VARIABLE VOLTAGE HIGH CURRENT LINEAR STABILIZER WITH HIGH EFFICIENCY

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A 10 A power supply unit with output voltage stabilization and regulation from 0 to 12 V is described. In order to ensure a very low output noise a linear voltage stabilizer with serial regulating transistor is used. Using a tyristor rectifier, whose output voltage is controlled by the stabilized voltage value, reduces the power losses in this transistor. In this manner the voltage drop on the regulating transistor remains all the time below 2 V, thus providing very high efficiency independently of the output voltage.

On the base of this unit, a two-channel power supply is produced. The device is intended to supply the front-end electronics of the CMS muon chambers during the tests, where high current and extremely low-noise power supplies are needed.

In contemporary particle physic investigations very sophisticated detector systems, consisting of a few subdetectors, are used [1]. One of its main characteristics is very large number of measuring channels in each subdetector, requiring a multi-channel front-end electronic system [2]. For supplying such a system high current low voltage power supply with high stability and extremely low noises are needed. In the same time the problem of the efficiency of these power supply is very important, because of their big quantity.

A two-channel power supply, satisfying these demands is developed. The output voltage of each channel could be regulated from 0 to 12 V at a maximum output current of 10 A. The electrical diagram of the device is shown on fig. 1. (Only channel 1 is shown in details, because of the negligible differences between the channels, which are described later.) In order to achieve low output noises a linear voltage stabilizer is used.

The mains voltage is fed to the transformers of both channels (TR1, TR2) through the switch S1. A fullwave rectifier with middle point in which the diodes are replaced by tyristors TYR1 – TYR6 is used. The direct voltage is filtered by the capacitor C and fed to the input Uin of the base control unit CU (see fig. 2).

Each half of the base secondary winding has three sections. The commutation of the tyristors TYR1 – TYR6 is controlled by CU (outputs T1-T6): at the beginning, when the output voltage increases from 0, the tyristors TYR1 and TYR2 are operating (fed by the first sections of the secondary winding) and the direct voltage has a minimal value. With the increasing of the output voltage tyristors TYR3 and TYR4 are switched on and the direct voltage also increase, because they are supplied by the second sections of the base secondary winding. (Tyristors TYR1 and TYR2 switch off automatically because their cathode voltage is higher than the anode one.) At much higher output voltage the tyristors TYR5 and TYR6

are switched on and the direct voltage achieves its maximal value. When the output voltage is decreasing, the tyristors switches off in inverse order. The described

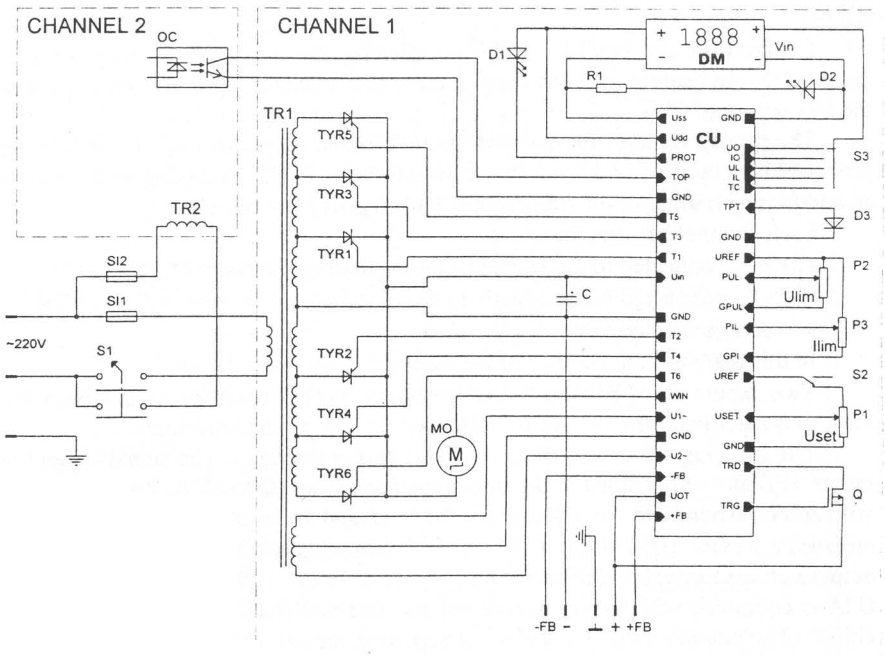

Fig. 1

method of tyristor control ensures minimal voltage drop on the regulating transistor Q and respectively minimal power losses and maximal efficiency.

The output voltage is regulated by the potentiometer P1. For this purpose it receives a stabilized reference voltage from the output UREF through the switch S2, by which the output voltage could be switch "on" and "off".

The digital measuring device DM indicates the value of the following signals (depending of the S3 position):

- voltage on the load (from CU output UO);
- output current (from CU output IO);
- set level of the over-voltage protection Ulim (from CU output UL);
- set level of the over-current protection Ilim (from CU output IL);
- temperature of the regulating transistor Q (from CU output TC).

The level Ulim could be adjusted by the potentiometer P2, the level Ilim – by the potentiometer P3. The temperature of the regulating transistor Q is measured by the diode D3. Besides the generation of the corresponding signal TC, CU switches

on the cooling fan MO at a Q temperature of 40 ^{0}C and activates the protection system at 70 ^{0}C. The device has only one fan for both channels. For this reason CU of channel 1 receives also information about the temperature of the regulating transistor in channel 2 by an optron (OC) and when it achieves 40 ^{0}C, switches on the fan.

CU controls also two LED's: D1 – indicating the activation of any protection circuit; D2 – indicating the switch on of the mains voltage by S1 (it is connected to the Uss output of CU).

The supply voltages for the control unit CU and for measuring device DM are produced by a rectifier and a few one-chip stabilizers in CU, receiving voltage from an additional winding of the transformer TR1 (inputs U1~ and U2~).

Each channel has 3 outputs:

- "+" - connected to the source of the regulating transistor Q;
- "–" - connected to the negative pole of the output voltage in CU (GND);
- ⊥ - connected to the device mass.

In this manner both polarity of the output voltage could be used.

Two inputs – "+FB" and "–FB" permit to take a feedback signal from the load, thus stabilizing the voltage on it (in case of long connecting cables).

The full diagram of control units CU is shown on fig. 2. The signals from the inputs +FB and –FB are fed to the operational amplifier (OA) U2A. Thus its output voltage corresponds to the voltage on the load and is fed (by UO output) to the measuring device (DM, fig. 1). When +FB and –FB are free U2A receives the output voltage through the resistors R13 and R15. In OA U2B the output voltage of U2A is compared with the regulating voltage received from P1 (see fig. 1) – input USET. (The potentiometer P4 serves for adjusting the maximum value of the output voltage - 12 V, when P1 is in upper position.). The output voltage of U2B is fed (output TRG) to the gate of regulating transistor Q (fig. 1) thus closing the stabilizing feedback loop.

The protection diodes D4–D7, which are in parallel of R13 and R15, limits the output voltage increasing if the connection between the load and any of the outputs "+" or "–" is lost: without these diodes the entire load current would pass through the resistor R13 (or R15) causing an uncontrolled increasing of the output voltage.

The switching of the tyristors (TYR1–TYR6, fig. 1) is controlled by the signals fed to the outputs T1–T6. TYR1 and TYR2 (connected to the lowest alternative voltage) receive opening currents all the time (with the exception when any protection circuit is activated). The commutation of the other tyristors depends on the difference between rectified and output (stabilized) voltages. This difference is determined by the OA U4A – its inputs are connected to the CU inputs Uin (through R9) and UOT (see also fig. 1.) The control signals for tyristors TYR3 – TYR6 are generated by means of monovibrators U10A and U10B and comparators U11A and U11B. The method of the tyristor control used in this device has an

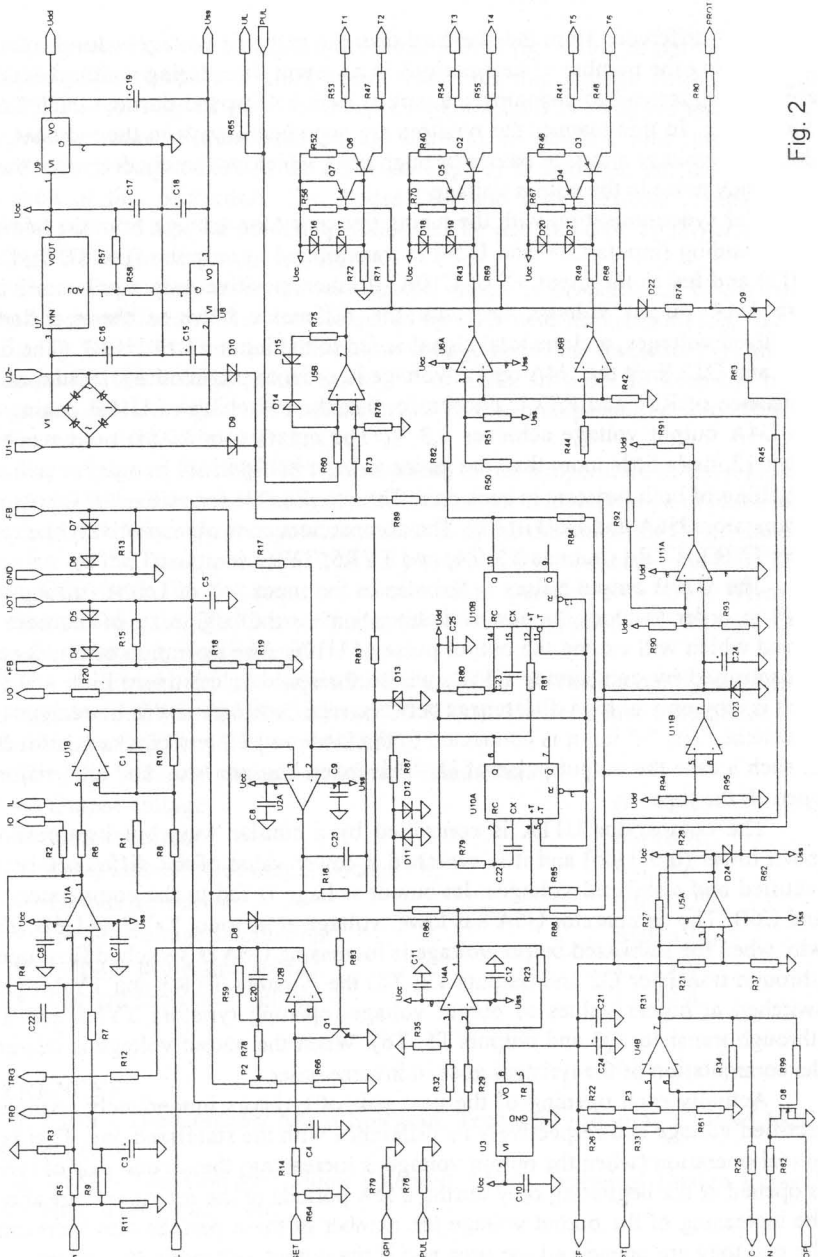

Fig. 2

important difference from the standard one: the rectified voltage value is regulated by changing the number of half-periods in a certain time during which the tyristors are opened, instead of changing the part of each half-period during which they are conducting. In this manner the tyristors are switched always in the moment, when the mains voltage sinusoid passes through zero, which extremely decreases the high frequency noise in the output voltage.

For synchronisation with the mains frequency the voltage from the additional TR1 winding (inputs U1~ and U2~) is transformed to unipolar (D9, D10), limited (D13) and fed to the input +T of U10A. Its short positive output pulses are added with U4A output voltage, i.e. with the difference between the rectified and stabilized voltages, and the total signal is fed to the input +T of U10B. (The diodes D11 and D12 limit the U4A output voltage in order to protect the U10B input.) The resistance of R81 and R87 is chosen so, that the switching of U10B begins when the U4A output voltage achieves 0,3 V. The duration of U10B output pulses is about 12 ms (a little more than the mains voltage half-period) in order to permit the switching of both tyristors in each pair. These pulses are fed to the "–" inputs of the comparators U6A and U6B in CU. The comparators control respectively the tyristor pairs TYR3, TYR4 (outputs T3, T4) and TYR5, TYR6 (outputs T5, T6).

The U10B output pulses is fed also to the input "+" of U10A (through R84, R85) in order to block its new switching "on" at the beginning of the next half-period which will extend the output pulse of U10B. The operation of this feedback is controlled by comparator U11B, whose threshold is relatively high – 0,5Udd. That is why only at high differences between rectified and stabilized voltages U11B is switched (its "-" input is connected to the U4A output) and blocks this feedback. In such a case the output pulse of U10B is extending non-stop and all tyristors are open all the time.

The comparator U11A is controlled by a similar way, but its threshold is much lower (0,05Udd) and it is switched at lower value of the difference between rectified and stabilized voltages. Its output voltage is fed to the comparators U6A and U6B. The comparator U6A has lower voltage at its input "+" than U6B. That is why when the stabilized output voltage is increasing U6A is switched first, opening (through transistor Q2 and outputs T3, T4) the tyristors TYR3 and TYR4. U6B is switched at higher values of output voltage, opening tyristors TYR5 and TYR6 (through transistor Q3 and outputs T5, T6). When the output voltage is decreasing the commutation of the tyristors goes in inverse order.

Actually each opening of the next pair of tyristors immediately changes the rectified voltage and respectively its difference with the stabilized one. That is why in real operation (when the output voltage is increasing) the second pair of tyristors is opened at the beginning only during a few periods of the mains voltage and with the increasing of the output voltage the number of these periods also increases. At the end they are opened all the time and if the output voltage is still increasing the third pair of tyristors begins to open.

The protection circuit against the uncontrolled increasing of output voltage is realised by the comparator U5B, which compares this voltage with Ulim (from input PUL), fixed by P2 (fig. 1). When UO>Ulim U5B is switched and closes all tyristors (by means of transistors Q4, Q5 and Q7). In the same time (through D15, R74, R80 and output PROT) the LED D1 (fig. 1) is switched on, indicating the activation of this protection. The diodes D14 and D15 keep the comparator in switched position and the normal operation can be restored only by switching "off" and "on" the entire device (by S1, fig. 1).

The voltage drop over the resistor R9, which is proportional to the output current, is amplified by U1A and compared by U1B with Ilim (input PIL), fixed by P3 (fig. 1). When IO>Ilim the U1B output voltage opens the transistors Q1 and Q9. Q1 decreases the voltage at the input "+" of U2B, in order to keep the output voltage at a level, at which IO remains below its maximal permitted value Ilim. Q9 is saturated and activates LED D1 (fig. 1).

The voltage at the input TPT corresponds to the temperature of the regulating transistor Q (the voltage at D3 (fig. 1) depends on the temperature) and is fed to the amplifier U4B. When this temperature achieves 40 ^{0}C the transistor Q8 is saturated, switching on the fan. (In channel 2 at the place of Q8 is connected the LED of the optron OC, while its transistor is connected in parallel with Q8.) When the temperature achieves 70 ^{0}C the comparator U5A is switched and through Q9 it closes all tyristors and activates D1.

The stabilized supply voltages for CU and DM are carried out by rectifier V1 and stabilizers U7 (Ucc), U8 (Uss) and U9 (Udd). The reference voltage for P1 is taken from the stabilizer U3 (output UREF).

The base technical parameters of each channel are:

- Output voltage 0 – 12 V;
- Output current 0 – 10 A;
- Total instability of output voltage < 0,2%;
- Output resistance 0,002 Ω;
- Output voltage fluctuation <10 mV_{P-P};
- Voltage protection setting 1 – 13 V;
- Current protection setting 1 – 10 A.

REFERENCES

1. CMS - The Compact Muon Solenoid. Technical Proposal, CERN/LHCC 94-38, Dec. 1994.

2. CMS - The Compact Muon Solenoid. Muon Technical Design Report, CERN/LHCC 97-32, Dec. 1997.