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Special Purpose PC-Computer Program as a Design Tool for Optimizing Snubber Circuits for an IGBT-Inverter.

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1 Abstract.

A special purpose computer program running on a PC is proposed as a design tool which enables the user quickly and easily to make an optimum design of the values of the snubber components for an inverter with an asymmetrical circuit configuration. Design decisions for problem solving are discussed. A graphic presentation of the boundaries for the maximum ratings, defining the solution space is made in which the user can choose values to ensure safe operation. An evaluation criteria for making the optimum choice of the values the PC-based program further presents the turn-on switching energy loss in the IGBT, the turn-off switching energy loss in the IGBT, the energy loss in the snubber resistor for a single one turn-on and turn-off, and the total turn-on and turn-off switching time of the snubber circuit so that these criteria can be taken into account in the actual application.

2 Snubber Circuit

The purpose of snubber circuits is to prevent destruction of the switching element and to reduce the stress on the switch.

Snubber circuits can control di/dt and in this way control the reverse recovery of the free-wheeling diodes, and can control dv/dt to prevent latch-up and capacitive turn-on and minimize noise, and can control the maximum off-state voltage and the maximum on-state current to prevent destruction, and can reduce the switching losses in the switch and make the inverter operate at a much higher switching frequency. And snubber circuits can have few components.

In this paper a simple asymmetrical lossy snubber circuit [1,2] using a minimum number of components is discussed. The circuit is shown in fig. 1.

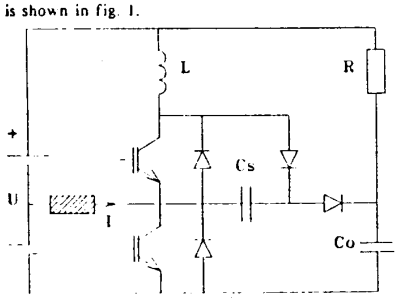

Fig. 1: Simple asymmetrical lossy snubber circuit.

The problem is: How to chose L, R, Cs and Co ?

Another snubber circuit also using the same minimum number of components is shown in fig. 2. This circuit was first presented in [4] and has been dealt with in [5,6].

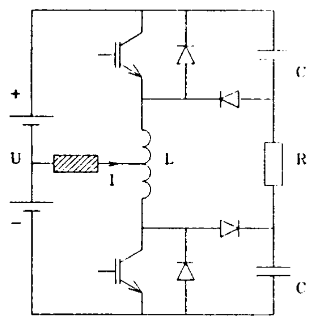

Fig. 2: Simple symmetrical lossy snubber circuit.

3 Problem solving.

3.1 General problem solving.

General problem solving is a basic activity in design work, to be used with any kind of "open" problem, i.e. problems with many solutions.

Foundations:

1. Formulate the problem. A problem is an interpretation of a need. System identification.
2. Determine the criteria. Even simple solutions carry so many parameters that we cannot trust our brain to make a fair comparison without relevant criteria. Verbal problem formulation. Design specification. Check list.
3. Seek solutions. A preoccupation with one solution may colour our criteria. There are more good solutions in many alternatives than in few.
4. Evaluate and choose. We cannot evaluate a single solution-we can only compare alternatives. Only solutions on the same level of development may be fairly compared.
5. Implement.

3.2 Specifying the general problem solving.

We have a function of several variables and want a set of parameter values.

Use evaluation criteria as a way of controlling the basis of the design decisions.

Demands (conditions, relations between values, bindings, absolute demands) separates solutions from non-solutions. Each demand comes from a limit value (e.g. a maximum or minimum rating) and each limit value can be treated separately. The limit values in turn define a solution space whose boundaries are determined by the demands. The solution space is enclosed by the boundaries. The size of the solution space

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depends of the strictness of the demands. When we have the solution space we know where to seek our solutions and have eliminated impractical solutions. The demands or limit values should be seen as something positive as their existence reduces and rewinds the design process.

Quality (property, characteristic) is a measurement of a design decision as a function of the chosen criteria. The function of the criteria is to separate the good solutions from the bad solutions. The "goodness" of each criterion may be evaluated by some scale defined by the user and puts a weight on each criteria as to how well each is fulfilled. The weight may range from absolute demands such as obeying a law to wishes to be fulfilled if it is convenient. The process returns the sum of the products of the weights and the fulfilment of each evaluation criterion. The sum is an indicator of the quality of each solution. Now all the solutions can be compared and the best can be found.

4 Analysis

The asymmetrical snubber circuit shown on fig. 1 looks very simple. The maximum supply voltage U and the maximum load current I are given. Further more we have the IGBTs and the free-wheeling diodes each with some defined characteristics (e.g. The reverse recovery of the free-wheeling diode) and maximum ratings (e.g. maximum off-state voltage Umax, maximum on-state current Imax and maximum rate of rise of the off-state voltage dU/dt).

In the circuit we have control of four variables L, Cs, Co and R and we want to determine which combination to choose. The variables L, Cs, Co and R influence the switching sequence as shown in fig. 3,4,5 and 6.

Due to the asymmetry of the snubber circuit it is necessary to examine turn-on as well as turn-off of both the upper and the lower IGBT (load current in both directions). During examination of switching losses in the IGBT inert turn-on and turn-off have to be taken into account. When wishing to fully analyse and design this inverter using a minimum number of components in the snubber circuit it is difficult to get a general view of the influence of each component on the switching performance. That is because the system generates up with up to three coupled first order differential equations in every switching interval.

We have to choose the variables L, Cs, Co and R so that the maximum ratings of the IGBT and the free-wheeling diode are not exceeded. These maximum ratings define the boundaries of a four-dimensional solution space. Fig. 7 shows a simple example of a two-dimensional solution space where L and Co are kept constant.

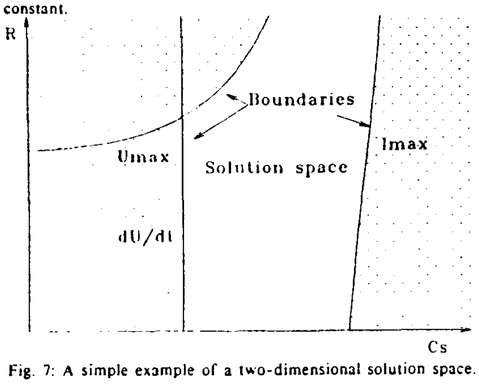


Fig. 7: A simple example of a two-dimensional solution space. L and Co are kept constant.

Once we have our solution space we know where to seek solutions. There are some characteristics or evaluation criteria of a snubber circuit that can be used as a measurement of the quality of each solution. These are the turn-on switching energy loss in the IGBT, the turn-off switching energy loss in the IGBT, the energy loss in the resistor R for a single turn-on and turn-off, and the total turn-on and turn-off switching time of the snubber circuit. Different applications may put different weights on each of these evaluation criterion. PWM regulation may want a very short switching time in order to produce very short pulses. Other applications may focus on the energy losses in order to improve the efficiency.

5 The special purpose PC-based computer program as a design tool.

A PC-base computer program is proposed which enables the user quickly and easily to make an optimum design of the values of the snubber components for an inverter which uses a minimum number of components in an asymmetrical snubber circuit configuration. A graphical presentation of the boundaries for maximum ratings, solution space, is made in which one can choose the values which ensure safe operation. As evaluation criteria for comparing the solutions and for making the optimum choice of the values, the computer program further presents the switching energy losses during turn-on and turn-off in the IGBT and in the resistor and the total turn-on and turn-off switching times of the snubber circuit so that the user can assign weights to these criteria and in this way make the optimum choice for the actual design.

This PC-based computer program is written in the programming language C and uses numerical integration of the differential equations in each of the switching intervals. The numerical method is a fourth order Runge-Kutta with adaptive stepsize control as set out in Press et al [3] and. The numerical method has previously been described in [5,6].

The PC-based computer program is called ASYMDIM and is menu oriented. The use of the program starts by entering all the data, for the inverter and the IGBT and the free-wheeling diode. The program then varies the values of the snubber components and monitors the maximum values of the currents and voltages and dU/dt. The boundaries for the values of the snubber components are then found where the maximum ratings are just not exceeded. In this way a graphical presentation of the solution space is obtained. A cursor can now be moved inside this solution space. At each cursor position indicating a certain combination of the values of the snubber components the evaluation criteria (in relation to turn-on and turn-off switching losses in the IGBT, energy losses in the resistor and the total switching time of the snubber circuit) are computed and presented on the screen. As the cursor is moved these values are updated. In this way the user is able to familiarize himself with the consequence of choosing different combinations for the component values and to find his optimum combination.

System requirement: PC-compatible computer 80286 or higher.
Math-coprocessor 80287 or higher.
DOS operating system.
Harddisk.
VGA, EGA or Hercules screen.
IBM-graphics compatible matrix-printer.

The computer program and its source code are available from the author free of charge.

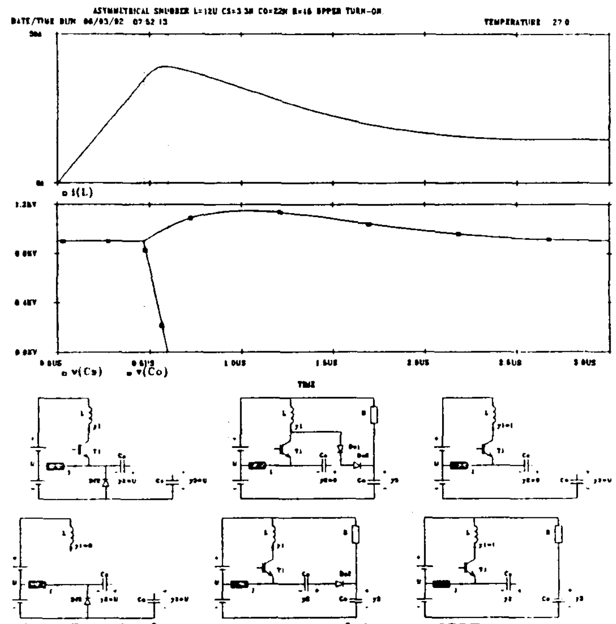


Fig. 3: Example of a momentary turn-on of the upper IGBT. Top: current in the inductor L. Bottom: voltage across the capacitors *Cs* and *Co*.

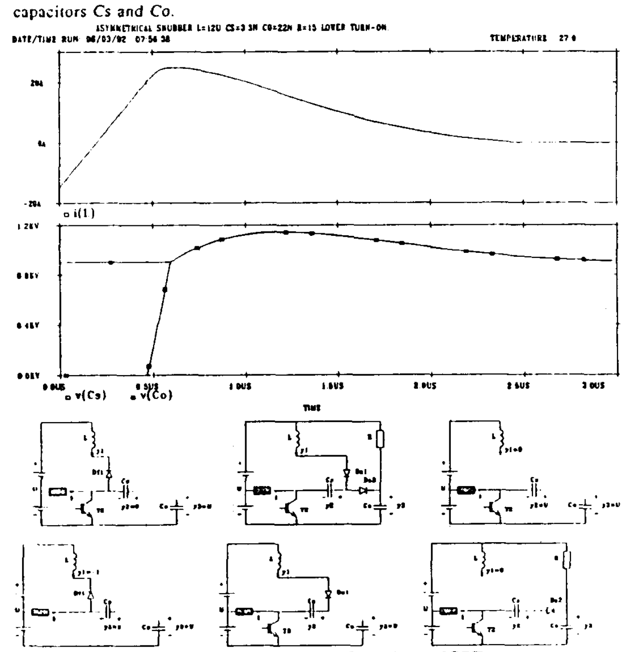


Fig. 4: Example of a momentary turn-on of the lower IGBT. Top: current in the inductor L. Bottom: voltage across the capacitors Cs and Co.

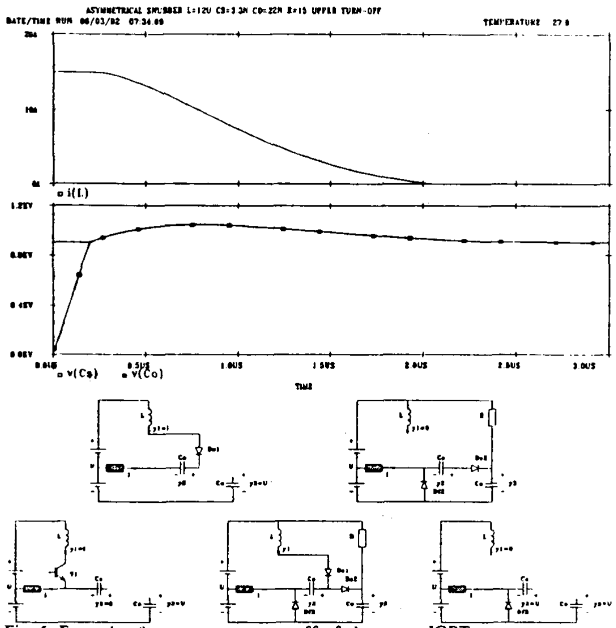


Fig. 5: Example of a momentary turn-off of the upper IGBT. Top: current in the inductor L. Bottom: voltage across the capacitors Cs and Co.

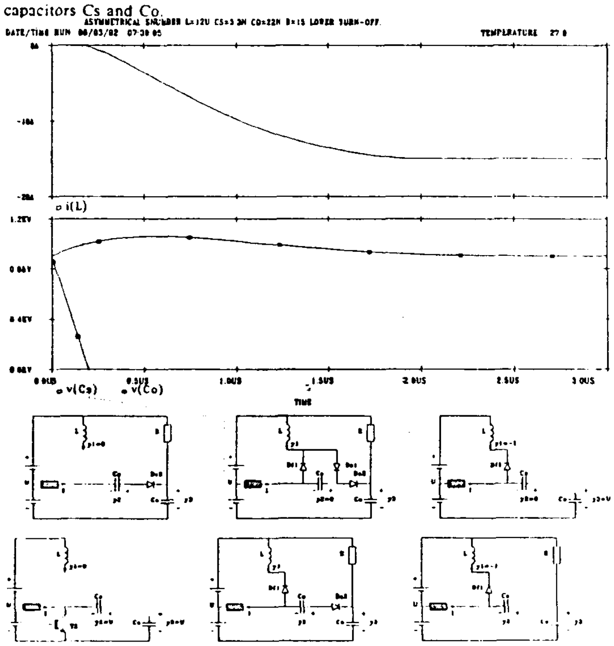


Fig. 6: Example of a momentary turn-off of the lower IGBT. Top: current in the inductor L. Bottom: voltage across the capacitors Cs and Co.

6 Computer program ASYMDIM, design procedure, an example.

The snubber circuit in this example is from a dynamic current compensator. The compensator is to compensate reactive power and harmonics dynamically on the mains as shown in fig. 8. The four inverters with snubber circuit are just shown as simple switches.

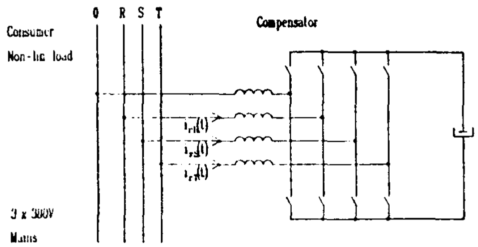
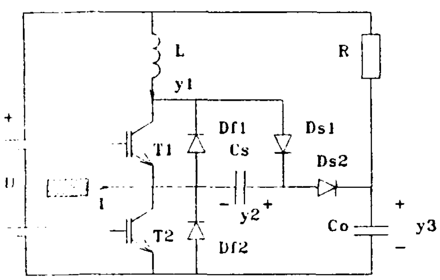


Fig. 8: Dynamic compensator to compensate reactive power and harmonics on the mains.

One of the four snubber circuits for the compensator is shown on fig. 9 together with the data.



Given: U=900V I=15A fs=20kHz

IGBT: Umax=1200 Imax=50A dU/dt=10kV/us

tr=200ns tf=200ns

Diode: Ir=20A at di/dt=75A/us

Fig. 9: One *of the four snubber circuits for the compensator.*

The use of the inductance in this snubber circuit is very favourable because it makes it possible to design the inverter with zero turn-on switching losses as shown in fig. 10.

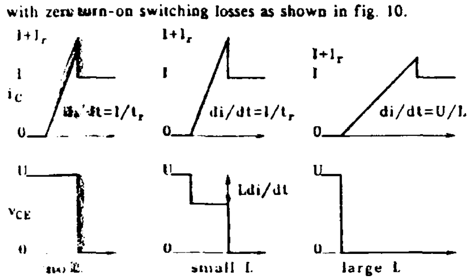


Fig. 10: The favourable possibility of reducing the turn-on switching losses to zero with the use of the inductance.

The condition is that the inductance value is equal to or larger than a minimum value given by:

$$\frac{U}{L}=\frac{I}{t_r} \rightarrow L=\frac{U \cdot t_r}{I}=12\mu H$$

This is a very good start because a larger inductance value will cause excessive switching losses in the resistor R.

The use of the program starts by entering all the data into the program.

When the entered data has been saved the program calculates the solution space. At the end of the calculations the curves made of small circles, where the maximum data are just not exceeded, are found by interpolation in the screen tables and the solution space is shown as the non-dotted area and can be saved. In this way the user can make several solution spaces for different values of L (and Ir) and Co. A solution space is a part of the evaluation criteria screen.

In fig. 12 to 14 Evaluation criteria screens for different values of the capacitor Co are shown with L kept constant. The solution *space is the white area. And the dotted area is the part in which* one or more of the data of the IGBT are violated. The axes are logarithmic and the values of the resistor R and the capacitor Cs at the cursor position are shown in the bottom left corner. The cursor can be moved by using the arrow keys. The boundaries of the solution space are at the right the maximum currents at turn-on, at the top the maximum off-state voltages at turn-off, and at the left the maximum dU/dt's as shown on fig. 12. The dotted line across the screen is indicating where the switching time has its minimum, it can be used as a guide.

The user can chose combinations of R and Cs in all part of the solution space. And there are still plenty of combinations so additional criteria can be taken into account in the actual design.

As evaluation-criteria for making the optimum choice of the values the computer program further presents the switching energy losses during turn-on W_i and turn-off W_u, total energy losses in the resistor W_r and the total turn-on/off time of the snubber circuit *T for the upper and the lower IGBT switching.* These evaluation-criteria are shown in the upper right corner as values relating to the current cursor position. When the cursor is moved these values are updated. In this way the user is able to familiarize himself with the consequence of choosing different combinations of the component values. The user can pop up and down between different Evaluation criteria screens (different values of Co in this example) with the PgUp/PgDn keys. In some part of the screen it takes very long time for the computer program to calculate the total switching time and this is why the option Toggle time has been included to omit this calculation if *the user wants to move the cursor quickly.*

From the cursor position at the Evaluation criteria screen it is possible to get a look at turn-on and turn-off switching sequences with the option Waveforms. In fig. 15 the Waveforms screen is shown when called from the cursor position in fig. 13.

In the top of fig. 15 the current in the inductance is shown and in the bottom the two voltages across the capacitors are shown. Compare fig. 15 to fig. 3 to 6.

Moving the cursor around in fig. 12 to 14 the user can find the combination of R and Cs where the switching time has its minimum. It is in fact at the present cursor position in fig. 12 to 14. It can be seen that the switching time is smallest for Co=22nF. In this application the switching time should be as low as possible because the switching frequency is 20kHz.

In this application the optimum combination of the snubber *components become:*

L=12uH Co=22nF Cs=3.3nF R=15 Ohm

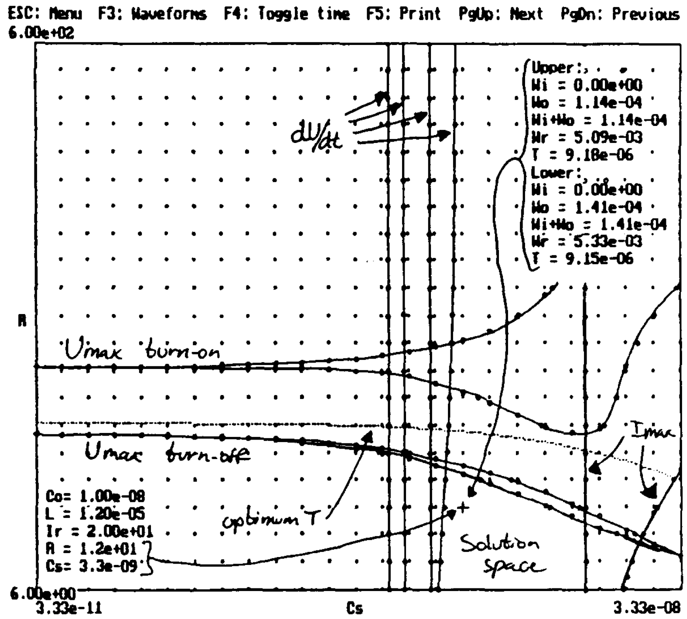


Fig. 12: The Evaluation criteria screen for L=12uH and Co=10nF.

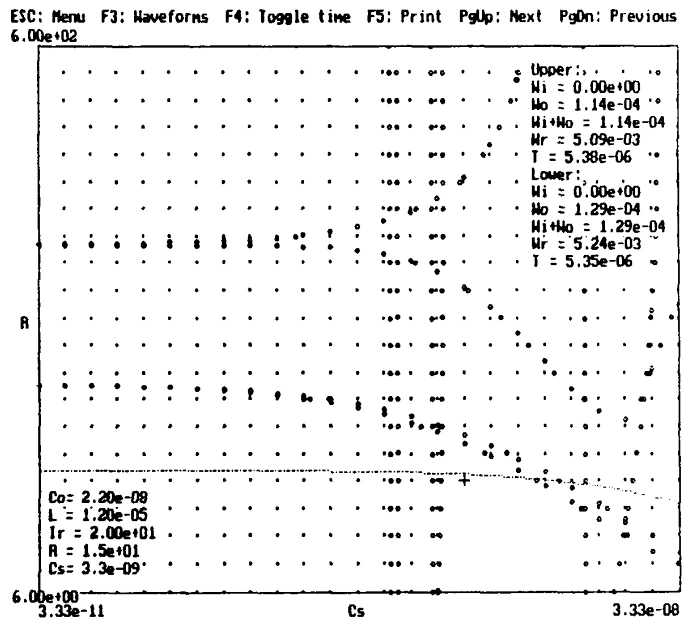


Fig. 13: The Evaluation criteria screen for L=12uH and Co=22nF.

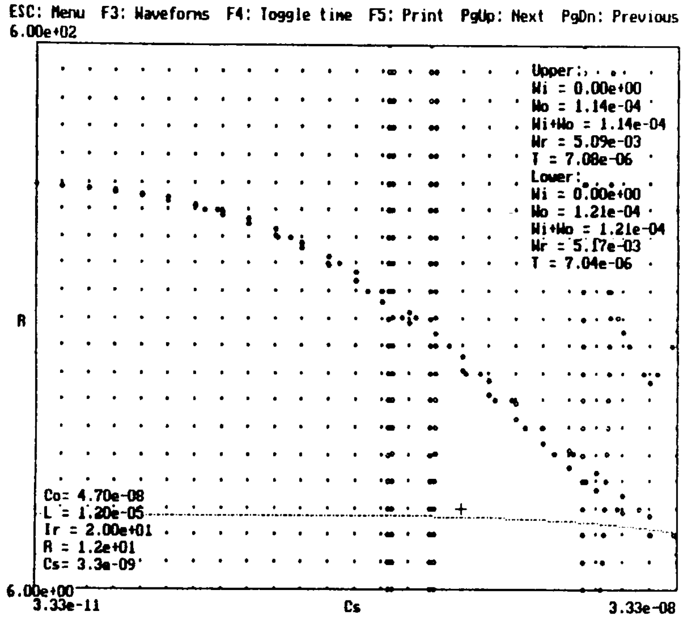


Fig. 14: The Evaluation criteria screen for L=12uH and Co=47nF.

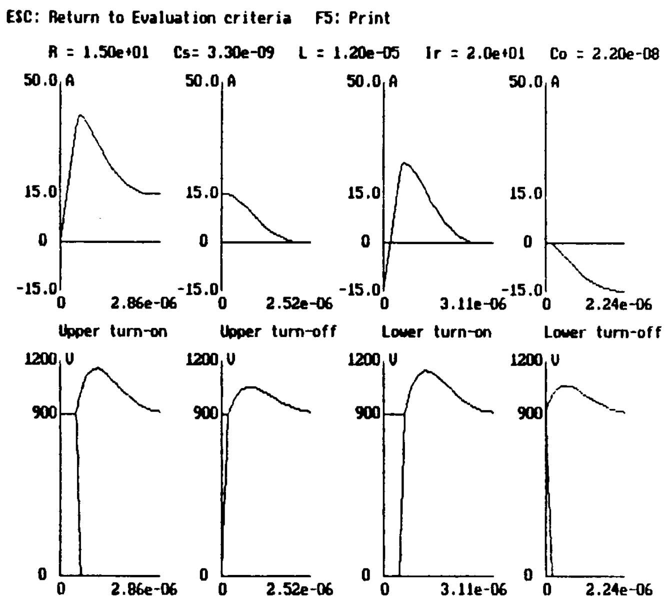


Fig. 15: The Waveforms screen with the snubber combination given by the cursor position in fig. 13.

This combination gives a maximum switching power loss in the IGBT of:

$$P_{sw} = 20kHz \cdot 0.129mJ = 2.6W$$

and a switching power loss in the resistor R of:

$$P_{R} = 20kHz \cdot 5.24mJ = 105W$$

Without use of the snubber circuit the switching power losses [5] in the IGBT would be at least:

$$P_{sw\ snub} = f_s\left(\frac{U \cdot t_r \cdot (I + I_r)^2}{2 \cdot I} + \frac{1}{2} \cdot U \cdot I \cdot t_f\right)$$

$$= 20kHz \cdot \left(\frac{900V \cdot 0.2\mu s \cdot (15A + 20A)^2}{2 \cdot 15A} + \frac{1}{2} \cdot 900V \cdot 15A \cdot 0.2\mu s\right)$$

$$= 20kHz \cdot (7.35mJ + 1.35mJ)$$

$$= 174W$$

It means that the stress on the IGBT is greatly reduced.

7 Conclusion.

The special purpose PC-based computer program ASYMDIM is an menu oriented easy to use program and it is a very powerful design tool for the designer of inverters and it can provide the user with an optimum combination of the snubber components in a very short time. Further it can, on a long-term basis, provide the designer with a general understanding of the relationship between the inverter and the semiconductors used. The program and the snubber circuit can also be used for inverters with other semiconductors as MOSFETs, bipolar transistors, GTOs and MCTs.

8 References.

[1]: Undeland, T. M.:"Snubbers for Pulse Width Modulated Bridge Converters With Power Transistors or GTOs." IPEC 1983, p.313-323.

[2]: Undeland, T. M., Jenset, F., Steinbakk, A., Rogne, T. and Hernes, M.:"A Snubber Configuration for Both Power Transistors and GTO PWM Inverters." PESC 1984, p. 42-53.

[3]: Press, W. H., Flannery, B. P., Teukolsky, S. A. and Vetterling, W. T. (1988). Numerical Recipes in C. Cambridge University Press. Cambridge.

[4]: Hansen, A. and Havemann, H.: "Design of Snubber Circuits for a Transistor-inverter Using a Minimum Number of Components." IFAC Symposium 1983, Lausanne, p. 165-171.

[5]: Andersen, M. A. E. and Havemann, H.: "Computer Program for Designing Snubber Circuit for an IGBT-Inverter." EPE 1991, Firenze, vol. 1, p. 155-159.

[6]: Andersen, M. A. E. and Havemann, H.: "Computer Program with Supplementary Design Graphs for Designing Snubber Circuit for an IGBT-Inverter." UPEC 1991, Brighton, p. 56-59.

[7]: Andersen, M. A. E.: "Novel Simple Lossless Snubber Circuit for an IGBT-Inverter." ACEMP 1992, Kusadasi, p. 624-631.