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OPTIMIZED DESIGN OF VARIABLE-SPEED DRIVES AND ELECTRICAL NETWORKS BASED ON NUMERICAL SIMULATION

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Abstract: The present paper describes the modelling and the prediction of the steady-state or transient behaviour of different modern variable-speed drives and electrical networks. The necessity of a performant numerical simulation tool in order to guarantee an optimized design is illustrated by examples based on existing large variable-speed drives and power plants.

Keywords: variable speed drive, electrical network, converter, regulator, dynamic behaviour.

Summary

During the last few years the performances and therefore the complexity of the variable-speed drives as well as those of the modern power plants have considerably increased. Consequently, an optimized design of these equipments requires suitable numerical simulation tools in order to guarantee the feasibility and the performances of such equipments in steady-state or transient operation. More precisely, it is no more sufficient to simulate separately the behaviour of the different elements, even based on sophisticated models, it is necessary to simulate globally all the system in order to take into account all the possible interactions which are often primordial for the system performances.

In a practical viewpoint a suitable simulation tool should be able to consider all the elements used in a complex system (machines, converters, load, supply, control and regulation equipment, protection devices, filters, ...) for any system topology.

In this paper, the modelling of different existing large industrial drives or electrical networks based on modern technologies are described, including the synchronous machine with 2x3 phase stator winding. It is shown how the use of performant simulation tools helps to reach an optimized design [1,2,3].

Examples of applications.

The following examples of application concern existing large variable-speed drives and power plants. These examples have been simulated with the simulation tool SIMSEN described in appendix.

Example 1: 12 pulse LCI-fed synchronous Motor

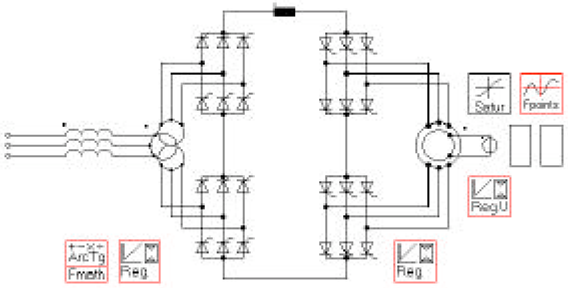
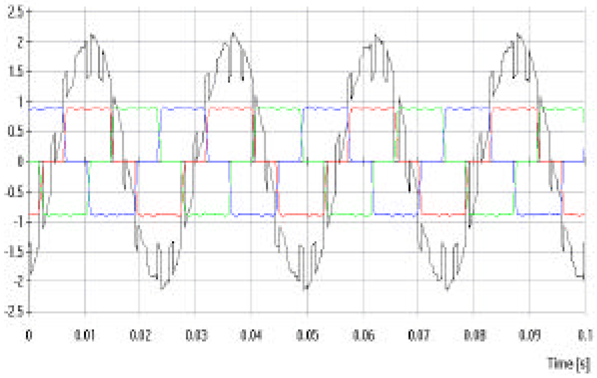


Fig.1: 12 pulse LCI-fed synchronous motor
21 MVA, 2x3.3 KV, 39.17 Hz, 2p = 10

ia1, ib1, ic1, uab1



tem

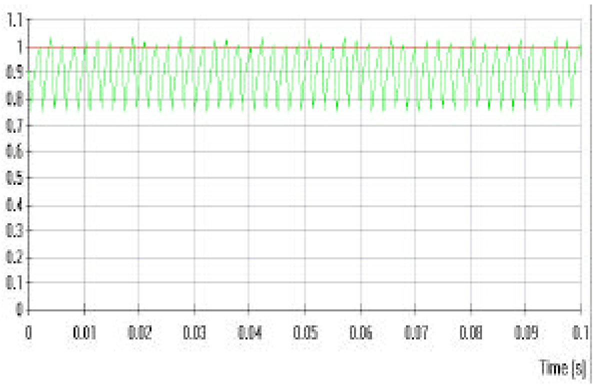
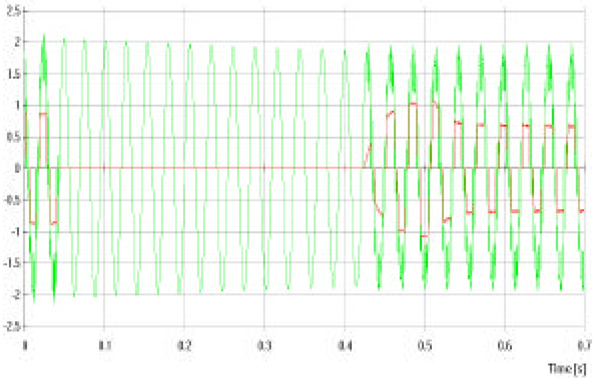


Fig.2: steady-state operation, tmec = 0.9, n = 1.

ia1, uab1



n, tem

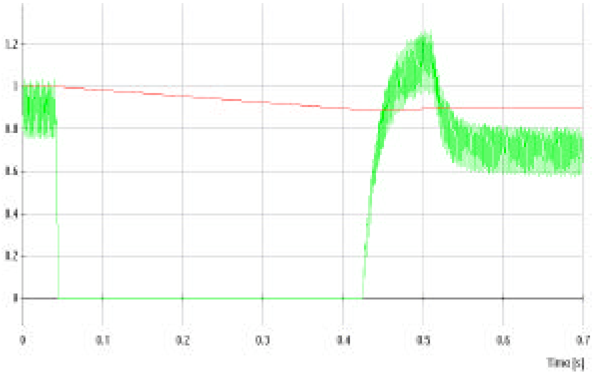


Fig.3: transient operation, modifications of the speed and torque set values

Example 2: Induction motor with a 6-pulse-cascade

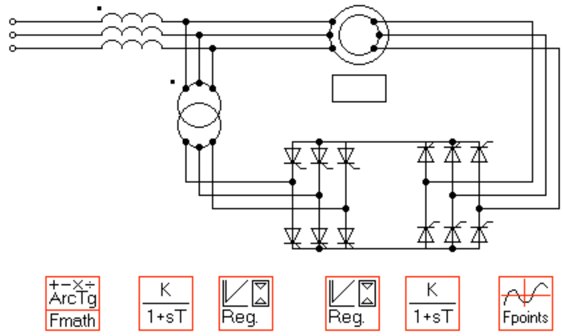
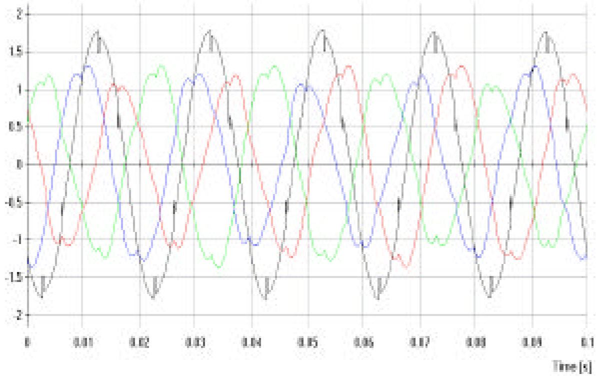


Fig.4: Induction motor with a 6-pulse cascade

6 MVA, 11 KV, 50 Hz, 2p = 6

ia1, ib1, ic1, uab1



n, tem, prot

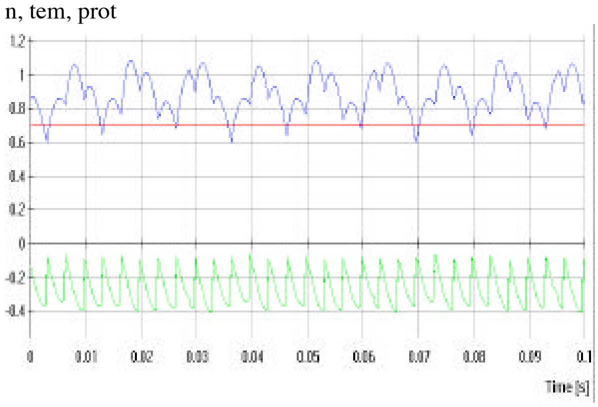
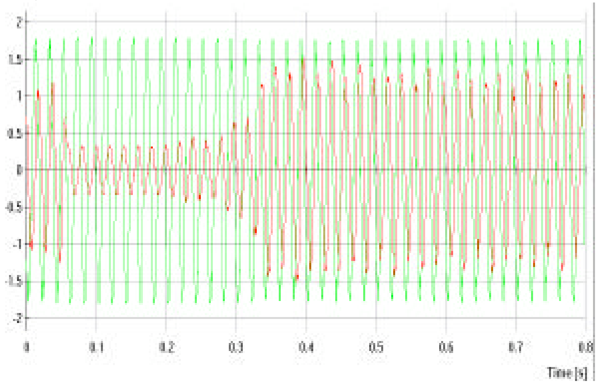


Fig.5: steady-state operation, n = 0.7, tmec= 0.89

ia1, uab1



n, tem

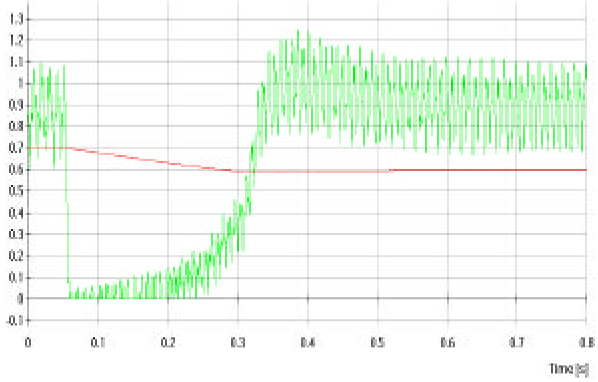


Fig.6: transient operation, change of the speed set value

Example 3: Induction motor with a 12-pulse cascade

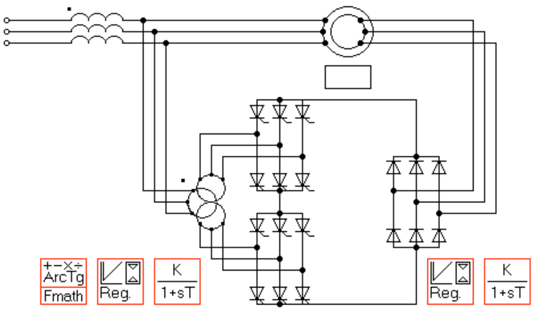
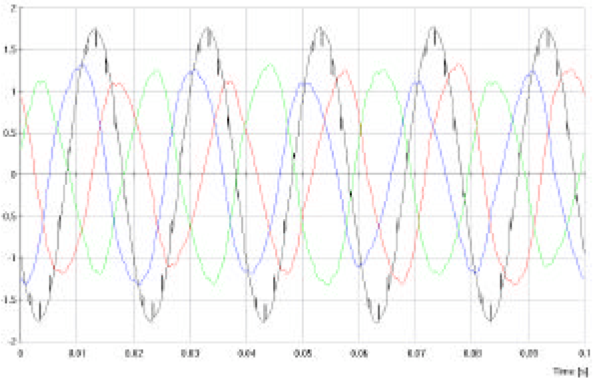


Fig.7: induction motor with a 12-pulse cacade
6 MVA, 11 KV, 50 Hz, 2p = 6

ia1, ib1, ic1, uab1



n, tem, prot

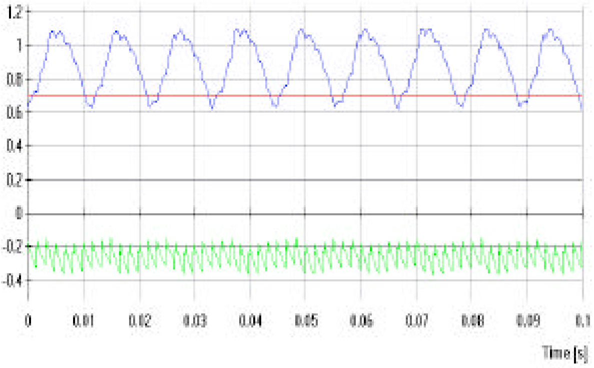
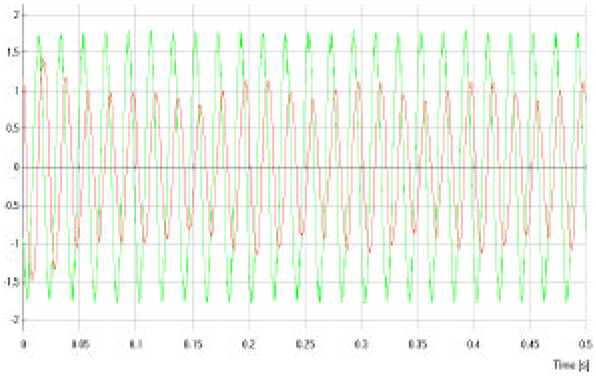


Fig.8: steady-state operation, n = 0.7, tmec =0.89

ia1, uab1



n, tem

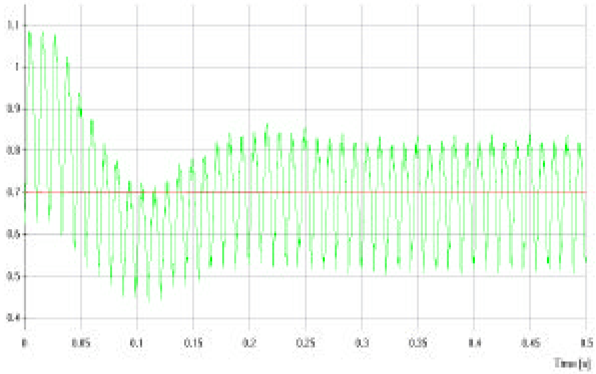


Fig.9: transient operation, change of the torque set value

Example 4: Slip-energy recovery drive with induction machine and cyclo-converter (doubly fed induction machine)

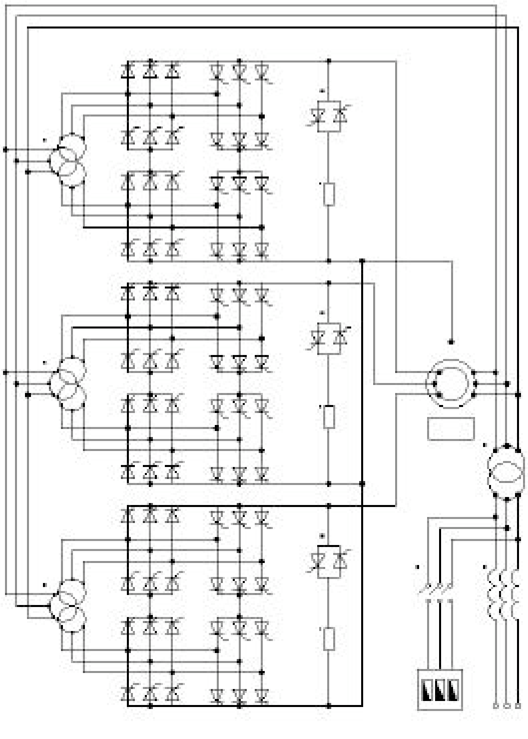


Fig.10: Slip-energy recovery drive with induction machine and cyclo-converter
230 MVA, 15.75 KV, 50 Hz, 2p = 18

In comparison with a conventional synchronous motor-generator operating in a pump-storage plant, a doubly fed induction machine offers the following important advantages[5]:

Possibility of active power control in pumping mode in a specified pump head range (contribution to the network frequency control).

High efficiency and wide range operation in generating mode.

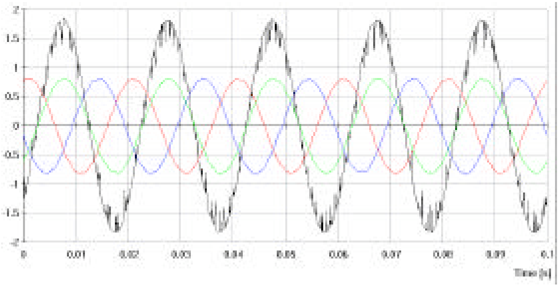
Possibility of instantaneous power injection into the grid for eliminating power system fluctuations.

Possibility of reactive power control at the interconnection point to the grid.

Starting-up into pumping mode without any constraints for the machine and for the grid.

Such a large doubly fed induction machine must be designed and optimized very carefully by taking into account all the interactions between the different components of the system (induction machine, type of cyclo-converter, control equipment and strategy, pump-turbine, grid, operation requirements). It is therefore indispensable to work with a suitable simulation tool, also in an economical point of view.

ia1, uab1



tem, prot

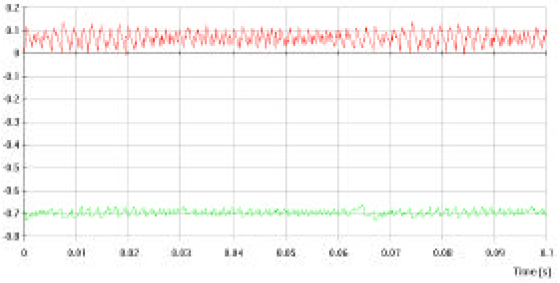
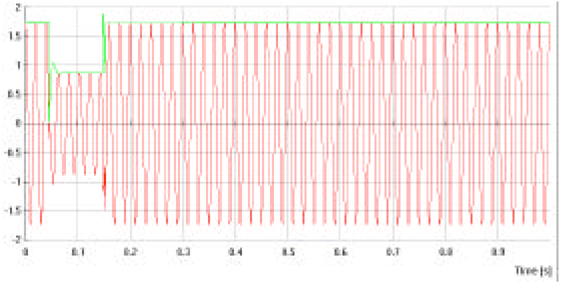
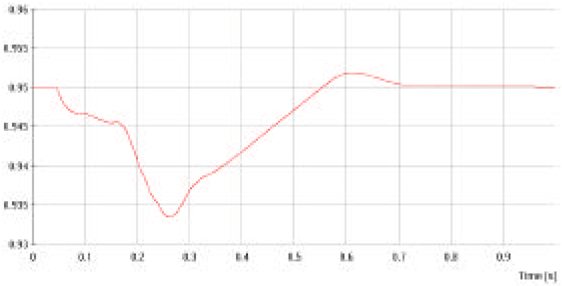


Fig.11 steady-state operation, n = 0.9, tmec = -0.7

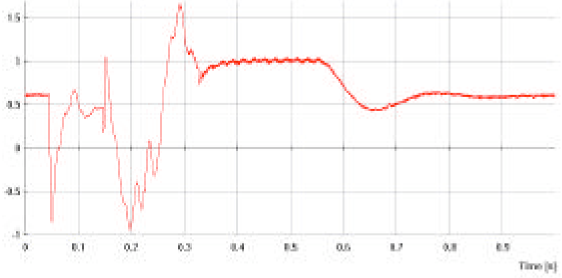
uab1, uab1eff (HV side of the transformer)



n



Tem



ia1, uab1 (induction machine)

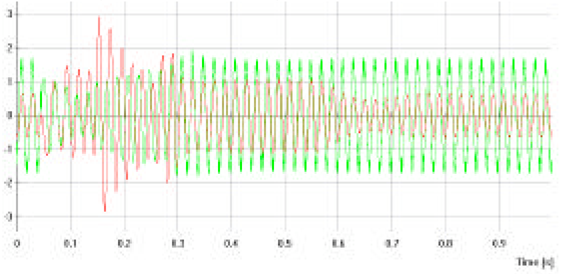


Fig.12: transient operation, voltage dip 50 % during 100 ms on the HV side of the transformer with a constant speed set value

Example 5: Shaft train torsional oscillations of large turbo-generators

The power plant shown in fig.13 consists of 4 groups, each including: a turbogenerator with its shaft train, a voltage regulation and a transformer. The 4 groups are connected to the grid through the same transmission line. One circuit breaker is used to produce and to clear a three -

phase fault on the HV side of the transformers in two different cases.

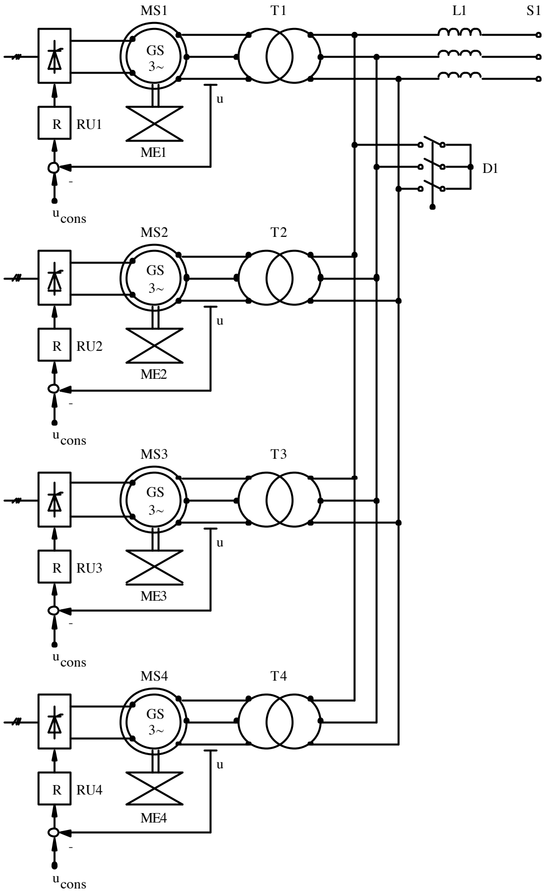


Fig.13: Shaft train torsional oscillations of large turbo-generators

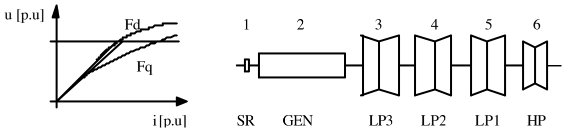
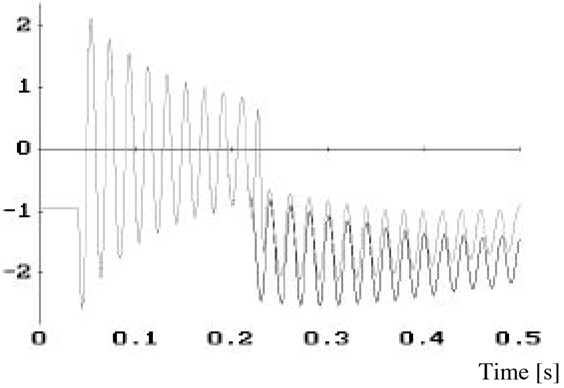


Fig.14: No-load characteristics and shaft reduction.

In the first case only the generator 1 is in operation, in the second case all generators are in operation but unequally charged. In both cases the generator 1 has the same conditions of operation.

As expected, the plots on the fig. 15 show the same behaviour of the generator 1 in both cases till the fault clearing time and another one after this time.

tem, tem1



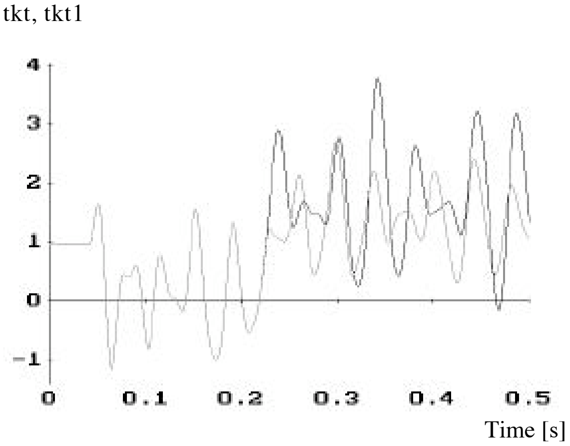


Fig.15: Electromagnetic torque of the generator MS1 ("tem": 1gen., "tem1": 4 gen.) Mechanical torque between GEN and LP3 ("tkt": 1 gen., "tkt1": 4 gen.)

Example 6: Subsynchronous resonance

Fig. 16 shows an example of the torsional interaction phenomenon [4]. A generator operating on full load feeds two lines. The uncompensated line S2 carries approximately 1% of the total power. At time 0.033 s this line is disconnected, this small change leads to an interaction effect during which the torque in the shaft section GEN - LP3 begins to pulsate with an increasing amplitude. At time 3.8 s the disconnected line is reconnected and the torsional oscillations begin immediately to decrease, but with another time constant.

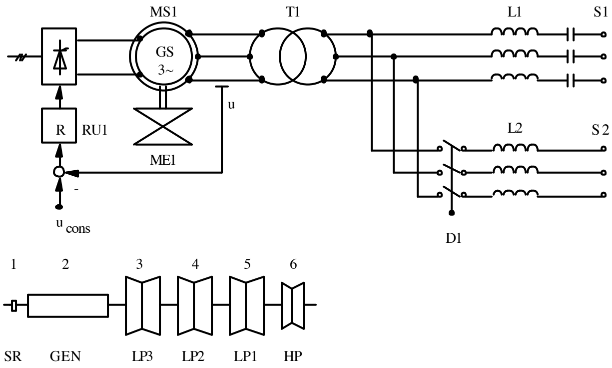


Fig.16: Subsynchronous resonance due to a torsional interaction

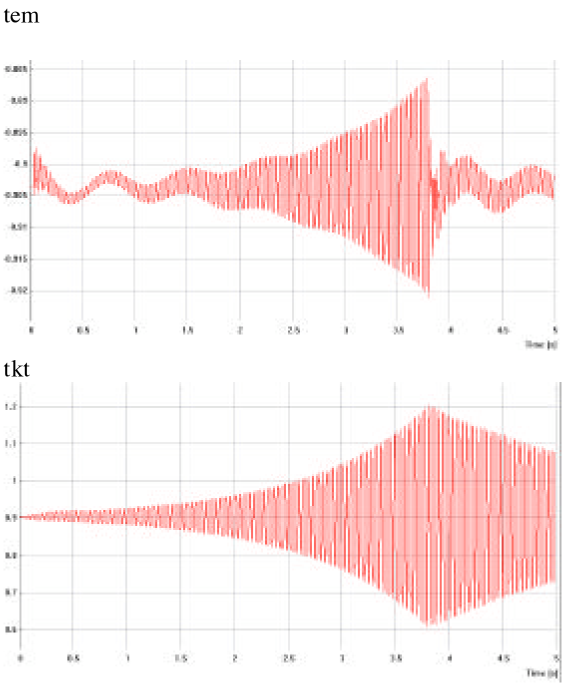


Fig.17 Subsynchronous resonance due to the interaction effect
tem : electromagnetic torque
tkt : mechanical torque GEN - LP3

Conclusions

Based on different examples of practical applications it has been shown how a performant simulation tool can be useful for an optimal technical, feasible and economical design of a complex variable speed drive or of an electrical network. Such a tool permits the comparison between different possible technical solutions and the verification of the required performances of the equipment.

References:

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Appendix: SIMSEN - a new modular software package for the numerical simulation of power networks and variable speed drives.

The above described variable speed drives have been simulated with a new software package developed at the Federal Institute of Technology in CH-Lausanne. The main features of this simulation tool running on PC are the following:

SIMSEN is based on a modular structure which enables the numerical simulation of the behaviour in transient or steady state conditions of power networks or variable speed drives with an arbitrary topology.

The user builds its network directly on the screen by choosing and linking adequately the suitable units shown in table 1 in order to create the desired topology. Each unit represents a specific element in the network, it includes a set of differential equations based on the unit modelling.

An original algorithm generates automatically the main set of differential equations for all the system taking into account all the possible interactions between the different units.

A transient mode of operation may include several successive perturbations.

For applications without units having semi-conductors the initial conditions are obtained with a load-flow program.

The numerical integration works with a variable step size, it is therefore possible to detect exactly all the events in time as the on-off switching of a semi- conductor or of a circuit - breaker.

The open structure of SIMSEN allows newly developed units to be easily implemented. An existing unit can also be modified without difficulties. It is thus possible to widen the applications field furthermore in the future.

The only restriction on the size of the power network to simulate is prescribed by the available memory of the microcomputer. The dynamic administration of the memory makes possible the simulation of large networks (up to 1000 state variables).

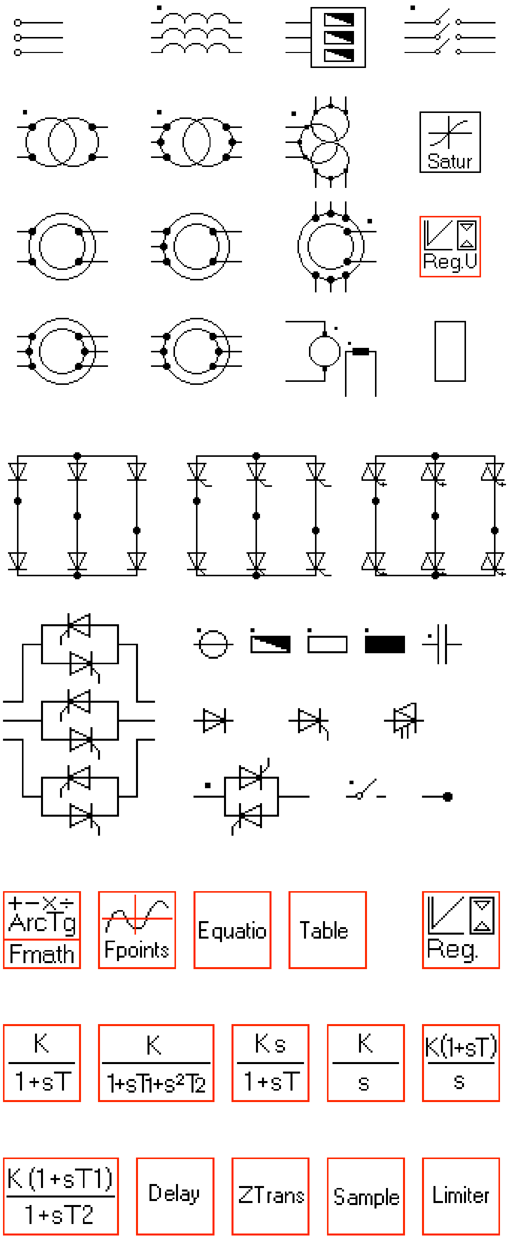

Table 1: non-exhaustive list of SIMSEN units.