USEFUL SOFTWARE TOOL FOR SIMULATING SWITCHED RELUCTANCE MOTORS

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ABSTRACT

Simulations are widely used in the study of both electrical machines and drives. In the literature, several simulation approaches can be found which can be also applied in the study of the switched reluctance motors (SRMs). The on-line SRM simulation tool developed by the authors and presented in this paper proved to be very useful both in checking the design of the motor, but also in setting up and verifying the proper control strategy of the motor. The simulation program can be very practical in teaching electrical machines and drives, and it can be extended to be used also in remote laboratories.

INTRODUCTION

The on-line (real-time) simulations are the one of the most advanced techniques used in studying both the electrical machines and drives (Asghari 2009, Bauer 2005).
The on-line simulation of electrical machines and drives is an efficient and cost-effective approach to evaluate the behavior of both newly designed machines and controllers before applying them in a real system. Using such software tools new electrical machines and their controllers can be rapidly and easily tested (Mohan 1995, Ong 1998).
Therefore on-line simulation techniques can be very helpful also where interactive changing of parameters immediately affects a change of the corresponding results (Perl 2000).
The switched reluctance motors (SRM) look like being one of the most significant new developments in the field of electrical machines for variable speed drives. They have several attractive features, such as high output power, high starting torque, wide speed range, rugged and robust construction and low manufacturing costs (Miller 2001).
Therefore the on-line simulation tool for studying the SRM's performances presented in this paper could be of real interest for all the specialists working in these fields.

In the paper, the simulation program will be detailed, both with its algorithm and easy-to-use graphical interface. Its usefulness will be highlighted by the results of simulations carried out on a typical structure of SRM.

THE SWITCHED RELUCTANCE MOTOR

The SRM is a double salient electrical machine with a passive rotor (Henneberger 2001). In the SRM the torque is produced by the tendency of its rotor to get to a position where the inductance and the flux produced by the energized stator winding are maximized (variable reluctance principle).
The SRM's rotor and stator both have salient poles, as it is shown in Fig. 1.

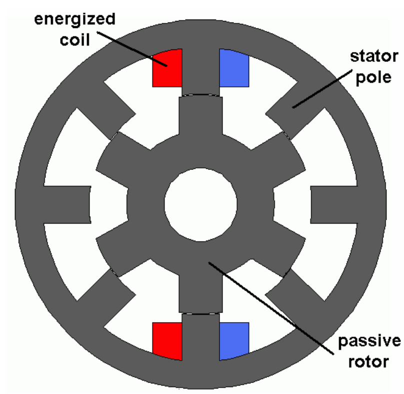

Figure 1: The switched reluctance machine

The stator is formed from punched laminations that have been bonded into a stack. The rotor is made of conventional laminations without any kind of winding, excitation, squirrel-cage or permanent magnet (Krishnan 2001).
The stator winding consists of coils placed on the stator poles. Typically, a phase is created by two series or parallel connected coils placed on diametrically opposed poles of the machine. Each phase is independent and the machine's excitation is a sequence of current pulses applied to each phase in turn. The commutation of the SRM's phase currents must be synchronized precisely with the rotor position (Miller 2001). The SRM cannot be separated from the electronic supply device and its control (Henneberger 2001).

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The various advantages of the SRM make it an attractive alternative to the existing dc and ac motors in adjustable speed drives. The SRM drives can also deliver servo-drive performance equivalent to dc brushed motors. The rotor position sensing requirements, the need for an electronic converter and the higher torque ripple and noise, compared to other machines, are the main disadvantages of the SRM drives.
In the literature several classical simulation approaches for the SRM can be found (Radun 2000, Soares 2001, Bauer 2008, Strete 2010). All of them have the drawback of obtaining the results only after finishing running the simulation programs and the user cannot modify neither the parameters of the simulation and control, nor of the machine.

THE SIMULATION PROGRAM

The program is written by the authors in Borland Turbo Delphi 2006 (Cantu 2005, Borland 2006). It is structured in 7 libraries, 3 for window forms, 3 for configurations and the last, for motor controllers, in total over 3000 lines of code (over 100 subprograms).
To make the simulation in real-time, in addition to the main thread, used for graphics, the program uses two additional threads, one for the motor simulation and the other for the built-in motor controller (Szász 2009).

If the user wants to connect the program to an external motor controller, through TCP/IP connection the integrated server module generates one more thread (Chindriş 2010).
When the motor is simulated in real-time, the system needs a huge processing power. The program makes available the possibility to simulate the controller using an external simulator (see Fig 3).

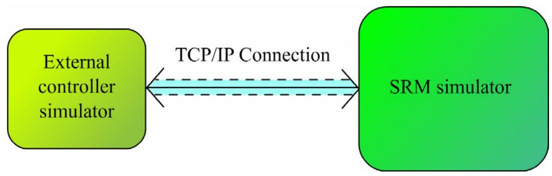


Figure 3: Connection to the external simulator

The two simulators use a TCP/IP connection, where the SRM simulator is the server and the controller simulator is the client, running on different computers (Kozierok 2005).
The block scheme of the simulation program is shown in Fig. 2, where the logical way as the program is built up can be followed.
The easy use of the simulation program is assured by the user-friendly graphical user interface (GUI) given in Fig. 4 (Miller 2009).

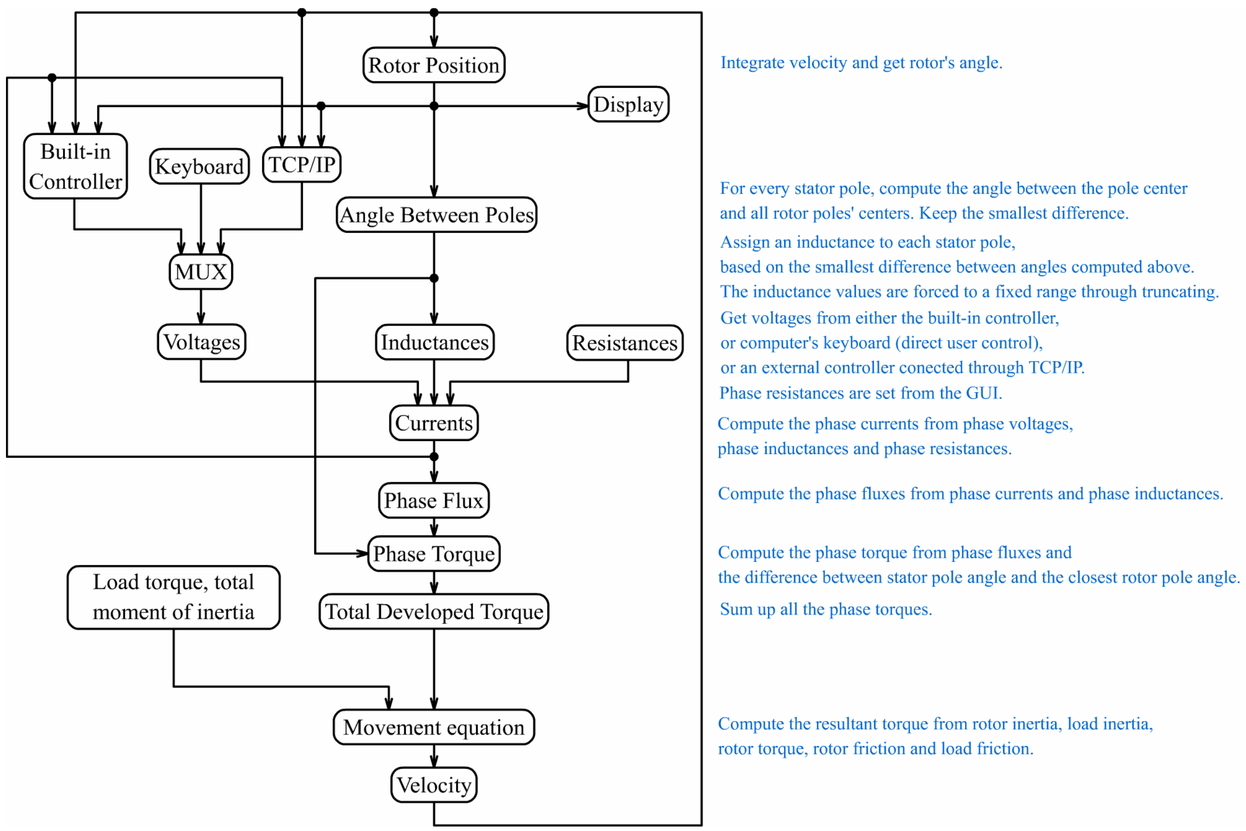


Figure 2: The block scheme of the simulation program

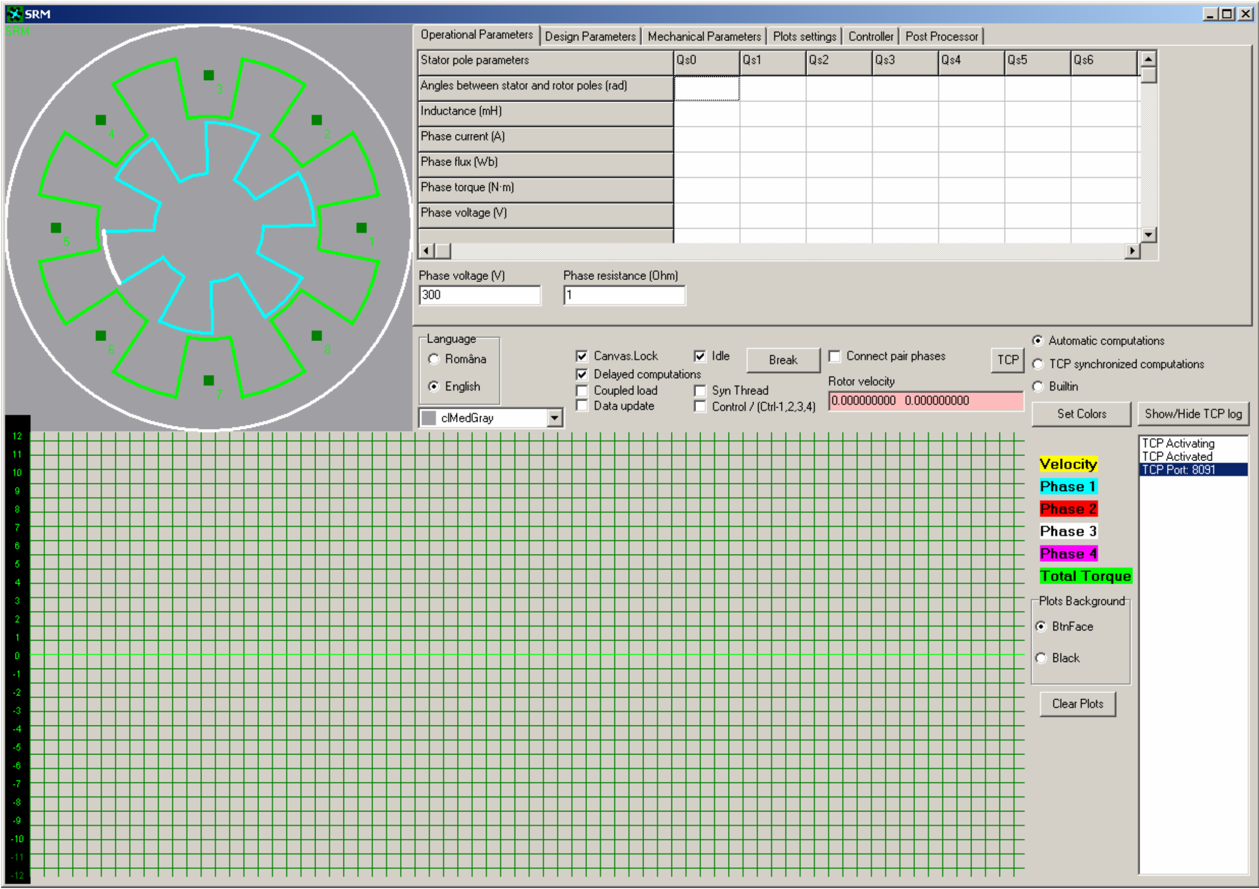


Figure 4: The main GUI of the simulation program

The GUI has three main parts. In the upper left corner the outline of the studied machine's cross section can be seen. In the right side, several pop-up panels can be opened for setting the parameters of both the machine and the simulation itself. In the lower part of the GUI, the results of the simulations can be plotted.

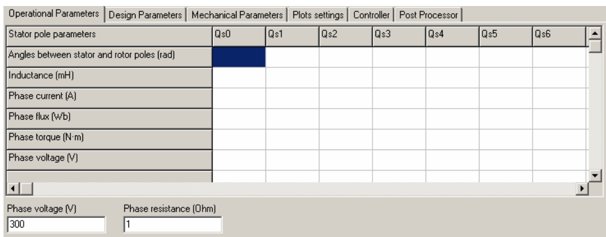
The parameters of the SRM in study can be set in three of the pop-down panels of the GUI:

i.) in the *Operational parameters* panel, the phase voltage and the phase resistance can be set (Fig. 5a). During the simulations, several data regarding each pole of the SRM (the angle between stator and rotor poles, phase voltage, inductance, current magnetic flux, electromagnetic torque generated) are visualized.

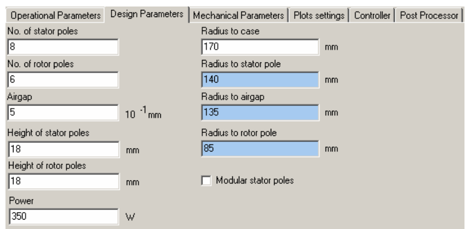
ii.) the main geometrical data of the machine can be set in the *Design Parameters* panel: the number of stator and rotor poles, the air-gap and the machine's main geometrical (Fig. 5b)

iii.) the mechanical parameters (the friction torque, the load torque, the moment of inertia of both the motor and of the load, etc.) can be introduced in the text fields of the *Mechanical parameters* panel (Fig. 5c).

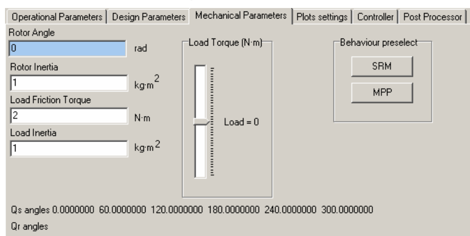
As it can be seen, all the variables of the simulation program can be set up very easily in the GUI, given in Fig. 4. By this, a high flexibility is assured for the



a) the *Operational parameters* panel



b) the *Design Parameters* panel



c) the *Mechanical parameters* panel

Figure 5: The pop-down panels of the GUI

program. By a few changes, practically any SRM structure can be easily simulated.

The main parameters of the SRM's controller can be adjusted by very simple sliders in the Controller panel of the main GUI, as shown in Fig. 6.

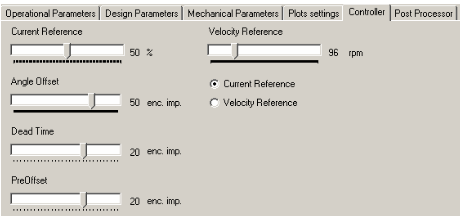


Figure 6: The *Controller* panel of the GUI

The main results of the simulation can be plotted versus time, this being the best way to understand and verify the working regimes of the SRM in study.

The plotting of the results can be coordinated from the *Plot settings* pop-down panel (see Fig. 7).

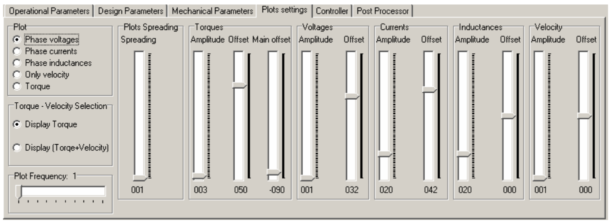


Figure 7: The *Plot settings* panel

The program is able to plot on-line the following results of the simulations:

i.) the phase voltages
ii.) the phase currents
iii.) the phase inductances
iv.) the speed
v.) the torque

For all the plots, their amplitude and offset can be set in order to obtain the best view of the results in the plotting panel of the GUI.

RESULTS OF SIMULATION

To emphasize the usefulness of the above presented program, results of simulations, performed for a sample motor, will be given.

The main data of the sample SRM motor are:

i.) stator poles number 8
ii.) rotor poles number 6
iii.) rated current 5 A
iv.) rated speed 300 r/min
v.) rated torque 5 N·m

The simulations were performed for a 1 s long time starting and steady state run when a ramp-type speed profile was imposed.

The results of the simulation were saved in text files and exported to MATLAB for advanced graphical processing.

The most important results obtained via the simulation (the torque and the speed of the SRM versus time are given in Fig.8. In this case, the currents are not plotted because due to the high frequency of the phase current's commutation the current pulses could not be distinguished at this time scale.

As it can be seen in Fig.8 the controlled SRM follows very strictly the imposed speed profile.

To be able to distinguish the phase current pulses, the waveforms were also plotted in Fig 9, only for a short simulation time (150 ms).

To more emphasize the details of the obtained phase current waveforms, zooms of the plotted quantities are given in the right side of the figures.

Upon the results given in Fig 9 it can be stated that the simulated phase current's waveforms are quite in accordance with the theoretically expected ones (Hennebergeer 2001). Also the inherent torque ripples of the motor can be clearly observed.

Using this advanced simulation tool, any SRM configuration, using any control strategy, can be effectively simulated on-line.

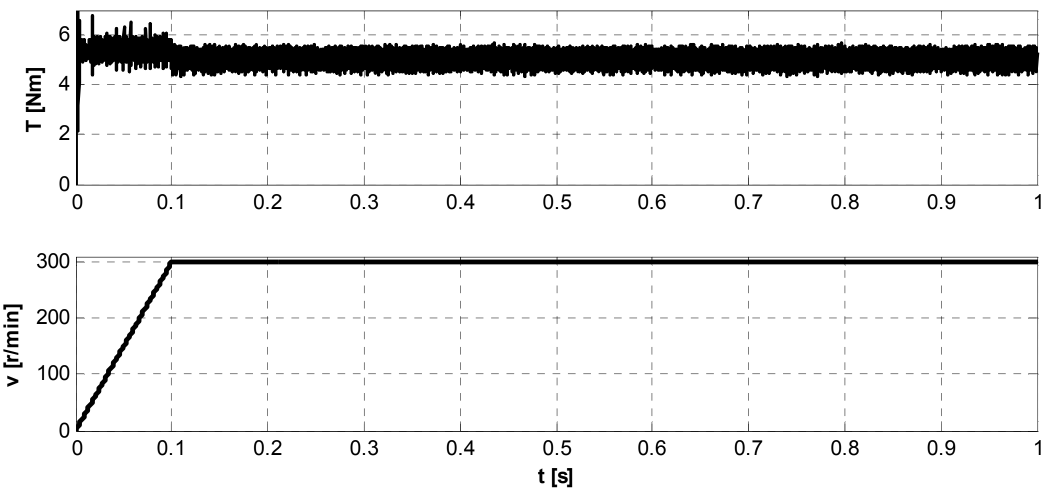


Figure 8: The results of a simulation

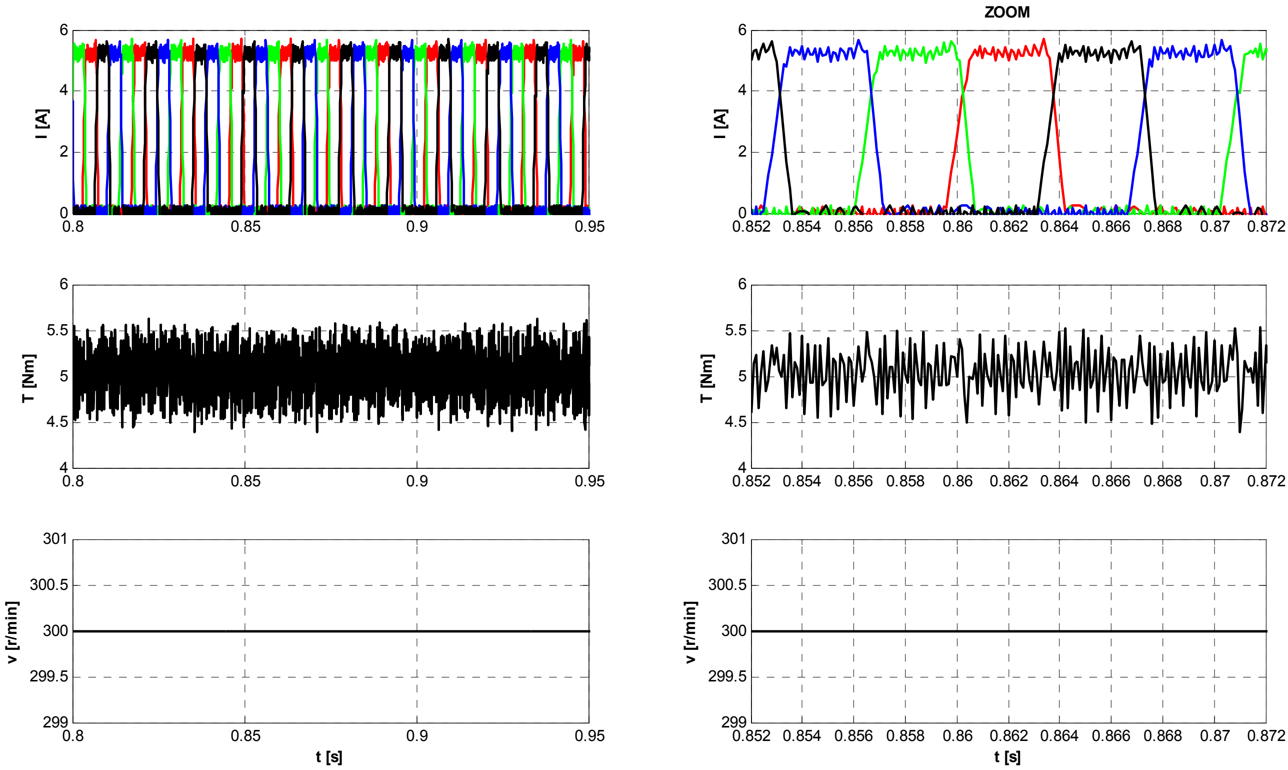


Figure 9: The details of the simulation's main results

CONCLUSIONS

In the paper an advanced simulation program, developed by the authors, of the SRM and its control system has been presented. It can be useful to show to the users how the SRM behaves in real time. Several simulations performed using this program proved its high credibility simulation qualities.

The main advantage of the proposed software tool is its capability to perform on-line simulations, offering the user the possibility to make real time changes even during the machine's simulation. By this, the influence of any parameter modification can be easily observed and studied.

The program can be successfully used both in research (for testing diverse SRM configurations and control strategies) and in higher education.

By minor extensions the SRM's the simulation program can be also used in remote (virtual) laboratories (Aldrich 2009).

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