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FLOATING CURRENT LIMITER UNIT FOR SQUARE-WAVE UPS APPLICATIONS

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Abstract

In this paper a new current limiter circuit for uninterruptible power supplies with square — wave output voltage is presented. Using it the frequent cause of failures — the operating point of one of the switching devices in the UPS leaves the SOAR area — can be avoided. Analysis and simulation of the proposed scheme is carried out to show the high performance features. Finally, selected experimental results verify the characteristic of the laboratory prototype model.

Keywords: UPS, current limitation, SOAR, floating supply unit.

Introduction

By the wide-ranging spread of microcomputers and other microprocessor-based delicate equipment the interest in small power, portable uninterruptible power systems has increased. A big part of these UPS supplies the protected equipment with square-wave voltage in case of any mains disturbance, providing the continuity of operation. However, it is a frequent type of failure in those systems that the noise filtering capacitors at the input of the usual loads generate big current surges.

The best solution we found for this problem was the application of an active floating current limiter. This unit can be placed in any critical current line as a two-pole and it contains a controlled forward switch in parallel with a resistor. This MOSFET switch is regulated by the total current that flows through the limiter. The switching devices in this unit and at the output of the UPS are high current, high voltage MOSFET-s which are now available. However, their stresses are close to the specified limits.

To comply with the severe requirements we searched for the best operating point by computer aided simulation where the stresses of both switches at the output and of the controlled switch of the current limiter are within the specified limits. During the simulation we optimized the current limiting value of the controlled MOSFET and the value of the parallel resistor. The aim was that the current surge appearing during the $10\mu s$ long rising edge of the 300 V square-wave output voltage could not move the operating point outside the safe operating area for the forward switch while observing also the current limit of the switches at the output.

An experimental prototype was tested so that different noise filtering capacitors were placed parallel with the resistive load. The experimental results are in accordance with the simulation and they show that the critical stresses are below the limits supposing even $1\mu F$ capacitive load. Since the noise filtering capacitors are about 200–300 nF, this unit will work reliably.

1. Short Review of the Square-wave UPS

Many types of square-wave UPS have been imported to Hungary in the last few years. We have examined an ACCTON product named 'Power UPS–600' [1]. Hungarian importer of these equipment gave us an order for a design review because these supplies generally broke down in a very short time.

Fig. 1 shows the basic structure of the UPS without its control circuits. This UPS was originally made to support a computer and its monitor or another similar equipment.

This is an off-line AC UPS thus when the supply of the electric current is normal then the protected loads are supplied with the mains voltage, and in case of brown-out or black-out the inverter starts to work, and it will generate the output voltage.

The main part of an UPS is the inverter. This unit has to produce the alternating current from the DC voltage of batteries. This DC-AC conversion with usually 10 times or more step-up is quite difficult.

Although the square-wave inverters that are used also in this UPS are not so complicated as the inverters that produce sinusoidal output voltage, they have a severe drawback. The main problem is that they cannot work normally with highly capacitive load.

This is very disadvantageous because almost every electronic instrument, also this UPS, contains noise filtering capacitors at the mains input.

In *Fig. 2* we have depicted the main parts of the inverter. The first unit is a switched-mode DC-DC converter that works at high frequency. This unit produces 300 Volts direct voltage from the battery's 24 Volts.

The second unit is the pole-changing bridge. The four switches in this bridge are controlled in a way, that the voltage on the load is of alternating polarity with 70% duty ratio as it is shown on the first time diagram. Both

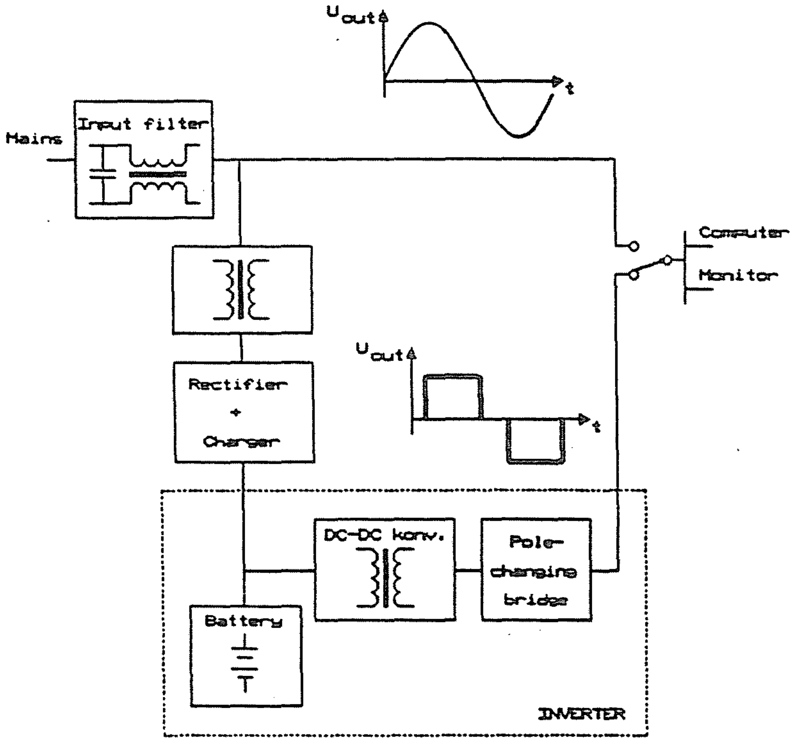

Fig. 1. Basic structure of the square-wave UPS

the peak and the effective values of this square-wave voltage are the same as for the 220 V sinusoidal mains voltage.

It can be seen on the second time diagram that the main drawback of the square-wave approach is that a capacitive load is very critical for the inverter, because the charge of a capacitor causes big current spike in the output current at every change of the output voltage of the inverter. This voltage step together with the current spikes may move the operating point out of the SOAR (Safe Operating ARea) of a bridge switching device.

The noise filtering capacitors at the input of the power supplies of almost every electronic equipment are very often big enough to cause a failure of this type of inverter. Of course removing these capacitors would not be appropriate because the input filter that this UPS already contains does not provide appropriate filtering for the line between the UPS and the equipment.

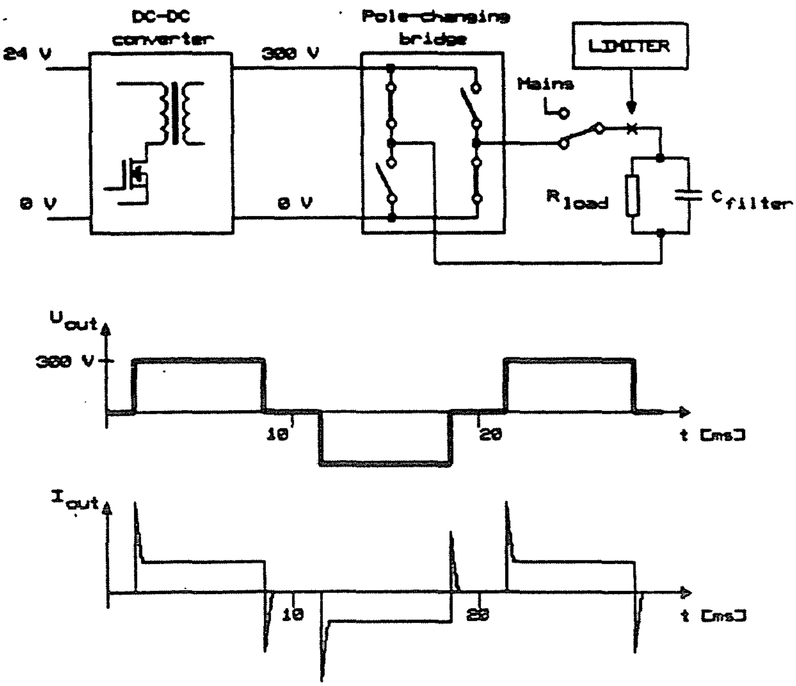

Fig. 2. Main parts of the inverter

2. Current Limiter

While improving the UPS described above, the best solution we found for this problem was the application of an active floating current limiter. This unit can be placed in any critical current path as a two-pole one. In our case it was installed later in the path of the output current, see *Fig. 2.*

There are different kinds of methods for limiting a filter capacitor's inrush current [2], [3]. Also it is known how to form a bi-directional current source combining four diodes and half of a current source [4]. Our task was to evaluate an active limiter circuit, which can operate periodically. At the mains frequency it was easy to provide a good transient response.

Our limiter contains a MOSFET device, the same type as the switches in the pole-changing bridge thus there are negligible extra static losses in most of the time. The unit has to limit only during the four state-changing of the load voltage. These stages are less then 100 μs long what is less than 1% of the full period.

Fig. 3 shows the circuit diagram of the limiter. It contains a controlled forward transistor in parallel with a resistor. The transistor is controlled

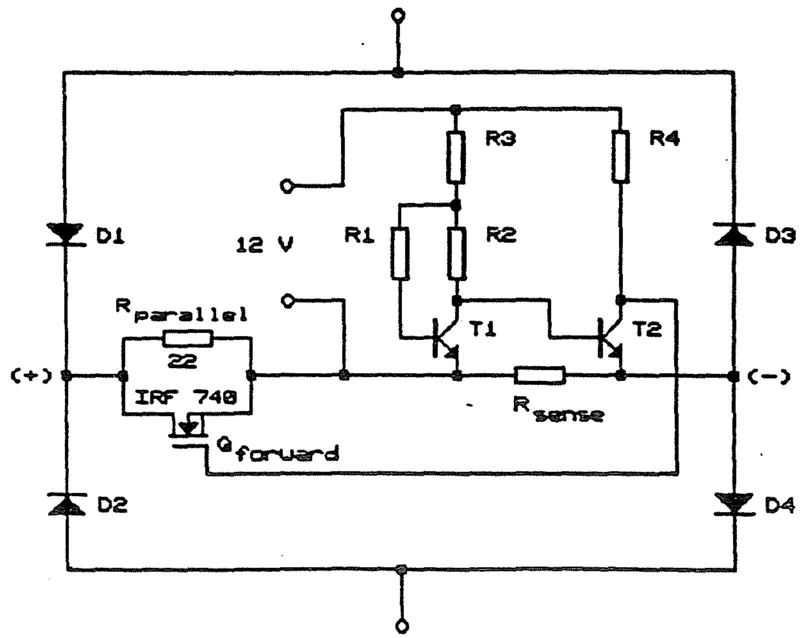

Fig. 3. Circuit diagram of the current limiter

by the total current that flows through the limiter. The total current is sensed by the resistor R_{sense}. When the current exceeds the reference value determined by R_1, R_2, R_3 and the auxiliary 12 V, the series transistor begins to limit the current.

3. Analysis and Simulation

The switching devices in the pole-changing bridge and in this unit are high current, high voltage MOSFET-s, which are now available. Still, their stresses are close to the specified limits. To comply with the severe requirements we searched for the best operating point by computer aided simulation, where the stresses of both the switches at the output and of the controlled switch of the current limiter are within the specified limits.

During the simulation we have examined the stresses of the controlled switch without a parallel resistor and placing different resistors in parallel with it, and also modifying the current limit value.

Owing to the gate drive circuits of the switches in the pole-changing bridge the rising and falling edges of the 300 V square-wave output voltage are about 10 μs long. The value of the noise filtering capacitors are usually

200-300 nF. We made the simulation assuming different capacitive loads ranging from 100 nF to 1.5 μF.

The aim was that the current surges that appear during the rising and falling edges of the 300 V square-wave output voltage should not move the operating point outside the safe operating area for the controlled forward switch while observing also the current limit of the switches at the output.

Considering the different values of the load capacitors, the best value of the current limit we found was 5 A and that of the resistor in parallel with the forward switch was 22 ohm.

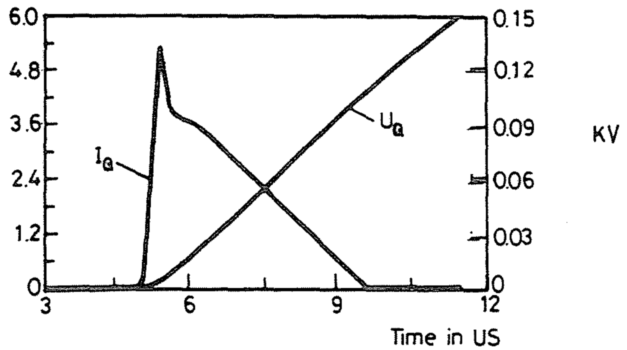

Fig. 4. Result of the simulation with 1 μF capacitive load

Fig. 4 shows the result of the simulation that we had assuming a 1 μF capacitor in parallel with a load of 140 ohm.

It can be seen on the two time diagrams that if the total current exceeds 5 A then the forward transistor conducts no current and only the parallel resistor is exposed to the current stress. However, this 22 ohm resistor is large enough to limit the current spike to 10 A which is the specified limit for continuous stress of the switches in the pole-changing bridge.

When the total current falls below 5 A then only the forward transistor will conduct again. During the voltage change the states of the limiter can easily be followed on the time diagram (on – active – off – active – on). Thus the energy stored in the capacitor is dissipated in a controlled way assuring that the operating point of the switching devices does not leave the safe operating area.

Fig. 5 shows the result of the simulation during the first active state which lasts until the current of the transistor falls to zero. By the current and voltage diagram we drew the curve of the operating point into the safe operating area which is shown below [5]. It can be seen on the diagram

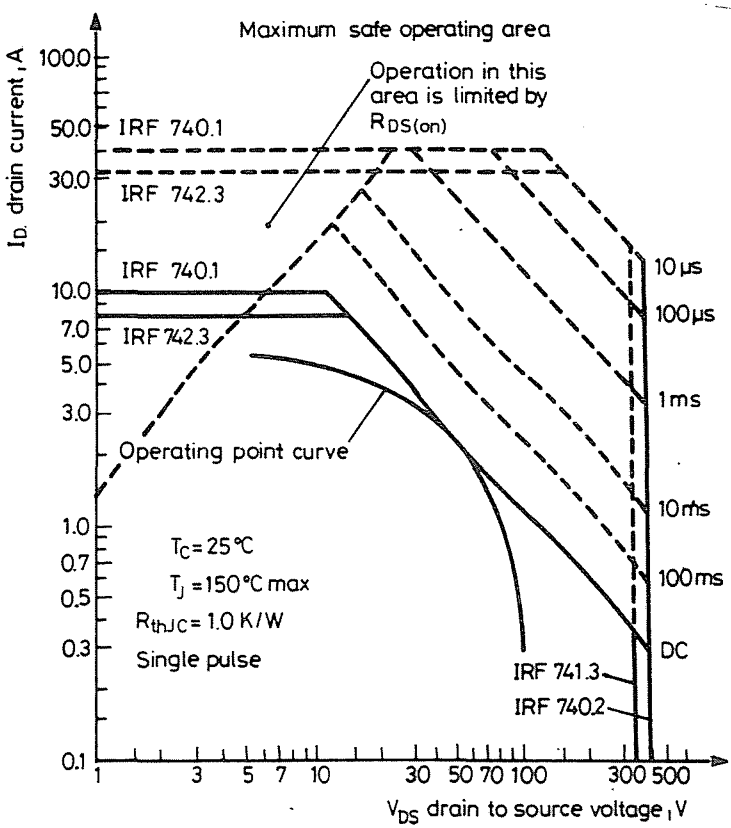

Fig. 5. Current and voltage stresses of the controlled transistor during the active state

that the operating point stays inside the SOAR for constant stress whereas the first active state is only 5 μs long and the second is not more than 35 μs long.

4. Experimental Results

We have built and tested an experimental prototype setting its operating point by the simulation results. The experimental results are in accordance with the simulation and they show that the critical stresses are below the specified limits assuming even 1.5 μF capacitive load.

On the top, *Fig. 6* shows the current of the forward switch and of the parallel resistor using 1.5 μF capacitive load. The total output current, and the voltage of the forward switch are also shown.

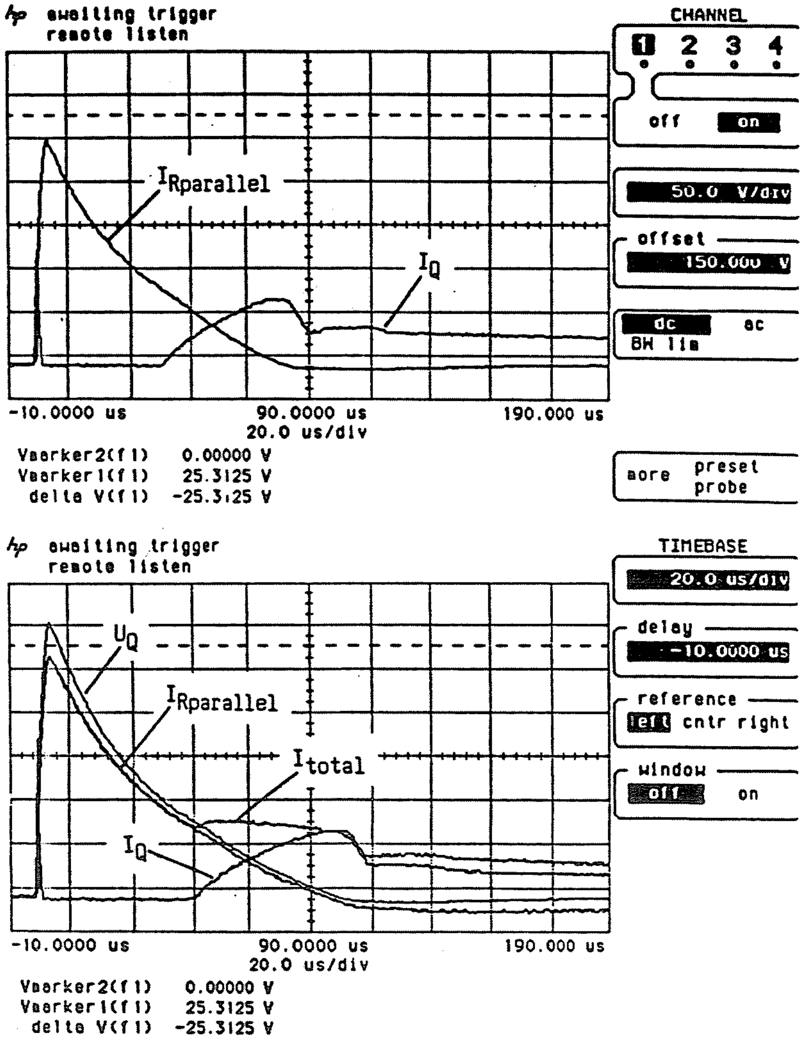

Fig. 6. Experimental results with 1.5 μF capacitive load

If we calculate the value of the current spike from the data of our sensing device we found that the current spike is about 10 A. It can be seen also in the diagram that the time while dissipation takes place on the parallel resistor and on the forward switch is about 100 μs long. During half of this time the controlled switch does not conduct so most of the stresses is passed to the parallel resistor.

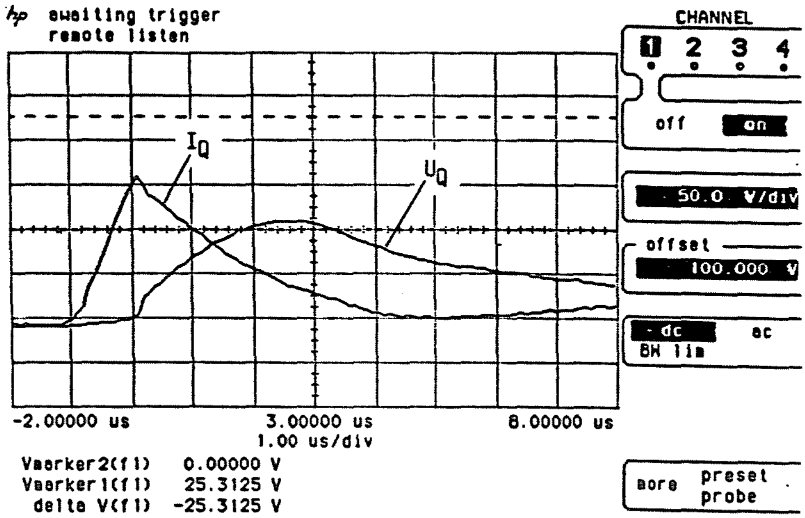

Fig. 7. Experimental results with 100 nF capacitive load

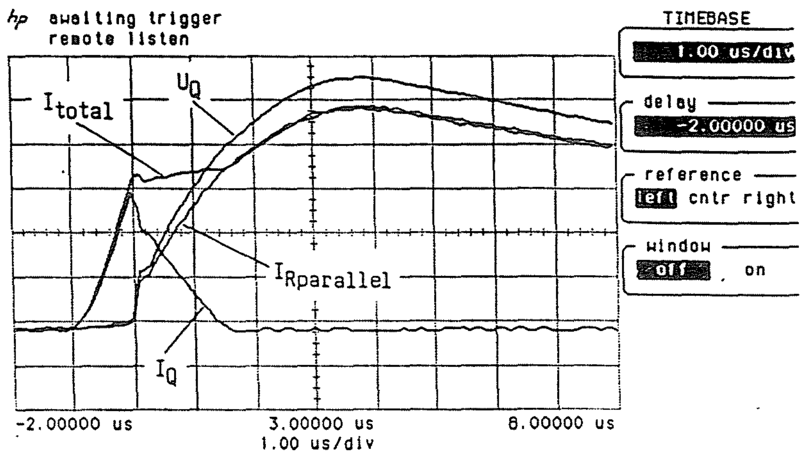

Fig. 8. Experimental results with 800 nF capacitive load

Fig. 7 shows the current and voltage waveforms of the controlled switch at the beginning of the rising edge using 100 nF capacitive load. It can be seen in this diagram that the forward switch has to limit but this

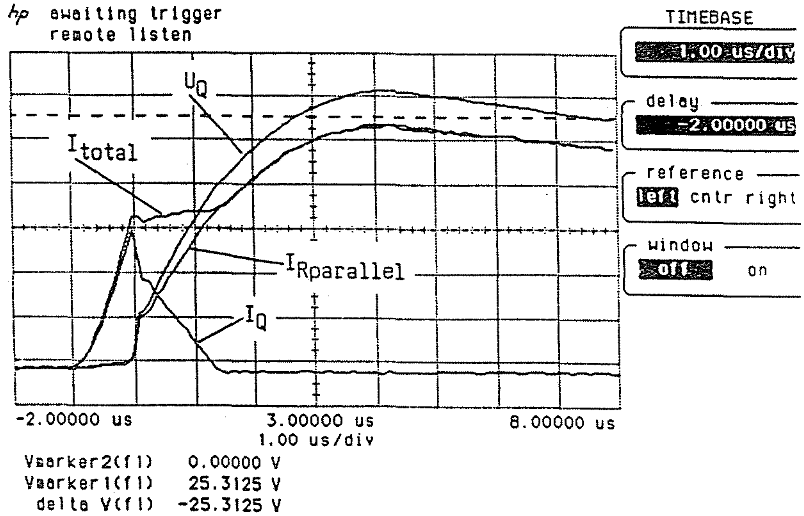

Fig. 9. Experimental results with 1.5 μF capacitive load

current spike is not big enough to make the current of this switch fall to zero.

Fig. 8 shows the typical waveforms with 800 nF capacitive load. It can be seen on this diagram that the limiter limits the output current for more than 1 μs but as the input voltage is further increasing the current of the forward switch is decreasing to zero and the total current is growing to a value limited by the parallel resistor. However, the maximum current value is again less than 10 A.

Finally, *Fig. 9* shows the waveforms with 1.5 μF capacitor. The waveforms are quite similar to the previous one but the values of the related current and voltage values are now bigger.

Conclusion

During our examination it was proved that the unit can handle the stresses reliably at the usual capacitive loads.

By utilizing a supplementary limiter unit in series with the load, the square-wave supplying method that was suitable at lower mains voltage (Japanese Power Lines, U. S. Power Lines), can be adapted also for the equipment working off the 220 V mains (European Power Lines).

Acknowledgement

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References

1. Power UPS–600 User's Guide, ACCTON Technology Corporation, November, 1990.
2. Unitrode Applications Handbook 1987–88. U–83.
3. BUCHANAN, J. E.: Limiting a Filter Capacitor's Turn-on Inrush Current, *Electronic Design* 17.11.1983
4. MARK STITT, R.: Limiter Steered by Current *Electronic Design* 12.04.1990.
5. Power MOSFET Designer's Manual 1987 International Rectifier.