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High Efficiency Drive of SRM using GA-Neural Network

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ABSTRACT

The torque of SRM depends on a phase current and the inductance of the motor. But the inductance is saturate nonlinearly according to the position and current. To drive the motor effectively, the control scheme should take int account the nonlinear characteristics of the magnetic material.

This paper proposes an optimal control scheme for high efficiency drive of SRM by adjusting both the turn-on and turn-of angle. The high efficiency drive points are simulated and searched by using GA-Neural Network. The switching angles ar nonlinearly varied with rotor speed and load.

Key Words: Switched Reluctance Motor (SRM), GA-Neural Network, high efficiency drive

1. Introduction

The Switched Reluctance Motor (SRM) experiences a revival due to improvements in power devices and low cost microcontrollers. In comparison with ac motor or commutated dc motors, the intrinsic simplicity, ruggedness, and simple power electronic drive requirement of an SRM make it possible to use in many commercial adjustable speed applications. Recently, the SRM is studied on optimization of electromagnetic design, combination of control units, the improvement of control scheme, the minimization of noise, vibration and torque ripple[1-3].

The principle of operation of a switched reluctance motor is based on the well-known principle leading electromagnetic systems toward a stable equilibrium position minimizing magnetic reluctance. This makes the SRM principle of operation easy to understand. However, actual performance calculations are more difficult. In particular, magnetization characteristics of the motor vary strongly as a function of the excitation current and roto position. And as the SRM drive is operated in a high leve of flux density, the magnetic circuit is saturated severely This saturation distorts the current waveforms.

An SRM is controlled by parameters of input voltage and switch-on, -off angle. The switch-on and -off angle o an SRM affects magnitude and shape of current an conclusively magnitude and shape of torque. Recently some control schemes have been suggested in whicl current waveforms are controlled to optimize drivin performance. The amplitude and shape of curren waveform is dependent on the following factors; i) initia mmf current, which is regulated by the advance switchin angle, ii) applied voltage, iii) speed e.m.f and iv impedance drops in variable inductance. The first an second factor are controlled by the switching inverter while the others are characterized by driving conditions Therefore, the advance angle and applied voltage could b controlled appropriately to have a stable and hig efficiency drive. To optimize driving performance, closed-loop control system is needed. The system has t have the capability of controlling advance angle an applied voltage adaptively. This control scheme i controlled to form the desired current waveform that i decided or selected by any means in advance. This schem

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is, however, incompatible with dynamic driving condition.

This paper suggests an optimization control scheme by adjusting both the turn-on and turn-off angle according to high efficiency points that are simulated by Genetic Algorithms (GA)–Artificial Neural Network(ANN), which has good property to simulate nonlinear system.

2. High Efficiency Drive of SRM

The SRM is a doubly salient, singly excited machine. The torque is developed by the tendency for the magnetic circuit to adopt a configuration of minimum reluctance, i.e. for the rotor to move into in line with the stator poles and to maximize the inductance of the coils excited.
The torque developed in SRM is proportional to the square of switching current and the gradient of phase inductance according to rotor angular position as shown in (1).

$$\tau(\theta)=\frac{1}{2}i(\theta)^2\frac{dL(\theta)}{d\theta} \quad (1)$$

where, $L(\theta)$ is inductance profile of the motor.

If $dL(\theta)/d\theta$ is constant, the magnitude and shape of torque is decided by phase current $i(\theta)$. But the magnetic circuits are saturated severely to achieve the high rate of electromagnetic energy conversion system. When the stator and rotor poles meet, the leading edges are saturated locally and the aligned poles are saturated bulkily. The inductance profile and currents in 8/6 pole prototype SRM is varied as shown in Fig. 1.

It is known that the motor has a significant torque ripple when operated with rectangular or flat-topped currents. This is caused by the change of inductance gradient $dL(\theta)/d\theta$ is not varied linearly. Therefore, some investigation of the change of variable inductance is needed to generate flat-topped torque.

The current level depends on the applied voltage, initial current, back speed e.m.f. and impedance voltage drop. The voltage equation for an SRM is (2).

$$V(\theta)=R\cdot i(\theta)+L(\theta)\frac{di(\theta)}{d\theta}+i(\theta)\frac{dL(\theta)}{d\theta} \quad (2)$$

where, the first in the right terms is resistance voltage drop,

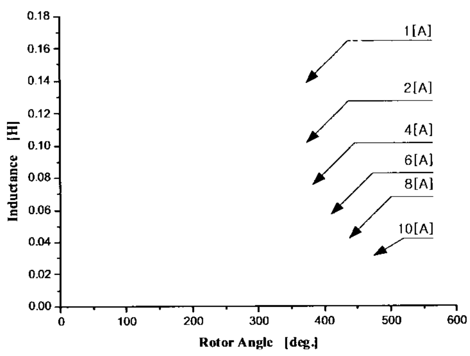


Fig. 1. Inductance profile and currents.

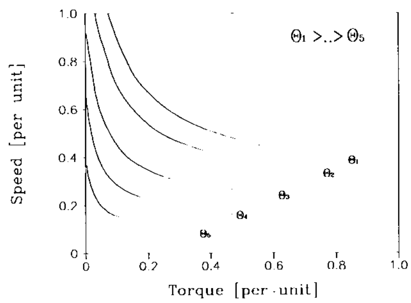


Fig. 2. Torque/speed curve condition on fixed voltage anı switching angle.

the second is reactance voltage drop, and the last is thı back speed e.m.f which can be converted to mechanica energy.

In control of SRM, natural characteristics occur unde conditions of fixed supply voltage and fixed switchin angles. The torque/speed curve is then the same as that o the DC motor as shown in Fig. 2.

The analogy with the DC series machine immediatel points out the possibility of control through termina voltage or supply current. The control parameters of SI drive are advance angle (switch-on angle), switch-of angle and applied voltage. The control of switching angl is easily and economically achieved, involving only th appropriate condition of timing pulses, and make available very wide range of performance characteristic and control possibilities. In practice, control parameter are chosen so as to optimize overall system performance The switch-on and switch-off angle of the SRM regulat the magnitude and shape of the current waveform. Also i results in affecting the magnitude and shape of the torqu developed.

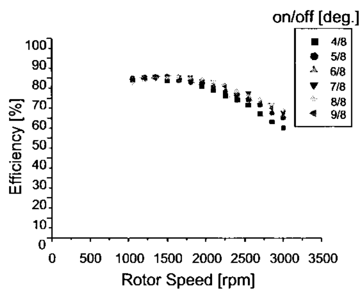
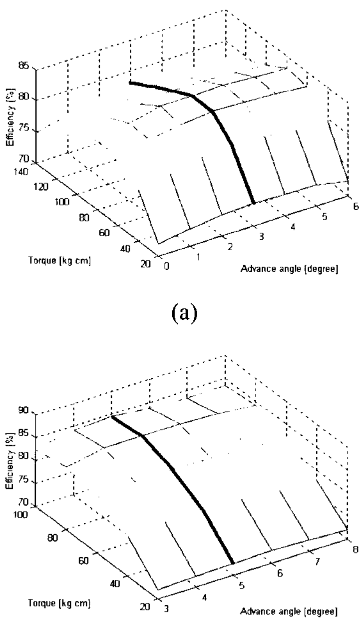


Fig. 3. Efficiency according to switch-on, -off angle.



(a)

(b)

Fig. 4. Efficiency according to torque and advance angle; (a) 1000[rpm] (b) 1500[rpm].

To build up the current effectively in the voltage source, an advance switching before the poles meet is needed. The switch-on angle is one of the main factors to control the build-up currents. Therefore, this angle is controlled precisely to get optimal driving characteristics. The switch-off angle is usually limited by some constraints which is the condition not to develop excessive negative torque [1].

This switching angle is derived from (2) not to develop negative torque at the rated output. The approximated switch-off angle, θ_{off} is calculated from (3).

$$\theta_{off} = \frac{L_{max}}{k} \tag{3}$$

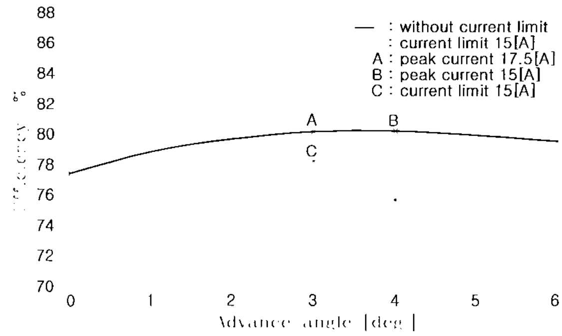


Fig. 5. Efficiency with current limit and advance angle control.

where, $k = dL/d\theta$ and resistance of stator winding is neglected.

The real drive efficiency is found through efficiency tests. Fig. 3 shows the test results at the rated output. It shows that switch-off angle of 12[deg.] is the best angle for high efficiency drive with this SRM. This switch-off angle is 8[deg.] calculated from (3).

Fig. 4 shows an efficiency test at 1000 and 1500[rpm] with torque variation respectively. In this test, the switch-off angle is fixed. The reference position for the switching angle is the increasing position of inductance profile, where switch-on is advance angle, switch-off is delay angle from that position.

The dwell angle control is also very effective for dynamic torque-speed control. Therefore, a dwell angle control is used both for high efficiency and for dynamic torque control.

The current shape is also influence to the efficiency. Fig. 5 is the test results of current shape. A current limit technique is easy and popular to control current and/or torque. But, the dwell angle regulation is better for efficiency than that of current limit technique.

3. Inductance Modeling by GA-ANN

To control phase current for high efficiency, the change of inductance should be known. But it is difficult to express as mathematical equation because of nonlinear characteristics. Therefore, optimization control model is adapted by GA-ANN that is used to simulate nonlinear system.

Genetic algorithms (GA) are search algorithm based on the mechanics of natural selection and nature genetics.

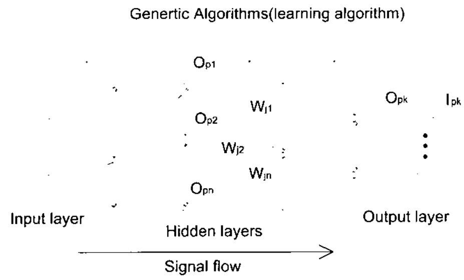


Fig. 6. Block diagram of training algorithm.

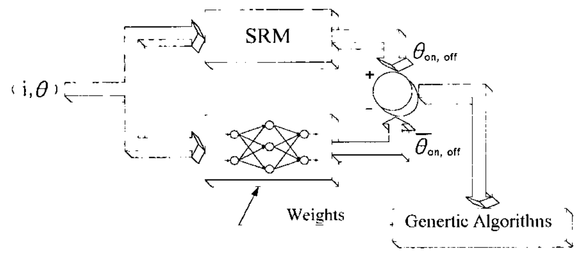


Fig. 7. GA-ANN training algorithm.

They combine survival of the fittest among string structures with structures yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. It works with a coding of parameter set, not the parameters themselves, It searches from a population of points not a single point. It uses pay off information and probabilistic transition rules.

ANN tries to mimic the biological brain neural networks into mathematical model. The brain has many excellent characteristics: parallel processing of information, a learning function, self-organization capabilities, and so forth. Moreover, because of their nonlinear nature, ANN can perform functional approximation and signal-filtering operations that are beyond optimal linear techniques.

The learning procedure involves the presentation of a set of pairs of input and output patterns. The system first uses the input data and to proceed its own output data and then compares this with the desired output.

GA-ANN system has the learning capabilities of neural networks and the structured knowledge base of ANN, overcoming the major drawbacks of ANN [4,5].

A very popular model of artificial neural network is a multi-layer perception that has an input layer, an output layer, and one or more hidden layers. This paper uses a multi-layer perception with GA as shown in Fig. 6.

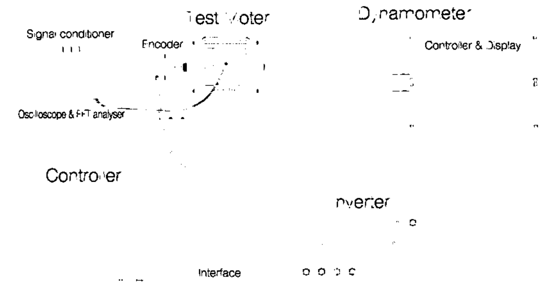
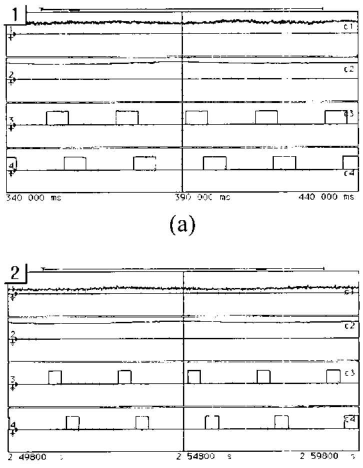


Fig. 8. Test set-up.



(a)

(b)

Fig. 9. Variation of dynamic dwell angle when load decrease; (a light liad (b) normal load: C1; load torque, C2; speed, C3 control signal phase 1, C4; control signal of phase 2.

Fig. 7 shows GA-ANN training algorithm to optimiz driving performance. GA algorithm is used as the learnin algorithm of the feed-forward neural network.

The input data are rotor speeds (ω) and rotor positio angles (θ). The output data are optimal switching angles.

4. Experiments

The drive system is set-up with 8/6 SRM which ha asymmetric inverter, encoder and controller as shown i Fig. 8. Fig. 9 shows the variations of the dynamic dwel angle when load increase. Motor speed is lowered and th dwell angle is widened when the load increases. Th switch-off angle is regulated to remain within th maximum value. It is selected not to develop negativ torque. The motor is starting with 15 [deg] dwell angle.

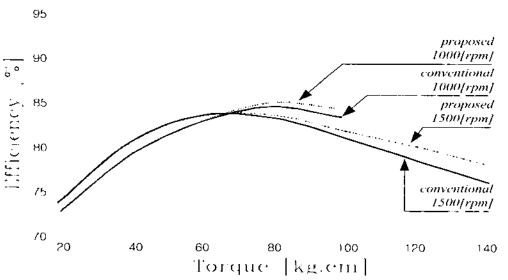


Fig. 10. Drive efficiency comparison.

This is the maximum angle without overlap between phases. The speed control loop is adapted PLL technique which is proposed and described in reference [6]. Efficiency comparisons are shown in Fig. 10. The efficiency is up to 2% higher than that of the conventional drive which adapts current limit control.

5. Conclusion

To control phase current for high efficiency drive, the change of inductance should be known. But it is difficult to express it as mathematical equation because of nonlinear characteristics. A high efficiency drive with a precise speed control scheme is suggested and tested. The switching angle condition for high efficiency is tested and calculated by GA-ANN. This system has a good speed and torque control characteristics

This paper suggests an optimization control scheme by adjusting both the turn-on and turn-off angle according to high efficiency points that are simulated by GA-Neural Network, which has good property to simulation nonlinear system. Test results show that this system has both dynamic and precise speed control capability with high efficiency drive.

Acknowledgments

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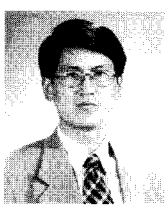

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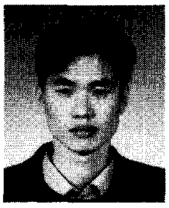

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