SIMSEN : A MODULAR SOFTWARE PACKAGE FOR THE ANALYSIS OF POWER NETWORKS AND ELECTRICAL MACHINES

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1. Abstract

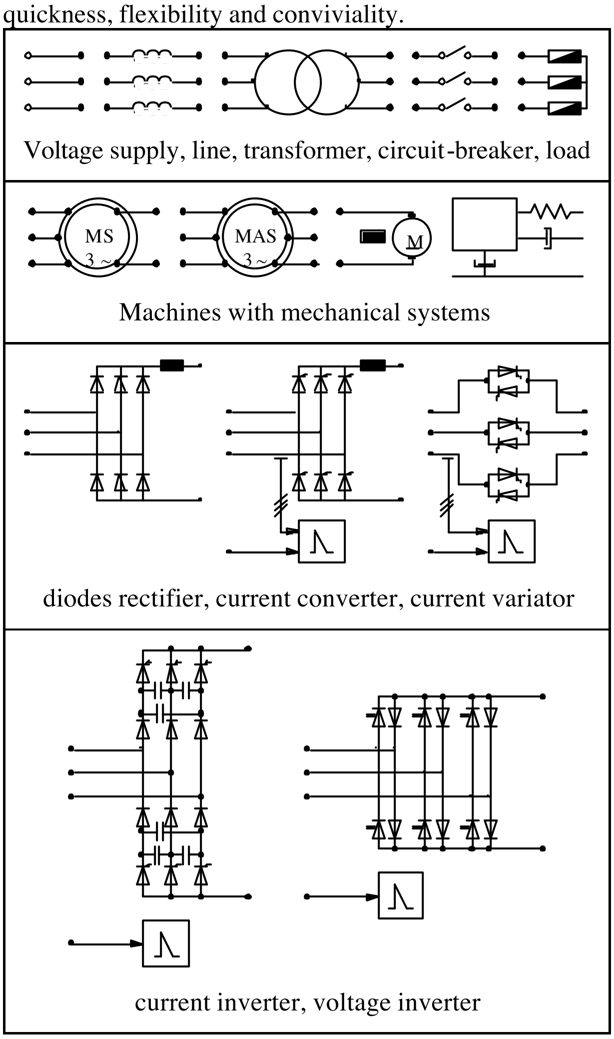
This paper deals with a software package for the numerical analysis in transient and steady-state modes of power electrical networks or variable speed drives with arbitrary topologies. The package is composed of a series of units, each representing a specific cell in the network : voltage supply, electrical machine, mechanical system, transmission line, circuit-breaker, phase shifting transformer, static converter with control and command organ, regulator, etc. *SIMSEN* is highly flexible and efficient. It is implanted on microcomputer or on workstation.

The network or the variable speed drive to be simulated is assembled using a graphic input interface by adequatly choosing and linking the building units, so as to fulfill a desired topology. An existing system may be easily extended or modified. A simple procedure can be used in order to define a new unit or to modify an existing one. The initial conditions of operation can be partly or entirely specified by the user. A transient mode of operation may include several successive perturbations. The simulation results are displayed through an efficient graphic interface.

An original feature of *SIMSEN* is its ability to analyse electrical networks involving semi-conductors (diodes rectifiers, thyristor or GTO current converters, voltage inverters, etc.). Thus, systems having a complex structure can be simulated. Practical examples of applications to such systems constitute the main part of this paper : constant or variable speed groups involving induction and synchronous machines, HVDC networks, reactive power static converter SVC. These examples show how *SIMSEN* can be used for an optimized design of complex networks.

2. Introduction

The numerical simulation is an essential tool for the conception, design and exploitation of power networks or systems. An efficient numerical software package must have the following properties : high modelling level, wide application field, precision, quickness, flexibility and conviviality.



Voltage supply, line, transformer, circuit-breaker, load

Machines with mechanical systems

diodes rectifier, current converter, current variator

current inverter, voltage inverter

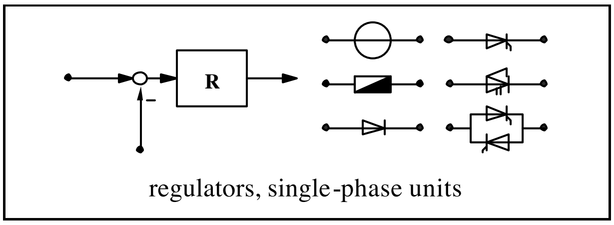


Fig. 1 List of available units

The modular software package *SIMSEN* for the numerical simulation in transient or steady-state modes of power networks and electrical machines joins these whole properties. Its two main targets are on the one hand the application to the power electrical networks with arbitrary topologies, involving semi-conductors units [1] and regulators [2], and on the other hand, the possibility to analyse rapid transient phenomena [3] (short-circuits, on-off switching of circuit-breakers, starting of motors, semi-conductor commutations).

Another feature of *SIMSEN* is its open structure which allows newly developped units to be easily implemented. I is thus possible to widen the applications field furthermore in the future. In comparison with two well known simulation packages, *EMTP* [4] and *EUROSTAG* [5], the following remarks can be formulated. *EMTP* is suitable for the simulation of rapid transient phenomena in complex electrical networks, also in those having elements with semi-conductors. However, in order to define his network, the *EMTP* user must start with the basic elements (resistance, condenser, diodes, thyristors, etc.) which, depending on the complexity of the system studied, may become long and tedious. *EUROSTAG* is a very modern system, highly interactive and based on a reliable macro-language using an automatic and variable stepsize managed by the dynamic behaviour of the power system. The fact that the *EUROSTAG* macro-language does'nt contain elements with semi-conductors represents a restriction in relation with the possible field of applications.

3. Structure and properties of *SIMSEN*

SIMSEN is based on a modular structure which enables the numerical simulation of the behaviour in transient or steady-state modes of a power network with an arbitrary topology. The user builds its power network by choosing and linking adequately the units shown in figure 1 in order to create the desired **TOPOLOGY**. This operation is made by using a graphical input interface. Then, the user has to introduce the **PARAMETERS** of each unit. The initial conditions of operation can be partly or entirely specified by the user. The **SIMULATION** of a transient mode can involve a lot of successive perturbations. All the simulation results are displayed through an efficient graphic **OUTPUT** interface. A specified network topology can be easily modified or extended by adding or retrieving units. The main devices of *SIMSEN* are shown in figure 2.

Each of the networks units shown in figure 1 includes a set of differential equations based on the units modelling. An original algorithm has been developed in order to generate automatically the main set of differential equations, written in phase values and resolved by numerical integrations.

The solution takes into account the whole interaction between the different units of the power system. The integration system works with a variable stepsize [6]. This method allows to detect exactly all the events in time as the on-off switching of a semi-conductor [7] or the on-off switching of a phase of a circuit-breaker.

The structure of *SIMSEN* allows newly developed units to be easily implemented, an existing unit can also be modified easily.

The only restriction on the size of the power network to simulate is prescribed by the available memory of the microcomputer. *SIMSEN* administrates its memory with dynamic variables and can, in this way, simulate large networks size.

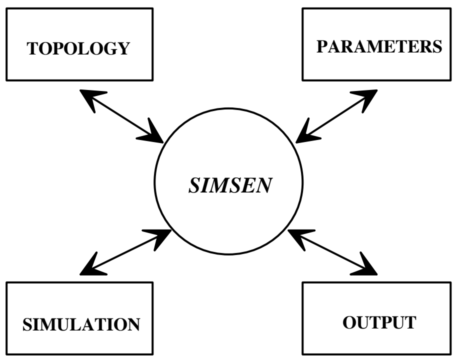


Fig. 2 Main devices of SIMSEN

4. Application examples

In addition to the examples shown below, other applications of *SIMSEN* are described in [8, 9].

Example 1 : HVDC transmission with reactive power static converter

The system studied is shown in figure 3. It consists of a synchronous machine *MS1* with its mechanical system *ME1*. The voltage and the speed of this machine are tuned by the regulators *RU1* and *RN1*. The stator of this machine is connected to a HVDC transmission constituted by 4 current converters *CONV1 - CONV4* and 4 transformers *T1 - T4* with phase shifting Yy0 and Yd11. Both AC sides of the transmission are equipped with filters C1- C4 for the elimination of the 12th and the 24th harmonics. The capacitor effect of the DC line is taken into account by the condenser *CCC1*. The DC transmission line is tuned by 2 current regulators *Ri1* and *Ri2*, a power regulator *RP1* and an extinguishing angle regulator *RG1* for the inverters *CONV1* and *CONV2*. At the inverters side, the voltage is tuned by a reactive power static converter. It is constituted by 2 transformers *T5 - T6*, 3 filters *C5 - C7* for the elimination of the 5th, 7th, 11th and 13th harmonics and the production of reactive power, a current variator *VAR1* and a reactive power regulator *RQ1*. All the system is connected to the AC network *S1* through the line *L1*. This example is an academical one in order to show the ability of *SIMSEN* to simulate complex networks. The aim of the study is to analyse the dynamic behaviour of the system after a sudden change of the power set value p_{cons} of the power regulator *RP1*. In this simulation, the extinguishing angle set value of the regulator *RG1* keep a constant value of 30°. Figures 4 to 11 show the results of the simulation. All these results are referred to the rating values of the synchronous machine *MS1*. Therefore *SIMSEN* is a suitable tool for the determination of optimal regulators and filters parameters relative to a complex structure as presented in figure 3.

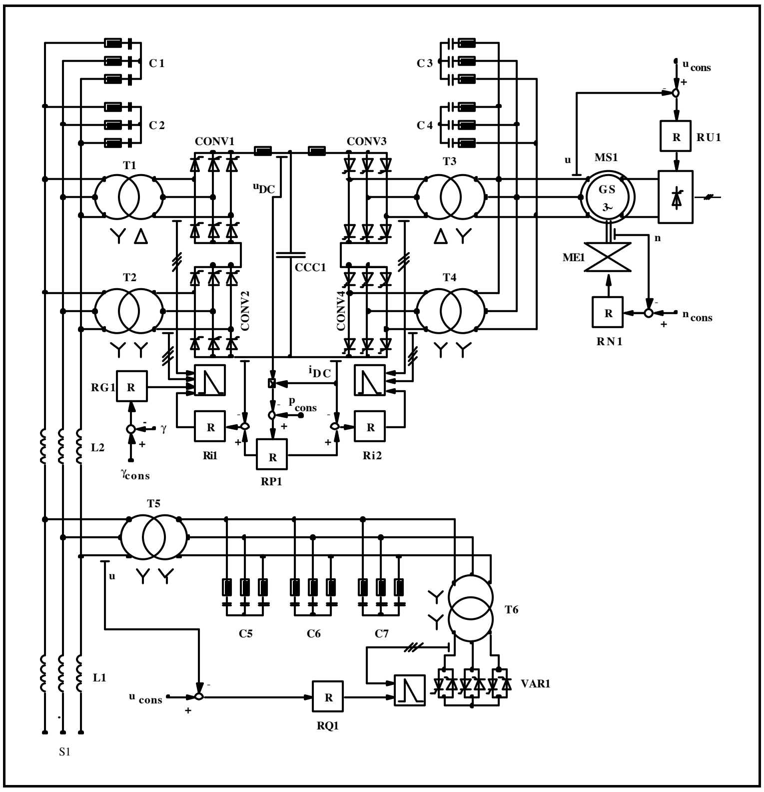


Fig.3 Power network studied in example 1 : HVDC transmission with reactive power static converter (SVC)

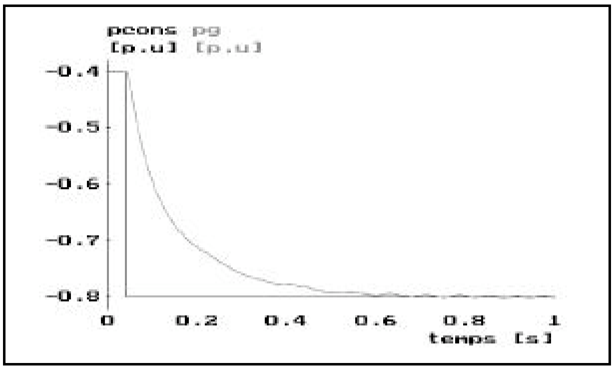


Fig. 4 Power set value "pcons" of the power regulator RP1 and power "pg" of the HVDC transmission

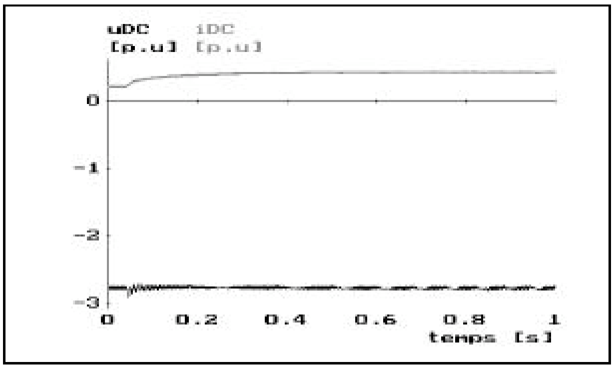


Fig.5 Voltage "uDC" and current "iDC" in the DC link of the HDVC transmission

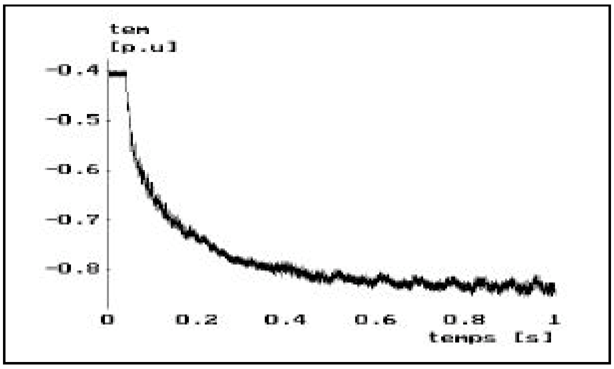


Fig. 6 Electromagnetic torque "tem" of the synchronous machine MS1

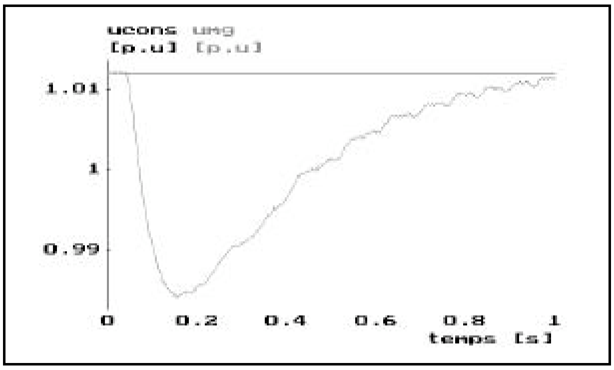


Fig. 7 Voltage set value "ucons" and voltage "umg" of the synchronous machine MS1

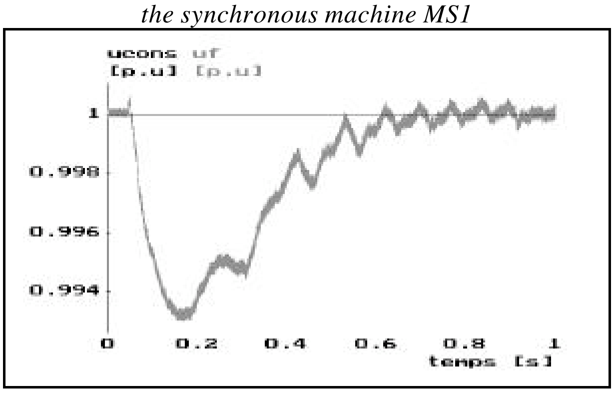


Fig. 8 Voltage set value "ucons" and voltage "uf" of the transformer T5 (SVC)

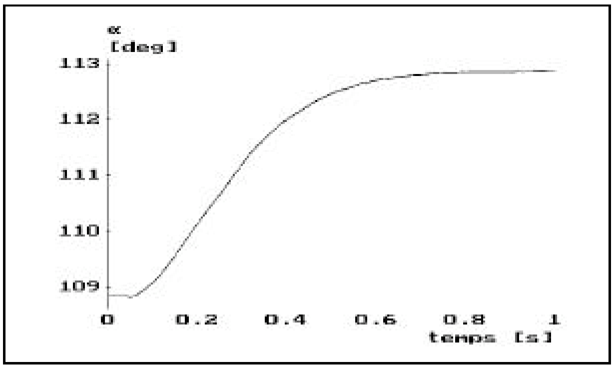


Fig. 9 Firing angle "α" of the current variator VAR1

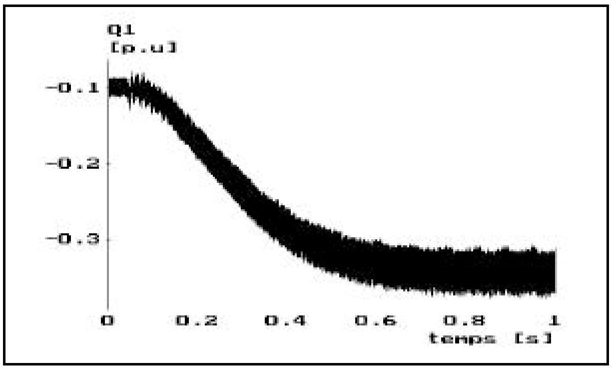


Fig. 10 Reactive power "Q1" of the transformer T5 (produced by the SVC)

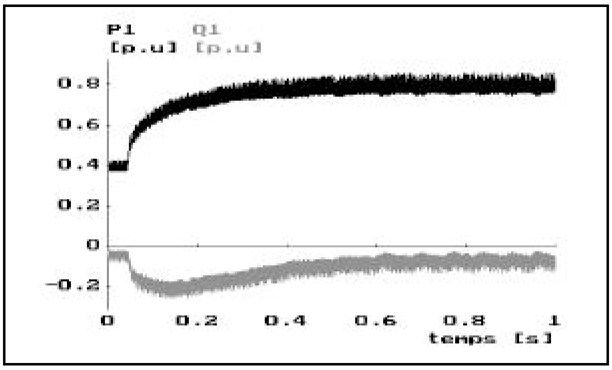


Fig. 11 Active power "P1" and reactive power "Q1" of the AC network S1

Example 2 : Static slip-energy recovery drive with induction machine and cyclo-converter

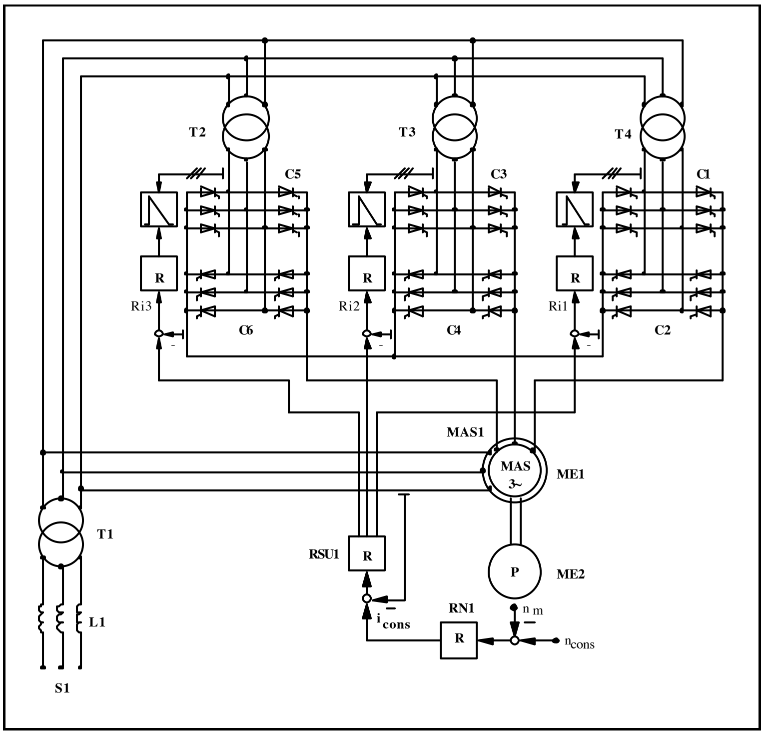


Fig.12 Electrical drive studied in example 2 : Slip-energy recovery drive with induction machine and cyclo-converter

The system studied is shown in figure 12. It consists of an induction machine *MAS1* with a rotor winding connected to a cyclo-converter constituted by 6 current converters *C1 - C6*. All the system is connected to the AC network *S1* by 4 transformers *T1 - T4*. The rotor phase currents are tuned by 3 current regulators *Ri1 - Ri3*. The current set value of these 3 regulators are given by the stator currents regulator *RSU1*. The stategy of regulation is based on the voltage stator oriented method and depends on the rotor position. The aim of this method is to separate the active and reactive stator currents. So, it is possible to guarantee a high power factor for this electrical drive. The speed of the machine is tuned by the speed regulator *RN1*. The induction machine *MAS1* drives the pump *P*.

Figures 13 to 18 presents results of a variation of the speed from 0.9 [p.u.] to 1.1 [p.u.] with a constant mechanical torque of -0.5 [p.u.]. All the results are given in the rating values of the induction machine *MAS1* : 80 MVA, 12.5 kV, 50 Hz, p = 6.

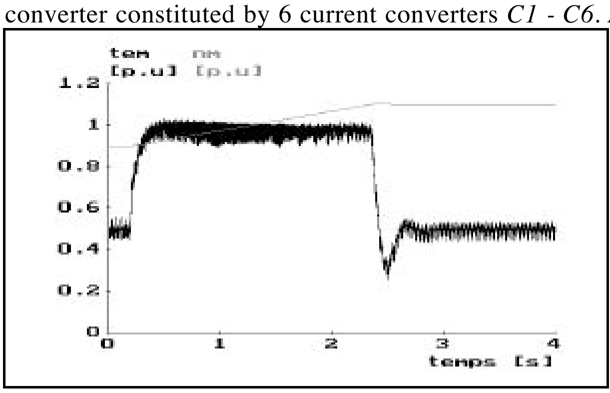


Fig. 13 Electromagnetic torque "tem" and speed "nm" of the induction machine MAS1

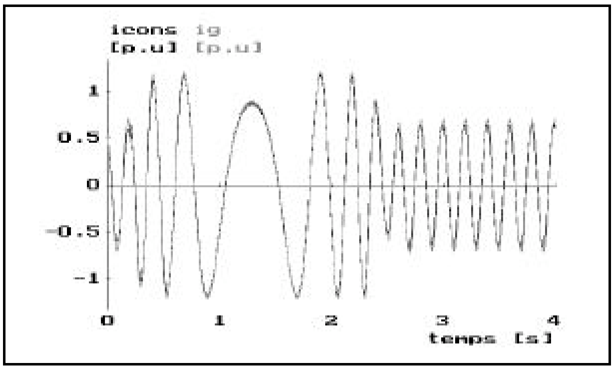


Fig. 14 Current set value "icons" and rotor phase current "ig" of the induction machine MAS1

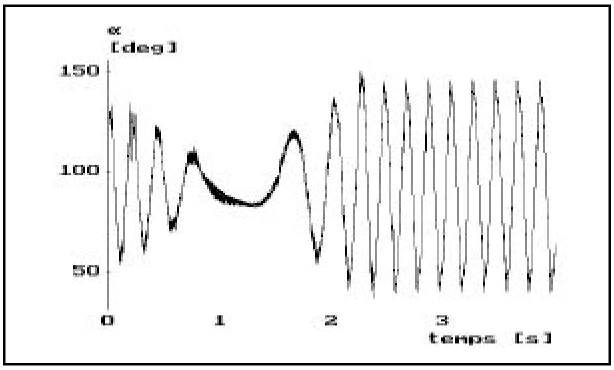


Fig. 15 Firing angle "α" of the current converter C1

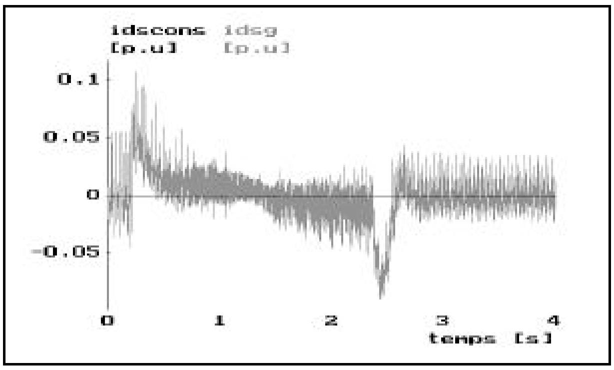


Fig. 16 Current set value "idscons" and current "idsg" in the d axis of the induction machine (reactive power)

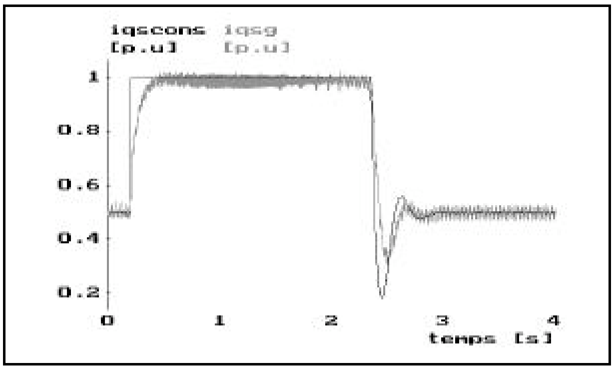


Fig. 17 Current set value "iqscons" and current "iqsg" in the q axis of the induction machine (active power)

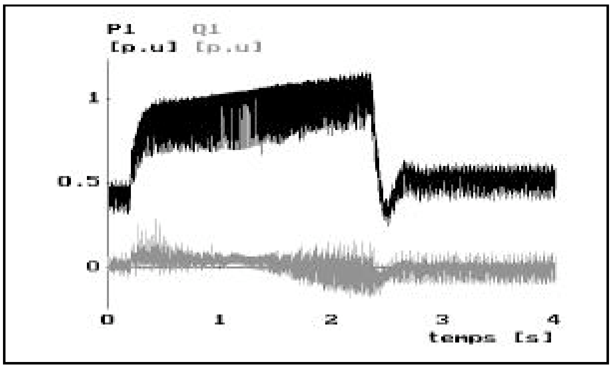


Fig. 18 Active power "P1" and reactive power "Q1" of the main transformer T1

Example 3 : Shaft train torsional oscillations of large turbo-generators

The system studied is shown in figure 20. It consists of 4 groups including : a synchronous machine *MS*, a mechanical shaft train *ME*, a voltage regulator *RU* and a transformer *T*. The 4 groups are connected to the AC network *S1* through the line *L1*. A circuit-breaker *D1* allows to generate a three phase default on the high voltage side of each transformer. The main field saturation in the d and q axis of the synchronous machine have been taken into account as well as the complete shaft train (slip rings, large turbo-generator and 4 turbines) of the mechanical system as represented in figure 19.

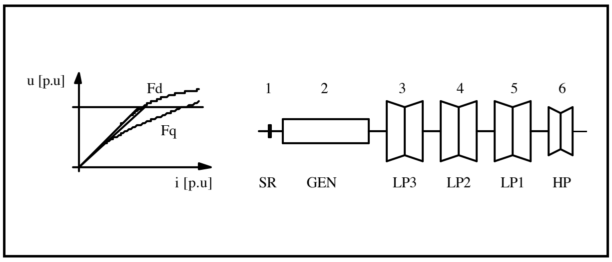


Fig. 19 Saturation of the synchronous machine and shaft train for the mechanical system

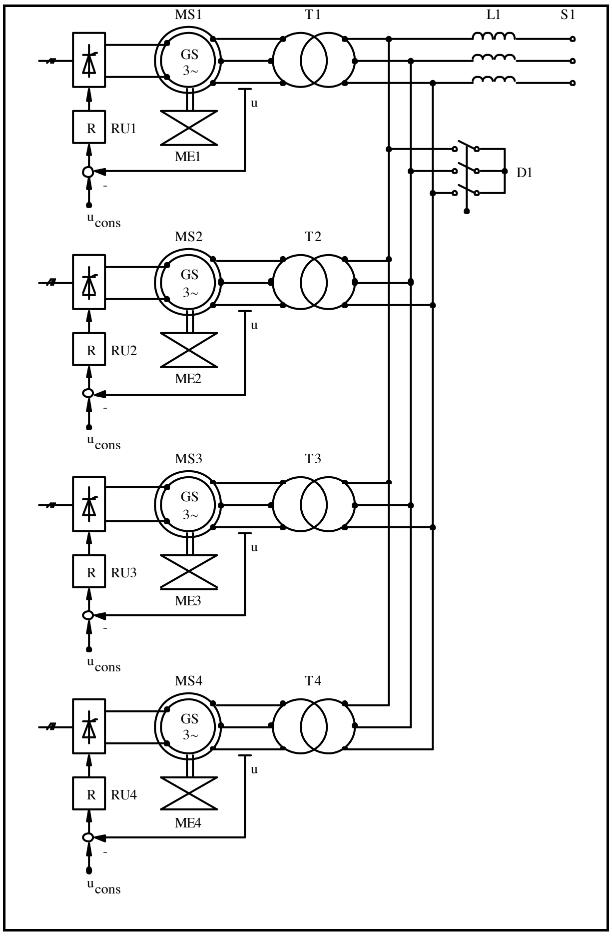


Fig. 20 Power network studied in example 3 : Shaft train torsional oscillations of large turbo-generators

The aim of the study is to analyse the dynamic behaviour of the system with 1 or 4 machines after a on-off switching of the circuit-breaker *D1*. The operating point of the first turbo-generator *MS1* is the same in both cases. Figures 21 and 22 show the results of the two simulations. All the results are given in the rating values : 1200 MVA, 28.5 kV, 50 Hz, p = 1.

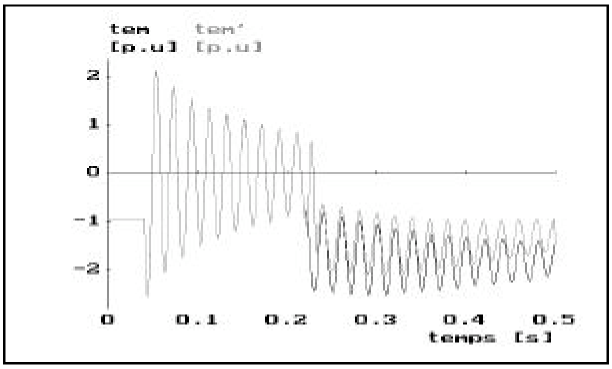


Fig. 21 Electromagnetic torque of the synchronous machine MS1 ("tem" : 1 machine, "tem' " : 4 machines)

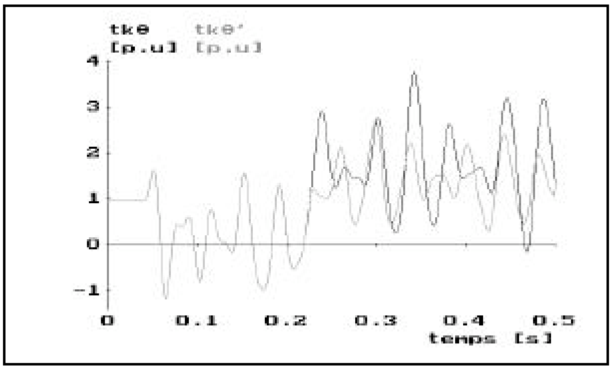


Fig. 22 Torsional torque between the generator and the turbine ("tkθ" : 1 machine, "tkθ' " : 4 machines)

5. Conclusion

A modular software package for the analysis of power networks and electrical machines - *SIMSEN* - has been described. This package is a flexible, convivial and evolutive tool for the conception, design and exploitation of complex power systems with an arbitrary topology including also elements with semi-conductors. The field of applications of *SIMSEN* is very wide, the numerical simulation is possible under steady-state or transient conditions. A possibility exists for the user to introduce in a simple manner a new unit or to modify an existing one.

6. References

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