

PROGRAM FOR COMPUTER - AIDED ANALYSIS OF POWER ELECTRONIC CIRCUITS

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SUMMARY

Basic requirements laid on universal programs for computer-aided analysis of electronic circuits are stated. Then basic properties of program MININAP are shown together with general principles of the program. Two examples illustrate the use of the program and its capabilities.

INTRODUCTION

The development of modern power electronic equipment requires that the designer's work should be more efficient than in the past. The complexity of control and especially power circuits is growing continuously and causes that the approximate designing methods used do not secure sufficiently reliable results. Thus many details are left for experimental verification with the inevitable risk of damaging expensive circuit elements or at least of not obtaining the best possible results.

The digital computer with its vast capabilities offers some new possibilities to help the designer. A suitable program can fulfil many tasks both in analysing and synthesising the network. Individual requirements laid on such a program (or system of programs) can be stated as follows:

The program makes it possible:

1. to create a faithful model of the network,
2. to compare different realisations of networks for the same overall function,
3. to follow the influence of parameters tolerances on the operation of the network,
4. to analyse the influence of various external conditions,
5. to model various dangerous conditions without risk of damaging the network or other equipment,
6. to forecast the reliability of network,
7. to optimise the network for best performance (efficiency, reliability, cost, etc),
8. to help the designer to deeply understand the function of the network under different operating conditions,
9. to prepare data for experimental verification of the realised network.

There exists a number of further requirements that must be fulfilled by a really good program beside those listed above.

The program must be operable by any electronic circuit designer who knows nothing about Fortran, Assembler and such things. The program should be prepared to a dialogue with the user offering him a selection of possibilities how to continue, alphanumerical as well as graphical output of results, easy control and of course quick and sufficiently accurate calculations.

As the literature devoted to CAD (Computer-Aided Design) shows (see e.g. R.1), many different programs have been created and are more or less available. Majority of these programs are directed to linear or linearised networks. An admirable work has been done in the field of linear active filters, wideband as well as selective amplifiers, phase and amplitude correctors and the like. There are not so many good programs for substantially nonlinear systems that come in question in power electronic circuits. Some of these can be run only on sufficiently large computer installations and moreover are expensive in use (for instance programs ECAP 2, ASTAP, ...).

A really good program NAP 2 (R.2) can be obtained from the authors without difficulties. It is able to simulate complicated electronic circuits with very general nonlinearities and parametric dependences. The program is well prepared to work with medium-sized computers as IBM 370 or 360 or some computers of the so-called Unified Series (EC 1030, EC 1040) produced in Socialist countries. Its basic disadvantages can be seen in fact that the program does not allow interactive control and that it is written in an advanced version of Fortran the compilers for which are not quite usual in other computers.

PROGRAM MININAP

In our Institute we are using NAP 2 on our EC 1030 with a 256 kbyte operational memory. Our good experience with the program and our wish to be able to cooperate with the computer during the analysis process made us to create a simplified version of NAP 2 called MININAP. The basic features of MININAP can be summed up as follows:

- The program is run on a PDP 11-40 with 16 kwords (32 kbyte) of memory. The installation contains further a disk unit RK 05, and a TEKTRONIX graphic terminal 4010. In some cases also tape reader, tape punch and Calcomp drum plotter can be used.
- The program can be used to analyse time waveforms in networks containing linear passive G, R, L, C elements, controlled sources, independent sources of prescribed voltage and current waveforms and typical nonlinear elements (diodes, bipolar transistors, thyristors).
- The network to be analysed is described in a simple and easily comprehensible way. The user is only supposed to draw the scheme, to numerate its individual nodes and to prepare the list of elements and their connection to these nodes. Nonlinearities are modelled in a standard way. Several typical

models are built in the program. Other models can be added or standard models modified when necessary.

- Results can be output in form of tables of numerical values or in graphical form (time dependences or dependences of one or several variables on some other).
- The complete calculation can be prepared beforehand or it can be user controlled according to the results obtained. The interactivity enables the user to
 - choose the form of results,
 - modify the scheme or parameters of elements,
 - modify the initial conditions,
 - change input waveforms.

Both programs NAP 2 and MININAP have been in use in our Institute for more than one year. NAP 2 is used for analysing larger schemes (up to 50 variables) and schemes with general nonlinearities and parametric dependences. MININAP is suitable for smaller networks (up to about 15 variables) or for analysing small details of more complicated systems. Very often both the programs are used simultaneously to solve the same network from different viewpoints.

BLOCK SCHEME OF MININAP

The overall simplified block scheme of MININAP is shown in Figure 1.

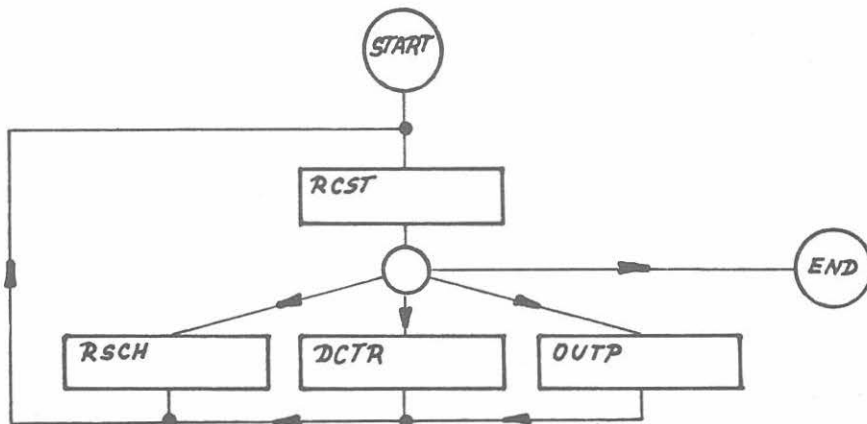


Fig.1. Block scheme of program MININAP

The program is subdivided into the resident and 4 basic segments that are stored on disk and only one of which is in the main memory at a time. Transfer of data from segment to segment is done through common blocks that reside in the memory all the time.

Segment RCST (Read Control Statements) reads and decodes control statements. Some of these statements are used to control the process of analysis (indication that there follows the description of network to be solved, allocation of time interval, initial conditions, commentaries, and of calculation); others enable the user to indicate the concrete form of results (tables of values, graphs) he wishes.

After certain control statements the control is handed over to segments RSCH, DCTR or OUTP.

Segment RSCH (Read the Scheme) organizes reading, decoding and storing information about configuration of the scheme to be analysed and about the parameters of network elements. The segment creates tables containing in condensed form all information necessary for subsequent building and solving differential equations in the segment DCTR (DC and Transient Analysis). Segment OUTP takes care of all forms of output.

MODELS OF NONLINEAR NETWORK ELEMENTS IN MININAP

Program MININAP accommodates three basic nonlinear network elements: the diode, the bipolar transistor (both NPN and PNP) and the thyristor.

For diode and bipolar transistor well known mathematical models are used. Diode (PN junction) and the corresponding definitions of voltage and current are shown in Figure 2a. For the use in the program the diode is substituted by an electrical scheme shown in Figure 2b.

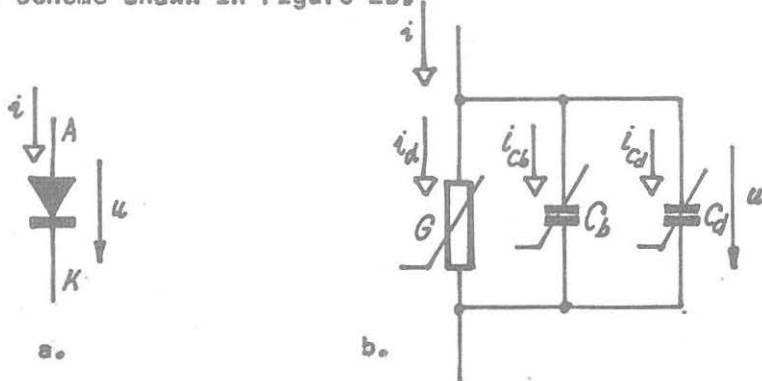


Fig.2. Diode. a. Scheme and definition of u and i .
b. Scheme equivalent to mathematical model.

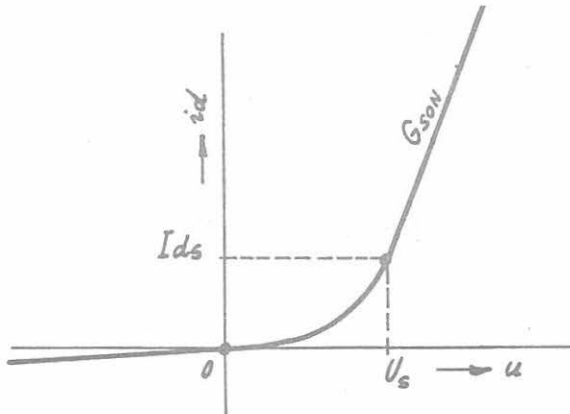


Fig.2. Diode. c. Static characteristic of the model

The total diode current i consists of three parts:

- the current i_d through nonlinear static conductance G
- the current i_{cb} through the barrier capacitance C_b
- the current i_{cd} through the diffusion capacitance C_d .

The first of these three currents depends only on the instantaneous diode voltage u . It represents the diode current under the conditions of slowly varying voltage u . Mathematically it is given as (see graph in Figure 2c):

$$i_d = \frac{I_s}{V_T} u \quad \text{for } u \leq 0, \quad (1)$$

$$i_d = I_s (\exp(u/V_T) - 1) \quad \text{for } 0 \leq u \leq U_s, \quad (2)$$

$$i_d = G_S (u + V_T - U_S) \quad \text{for } u \geq U_s, \quad (3)$$

where

$$G_S = \frac{I_s}{V_T} \exp(U_S/V_T). \quad (4)$$

Equation (2) describes the static diode characteristic according to basic theoretical formulae for P-N junction. Validity of this expression is limited both on lower and upper side of voltage axis. In cut-off region ($u \leq 0$) the diode behaves like a linear conductance I_s/V_T , while in the region of

heavy forward currents ($u \approx U_s$) the exponential characteristic is substituted by a linear one with the slope G_s resulting from parasitic series resistances of the electrodes.

The dynamic behaviour of the diode is represented by 2 nonlinear capacitances, namely C_b and C_d .

The barrier capacitance C_b accumulates the charge

$$Q_1 = C_{bo} \int_0^u \frac{du}{(1 - u/\varphi)^m}, \quad (5)$$

where

C_{bo} is the differential barrier capacitance at $u = 0$,
 φ is contact potential,
 m is constant, $0.3 \leq m \leq 1$.

For the charge Q_2 accumulated by the diffusion capacitance C_d it holds

$$Q_2 = T_t i, \quad (6)$$

where

T_t is transit time.

For bipolar transistors the so-called modified Ebers-Moll model is used, see Figure 3a,b. The model consists of two diodes (base-emitter, base-collector) described in correspondence with Figure 2 and equations (1) to (6). In addition, the transistor amplifying effect is taken into consideration by two current sources controlled by currents i_{dbe} and i_{dbc} flowing through both static conductances G_{be} and G_{bc} .

The PNS transistor model is similar. Only the orientation of the two diodes is reversed.

The thyristor model is also based on the diode. The switching effect is modelled by changing the slope G_s of the linear extension of characteristic in the forward region. The slope can be either G_{SON} in case of conducting thyristor or G_{SOFF} in case of nonconducting thyristor, see Figure 4.

The thyristor state can be changed under one of the two following conditions:

1. Thyristor switches from OFF to ON:

- firing impulse is applied to the gate while anode voltage is positive,
- firing impulse is already present while anode voltage is changing its polarity from negative to positive.

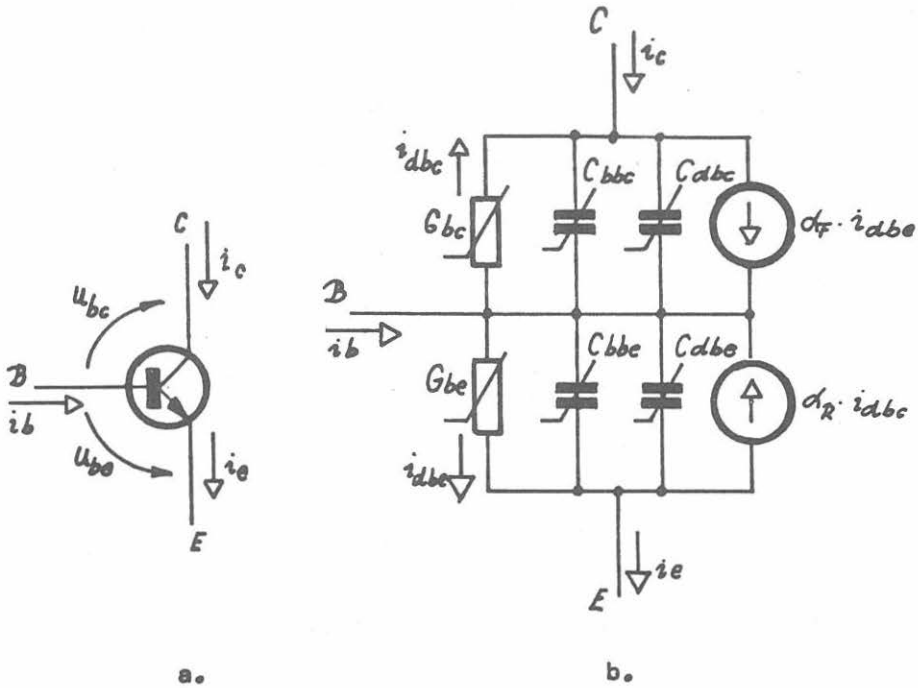


Fig.3. Bipolar transistor NPN.

a. Scheme.

b. Scheme equivalent to mathematical model.

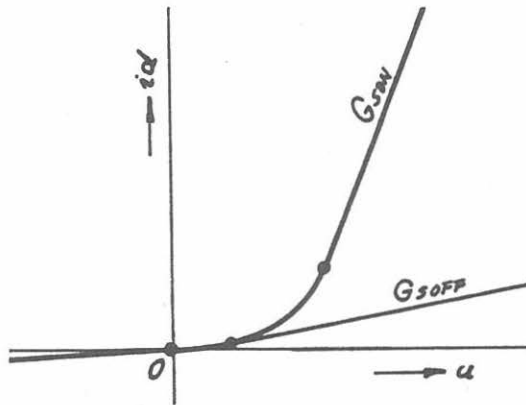


Fig.4. Static characteristic of thyristor model.

2. Thyristor switches from ON to OFF:

- anode current was decreased under holding value (irrespectively of presence or absence of firing impulse).

As the described thyristor model contains also both the barrier and diffusion capacitances it can model the finite switching-off time of the thyristor and its dependence on forward current as well as its rate of change just in the preceding instants. The model however cannot take into consideration the controlling gate characteristic or the firing of the thyristor caused by excessive rate of change of anode voltage du/dt .

SETTING UP AND SOLVING THE NETWORK EQUATIONS

The set of nonlinear equations describing the network has the form

$$f(x) + A \dot{x} + B \ddot{x} = u(t), \quad (7)$$

where

- x is vector of so-called primary variables,
- \dot{x} is vector of first time-derivatives of x ,
- A and B are constant matrices,
- $f(x)$ is vector of nonlinear dependences,
- $u(t)$ is vector of exciting functions.

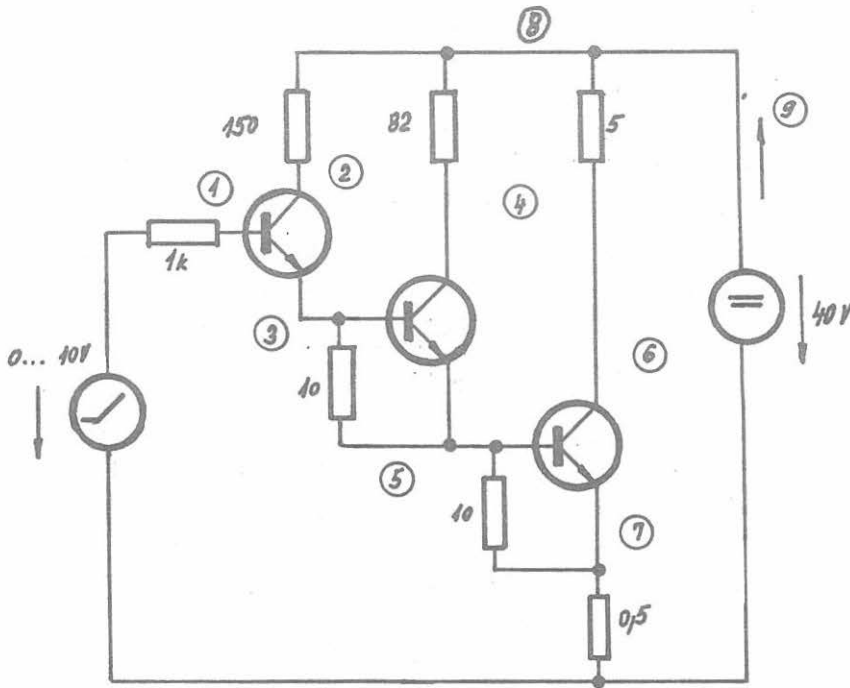
As primary variables node voltages with respect to reference node and some branch currents are chosen. This choice indicates that the method used is the so-called modified node voltage method (R.3). Its basic advantage is that setting-up the equations can be easily automatized. All what the algorithm needs is a simple description of the scheme to be solved saying how the individual circuit elements are connected together. The branch currents added to the node voltages are currents of all inductors, ideal voltage sources and, if present, of all resistances with zero value.

For the solution of equation (7) the modified variable-step variable-order implicit integration algorithm is used (R.4). This numerical algorithm uses a combination of polynomial prediction of solution x in the next time instant with the Newton-Raphson iteration procedure. The algorithm is able to solve simultaneously both differential and algebraic nonlinear equations of (7).

EXAMPLES OF USE OF PROGRAM MININAP

For illustration 2 typical solution examples with program MININAP will be shown.

Scheme in Figure 5 represents a multistage transistor amplifier used as continuous exciting current regulator for a synchronous generator. The exciting winding is represented by the resistor 5 ohms between nodes 5 and 8. Resistor 0.5 ohm between node 7 and reference is prepared for sensing output

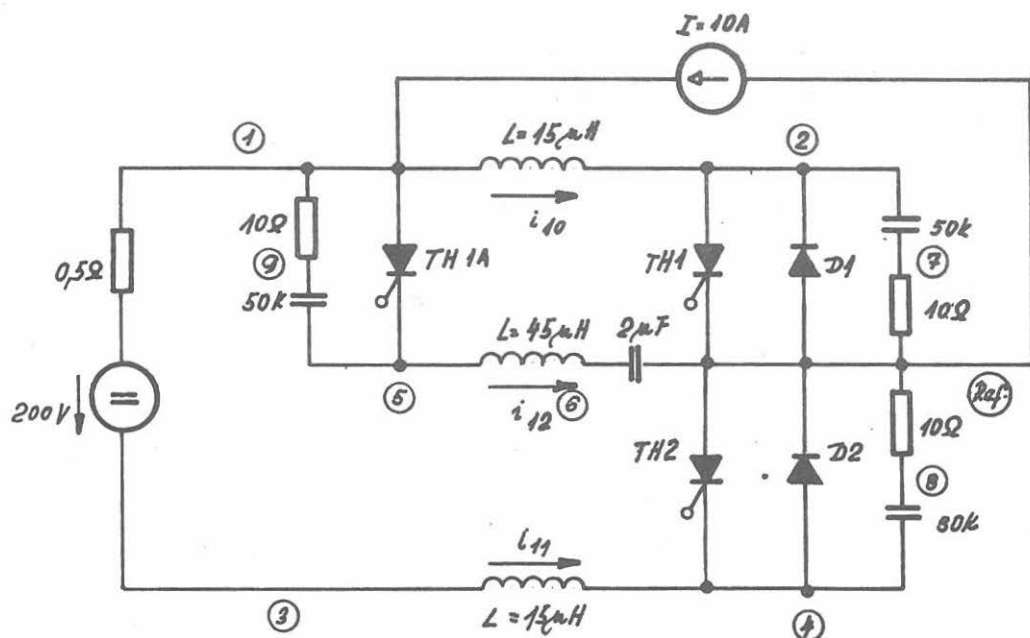


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:: TRANSISTOR POWER AMPLIFIER
:CIR 8,
MT 1,1E-12,.03,1,,,,.985,5,.8,,,,5,
MT 2,1E-11,.03,2,,,,.95,5,.8,,,,5,
MT 3,1E-10,.03,5,,,,.97,5,.8,,,,5,
NPN 1,2,3,1,
NPN 3,4,5,2,
NPN 5,6,7,3,
R 2,8,150,
R 3,5,10,
R 4,8,82,
R 5,7,10,
R 7,0,0.5,
R 6,8,5,
RE 0,8,0,-40,
R 1,0,1000,
I 0,1,2,1,
F2 1,2,0,0,1,10E-3,
LAST
:TIM 0,1,
:RUN

```

Fig.5. Multistage transistor amplifier.
a. Scheme.
b. Problem allocation for MININAP.



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:: MC-MURRAY INVERTER
:CIR 9,
RE 1,3,,.5,200,
R 7,0,10,
R 8,0,10,
J 0,1,10,
C 2,7,50E-9,
C 4,8,50E-9,
R 1,9,10,
C 9,5,50E-9,
L 1,2,15E-6,.3,
L 3,4,15E-6,.3,
L 5,6,45E-6,.3,
MD 2,1E-11,.025,2,1E-7,1E-10,.5,
D 0,2,2,
D 4,0,2,
MS 2,1E-11,.025,1E-4,1E-7,1E-10,1,.5,10,
TH 1,5,2,2,1,
TH 2,0,2,2,1,
TH 0,4,2,3,0,
C 6,0,2E-6,
EAB 2,1,0,25E-6,
FIR 3,1,30E-6,100E-6,
LAST
:TIM 0,100E-6,
:RUN

```

Fig.6. Mc-Murray thyristor inverter solved by MININAP

current for eventual feedback purposes. The aim of the computations was to find optimum values of collector resistors for the first two transistors.

Graphs of node voltages v_2, v_3, \dots, v_7 and supplying source current i_9 as function of input voltage show clearly how individual transistors amplify and how the overall characteristic as well as the current consumption and power lost in the amplifier depend on components parameters.

The Figure 6 shows one phase of a modified Mc-Murray inverter. The program was used to analyse the commutation process starting from the instant of firing the thyristor TH1A. From the graphical results it can be found out how some important details of the waveform, for instance voltage spikes, di/dt and du/dt rates of change, energy losses etc. depend on parameters of RC snubber networks, load current, thyristor TH2 timing or thyristors and diodes dynamic parameters.

In all the cases the computer-aided analysis is carried out parallel to theoretical investigation of the circuit. The computer makes it possible to solve the circuit in its original complexity and to show which elements are important in individual time intervals. In this sense it prepares ground for successive simplification of the problem and derivation of general design formulae. At the same time by comparing the experimental and calculated waveforms it allows to improve the model of the network (including e.g. stray inductances) as well as the models of network elements.

CONCLUSION

Program MININAP is a powerful program for a small digital computer designed to analyse time waveforms in power electronic circuits. It can be used to speed up designer's work and to make the results more reliable.

REFERENCES

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