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Switched Reluctance Motor Drives Speed Control Using Optimized PID Controller

***Abstract**. The switched reluctance motor (SRM) has turned out to be an outstanding resolution for a various appliances. The modern invents of SRM grant consumers to yield advantage of small starting currents , better efficiency and robust structure that illustrates this kind of motor. This article aims at analyzing and modeling the switched reluctance motor speed controller utilizing a Proportional Integral derivative (PID) controller. The non-linear character of the SRM magnetic properties is currently fetched into attention for modeling . These nonlinearities of the switched reluctance machines attain the traditional PID controller an inadequate selection for appliance where high dynamic performance drive is required. Genetic Algorithm (GA) is manipulated to adjust the PID coefficients for the SRM drive. The consequences achieved indicates that the utilization of these established algorithms controller enhances the transient and steady state performances.*

Streszczenie.** Silnik z przełączaną reluktancją (SRM) okazał się być znakomitym rozwiązaniem dla różnych urządzeń. Nowoczesne wynalazki SRM dają konsumentom korzyści w postaci małych prądów rozruchowych, lepszej wydajności i solidnej konstrukcji, która ilustruje ten rodzaj silnika. Celem artykułu jest analiza i modelowanie regulatora prędkości silnika z przełączaną reluktancją, wykorzystującego regulator proporcjonalno-całkująco-pochodny (PID). Obecnie zwraca się uwagę na nieliniowy charakter właściwości magnetycznych SRM. Te nieliniowości przełączanych maszyn reluktancyjnych powodują, że tradycyjny regulator PID jest nieodpowiednim wyborem dla urządzeń, w których wymagana jest wysoka dynamika napędu. Algorytm genetyczny (GA) jest manipulowany w celu dostosowania współczynników PID dla napędu SRM. Uzyskane konsekwencje wskazują, że wykorzystanie tych ustalonych algorytmów kontrolera poprawia wydajność w stanie nieustalonym i ustalonym.* (Sterowanie prędkością silników z przełączaną reluktancją za pomocą zoptymalizowanego regulatora PID***)

Keywords: Switched reluctance motor (SRM) , Speed control , PID Controllers , Genetic algorithm (GA), Integral Square Error (ISE).
Słowa kluczowe: silnik reluktancyjny, sterowanie szybkością, sterownik PID.

Introduction

In the last years, extensive work employed in utilizing SRM recommends for variable-speed appliances for example electric cars or engineering drives. This motor is a specific kind of the AC motor category. It can deliver numerous useful characteristics specifically the fault-tolerant operation , robust construction and less component compared with the other AC motor drive types . [1,2,3]. Electric motors are used in electric vehicles for many features such as: they represent clean and safe alternatives compared with the internal combustion engine to preserve the environment as well as the high prices of fuel and the scarcity of its presence in nature .The subject is therefore oriented to special and exceptional strategies to address the process of replacing traditional cars with electric ones in terms of efficiency, cost, energy and its impact on the electrical network[3,4]. Dynamic performances can be improved by introducing feedback control. The basic Functional block diagram of a switched reluctance motor drive system is explained in Fig.1[5].

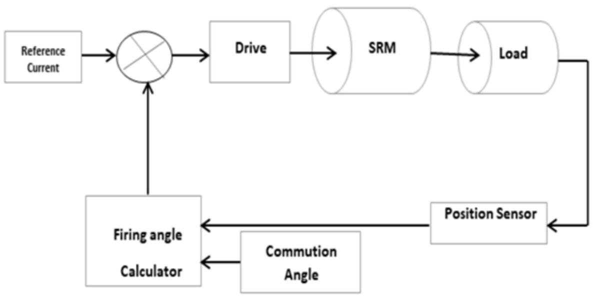


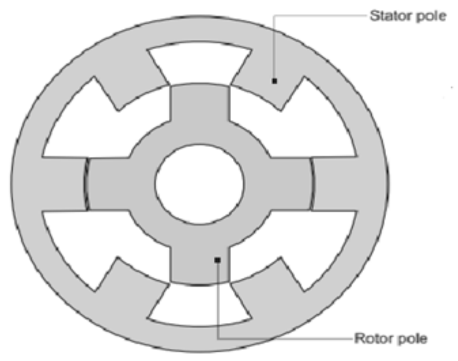
Fig.1. Feedback control system block scheme of the SRM drive

A inclusive published study has been performed for SRM modeling, analysis, control and simulation. The traditional controller scheme (i.e PID) is constructed on the precise model of the process to be controlled which might frequently be unspecified, inaccurate, complicated and nonlinear. The PID controller has scheduled coefficients. It is definitely the very usually utilized control algorithm currently. The major motivation for utilizing it till present is its comparatively simple configuration which can be simply comprehended and realized in actual world industrial applications.

In [6] the switched reluctance motor with quasi-linear model is investigated. The AC small signal for magnetization characteristics of switched reluctance motor is developed on MATALB software program. The simulation outcomes demonstrate that fuzzy parameters self-adjusting PID controller are able to enhance steady state and dynamic state operation of the drive scheme and give satisfactory robustness. In [7] adaptive pulse width modulation speed controller method for SRM using artificial neural network (ANN) is presented . This technique develops a rotor speed controller algorithm which has effective estimating capability and speedily convergence property. In [8] the procedure of constructing dynamic magnetization simulation model of SRM is established. Two enhanced PID controllers instituted on fuzzy set method simulated in MATALB software program. The simulation outcomes show that proposed fuzzy logic method to SRM drive system can clearly enhance the dynamic operations of the system. In [9] The linear PI controller is intended based on linear system analysis using frequency response method of the boost DC-DC converter. The simulated outcomes present that the just switch utilized in this type of DC-DC converter is switched on at (zero current state) and switched off at (zero voltage state). It also keeps a stable speed response for any applied load changes. In [10] a simple fractional order proportional integral (FOPI) controller is intended for the control of rotor speed of SRM motor drive for high speed applications. A simulation analysis is perceived the significances of time response (peak overshoot , settling time rise time,) for FOPI beneficial to the other controllers. The (FOPI) controller is a suitable selection for a SRM drive for high speed applications with decreased torque ripple. In [11] organizes a photovoltaic attended water pumping system design involving a SRM drive system . The SRM operates in a rotor speed range which is controlled by varying the source voltage which fits to the central-point power converter unit. The suggested schematic showing to dynamically special conditions is simulated and modeled by employing MATLAB/SIMULINK environment. In [12] a robust artificial neural network(ANN) speed controller for SRM drive represented with both load perturbation and parameter variants. The simulation outcomes validate that the planned controller has higher capability for parameter variants and robustness besides external perturbation. In [13] a novel scheme for converter-based speed response control optimization for SRM drive presented . The potential advantages of matrix converter are variable current profile , minimal loss and lowest switching frequency. In [14] modern current controller is intended founded on a revision of a proportional-derivative (PD) controller. From the analysis carried out on a power drive, it was realized that some control approaches can deliver a good transient response while maintaining low computational prerequisites. This is significant for reliable drive operation and minimization the torque ripple. In [15] metaheuristic method with linear quadratic with integral (LQI) and PID utilized in the SRM drive system is proposed . Also, it shows a procedure for selecting Q and R parameters using the genetic algorithm(GA). Outcomes observed that the (LQI + GA) reported improvement in relative computational effort and a faster dynamic response than the typical LQI and PID controllers.

The switched reluctance motor drive has now reached a level of maturity that allows it to be used in industry as an efficient brushless drive with cost advantages. The aim of this study manuscript is to illustrate that 6/4 SRM motor utilizing the traditional PID controller. Its coefficients values can be attained and adjusted by genetic algorithm which provides improved results with starting and set point tracking.

a)



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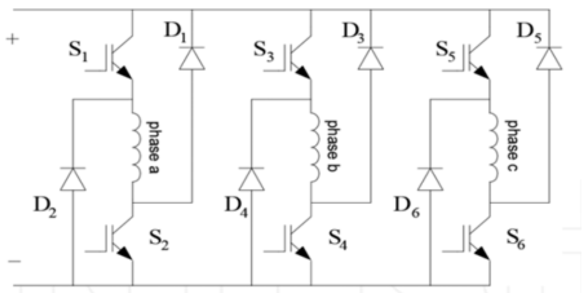


Fig. 2. a) Cross section view of switched reluctance machine b) Power converter[5].

Operation of 6/4 Switched Reluctance Motor

Fig . 2 illustrates the machine Cross section view and converter arrangement of a three-phase 6/4 SRM. The - phase 6/4 SRM respected within this manuscript contains 4 salient poles on the rotor and 6 salient poles on the stator. The clustered stator windings are dispersed as three diametrically equal sets coupled in series to make the motor phases. The rotor has no magnets and winding so that it be able to constructed to have low inertia. The stator windings are separately supplied by three arms of an unipolar power converter. Every converter phase involves two transistor and two free-wheeling diodes accepting energy revival to the dc source side. The working of a SRM is described by its magnetization characteristic which signifies the machine flux linkage(λ) as a nonlinear function of the rotor angular position (ɵ) and the stator current(I)[1,5].

The magnetic flux have a tendency to arise through lowly reluctance path. Consequently the rotor continuous position to bring into line beside the least reluctance path. This is the basic operating theory of switched reluctance motor SRM. Therefore when stator phase winding is energized the rotor align along this face as presented in fig. 3 [16].

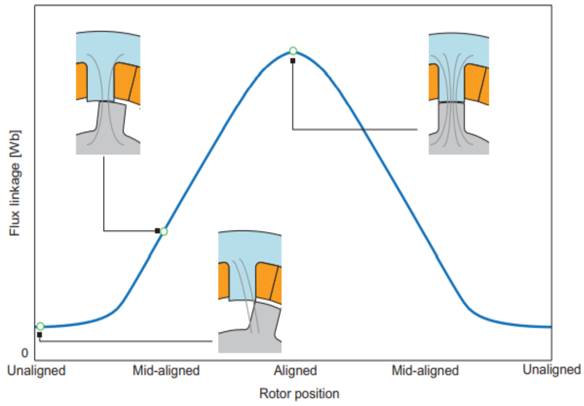


Fig.3. Phase flux linkage profile under constant current excitation for one electrical cycle[16].

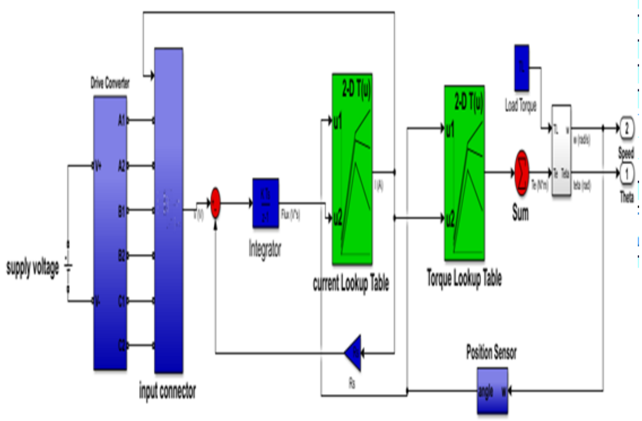


Fig.4. Simulink scheme characterizing the switched reluctance motor model.

Modeling and simulation of the SRM

One of the significant features in any control system strategy is to obtain a suitable precise model which characterizes the process for numerous operation conditions. Therefore. to appropriately assess the switched reluctance motor drive performance and the use of several control methods, a dependable SRM drive system model is necessitated. The SRM model must characterize the static and dynamic performance with satisfactory precision. [1,10]. The modeling of the SRM drive system is vital to analyzing the drive system dynamic characteristics . Fig.4 demonstrates a Simulink scheme characterizing a 6/4 SRM model in the current-controlled drive mode. The SRM is stand for by a nonlinear differential equations model that stands into description the magnetization characteristic of the SRM motor so as to prepare accurate characteristics. The magnetization of the SRM can be attained by finite-element analysis (FEA) if the SRM features and construction are identified or by measurements [17].

In this manuscript, we selected an 6/4 SRM (7) KW, the descriptions of which were reviewed and highlighted in [1,18]. Fig. 4 illustrates a full MATLAB/SIMULINK/SPS model of the 6/4 SRM . The 6/4 SRM motor is modeled for the mechanical section by the movement equation(Newton's law) and for the electric section by its voltage equations(Kirchhoff's law).The voltage delivered by the power converter is utilized to the three phases of the 6/4 SRM. The flux linkage in individually phase is computed by integrating the phase voltage difference the (R*I) reduction in the windings that given below :

(1) $$V = R_s i + \frac{d\lambda(\theta,i)}{dt}$$

With the flux linkage and the rotor position as inputs data , the current Lookup table yields the resultant current for each phase . With this resultant current and the actual position of the rotor, the torque established by every stage can be computed by the respecting equation :

(2) $$T_e(\theta, i) = \frac{\partial w\,(i,\theta)}{\partial \theta}$$

where W- magnetic co-energy computed based on equation as:

(3) $$W = \int \lambda(\theta, i)\,di$$

To accelerate the simulation process in Simulink model , the electromagnetic torque characteristic is pre-computed and kept in a lookup table (torque lookup table in figure 4).The values for current lookup table and torque lookup table are generated from the magnetization characteristic table which is specified in fig.5. The magnetization characteristic table includes the machine's flux corresponding to different rotor angles and stator current .

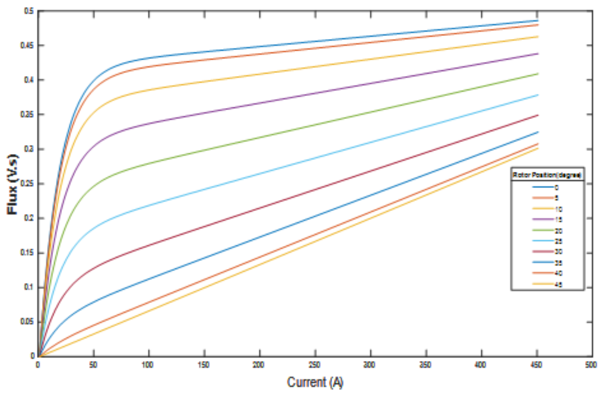


Fig.5. 6/4 SRM magnetization curves .

Fig. 6 illustrates the two lookup tables current lookup table and voltage lookup table used in the 6/4 SRM model.
The electromagnetic torques generated by the three phases are then summed up together to deliver the total electromagnetic torque produced on the rotor shaft of the motor. The mechanical part of the motor model and load is governed by the movement equation as below :

(4) $$T_e = Bw + j\frac{dw}{dt} + T_L$$

where: $J -$ is the total inertia; $B -$the total friction coefficient, $TL -$ is the load torque.

a)

b)

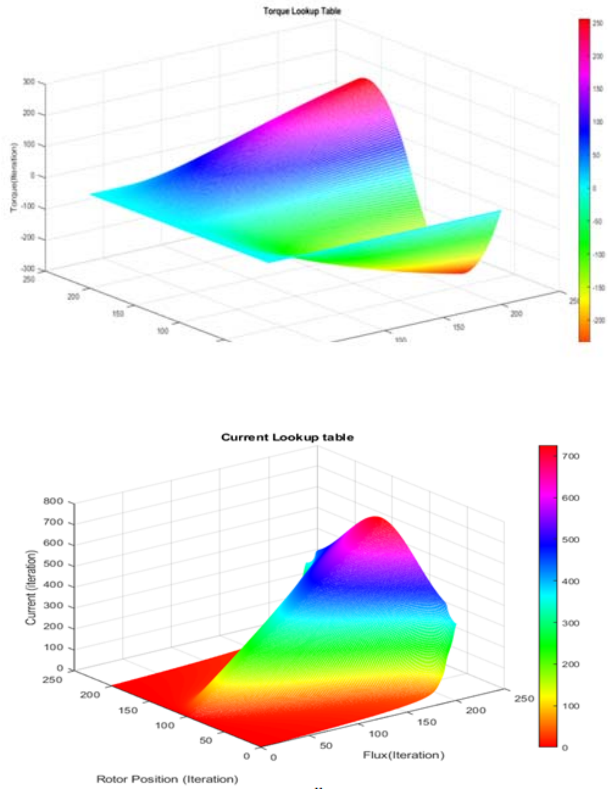


Fig. 6. Lookup tables in the SRM Simulink scheme. (a) torque(Te) versus current(I) and rotor position(θ) (b) Current(I) versus flux(λ) and rotor position(θ).

Control approach

Control implements a general responsibility in computerization and engineering developments. The usage of PID turn out to be global in essentially complex and nonlinear industrial practices that require exact control in system dynamic performance. The error signal is related to (Proportional(P), integral(I), derivative(D)) in a PID controller, where every portion provides some improvements for the complete system dynamic response.
The transfer function concerning the PID controller can be specified as [19,20]:.

(5) $$C(z) = P + IT_s\frac{1}{z-1} + D\frac{N}{1+NT_s\frac{1}{z-1}}$$

where: Ts − sampling time. P − Proportional gain. Integral gain. D − Derivative gain. N − filter coefficient.

intention PID controller for SRM drive system requirements to find accurate values of (P,I,D,N) coefficients . On the other hand, analytically finding the coefficients which approves the optimum operating for the control system with process is a problematic mission. Utilizing manual methods could cause deficiency of time and prime to scratch if it's worked on the real equipment's .

Genetic algorithm for PID controller design

Genetic algorithm (GA) is the typical kind of evolutionary algorithms (EA).It generates solutions to optimization complications preserving approaches inspired by regular stages for example: selection, reproduction, mutation and crossover. Genetic algorithm is organized to choose on optimizing the PID controller for the elected 6/4 SRM motor drive system. The controller is suggested to diminish the error(difference between set point and actual rotor speed) of the output response. The organization of the genetic algorithm adjustment PID controller coefficients is presented in the Fig. 7[21].

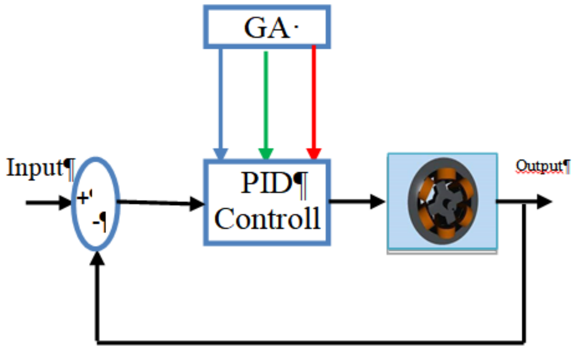


Fig .7. PID Controller tuning configurations.

Integral squared error (ISE) , integral absolute error criterion (IAE) are used as cost function for rotor speed response in the controller plan technique . The IAE and ISE calculated as performance index are given below with following expression [20-22].

.

(6) $$IAE = \int_0^{Tss} abs\,[e(t)]dt$$

(7) $$\mathrm{ISE} = \int_0^{\mathrm{Tss}} [\mathrm{e(t)}]^2 \mathrm{dt}$$

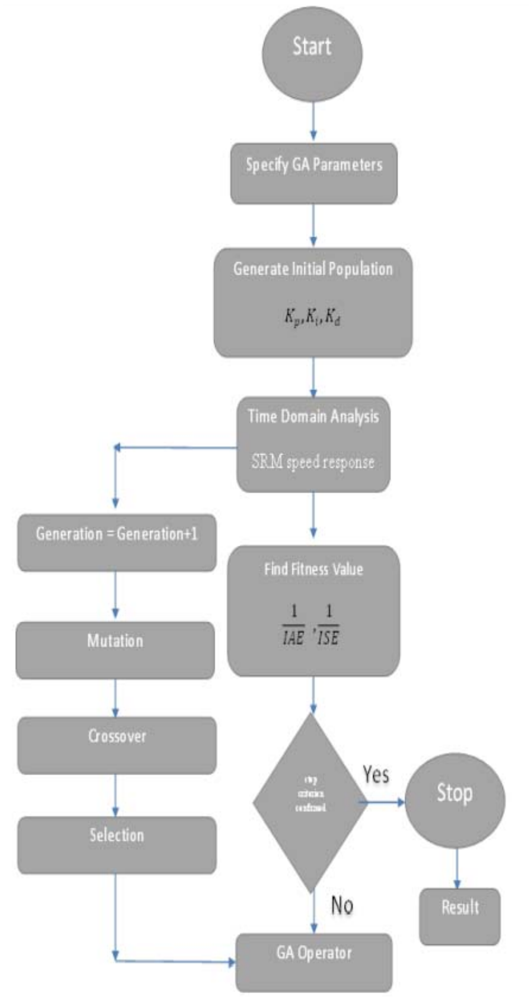


Fig. 8. Aimed genetic algorithm process design flowchart.

The intended flowchart diagrams the process of GA technique calculation more clearly in Fig. 8.

Simulation and results

This section reviews the closed loop system with controller of aimed SRM drive system using MATLAB/SIMULINK software. The system in several working situations are studied. Fig. 9, demonstrates the closed loop system of the SRM drive system. The output rotor speed is sensed and assessed with the reference tracking speed. The resulting error speed signal is supplied as an input signal data to PID controller to generate appropriate reference current that multiplied with commutation angles to produce suitable gate drive signal to the power converter.

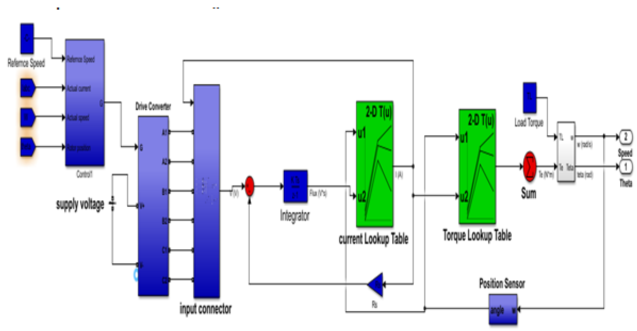


Fig.9. Simulink model of the SRM drive model with PID controller.

To investigate the efficiency of the intended methods, a MATLAB/SIMULINK software is used for the various intended controllers. The traditional PID, GA-PID-IAE and GA-PID-ISE controllers system can be perceived. In reference speed tracking test figure 10, shows the rotor speed tracks the reference speed at constant set point 500 ,1000 ,1500,2000 rpm respectively at time t=0 ,t=0.5,t=1,t=1.5 second respectively for three types control signals.

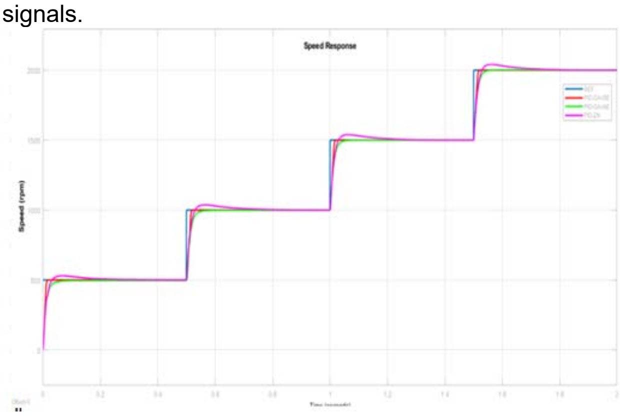
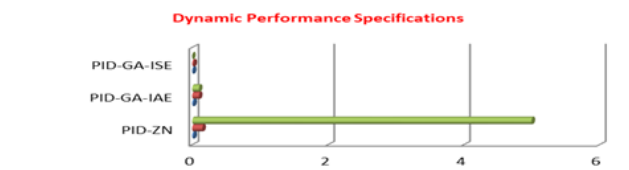


Fig. 10. The response of rotor speed with different set point tracking (500rpm ,1000rpm ,1500rpm,2000rpm).



	PID-ZN	PID-GA-IAE	PID-GA-ISE
Peak overshoot(%)	5	0.1	0
Settling Time (s)	0.15	0.1	0.02
Rise Time (s)	0.019	0.018	0.011

Fig. 11. Comparison between different control approach

The evaluated value of peak over shoot, rise time and settling time for time response characteristics are presented in fig.11.According the outcomes the rise time and settling time of PID-GA-ISE technique is better consequences than PID-GA-IAE method.

Conclusion

PID controller is the generally utilized type of control which delivers the straightforward and very operative resolution to special types of variable speed drive applications. The Simulation outcomes validate that the proposed PID controller regulates adequately the rotor speed of the SRM drive system. The PID controller coefficients are computed by improving the objective function using the GA algorithm. The intended controller illustrations an important reduction in variance between reference speed command and real rotor speed. Simulation outcomes presents that the control system methodology with PID-GA-ISE is the best compared to others two controllers in dynamic response characteristics. Therefore this intended controller can be realistic in industrialized drive applications such as EV- Electric Vehicle

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