Speed Control and Torque Ripple Minimization of Switch Reluctance Motors using Genetic Algorithms

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Abstract: - Switched Reluctance (SR) drive technology is a serious contender for replacing the existing technologies, because of its technical and economic advantages. If some remaining problems like excessive torque ripple could be resolved through intelligent control, it would enjoy enormous comparative advantages for grabbing significant market share. In this paper, the idea of Genetic Algorithm is generalized in order to control of the speed of Switch Reluctance Motor (SRM). Our proposed solution, can achieve very robust and satisfactory performance.

Key-Words: - SR Motor - Torque Ripple - Speed Control- Genetic Algorithms

1 Introduction

A Switched Reluctance (SR) motor is a rotating electric machine where both stator and rotor have salient poles. The stator winding is comprised of a set of coils, each of which is wound on one pole. SR motors differ in the number of phases wound on the stator. Each of them has a certain number of suitable combinations of stator and rotor poles. The motor is excited by a sequence of current pulses applied at each phase. The individual phases are consequently excited, forcing the motor to rotate. The current pulses need to be applied to the respective phase at the exact rotor position relative to the excited phase. The inductance profile of SR motors is triangular shaped, with maximum inductance when it is in an aligned position and minimum inductance when unaligned. When the voltage is applied to the stator phase, the motor creates torque in the direction of increasing inductance. When the phase is energized in its minimum inductance position, the rotor moves to the forthcoming position of maximal inductance. The profile of the phase current together with the magnetization characteristics defines the generated torque and thus the speed of the motor.

The control of the SRM is not an easy task. The motor's double salient structure makes its magnetic characteristics highly nonlinear. The motor flux linkage appears to be a nonlinear function of stator currents as well as rotor position, as does the generated electric torque. Apart from the complexity of the model, the SRM should be operated in a continuous phase-to-phase switching mode for proper motor control. The torque ripple and noise as a result of this commutation are the other two awkward issues which have to be tackled. All these make the control of the SRM a tough challenging. This paper focuses on solving these complex control problems via a novel approach: using of Genetic Algorithm Based PID Controller.

In Section 2 electromagnetic and mechanical equations of SRM is described and their block diagrams, which is used in simulation, is presented. Then in Section 3 the structure of Genetic Algorithm (GA) is explained. Simulation results are presented in Section 4. Finally, the conclusion is presented in Section 5.

2 Mathematical Model of SR Motors

The most important properties of the SRMs are their nonlinear angular positioning parameters and nonlinear magnetic characteristics. The first group contains: winding inductance, produced torque and Back EMF, which depend on the rotor angle. On the other hand magnetic saturation causes the nonlinear magnetic characteristics. The main principle for SRMs modeling is based on the Magnetic-position curve, which shows the linking flux versus current in different rotor angles. The appendix contains the proper model parameters for a three phase SRM with six poles on the stator and four poles on the rotor, which is used in this paper. The complete mathematical model for the SRM including the magnetic and electrical equations would be achieved with a whole considering of the magnetic saturation. The voltage equation in the motor phases is

$$V_j = Ri_j + \frac{d\lambda_j(\theta, i_j)}{dt} + \frac{d\lambda_l}{dt} \tag{1}$$

In which V_j stands for jth phase winding voltage, i_j for jth phase current, λ_j for linking flux, R for the ohmic resistance of phase winding and λ_l stands for leaky linking flux. The linking coupling between adjacent windings has been neglected. Using the chain derivation formula yields

$$V_j = Ri_j + \frac{\partial\lambda_j(\theta, i_j)}{\partial i_j} \cdot \frac{di_j}{dt} + \frac{\partial\lambda_j(\theta, i_j)}{\partial\theta} \cdot \frac{\partial\theta}{dt} + \frac{d\lambda_l}{dt} \tag{2}$$

$\partial\lambda_j(\theta,i_j)/\partial i_j$ is the increasing inductance(L_{inc}) and $\partial\lambda_j(\theta,i_j)/\partial\theta$ is the back emf coefficient(C_ω) both of which are dependent on current and rotor angular position. Considering L_k as the flux leakage

$$\frac{d\lambda_l}{dt} = L_k \cdot \frac{di_j}{dt} \tag{3}$$

Replacing symbols in this equation gives

$$V_j = Ri_j + L_{inc} \cdot \frac{di_j}{dt} + C_\omega \cdot \omega + L_k \cdot \frac{di_j}{dt} \tag{4}$$

The produced torque on the shaft satisfies the following equation

$$T(i,\theta) = \sum_{j=1}^{3} \left(\frac{\partial W'}{\partial\theta}\right)_{i_j = cte} \tag{5}$$

In which co-energy is defined as follows

$$W'(i_j,\theta) = \int_0^{i_j} \lambda_j(i_j,\theta) \tag{6}$$

And finally the mechanical equations will be

$$\omega = \frac{d\theta}{dt} \tag{7}$$

$$\frac{d\omega}{dt} = \frac{1}{J} \cdot \left(T(i,\theta) - T_L - B\cdot\omega\right) \tag{8}$$

in which, w stands for angular velocity, t_l for load torque, B for friction coefficient, and J for the moment of inertia. The complete motor model, which is used in the simulation, is as the figure1.

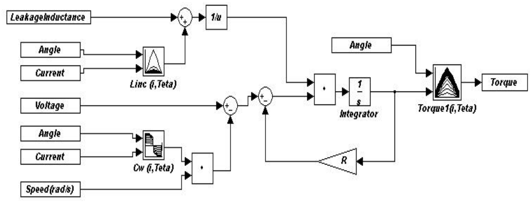


Figure1- Electromagnetic model of each phase of SRM

The mechanical part of the model is depicted in the figure 2.

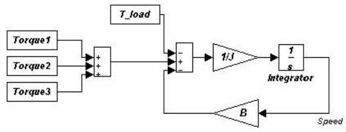


Figure2- Mechanical model of SRM

3 Genetic Algorithms

The genetic Algorithm is based on the mechanics of natural selection and natural genetics the combines the notion of survival of the fittest, random and yet structured research and parallel evaluation of the nods in the search space. In GA, a result of problem is represented by a chromosome which usually is encoded into a binary bit string in computer programming. Many chromosomes make up of a population evolves [9]. According to the principle of survival of fittest, the population reproduces, crossover and mutates, and produce a new generation. Those processes are done again and again until the fittest chromosome is found. So the result of the problem is got. In GA, there is several working principle:

Encoding: The process in which the parameters are translated in to binary bit string is encoding. When encoding is finished, the population is formed and evolution can be done.

Fitness: Function: In the current generation, each of strings is decoded to be its corresponding actual parameters. Then these parameters are sent to a judgment machine, which yields a measure of the solution's quality evaluated with some objective functions and assigned individually with fitness value. This judgment machine is usually called fitness function $f(x)$. To a chromosome Xi, its fitness value is $fitness[i] = f(Xi)$.

Reproduction: According to fitness, the fitter the chromosome is, the more it is reproduced. The reproduce number of a chromosome is determined by an equation as follow:

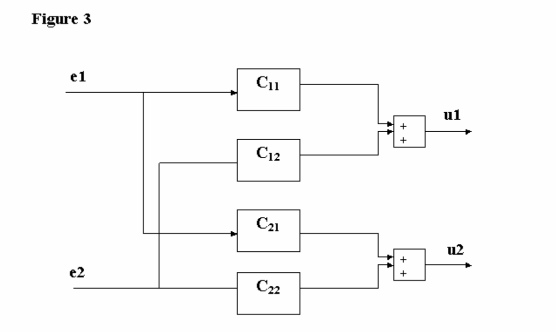
$$\text{The Choromosome Xi's reproduction number} = \frac{Fitness[i]}{\sum_{i}^{N} Fitness[i]} * N \quad (9)$$

Where N .is the number of all the chromosome. Thus, through reproduction operator, the chromosomes with high fitness are converted and the chromosomes with low fitness are deleted. This is survival of fitness.

Crossover: According to a certain proportion Pc, randomly selected two chromosomes from the population, randomly selected the position in which crossover is done, and the two chromosomes exchange a part of their bit string. So new gene combinations are produced and new chromosomes are produced. The evolution is doing on varying chromosomes, and the fitness of chromosomes is improved. The value of Pm usually ranges from 0.25 to 1.

Mutation: According to certain proportion Pm, randomly selected a chromosome, randomly selected a position of the chromosome. The number in the position is changed. That is 1 to 0, 0 to 1. Only depending on mutation operator can not get the optimization of the problem, but it can bring random value and make population cover the whole solving space. So we can get the global optimization. The value of Pm ranges from 0.01 to 0.3 From above introduction, we can see, GA is a search algorithm that continuously repeats these steps: Reproduction, Crossover, and mutation, then makes the new generation fitter than the old generation, until the requirements are completed. So in this paper GAs are used to optimized PID parameters K_p, K_i and K_d. Firs, K_p, K_i and K_d are encoded to 16 bits string. The length total chromosome is 48 bits. It is supposed that K_p, K_i and K_d are bounded in the closed intervals $[0\ K_{pm}]$, $[0\ K_{im}]$ and $[0\ K_{dm}]$ respectively. The decimal values of their corresponding binary strings are linearly related to their to range boundaries K_{pm}, K_{im} and K_{dm} Secondly, according to GAs operation: evaluation, crossover, mutation, K_p, K_i and K_d are optimized. After a prespecified number of generations, K_p, K_i and K_d are suitable enough to make system have good steady-state and dynamic performance.

GAs- consists of Encoding, Evolution, and Decoding sub-system [8]. GAs generates entire population of points (typically fixed-length chromosome like character strings) each with associated fitness value, test each point independently, and combines qualities from existing points to form a new population can be the fuzzy membership function parameters. The fitness value is computed using the information concerning the quality of the solution the produced by members of the population (objective function value). This adaptive evolutionary leaning process relates to the evolutionary selection procedure of genetic chromosomes. Genetic algorithms simulate this process, over generations, and identifies the most suitable candidate, i.e. gain the best membership function parameters. The Encoding sub-system uses a concatenated, mapped, using binary coding. Gaussion membership function is used for the fuzzy control module, two parameters, namely mean and standard deviation, control the Gaussion membership function. The value of each parameter can be encoded as a six bit binary number (for example, 000111).



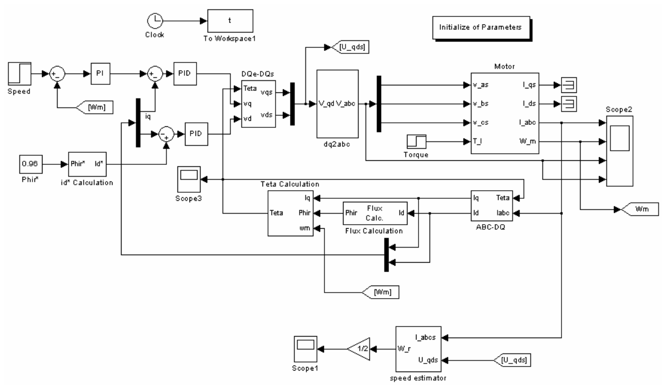


Figure3- the abstract structure of proposed method

4 Simulation Results

The control method for the SRMs is chosen based on some parameters including: usage, performance and speed range. Figure 4 shows the block diagram of the control system.

In this structure, the speed controller produces the demanded motor torque in order to tracking the speed set point, in spite of the existing torque disturbances. This controller could be based on one of the PID, fuzzy or CBBEL methods. The commutator's duty is to translate the demanded torque into the needed phase current, which enters the current controller. On the other hand, the current controller's duty is to track the needed current for each phase.

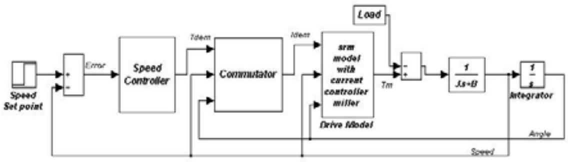


Figure4- The Control system structure

In the simulations, our purposes were to reduce the steady state error of the speed response, and torque ripple minimization. The results are represented in figures 5 and 6. It could be seen that the torque ripple is small, and steady state error of the system is zero.

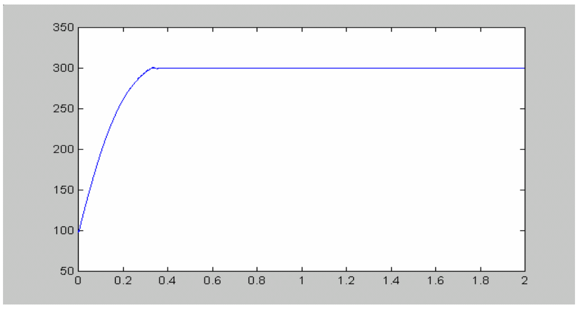


Fig 5a: speed of switch reluctance motor

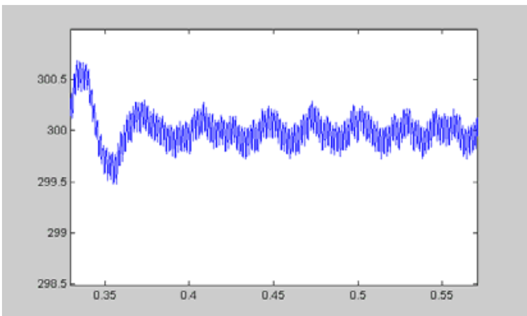


Fig 5b: Speed ripple of SR motor

5 CONCLUSION

In this paper, we showed the applicability of Genetic Algorithm to the fulfillment of complex tasks of adaptive set point tracking of a SR motor. Simulation results showed that our proposed method, which is biologically motivated, can track a set point, and the performance of the system is very well under this controller.

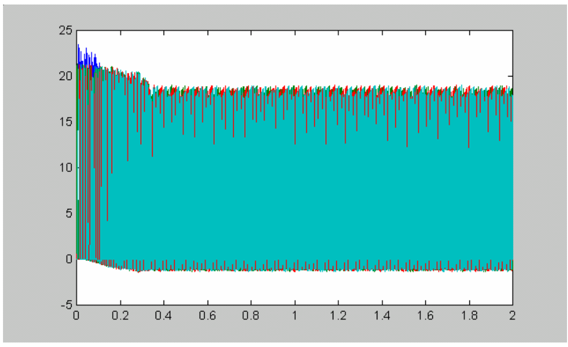


Fig 6: Torque of switch reluctance motor

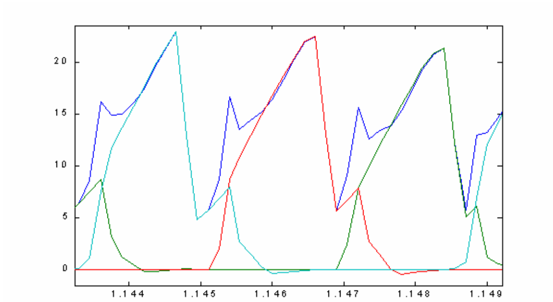


Fig 7: Currents of switch reluctance motor

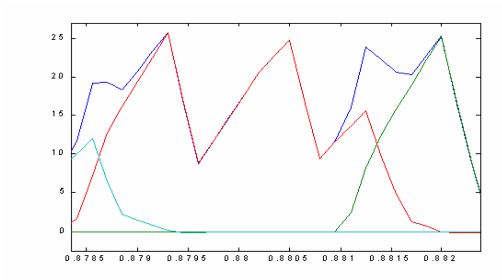


Fig. 8: Order of harmonics in terms of frequency

APPENDIX

The SRM considered in the paper, which is based on our first design in a project, intended to study the feasibility of using this technology to set up a new production line in Iran, has the following data and parameters:

P_N =4 kW,	Nominal Power
Ω_N =3000 rpm,	Nominal Speed
V_N =460 V,	V_{dc}
I_{max}=20 A,	Maximum Phase Current
N_s = 6,	Number of stator poles
N_r = 4,	Number of rotor poles
L_u =6.5 mh,	Unaligned Inductance (minimum)
L_a =126.3 mh,	Aligned Inductance (maximum)
β_s =38 deg,	Angle of stator poles
β_r =46 deg,	Angle of rotor poles

B=0.004*Nms/rad*, friction Coefficient

J=0.005 kgm^2 */rad,* Momentum of Inertia

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