CHAPTER 6

A NEW APPROACH FOR ROTOR POSITION ESTIMATION

6.1 INTRODUCTION

Several sensorless rotor position estimation methods have been patented and published for sensorless control of SRM drives. All of these methods use the instantaneous phase inductance variation information in some way to detect the rotor position indirectly. As the flux linkage-current-rotor position characteristics vary significantly between the aligned and unaligned positions of the doubly salient stator and rotor poles, it is possible to estimate the rotor position indirectly in SRM drives.

The main advantages offered by AI based sensorless control methods are saturation effect and mutual inductance effect are counted, good accuracy and suitability for four quadrant operation. The phase voltage and current of active phase are measured simultaneously. Flux linkage is calculated from the phase voltage and current of active phase. For a given flux linkage and current, the rotor position of the active phase is estimated from the flux linkage-current-rotor position characteristics of the motor which are mapped by AI techniques.

As discussed in Section 1.2.2, Bingni Qu et al. (2008) explained that in conventional laminated SRM, the average torque of SRM excited in short flux mode is relatively higher than that in long-flux-mode. For the same operating conditions of on and off angles and dc bus voltage, the motor runs
at a higher speed with short flux path excitation than with long flux path excitation. Thus two phase simultaneous excitation with short flux path mode leads to better performance when compared with single-phase excitation with short flux path mode.

In this Chapter, a novel rotor position estimation algorithm for the solid rotor SRM is discussed. As discussed in Chapter 2, performance of the test motor is better under two phase excitation with type 4 winding connections for which the polarity of adjacent phases are different. Hence two phase excitation with type 4 winding connections is followed for the proposed ANN based rotor position estimation approach.

6.2 THE PROPOSED ANN BASED ESTIMATION APPROACH

The phase flux linkage-phase current-rotor position characteristics are obtained when two adjacent phases are excited simultaneously as well as the motor is under running condition. DSP TMS320F2812 is used for collecting samples at running condition. The mutual inductance effect and eddy current effect are automatically counted in this approach. The non linear mapping between the phase flux linkage-phase current-rotor position characteristics is obtained using ANNs. As two phase excitation scheme is followed in the proposed ANN based rotor position estimation method, the number of voltage and current sensors used for position estimation is minimized and only two voltage sensors and two current sensors are used for rotor position estimation of the four phase test motor. If single phase excitation scheme is used, four voltage sensors and four current sensors are needed for rotor position estimation of four phase motor. Hence two phase excitation scheme not only provides maximum torque but also minimizes the number of sensors used for rotor position estimation
As the test motor is a four phase motor, the two phase excitation sequence for anti clockwise rotation is AD, AB, CB and CD and so on for the initial turn on position as shown in Figure 2.3. At any time either phase A or phase C is excited. Hence in this work, the reference phases are considered as A and C. Phases B and D can also be considered as reference phases. When the motor is running with position sensor, the phase voltage-phase current-rotor position readings of reference phases are recorded using DSP, TMS320F2812. The closed loop type Hall effect voltage and current sensors are used to connect the phase voltage, current signals to DSP.

The phase voltage and phase current (phase A and phase C) signals are fed to DSP through the ADC channels of DSP. Simultaneous conversion method is followed to get the samples of phase voltage and current signals.

Using CCS software, the proposed ANN based algorithm is implemented on DSP. In ADC interrupt subroutine routine, samples of phase voltage and current signals are measured and flux linkage is calculated for the corresponding voltage and current samples. The collected values of phase flux linkage, phase current of reference phases (phase A and phase C) and rotor position readings are used to obtain four different ANN models.

The details of the four ANNs are as follows, ANN named type 1 is used when phases A and D are on. When phases A and B are on, ANN named type 2 is used. ANN named type 3 is used when phases B and C are on. When phases C and D are on, ANN named type 4 is used. Hence any one type of four ANNs is used for a particular estimation. For type1 ANN and type 2 ANN, phase A is the reference phase. Whenever A phase is on, either B or D is on and the mutual inductance effect is counted in A phase voltage and current signals. As the data are collected at running condition, the eddy current effect is also counted.
For type 3 ANN and type 4 ANN, phase C is the reference phase. Whenever C phase is on, either B or D is on and the mutual inductance effect is counted in C phase voltage and current signals. As the data are collected at running condition, the eddy current effect is also counted in phase C signals. All four ANNs used in this work are of same 2-5-5-1 structure.

The phase flux linkage-phase current data are used as inputs and rotor position is taken as output for the four 2-5-5-1 ANN structures. For the above said ANNs, feed-forward networks are used. Adaption is done with training which updates weights with the specified learning function. TRAINLM training function is used for training. It is a network training function that updates weight and bias values according to Levenberg-Marquardt optimization. The activation functions for the hidden layer neurons are tansig functions. The activation function for the neuron in the output layer is purelin function.

### 6.3 IMPLEMENTATION AND ONLINE VERIFICATION

The hardware setup used to implement the proposed ANN based rotor position estimation method is shown in Figure 2.1. The phase flux linkage-phase current-rotor position samples are collected as explained in Section 2.4. To improve accuracy of estimation, a maximum of 15,000 data are collected for 60 degree mechanical for different turn on and turn off angles. Experimental sample data are shown in Table A3.1 of Appendix 3. Matlab version 7.3 software is used for further processing and to obtain ANN based offline trained simulink models. The simulink models are tested and verified with trained and untrained input data. ANNs are used to estimate rotor position from the active phase currents and flux linkage values. The weight and bias values obtained are used in DSP programming.
Figure 6.1 shows the simulation result (for trained data) obtained using Matlab7.3. The result is shown for 348 samples. The error range obtained is [-0.3775 degree to 0.4724 degree].

![Graph showing Rotor Position Estimation Error vs. Sample Number]

**Figure 6.1 Rotor Position Estimation Error (degree) vs. Sample Number**

Performance is measured with respect to MSE. Different ANN structures are trained and tested. But for implementation on DSP, the execution time has to be considered as sampling frequency is dependent on overall execution time of the ANN based rotor position estimation algorithm as discussed in Chapter 5. Hence different ANN structure based rotor position estimation algorithms are implemented on DSP, TMS320F2812. To implement the overall interrupt service routine which includes a 2-5-5-1 ANN based rotor position estimation algorithm, a maximum of 72000 instruction
cycles are needed. Within the 72000 instruction cycles, 22,000 cycles are for ADC conversion routine which is needed to get online samples and to feed the input data (current, flux linkage) to 2-5-5-1 ANN and 50,000 cycles are for executing 2-5-5-1 ANN based rotor position estimation algorithm.

The ANN based rotor position estimation algorithm is implemented on DSP, TMS320F2812 using CCS software. Figure 6.2 shows the flowchart for the novel rotor position estimation algorithm which is explained as follows:

1. If excitation phases are A and D, execute type 1 ANN to estimate rotor position. Type 1 ANN is trained with phase A flux linkage and phase A current as inputs and rotor position as output. The phase A flux linkage, phase A current and rotor position are measured when AD phases are on. The structure of ANN is 2-5-5-1.

2. If excitation phases are A and B, execute type 2 ANN to estimate rotor position. Type 2 ANN is trained with phase A flux linkage and phase A current as inputs and rotor position as output. The phase A flux linkage, phase A current and rotor position are measured when AB phases are on. The structure of ANN is 2-5-5-1.

3. If excitation phases are B and C, execute type 3 ANN to estimate rotor position. Type 3 ANN is trained with phase C flux linkage and phase C current as inputs and rotor position as output. The phase C flux linkage, phase C current and rotor position are measured when BC phases are on. The structure of ANN is 2-5-5-1.
4. If excitation phases are C and D, execute type 4 ANN to estimate rotor position. Type 4 ANN is trained with phase C flux linkage and phase C current as inputs and rotor position as output. The phase C flux linkage, phase C current and rotor position are measured when CD phases are on. The structure of ANN is 2-5-5-1.

Figure 6.2 Flowchart for the novel rotor position estimation algorithm

As the test motor rotates 60 degree for a single excitation sequence (AD, AB, BC, CD), type 1 ANN (A, D phases are on) is used to estimate first 15 degrees (from 0 degree to 14 degree), type 2 ANN (A, B phases are on) is used to estimate the next 15 degrees (from 15 degree to 29 degree), type 3
(B, C phases are on) ANN is used for the next 15 degrees (30 degree to 44 degree) and type 4 ANN (C, D phases are on) is used for the last 15 degrees (45 to 59 degree). Hence any one type of four ANNs is used for a particular estimation.

The estimated and actual rotor position online data are collected using data (.dat) files. The accuracy of rotor position estimation is verified by comparing the actual rotor position with the estimated one. The motor is run using position sensor and the proposed approach is verified at steady state running condition and transient condition.

Figure 6.3 shows online verification of the proposed approach, when the test motor is running at a steady state speed of 150rpm with a load torque of 7Nm.

**Figure 6.3** Online verification of the proposed approach under steady state condition (when the test motor is running at a steady state speed of 150rpm with a load torque of 7Nm). Red line shows the actual rotor position and blue line shows the estimated rotor position.
Figure 6.4 shows error obtained during online verification of the proposed approach, when the test motor is running at a steady state speed of 150rpm with a load torque of 7Nm. As per Figure 6.4, the error range obtained is [-1.06 degree, 0.4 degree].

![Error Graph](image)

**Figure 6.4  Error obtained during online verification of the proposed approach**

(When the test motor is running at a steady state speed of 150rpm with a load torque of 7Nm)

Figure 6.5 shows online verification of the proposed approach when the test motor is subjected to a load torque variation from 0.35Nm to 1.5Nm

The accuracy of estimation of the proposed estimation algorithm is better under steady state conditions. Under transient conditions, the maximum error range obtained is [-5 degree, 5degree].
Figure 6.5 Online verification of the proposed approach under transient condition

(when the test motor is subjected to a load torque variation from 0.35Nm to 1.5Nm)

If a single ANN is used to estimate rotor position for every 30 degree under two phase excitation scheme, the minimum error range obtained in simulation is [-2 degree to 1 degree]. The use of single ANN for 30 degree rotor position estimation can be explained as follows. When AD phases are on, phase A flux linkage and current are inputs to type A ANN trained for flux linkage-current data when A phase is on (when AD phases are on, when AB phases are on). When AB phases are on, the same type A ANN is used to estimate rotor position and the inputs to ANN are phase A flux linkage and current.
The error is reduced by a factor of 2 by using four ANNs to estimate the rotor position for 60 degree mechanical, when it is compared with a common ANN for every 30 degree under two phase excitation scheme. As the maximum time needed to execute the overall interrupt service routine which includes estimation algorithm based on 2-5-5-1 ANN is about 480μs, the maximum sampling frequency is taken as 2.08 kHz.

6.4 CONCLUSION

A novel ANN based rotor position estimation approach is introduced to minimise number of voltage and current sensors used. The proposed approach uses only four sensors instead of using eight sensors for the 8/6 SRM. Two phase excitation scheme is followed for the better performance of the test motor. The accuracy of ANN based rotor position estimation method is improved by a factor of 2 by using four different 2-5-5-1 ANNs for 60 degree mechanical instead of using a single ANN for every 30 degree under two phase excitation scheme. The online verification of estimated rotor position and actual rotor position has been done under steady state and transient operating conditions. The proposed approach proved its validity under steady state and transient operating conditions.