PERFORMANCE SIMULATION OF DC MACHINES CONTROL SYSTEM IN VIEW OF UNBALANCES IN AC NETWORKS

João R. Cogo *, Jocélio S. de Sá **, Valberto F. da Silva *
* Escola Federal de Engenharia de Itajubá
Av. BPS, 1303 - Caixa Postal 50 - 37500-000 - Itajubá/MG - Brazil
Phone: (035)629-1174 - Fax: (035)629-1187

** GSI - Engenharia e Comércio Ltda.
Rua Joaquim José, 481 - 37500-000 - Itajubá/MG - Brazil
Phone: (035)622-2337 - Fax: (035)629-2337

Abstract. This work purposes to present the results and the methodology used for simulation of DC machines operating in an unbalanced electrical network. For the system represented, simulations in steady and transient states are made aiming to verify the machine performance in view of disturbances in the AC power supply network. Results of time-related waveshapes and of harmonics are presented.

Keywords: Unbalanced systems, DC drives, Drives simulation.

INTRODUCTION

The industrial power systems change their operating characteristics when a line-ground fault takes place in the utility supply system, as it can be seen from several publications ([1],[2],[3]). In a practical case, the following considerations can be made:

1. During rainy seasons, for the industrial systems with voltage-dependent control equipment, switching-offs are more frequent. Concurrently, the local utility system is subject to a series of atmospherical surges, which give rise to, among other problems, the line-ground faults.
2. The line-ground faults cause switching-offs of transmission lines but not necessarily black-out in the industrial system facilities, since the utility electrical system is usually strong at transmission levels.
3. During line-ground faults, voltage drops appear in, at least, one phase of the network what causes an unbalance of the three-phase system causing the waveshapes crossing, that represents the line voltages, to occur no more with a uniform phase-shift of 120°, that is, equidistant from each other.
4. The converter bridges trigger circuit, which feeds the DC machine drives, particularly because of its operation way, is sensitive to the feeding with unbalanced voltages.
5. The operation with unbalanced voltages is enough to generate problems in the drives converters; in some cases, switching-offs take place and, furthermore, loss of production.

KINDS OF CONTROL OF THE TRIGGER ANGLE

Currently, the converter bridges in GRAETZ formation [3] have two kinds of trigger pulse production system for their thyristors.

The pulse production system, which is of the individual kind, that is, dependent of the line voltages crossing to count the trigger angle, has an operation philosophy that makes it sensitive to this kind of problem.

The independent kind pulse production system, which trip a thyristor and trips the next one after 60° entering in conduction, checking if the polarity of the voltage imposed by the network is suitable. This trigger form minimizes the rise of non-characteristic harmonics, so avoiding an amplification of the voltage drops in the supply network by the converter bridge.

DRIVE WITH INDIVIDUAL KIND TRIGGER PULSE SYSTEM

Figure 1 presents typically the electrical systems with trigger circuits of ther converter bridges in GRAETZ formation of the individual kind of pulses, the converter feeding power circuit, the synchronism transformer connection, as well as the signals path for actuation in the thyristor trigger circuit. It is important to observe that:

1. Thyristors T1 and T4 are connected to phase A; T3 and T6 to phase B and T2 and T5 to phase C.
2. In the 6 (six) phase synchronism transformer secondary, terminals a and d correspond to the feeding phase A of the converter, c and f to phase B and b and to phase C.
3. There is a phase angle (typically between 60° and 65°) between synchronism transformer output (terminals a, b, c, d, e, f) and the effective reference for the thyristors trigger pulses (terminals a´, b´, c´, d´, e´, f´), see figs 1c and 1d.
4. The thyristor prone to triggering does not receive as a reference the phase corresponding to which it is linked to (see figs 1b and 1d) where, it is taken as a basis that U_S is the control signal to generate the effective trigger pulses.

The Microtran program has an ALPHA SUBROUTINE that can be used to conduct a simulation of a control system as shown in Fig. 2.

Through the Alpha Subroutine it is possible to develop with ease an additional routine so the control system builds a new program with user's characteristics. The procedure is quite simple: the user compiles his version of ALPHA (written in standard LAHEY FORTRAN 77) and relinks it with the rest of the program which simulates the system.

This circuit works satisfactorily for the feeding system with balanced voltages and also when simultaneous oscillations of the voltages in the three phases take place. In this situation, the error is quickly corrected.

SYSTEM OPERATION WITH PHASE UNBALANCE

Figure 3 shows an unbalance in the converter power supply system, occurring in phase B what causes unbalance on phases f and c of the synchronism transformer secondary. Such unbalance of the phase-shifted voltages and c', causing different triggering angles in thyristors T2 and T5, that is, these thyristors are triggered with triggering angles less than the others. As a consequence, the triggering angle corrects the thyristors angle (in case T2 and T5) connected to the phase which remained normal (C) and not in thyristors T3 and T6 connected to phase (B) that suffered the disturbance.

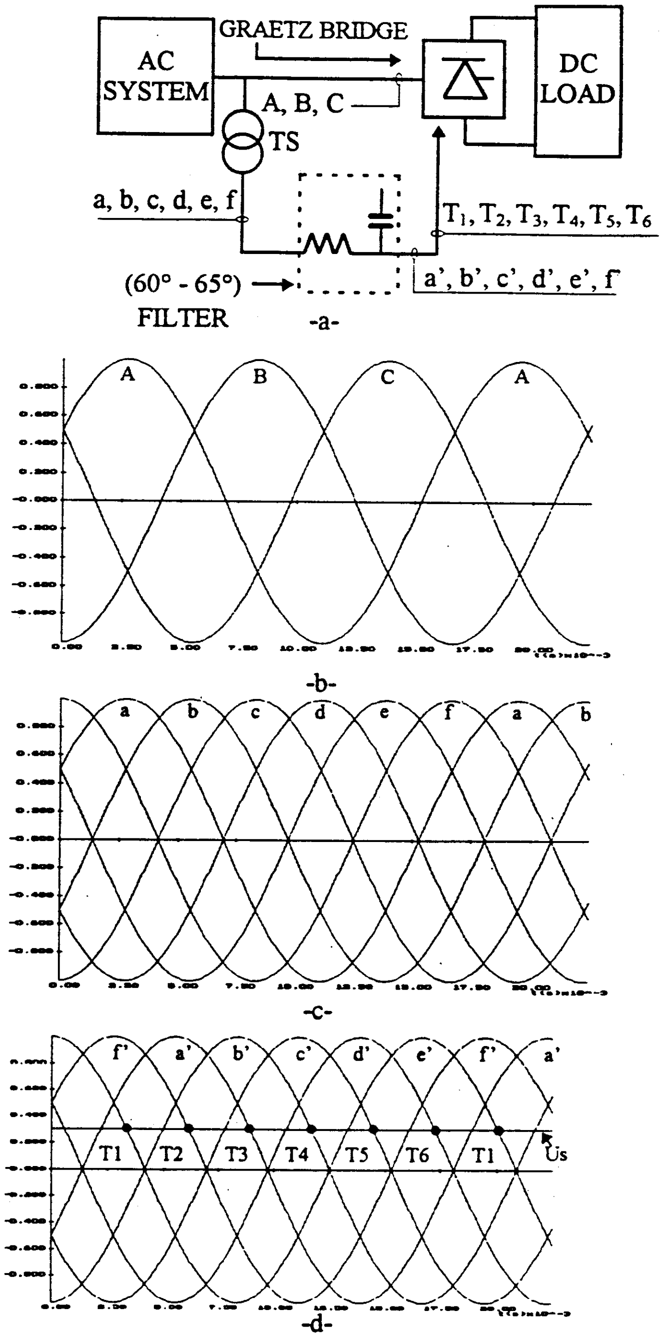

Fig. 1 - Control system with synchronism transformer.

a- Single-line diagram - power and control.
b - Reference neuter phase waveshape for the converter section thyristors.
c - Output waveshape of the synchronism transformer TS
d - Reference waveshape for thyristors triggering $T_1, T_2, ..., T_6$

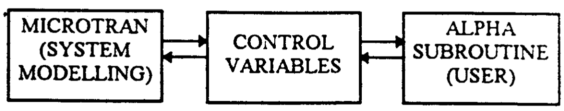

Fig. 2 - Basic scheme for use of the ALPHA SUBROUTINE.

Figure 3 shows that with the triggering angle correction advanced by the converter, when caused by an unbalance entails a bigger armature voltage of the motor. The corresponding behaviour of the armature current is shown in figure 3 as well.

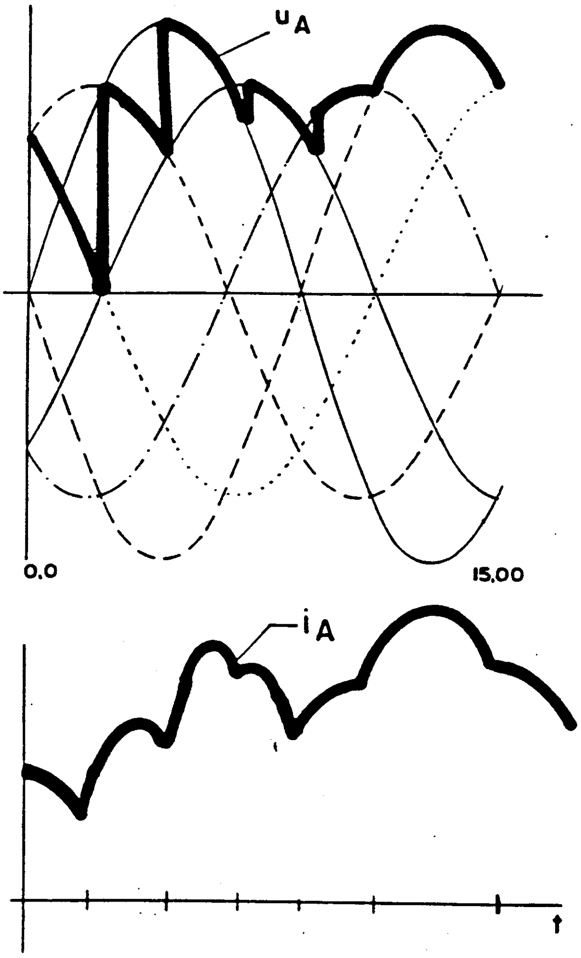

Fig. 3. Armature voltage and current resulting from phase unbalance (theoretical result)

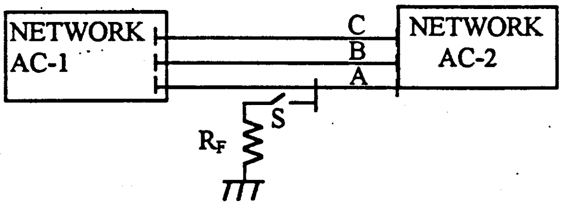

Fig. 4 - Fault simulated in phase A

MODELLING OF THE SYSTEM UNDER ANALYSIS

The details of the modelling of the components which make part of the system under analysis such as lines, cables, transformers, loads, etc., are found in APPENDIX I. The software used to simulate the program was the Microtran*. The unbalance in the network was simulated through a line-ground fault as shown in figure 4.

The line-ground fault is simulated considering a resistance connected to ground through a switch S.

In the Microtran program, the fault resistance value can be user-selected. Among the several possible values, in this simulation, the following fault resistance has been selected in:

$$R_F = 115 \text{ [ohm]}$$

The switch S can be closed at any instant and, while it is closed, a line-ground fault is taking place. In the simulation, the closing time of switch S (figure 3), (t_{close}) of 10[msec] (which corresponds to the fault beginning), and the switches switching-off (t_{open}) in 50[msec] (simulating the fault close) were used.

Thus, in the simulations presented through the cases indicated as follows, the t_{close} and t_{open} values will define the beginning and end of the line-ground fault; now, then, it is possible to simulate the system in the pre-disturbance condition, during the disturbance, and after the disturbance.

RESULTS OBTAINED

Aiming to check the results among the several cases simulated, three of them are presented for the system shown in figure 5.

Case 01 (figure 6)
The system is considered in normal operation. The triggering system simulated works with individual pulses. This is the current operating situation. The voltage waveshapes in phase "a" of the converter AC side, which feeds the driving system are given. In figure 6 (top) the armature voltage waveshape is found.
The voltage waveshapes in phases "a" and "b" in 22[kV] are presented as well.

Case 02 (figure 7)
In this case the system was simulated in the fault condition, by supposing a line-ground fault in the 345[kV] line. The triggering system simulated works with individual pulses. This is the situation that, usually, has caused the untrips by undervoltage in the AC side, of the drives feeding converters.

The voltage waveshapes in phase "a" of the converter AC side are found in this figure 7. The armature voltage waveshape is to be found in this figure (top). In this case, besides a drop in the voltage average value in the converter DC side (armature voltage), there is an assymetry in its waveshape.

The non-existence of a smoothing inductor in series with the armature circuit of the DC machine, permits to conclude that the armature current waveshape follows the oscillations occurring in the armature voltage waveshape.

The results obtained in this simulation show a steady state situation followed by a fault situation at 345 [KV] level.

The waveshapes of voltages in the 22[kV] side are shown in this figure 7 as well. It is noted that at the initial instant of occurrence of a line-ground fault in the 345[kV] line, the voltage waveshapes in the 22[kV] network present unbalance. It is important to see that the fault clearing is followed by an overvoltage.

Cases 05 and 06 (figures 8 and 9)
In this case, the system was supposed in fault condition with simulation of line-ground fault in the 345[kV] line. It is observed the rise of non-characteristic current harmonics, which occur when the pulse production system is individual.
Since the filters usually present in the industrial facilities are predicted for characteristic harmonics, they have little efficiency for the non-characteristic harmonics.

The presence of these non-characteristic current harmonics contribute to the converter feeding voltage drop, leading to its untrip.

CONCLUSIONS

The short period phase unbalance in the power supply system is unavoidable and is increased in the summer with the "tropical storms".
As shown both in the triggering circuit description and in simulations and confirmed in voltage and current oscillograms surveyed during the untrip, the armature current suffers a big distortion, which will become even more acute usually because of the non-existence of a smoothing inductor (according to information) between converter and the DC motor armature circuit.
The armature current distortion is evidently transferred to the converter AC side, with the corresponding increase of the current harmonic content of the converter.
This increase of the current harmonic content in the converter AC side is reflected on the amplitudes increase of the current characteristic harmonics, but even more on the rise of non-characteristic harmonics.
For the non-characteristic harmonics, the filters existing in the input to the power supply systems of rollers have little efficiency.
The consequence of the increase of characteristic and non-characteristic harmonics is an imediate reduction of the facility power factor and a consequent increase of voltage drop in the converter AC side, that is, the converter feeding voltage drops.
With the reduction of the converter feeding voltage, even transitorily, the protection relay against undervoltage of the converter itself actuates, futhering its switching-off.

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OBS.: Microtran is trademark of Microtran Power System Analysis Corporation - Vancouver - Canada

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APPENDIX I

TRANSFORMERS

The transformers are phase-modelled through their matrix representation by using the tecnique presented in [4].

CABLES OR TRANSMISSION LINES

Cables and/or transmission lines are represented through their lumped parameters equivalent circuit involving for medium voltage.
For high voltage (above 138 [KV]) the lines werw simulated by using distributed parameters [4].
The Microtran program has other cable and transmission line models available, but for converter analysis purposes, the model presented is enough.

POWER SEMICONDUCTORS

Diodes, thyristors and transistors are the power semiconductors capable to be used in the Microtran program [4].
The power semiconductors will be represented by ideal switches and the corresponding anode-cathode voltage will be represented by series-connected resistors.
This representation is used for conventional switches (breakers and disconnectors).

POWER SUPPLIES

The modelling of an AC or DC voltage supply not earthed is done by using the procedures to transform voltage supply in current supply. Figure 10 illustrates. The voltage supply e(t) is obtained by using two current supplies so that the potential difference on resistance R is given by:

$u(t) = R[i_k(t) - i_m(t) + i(t)] = e(t)$

where in the equation above:
$i(t)$ is the load current, R is a resistor of very small value and $i_k(t)$ and $i_m(t)$ are current supplies of very high values. So, it can be written:

$e(t) \cong u(t) \cong R\,[i_k(t) - i_m(t)]$

Example:
$R = 10^{-6}$ [Ω]; $i(t) = 100 \sin(wt - 100°)$ [A]
$i_k(t) = 175{,}5 \,.\, 10^6 \sin(wt - 95{,}5)$ [A] and
$i_m(t) = 175{,}5 \,.\, 10^6 \sin(wt + 95{,}5)$ [A],
$u(t) \cong e(t) = 175{,}5 \text{ sen } (wt - 5{,}5°)$

DC MACHINE

The DC machines can be represented by a constant current supply for a certain load current value or by a voltage supply. In any case, the inductances and armature resistances must be taken into account. In the machine model:

R_A - armature circuit resistance (ohm)
L_A - armature circuit inductance (mH).
E_{DC} - armature-induced electromotrix force (V)
I_{DC} - armature current, corresponding to the load torque.

R, L and C ELEMENTS

R, L and C elements which make part of the electrical system will be represented by the conventional way used in modelling of electrical systems [4].

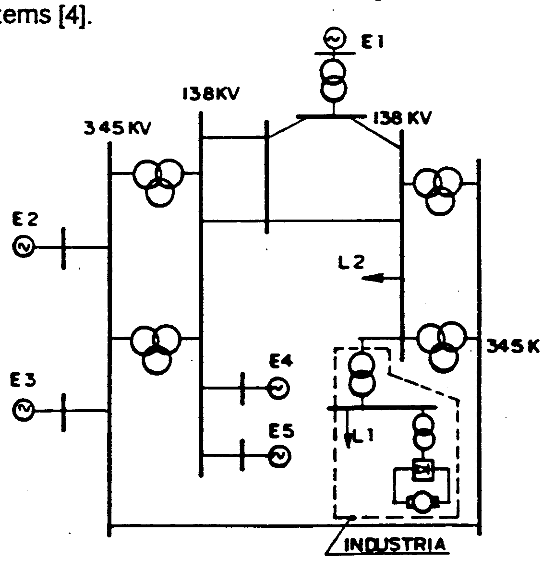

Fig. 5. System under analysis

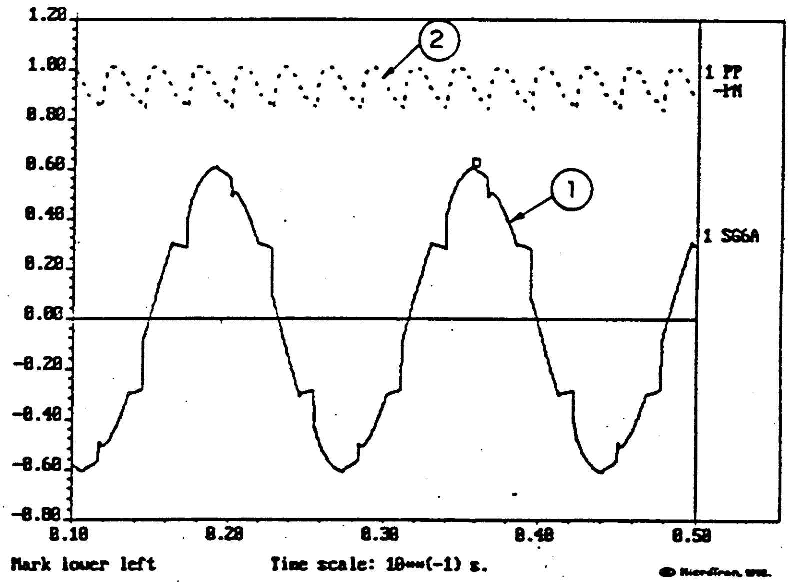

Fig. 6. Normal condition waveshapes

1 - 0,69 [KV] level
2 - armature voltage.
□ - t = 35,846 [msec]
u = 626,32 [V]

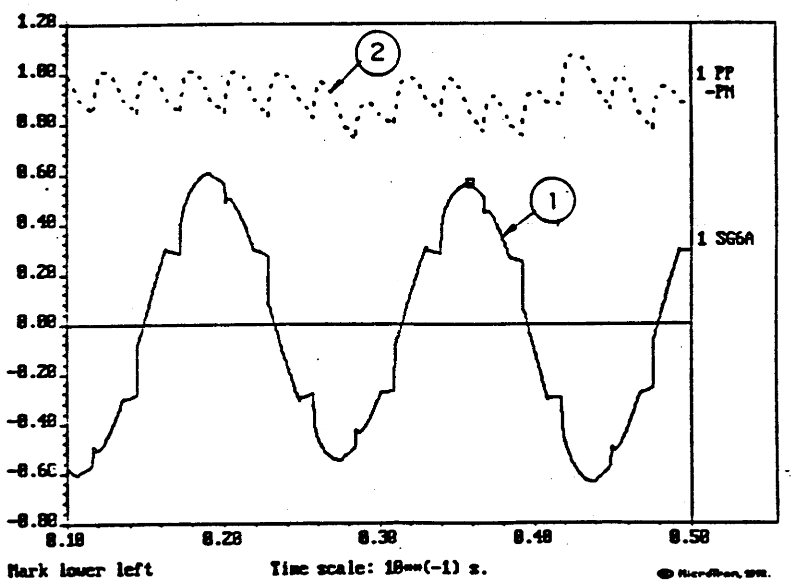

Fig. 7. Waveshapes under fault

1 - 0,69 [KV] level
2 - armature voltage.
□ - t = 35,846 [msec]
u = 563,16 [V]

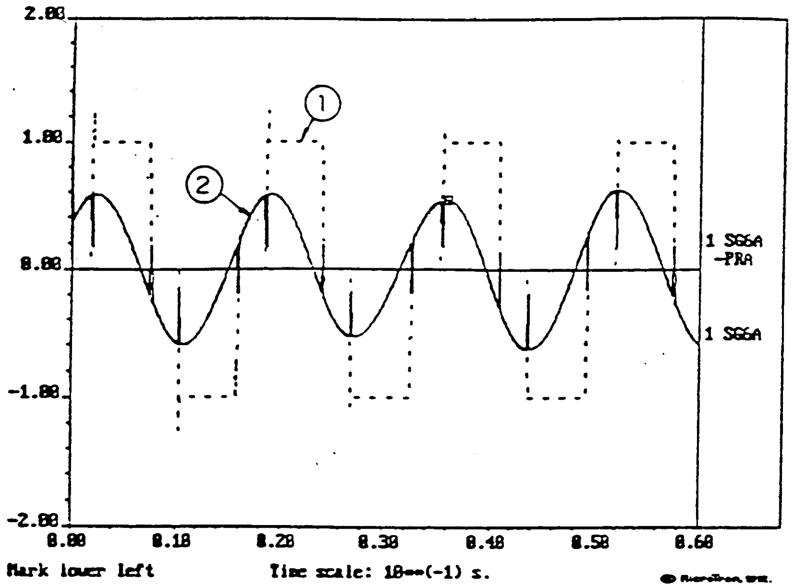

Fig. 8. Voltage and current waveshapes under fault 60° spaced independent pulses (symmetrical current)
1 - Current
2 - Voltage
□ - t = 35,862 [msec]
u = 546,39 [V]

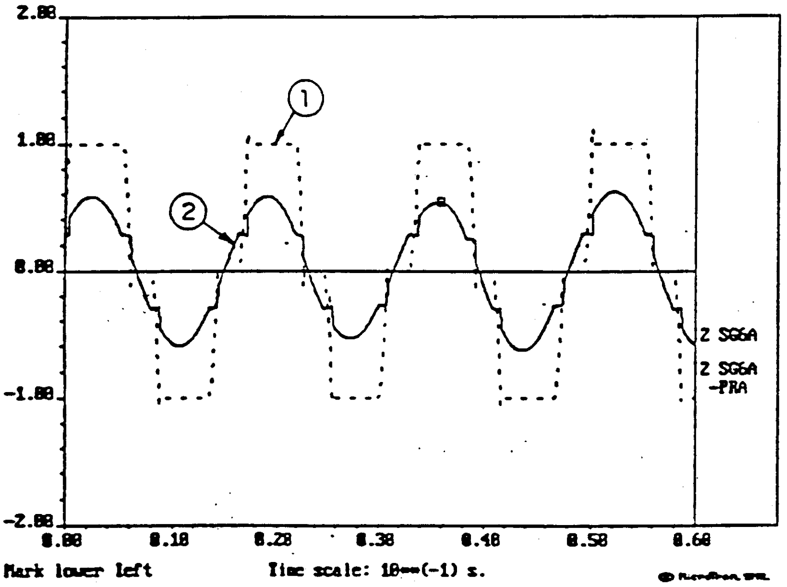

Fig. 9. Voltage and current waveshapes under fault in the pulse individual system
1 - Current
2 - Voltage
□ - t = 35,862 [msec]
u = 546,39 [V]

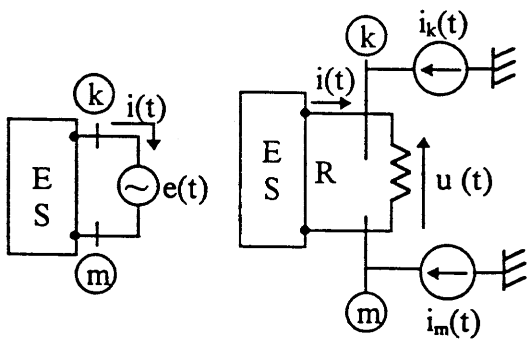

Fig. 10. Simulation of ungrounded voltage supply.
(ES = Electric System)