Artificial Intelligence Based Electronic Control of Switched Reluctance Motors

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***Abstract* – Electronic control seems to be one of the best approaches in electrical machine's control. The paper presents an approach regarding this matter, along with the various particularities attached to it, and also an example to which it can be linked to.**

***Keywords:* Electronic control, electrical machines, switched reluctance machines, artificial intelligence, fuzzy controller.**

I. INTRODUCTION

Over the past years, with the fast growing importance of electronics and programming, more and more devices' attributes are being augmented in a simple and reliable manner. Applicative results and ideas are being submitted for various needs and many tests have shown just how important it is to use the proper control in electronic and electrical devices and how future applications have deep roots in today's innovative technologies, such as *artificial intelligence* (AI). Researchers working in this field developed sophisticated mathematical tools to solve specific problems, and other sub-symbolic approaches, such as fuzzy systems and evolutionary computations are now studied collectively by the emerging discipline of computational intelligence

Electronic control tends to solve most of the modern issues in terms of controlling complex systems and machines, and has proven to be a reliable method for increasing both efficiency in production and safety in other cases. For example nowadays the electronic stability control program is one of the most important features of a vehicle for keeping the desired trajectory without compromising safety or comfort, by reducing crash risk and enhancing the controllability of vehicles, furthermore preventing skidding and loss of control [1]. In electrical engineering, among the most common uses, different electrical machines benefit from fast acting control with the aid of a computer and electronics, such as the switched reluctance machines and stepper motors.

But with the fast advances in all fields, especially in terms of AI, today's applications can benefit even more, to a degree where constant supervising and maintenance may become a thing of the past [2]. Various techniques for implementing AI have been in this particular field and continued having more and more impact since the early beginnings, coupled with the practice of engineering in the past two decades [3]. In the industrial field, AI has been primarily used for diagnosis and control, with various other fields taking their own interests in this approach.

II. SURVEY ON ELECTRONIC CONTROL

Since the beginning of the use of electronics in the field of motor control, techniques applied have evolved and incorporated different principles and concepts in order to achieve a more efficient means of control.

In the field of the *switched reluctance motors* (SRM) several ideas arose in order to improve the classical control system of a SRM given in Fig. 1 [4].

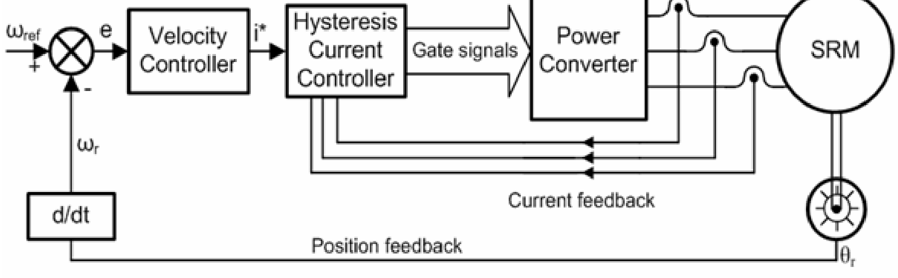

Fig. 1. Block schema of a SRM's classical control system [4]

The torque ripples of the motor can be reduced by using fuzzy techniques or adaptive intelligent speed control [5], [6], [7], [8]. In some cases, two phase angles were used as inputs, and the two adjacent phase currents were outputs and using torque error, it was possible to produce the desired torque value.

In other cases, using the *adaptive neuro-fuzzy inference system* (ANFIS) approach, the dynamic behavior of the motor has been improved, with no overshoot and a good rejection of impact load disturbance, thus leading to a better performance and higher robustness [9].

In [10] speed error was used as input and the reference current as output, which was modulated by subtracting the output of the fuzzy system from the sum of four phase currents computed at the previous sampling period. The modulated current was then fed into the phase windings of the motor through a converter, thus maintaining the speed constant and reducing the torque ripples. But due to the fact that both torque and speed are independent mechanical variables, in real life this technique might have drawbacks.

Other control techniques include using a neuro-fuzzy compensator such as in [11] where a compensating signal was added to the output of the proportional integral (PI) controller in the current regulated speed control loop. Although the practicality of the idea is questionable since the varying dynamic torque is difficult to measure.

In [12] and [13], the controller used is a sliding mode one, with the main advantage of having the motor parameters independent, but also the disadvantage of being sensitive to input noises and disturbances, due to the fact that it uses the derivative of the error in the sliding surface.

In the literature, there are several programming packages used in order to control the SRM, starting from Matlab / Simulink [14], C language [15], or C++ [16]. Spice has also been used in some cases, but due to the fact that it is mainly designed for electronic circuits, it shows few advantages [17].

III. THE CONTROL SYSTEM

First of all the main terms used for the description of the control system should be clarified.

a) a *signal* is one or more electrical or non-electrical parameter existing in the system.
b) a *property* of a signal is an information that characterizes the signal.
c) a *stimulus* is a sequence from a collection of input signals in which the values of the included signals are being represented.
d) a *command* is a sequence from a collection of output signals in which the values of the included signals are being represented.
Both stimuli and commands are sequences of groups of signals, and they do not describe the system's performance in time. For a system that evolves in time, the number of signals is variable, whereas for a non-evolving system it is a constant.
e) a *conclusion* is pair of stimulus-command signals, and it can be experimental or deduced.
f) the *experimental conclusion* contains only measured values.
g) the *deduced conclusion* is obtained by means of resemblance from more experimental conclusions.
h) a *constraint* is an imposed limit that makes the values of a property maintain between certain thresholds.
i) a *goal* is a state of the controlled element, such as the motor, defined by the user, which the controlled element should achieve.
j) a *trusted value* is a property of a conclusion, made from two numbers, one being the number of confirmation of a conclusion, and the other one being the number of invalidations.

The block scheme of the proposed control system is given in Fig. 2.

Next its main blocks are detailed in length.

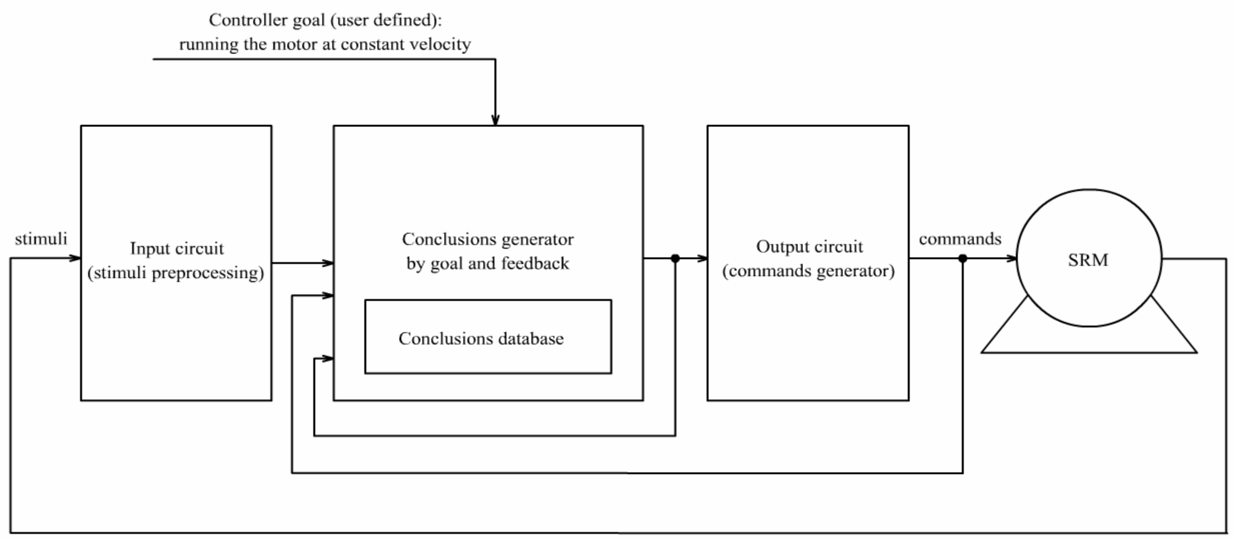

Fig. 2. Block schema of the proposed control system

A) The input block

The input circuit requires the measured phase currents, obtained from the current sensors, and the rotor position obtained by using a rotary incremental encoder and a counter. Therefore, the input circuit will receive the currents through the phases and the rotor angle. Since the direct control over the position (angle), speed and acceleration is preferred, the latter two will be needed to be calculated.

The block scheme of the input circuit is given in Fig. 3.

For a simplified view, a speed sequence will be computed as the difference between 2 consecutive samples of the angle, and the angle will be the difference between 2 consecutive speed samples (numerical approach of the derivatives). The angle given by the encoder can be used as a floating number (from 0 to 2π) or as an integral value (from 0 to 4095). The waveform of this signal will appear as a saw tooth towards the left or the right, depending on the rotation direction. The sign of the speed samples will determine the rotation direction (since they represent the difference between two of the angle samples). To obtain the speed, the sign of the angle cannot be correctly derived round the value of 0 (2π) due to the rollovers from 0 to 2π or below 0, so a rollover block is being used.

The speed and acceleration parameters are important from the behavioral point. For these measurements, the value which they tend to reach is important, and whether it oscillates with constant mean amplitude (sustained oscillation) or it is damped. A parameter is considered to be oscillating when it shows signs of several increases followed by decreases.

To determine whether a parameter is of a sinusoidal form, two consecutive derivations can be used. The result will be the same, but with a different sign.

For an oscillating load connected to the motor, it is important to compute the mean value for certain parameters, such as the speed, thereby eliminating the oscillating characteristics.

All these calculations derived from the rotor angle are obtained in the input circuit, including details about whether some values oscillate or vary between certain thresholds.

Thorough analysis of the input signals will help find the repetitive stimuli sequences. The user will only need to program the derived parameters that should be computed.

The monotonic variation detection block indicates whether the input signals varies and how; its detection is based on a set number of samples.

The variation limits indicate the minimum and the maximum values of a signal. The measuring process is done on a set number of samples.

The low-pass filter with programmable cut-off frequency block has the designation of eliminating the oscillations of the signal from its entry point. The cut-off frequency must be programmable in order to be adjustable to different cases.

The Sine Detection block checks whether a signal is of a sinusoidal type or not.

The AM Demodulation block (amplitude demodulator) is being used to obtain the signal envelope which indicates the oscillation type (sustained or damped).

If a complex processing of the stimuli is required, the input system will have the ability to learn and how to find and keep the limits for the parameters and the relationships between them.

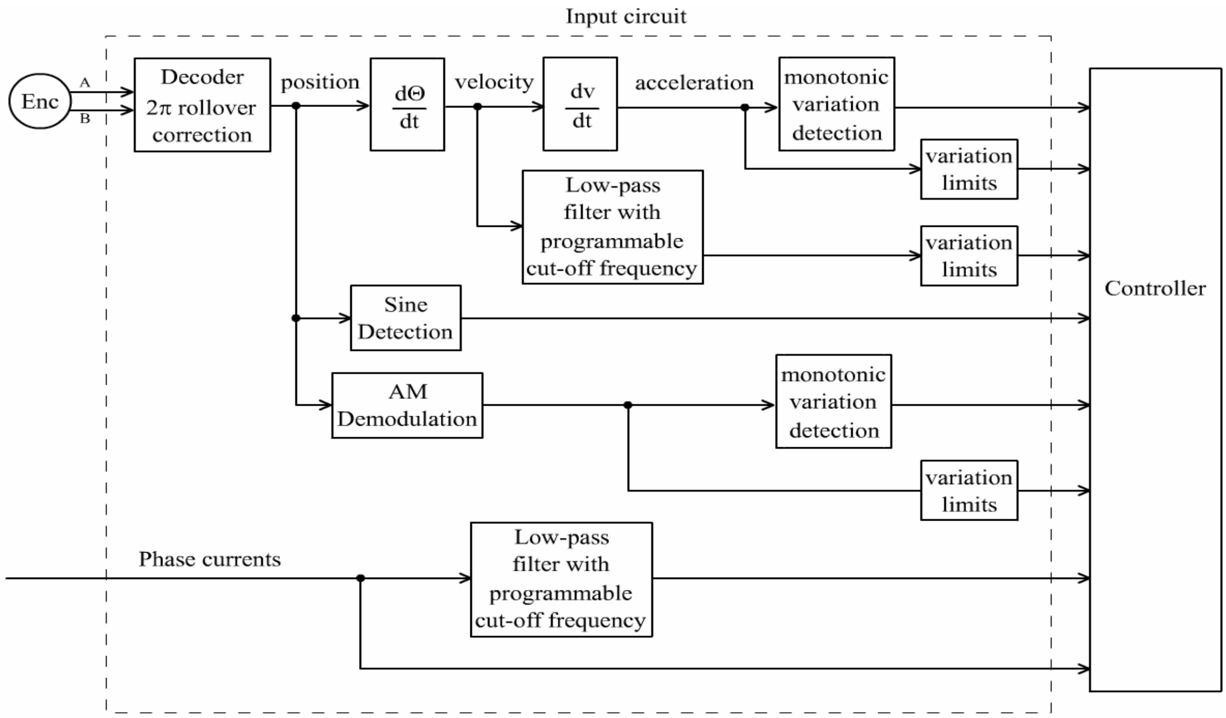

Fig. 3. Block schema of the input circuit

B) The control block

This particular block has the purpose of associating different commands with processed stimuli, in order to generate conclusions. The control circuit is based on two processes: *experimenting* and controlling. The process of experimenting has the purpose of creating conclusions, and in the controlling process, the motor is being controlled using the conclusions generated in the previous step, the experimenting one. For a typical functioning, the control circuit starts with the experimenting process, and then continues with the controlling one.

Due to the possibility of occurrence of events unknown to the control circuit or the input circuit, the controlling process must allow or not allow (depending on the user choices) its continuing functioning in order to experiment with new stimuli. After the experimentation, the controlling process can resume.

In order to create an efficient database of conclusions, the user has the ability to ask the control circuit to achieve an easier goal at first and then a harder one (perhaps even the final goal).

This operating type would resemble a control loop generation. For example, a first loop could adjust the current, and the second one could adjust the position (powering the phases according to the rotor position angle).

Therefore, the first goal would be to obtain a certain phase current, an experiment in which the control circuit would have to obtain relationships (conclusions) between the generated commands and the stimuli obtained as a reaction.

The increase rate of the speed of the current will depend on the rotor angle. This experiment can be divided into two parts, each with a desired goal. One of them could be used to determine how fast the current speed rises in the aligned position and the other one in the unaligned position (here one can use constraints to limit the phase current).

Dividing the experiments into sub-experiments can simplify the contents of the database (an intelligent control circuit should be able to do these divisions by itself, corresponding to the main goal imposed by the user).

The experimenting process starts by generating a list of several random commands (or programmed by the user) which should be tried out.

The next step is to record and process the measured stimuli.

As an empiric rule, a command is being experimented upon until the results are identical (the user must limit the maximum number of tries).

The obtained conclusions are experimental conclusions. They must always be confirmed. Instead of infirming an experimental conclusion, a new experimental conclusion will be generated upon the values measured.

Due to the fact that the measurements are made upon sequences (stimuli and conclusions), the control circuit will have a large database, made out of experimental conclusions. Their number can be reduced by replacing them with conclusions which contain intervals instead of discrete values. The replacing of conclusions based upon discrete values, with ones based upon intervals can be made only after the experimenting and confirmation of the whole interval.

From at least two experimental conclusions that contain properties with identical values, the controller infers a *deduced conclusion*.

Each time a deduced conclusion is generated, except the first deduction, the ones being generated are already in the database. Instead of overwriting these conclusions, the number for the trusted value will be increased. There are cases in which a deduced conclusion, with a large number of confirmations, can be invalidated by an experimental conclusion.

Therefore, it is useful to have a property that indicates whether a deduced conclusion has been invalidated previously through an experimental conclusion.

Due to the fact that the deduced conclusions have an 'exception filter' type behavior, these are the main information on which the control circuit relies upon in the controlling process.

The experimenting process is an iterative process consisted of two steps: measuring and concluding. The duration of the measuring step must be chosen by the user in such a way that a steady state can be achieved, or in order to contain the whole transient state desired.

The command must be generated shortly after the measuring step starts, in order to have at the user disposal, the 't_0 moment', when the command starts. Hence, the input circuit will have all the necessary values before the command is generated and will be able to determine the effect of the command.

The measured values must be processed so that they contain as many properties as possible (such as the increase/decrease rate, whether it has a harmonic oscillation etc). Stimuli that can describe certain intervals of time can be generated for the measured values.

After the measurement step, in the concluding step, the processed stimuli, combined with generated command, will lead to an experimental conclusion. The values of the properties of the created conclusion are being compared, one by one, with the values of the properties of each deduced conclusion, therefore leading to a new deduced conclusion, as a confirmation or invalidation.

Also, still in the concluding step, a logical deduction can be attempted, using the deduced conclusions. A logical deduction is therefore the adding of a new hierarchy level to the conclusions.

The logical deduction generates deduced conclusions for a certain level, by combining results with other deduced conclusions from the previous level. For example, a hierarchy level can be represented by the firing angles, obtained from a generated conclusion for each phase (found on a previous level).

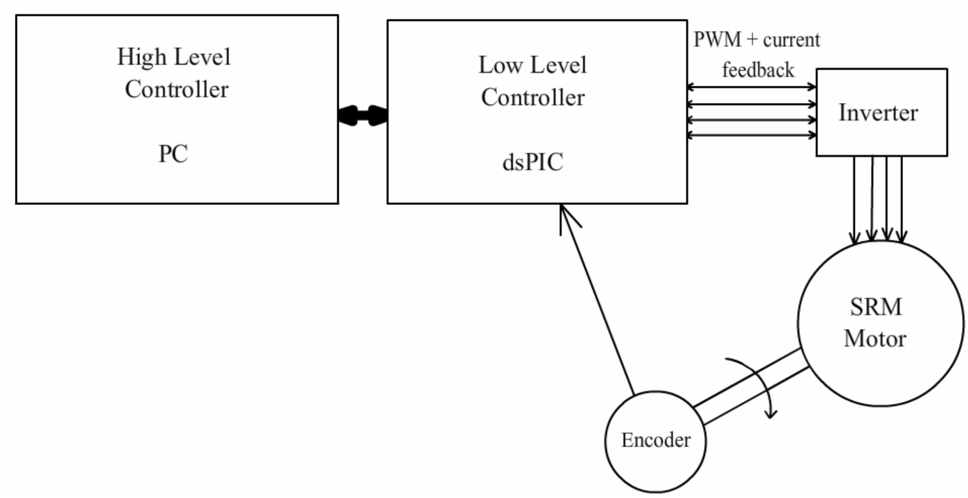

Fig.5. The hardware implementation scheme

C) The output (command) block

For a 6 / 4 stator/rotor pole configuration of the SRM, the input circuit will have 3 outputs. The commands sent to the inverter need to be simple, and have as few properties as possible. A command output will have 3 properties, for example: the on/off state, the filling factor for the PWM signal generated and the duration of that command.

This duration is mainly used in experiments in order to observe the stimuli received from the motor. While functioning, this property will not be used, because any phase of the motor is turned on according to the position.

Therefore, the output circuit will have 3 PWM generators, each being controlled by the corresponding signals linked to a command [18].

IV THE CONTROL SYSTEM'S IMPLEMENTATION

The designed electronic control system will be implemented on the hardware system given in Fig. 5.

The logical schema of the proposed control system is shown in Fig. 6.

The normal working regime typically includes 5 goals:

a) Current adjusting: a command is being generated in such a way that the measured value of the current is the desired one
b) Determining the phase that needs powering and the correspondence between the phases and the movement or lack of movement (in the aligned state) of the rotor.
c) Determining the phase successions: the absolute value of the speed has to be above 0, for a time period longer than the duration of the damped oscillations resulted from powering a single phase.
d) Random choosing of a phase with which the angle counter starts, which is used for the rotor position.

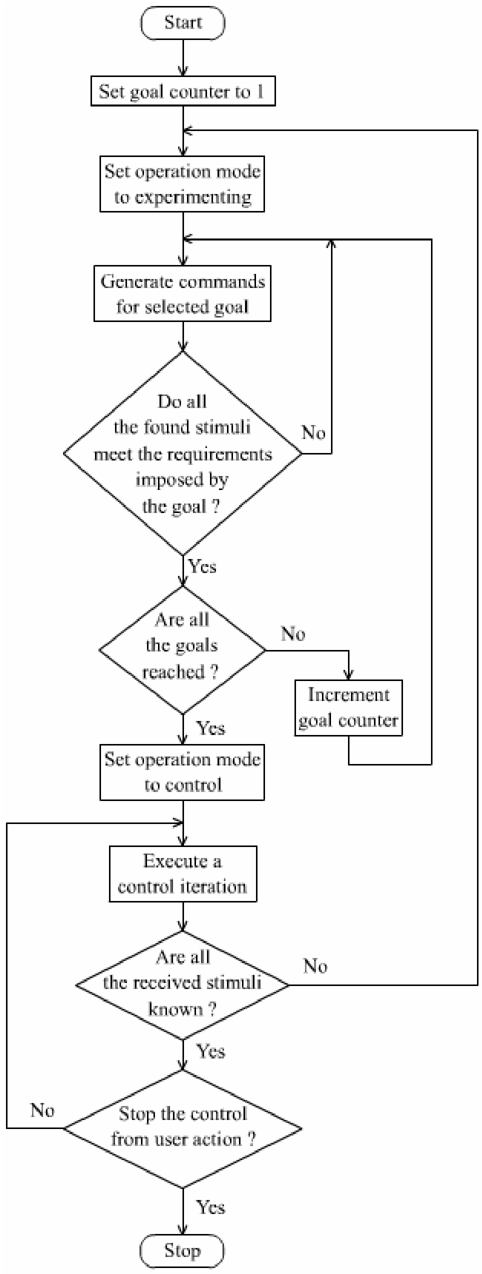

Fig. 6. The control algorithm

e) Using the goal from d), the command angles for which the absolute values of the speed are more than the values at goal c), are being determined

Once these primary goals are fulfilled, the controlling process can begin.

V. CONCLUSIONS

A theoretical model supporting the AI-based control the SRM has been presented, and the underlying ideas behind the concept have been explained in details.

The model can be used in simulation programs where it showed potential and future studies involve comparative results between more than one motor and various techniques that can perfect the AI-based command.

A hardware setup is under construction in order to properly implement the AI techniques for more than one motor.

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