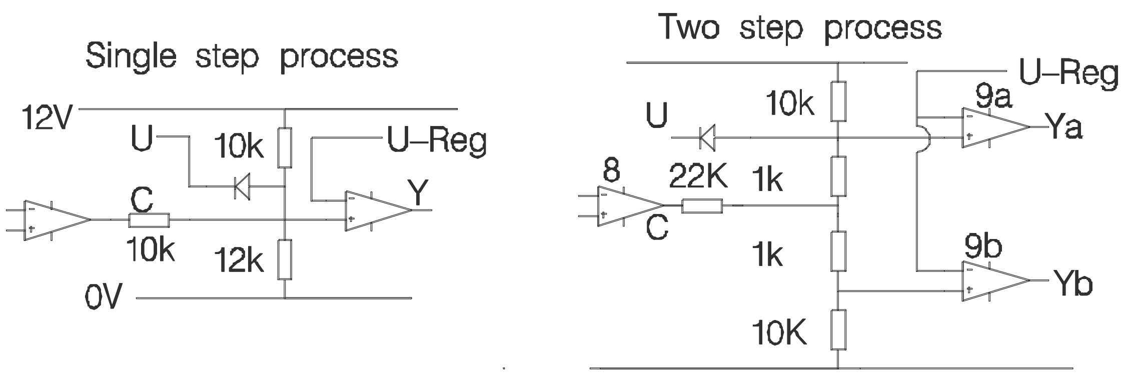

Figure 4 Comparator

2.12 Triac driver

The signal at Y goes through a capacitor and is amplified through two transistors. Jan Portegijs [1] has discussed the required current needed to start the TRIAC without doing any damage to the TRIAC. Here a 0.22 A current is fed into the gate.

2.13 Operative amplifier (OPAMP)

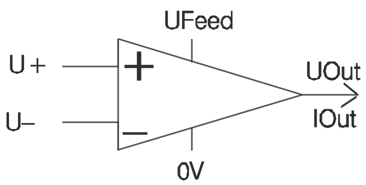

Figure 5 OPAMP

The card uses OPAMPs (OPerator AMPlifiers). Figure 5 shows the diagram for the OPAMP. U_{Out} is low (U_{Low}) when $U_+ < U_-$ (+/- 5 mV), and high (U_{High}) if $U_+ > U_-$. If U_- is connected to U_{Out} by a resistor or capacitor, and then it become $U_+ = U_-$, it become an amplifier or integrator.

Avoid having U_+ or U_- higher than U_{Feed} ï 1.0 V because this is where the OPAMP is not working properly.

Minimum output voltage voltage, U_{Low} and maximum output voltage U_{High} depends on the power taken from the OPAMP. For calculating and design voltages need to be known. They are shown in Figure 6 and Figure 7.

A IC LM358 is used that has 2 OPAMPs and a LM324 that has 4 OPAMPs. The OPAMPs in LM358 and LM324 have the same properties

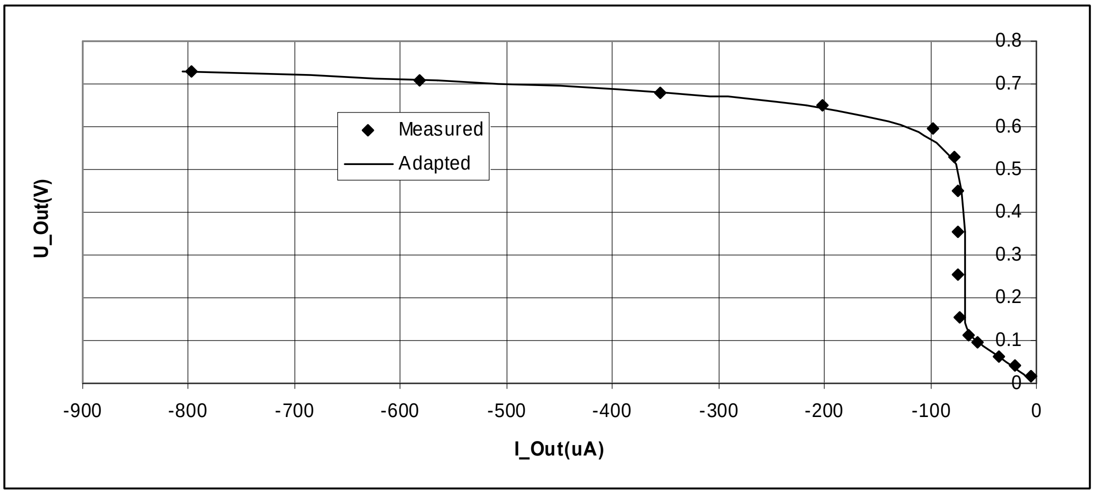

Figure 6 U_{Low} as function of current out (µA). Negative mean current is feed to the OPAMP outlet.

Curve adoption of Figure 6 gives:

$$I_{Out}(\mu A) = \begin{cases} -67 - 0.000432 * \exp(19.7 * U) & \text{for U} > 0.119\text{V} \\ -564.8 * U & \text{for U} < 0.119\text{V} \end{cases}$$

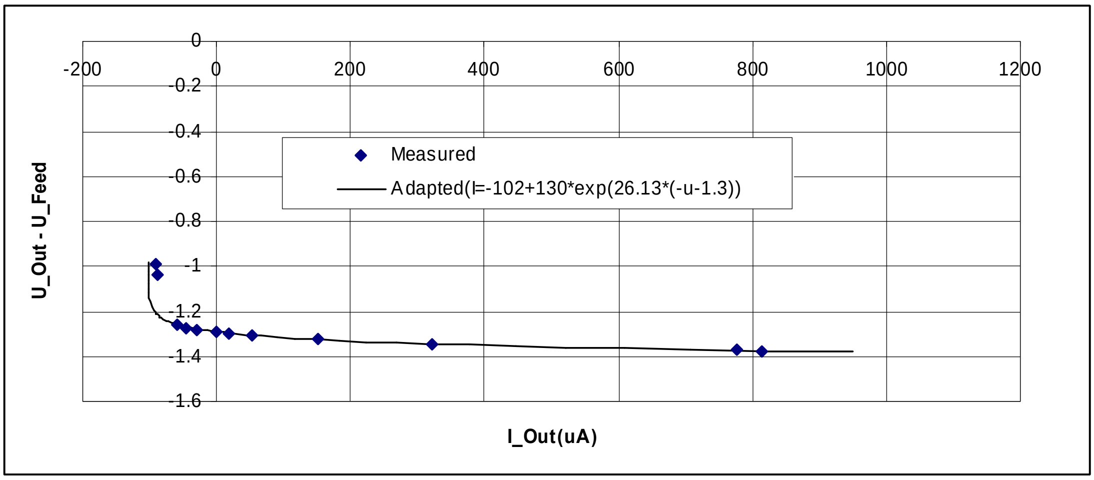

Figure 7 U_{High} - U_{Feed} as function of current out (µA)

3 Conclusion

Here the circuit and the working principle of the analog card are shown. See the Electronic Load control, ELC [1] for the other parts of the ELC.

VARIABLES

U^+: Voltage from power supply at point B in Figure 21.

FIGURES

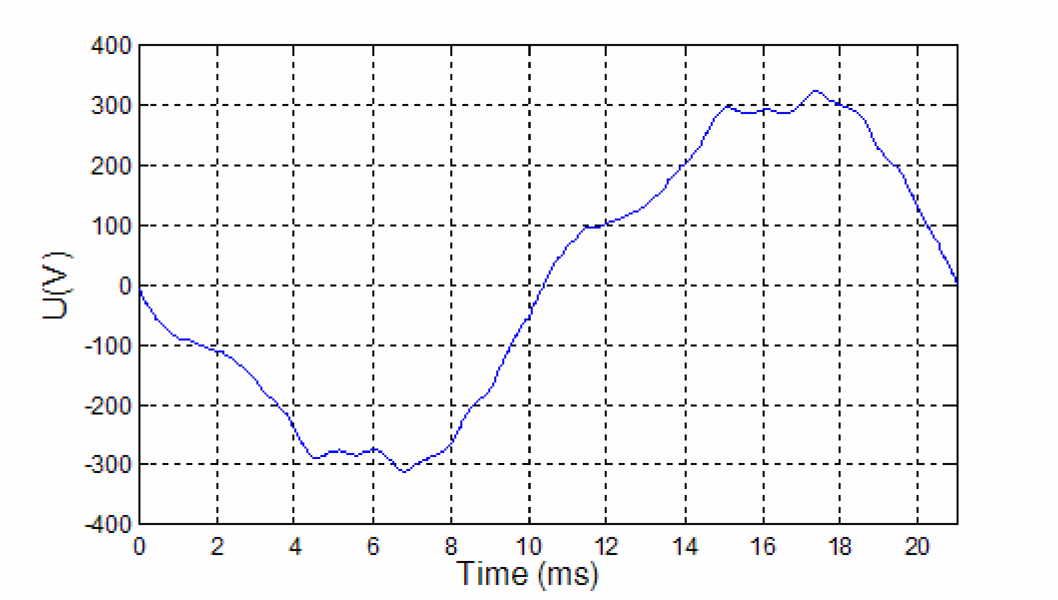

Figure 8 Voltage from alternator without any effect going to the heating

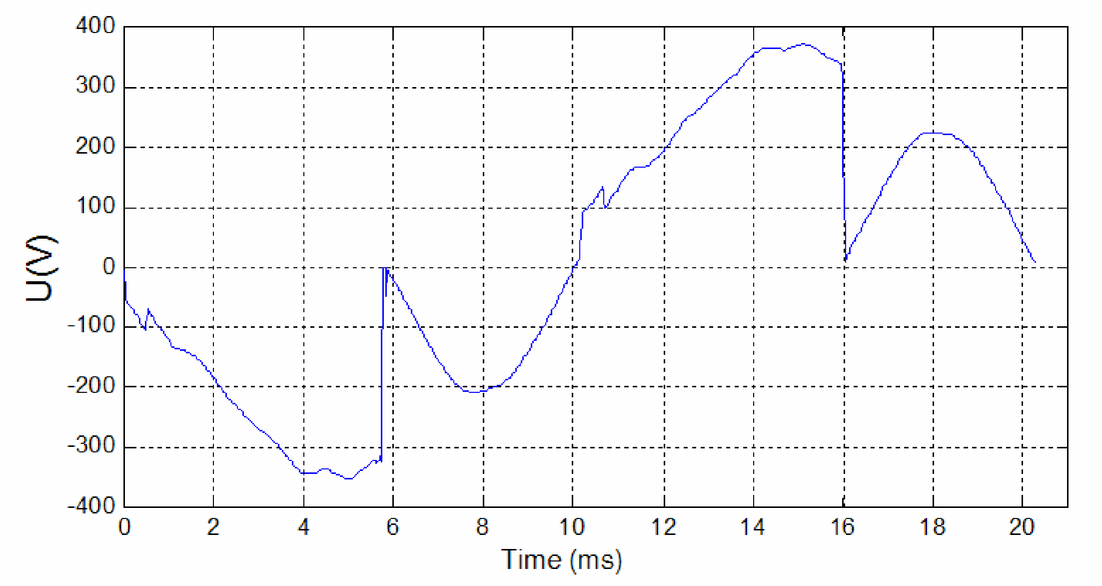

Figure 9 Voltage from the alternator with ELC connected, but no other load.

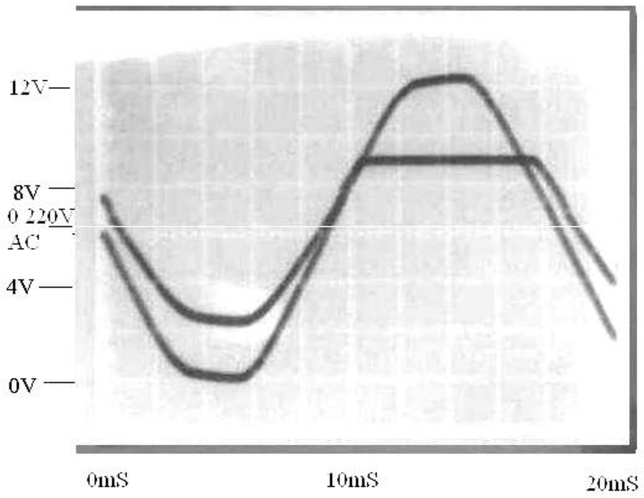

Figure 10 Input to OPAMP 5 and 6 at point J

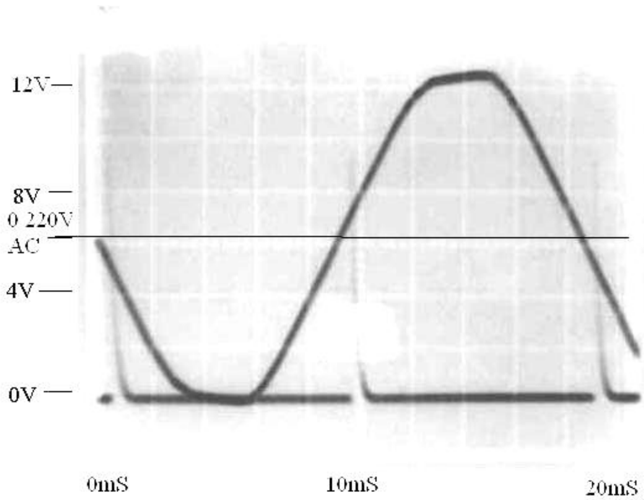

Figure 11 Voltage at point P, input to the saw toot generator compared with input voltage

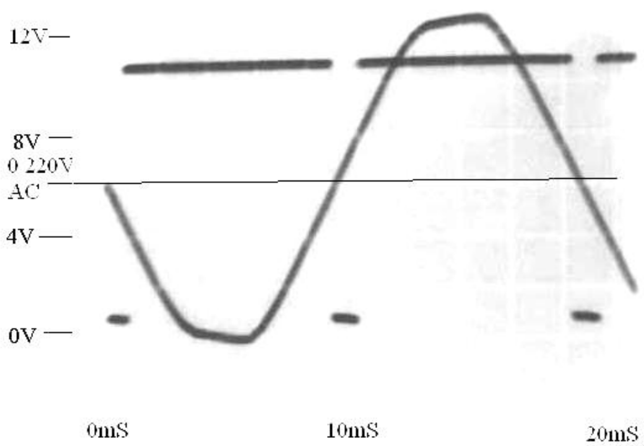

Figure 12 Voltage at point U, out of the forbidden zone generator compared with input voltage

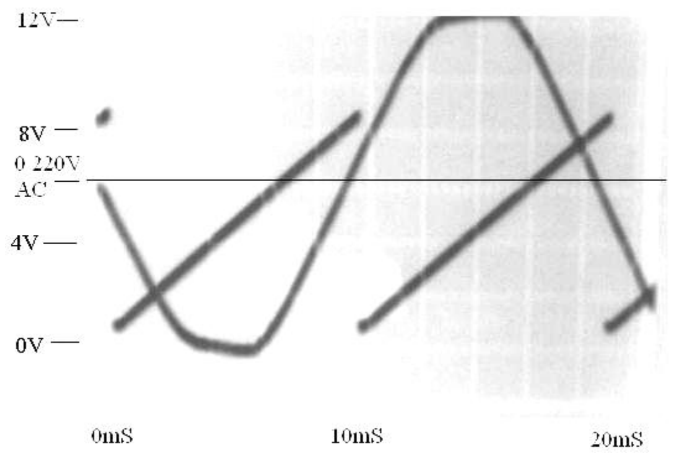

Figure 13 Voltage at point C out of the saw toot regulator

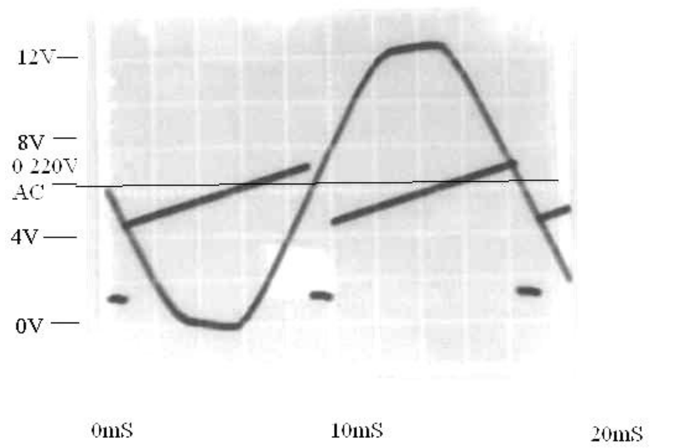

Figure 14 Voltage at point X. This is compared with the input signal

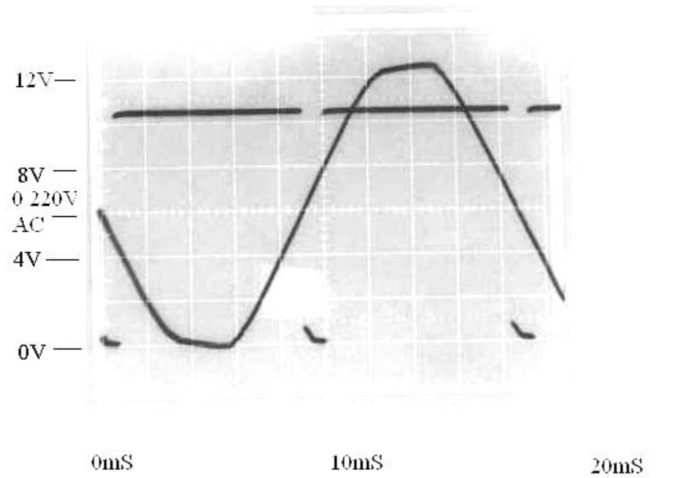

Figure 15 Signal at Y at of the comparator at close to full load

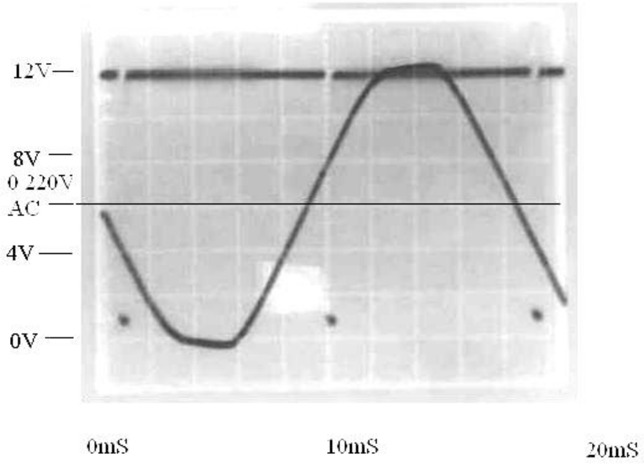

Figure 16 Signal at input to Gate at triac at ZZ close to full load,

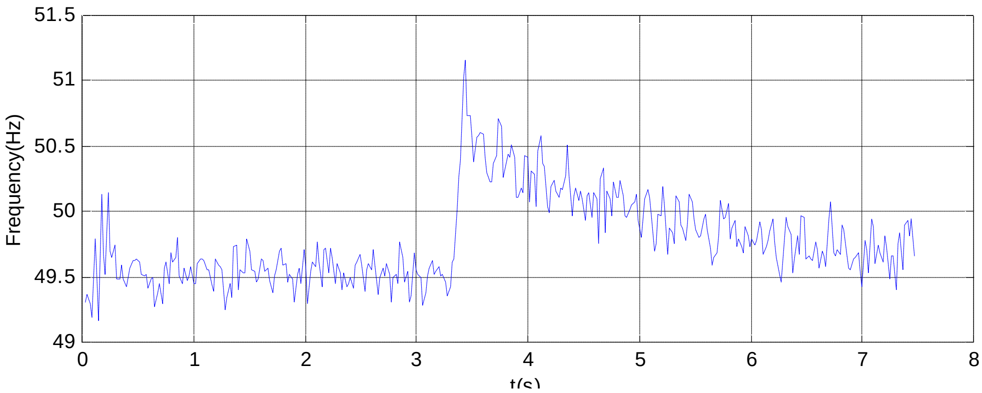

Figure 17 Frequency response when all load is turned off (Time axis in seconds)

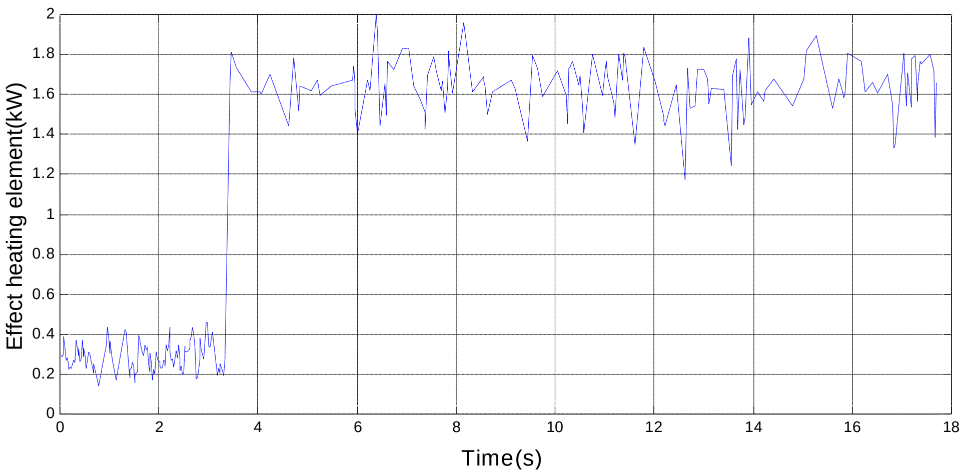

Figure 18 Effect over element, response when load is turned off

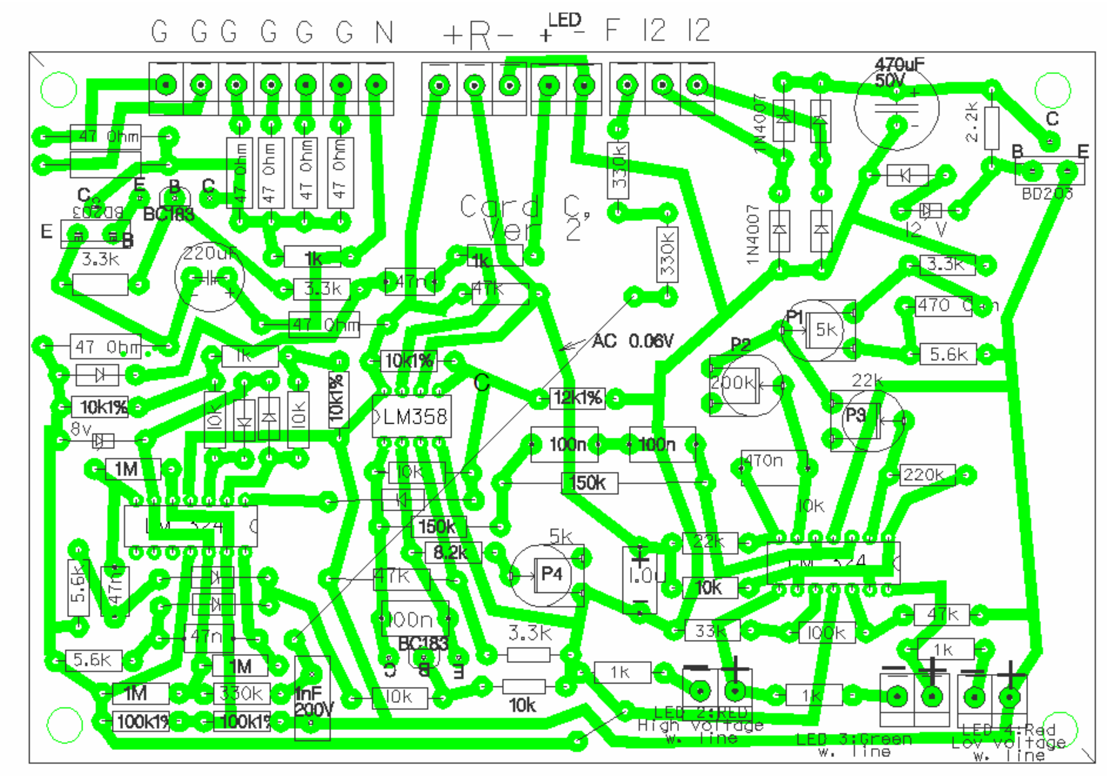

Figure 19 Printed circuit boards for single phase. Connections: "G": Gate, "F": Phase, "12": 14 V AC, "+" and "-": Power supply to card in Figure 20. "R": Output regulator.

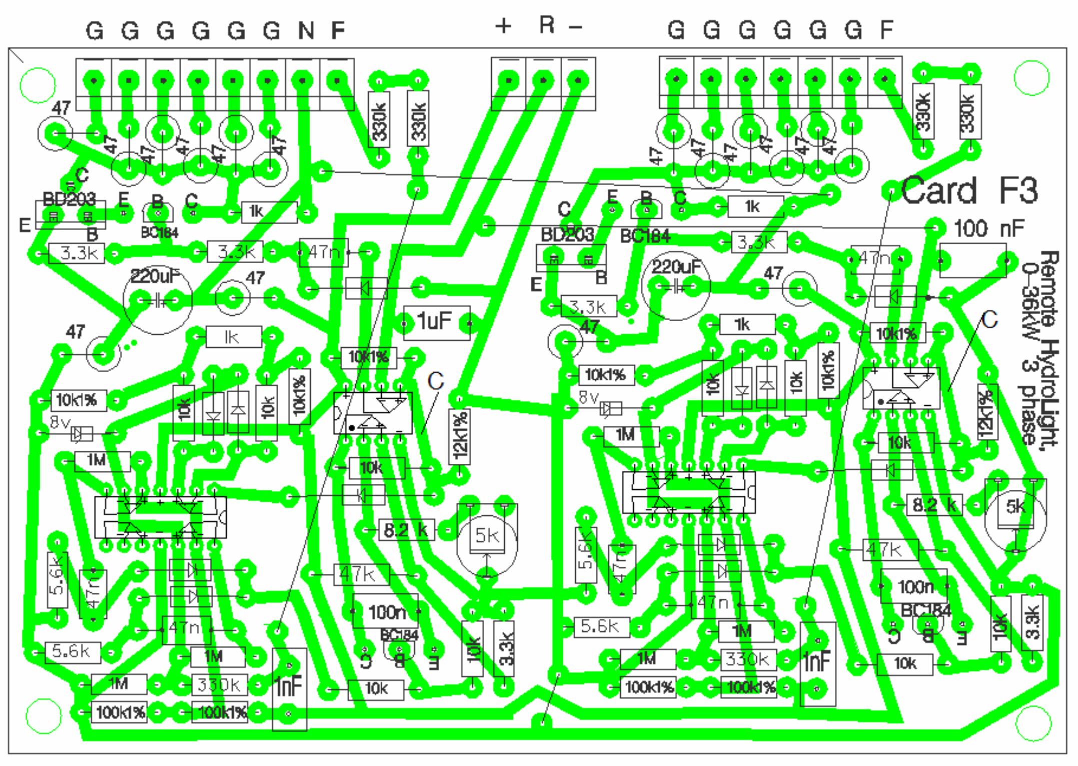

Figure 20 Printet circuit board for phase 2 and 3. Must connect "+", "R" and "-" to card in Figure 19.

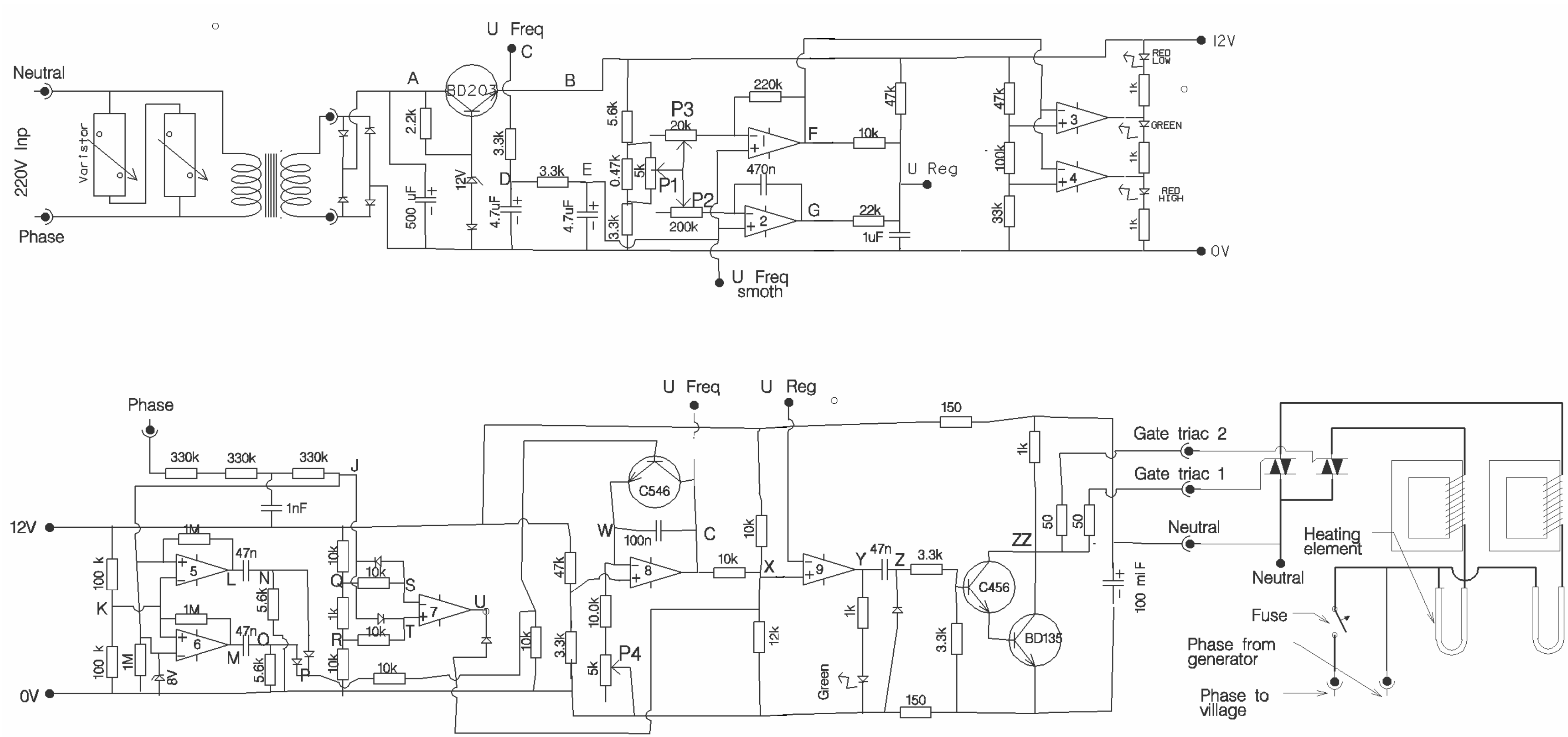

Figure 21 Circuit diagram. The lower part of the diagram is repeated or each phase.

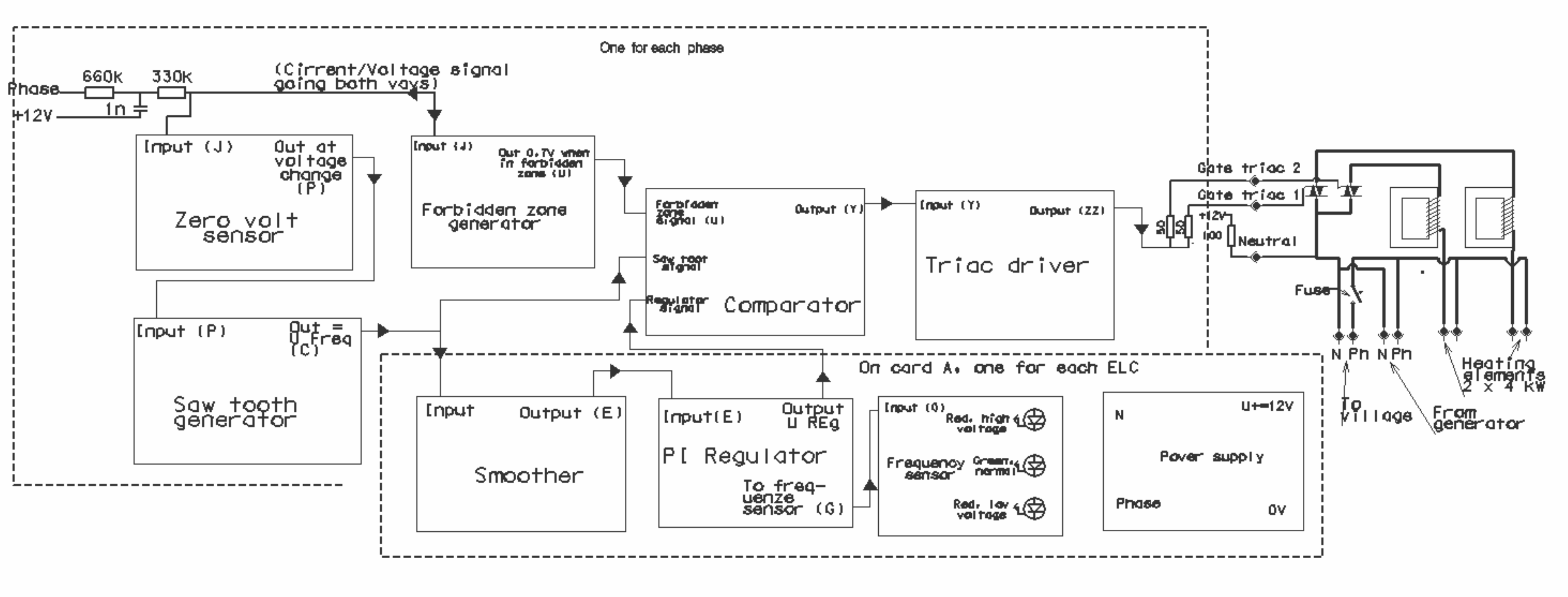

Figure 22 Diagram for single phase ELC, 0 to 8 kW.

REFERENCES

1 Anders Austegard, Electronic Load Control, ELC from Remote HydroLight, for Synchronous Generator, http://www.remotehydrolight.com

2 Jan Portegijs, The ñHumming Bird Electronic Load Controllerò http://microhydropower.net/mhp_group/portegijs/humbird/humb_main.html