ISSN (Print) : 0974-6846
Indian Journal of Science and Technology, *Vol 9(16), DOI: 10.17485/ijst/2016/v9i16/70123, April 2016* ISSN (Online) : 0974-5645

Selecting Best Interpolation Technique for Simulation Modeling of Switched Reluctance Machine

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Abstract

The available experimental data is often not sufficient enough and therefore, an interpolation technique is required to suit the trend of experimental data in simulation model of the switched reluctance machine. The objective of this paper is to present a suitable simulation model of the machine with help of different data interpolation techniques to overcome the missing intermediate data available from the experiments. The input data is obtained from experiments and missing required data is obtained through interpolation methods for range of desired samples. Matlab software is used for the simulation purpose. This methodology of finding best curve fitting technique and missing data points is simple and easy to implement. The findings of this research work are helpful for developing an accurate simulation model and to see the effect of different data interpolation techniques on instantaneous phase current waveforms of switched reluctance machine.

Keywords: Chopping Mode, Data Interpolation, Dual Saliency, Magnetization Characteristics, Polynomial

1. Introduction

Switched reluctance motor has many colors of attraction including simple construction, phase arrangements, variable speed and fairly good performance under varying load conditions[1]. Having said that it is still hard to set a final picture to represent it as an ideal machine and drive, main reason behind that could be certainly the non linear characteristics. Switched reluctance machine is a modern drive having many applications including industry, office and home[1].

The simulation model of this SR machine includes an outsized data which includes data tables of magnetization characteristics, $\Psi(\theta,i)$, co energy $W^{'}(\theta,i)$ and static torque characteristics $T(\theta,i)$ respectively[2].The input data table of flux linkage characteristics can be obtained through the experiments[3–5] or by software[6–8]. It is matter of distress if the experimental data points are not close enough due to complexity of experimental set up as shown in Figure 1 or processing of experimental data in computer programming which is necessary for getting the data of inductance profile. In order to obtain the true trend of experimental data the requirement of an appropriate data interpolation technique is unavoidable. Different simulation models of switched reluctance machine using different software and technique[9–12] and interpolation methods to suit the known data are available[13–16] in the literature. The purpose of this research is to see a well-defined difference of using different data interpolation methods in simulation model of the drive and based on suitable interpolation type an improved model can be developed.

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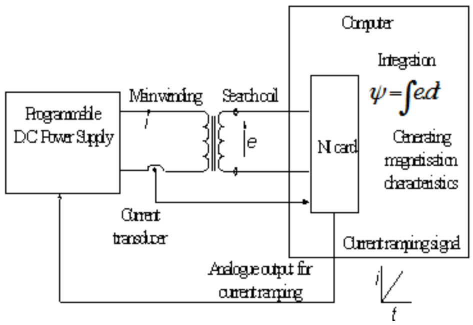

Figure 1. Experimental setup for measurement of flux linkage characteristics[7].

1.1 Input Data Tables required for Simulation Model of Switched Reluctance Motor

As mentioned in introduction that for the purpose of simulation of switched reluctance motor, the requirement of input data tables, $\Psi(\theta,i)$, co energy $W^{'}(\theta,i)$ and static torque characteristics $T(\theta,i)$ is obvious. The data table of flux linkage characteristics $\Psi(\theta,i)$, shown in Figure 2 is obtained by experiments or by simulation as discussed earlier, the author[1] has explained the experimental protocol of these characteristics in[17]. Once this data is in hand, the next step comprises of the inverting of the same data i.e. $i(\theta,\Psi)$[2] shown in Figure 3. Second step is co-energy $W^{'}(\theta,i)$ data table which is shown in Figure 4 can be obtained once the former data is available. Third one is data of static torque characteristics shown in $T(\theta,i)$ Figure 5 and Figure 6. The mathematical relations of calculating these data tables are given as the co-energy data table is expressed as:

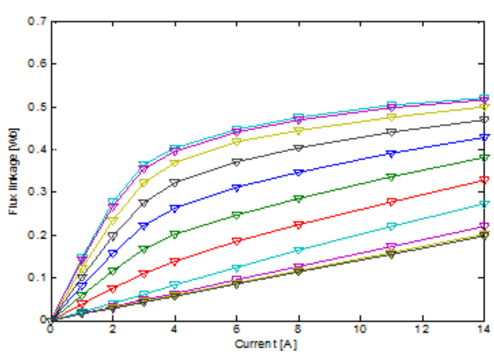

Figure 2. Flux linkage characteristics $\Psi(\theta,1)$[1]. ,i)[1].

$$W'(\theta,1) = \int_0^i \Psi(\theta,i)di \tag{1.1}$$

Whereas, the static torque data is computed as:

$$T(\theta,1) = \frac{\partial W'(\theta,i)}{\partial \theta} \tag{1.2}$$

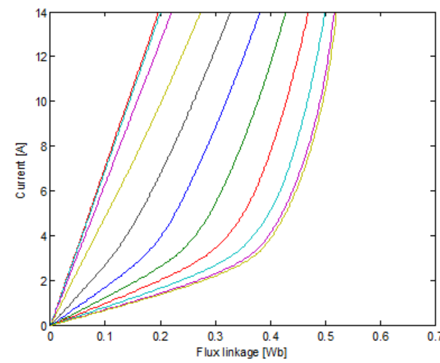

Figure 3. Flux linkage characteristics i.e. $\Psi(\theta,1)$[1]..

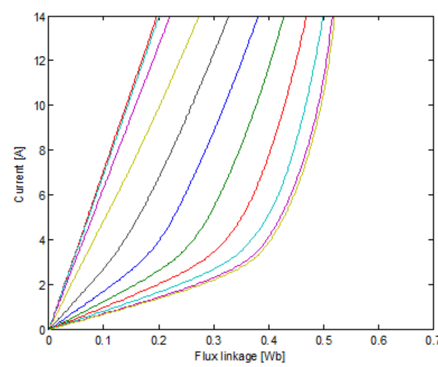

Figure 4. Co energy $W^{'}(\theta,i)$ characteristics[1].

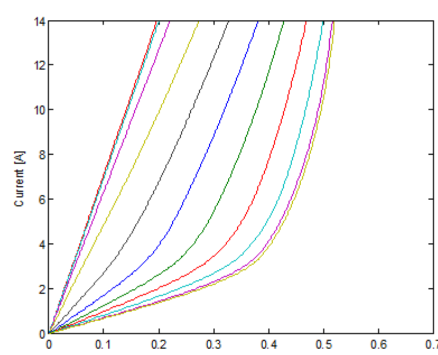

Figure 5. Computed static torque characteristics $T(\theta,i)$[1].

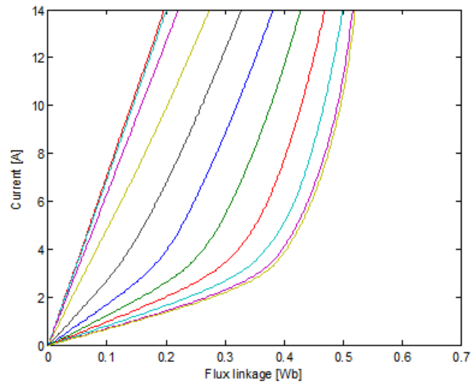

Figure 6. Experimentally obtained static torque characteristics $T(\theta,i)$ [1].

2. Data Interpolation

Data interpolation is the method of producing new, unseen data points between the known set of discrete points. Whereas, producing new data points outside the known data points known as extrapolation. It is not enough only to choose either interpolation type to find new data points between set of known points, but it is rather the matter of choice and knowledge to opt such a type of data interpolation that must fit the trend of curves/waveforms obtained through the experiments. If the fashion of the expected curves is not obtained, the use of that particular interpolation is meaningless. Data curve fitting using different interpolation methods is important in case of switched reluctance machine modeling due to non linear characteristics of the machine that comes from dual saliency of the drive[18].

2.1 Interpolating Polynomial

The name interpolating is given to this polynomial because it reproduces the given data:

$$P(x)_k = yk, \quad (1)$$

Where k = 1...n

2.2 Piecewise Linear Interpolation

It is the method of producing lines between two known points. Three quantities are included in the algorithm, k which is the interval index as shown in the Equation 1 can be calculated as:

$$x_{k\leq} x < x_{k+1} \quad (2)$$

Another relation given in Equation 3 helps in determining local variable:

$$s = x - x_k \quad (3)$$

Where s is local variable:

$$\delta_k = \frac{y_{k+1} - y_k}{x_{k+1} - x_k} \quad (4)$$

$$L(x) = y_k = x - x_k \frac{y_{k+1} - y_k}{x_{k+1} - x_k} \quad (5)$$

$$= y_k + s\delta_k \quad (6)$$

Due to not very precise, this technique of data interpolation is not highly preferable in simulation model.

2.3 Piecewise Cubic Hermite Interpolation

$$h_k = x_{k+1} - x_k \quad (7)$$

Where:

h_k is length of k[th] sub interval

Where δ_k is first divided difference.

2.4 Cubic Spline

Spline can be defined as a piecewise function which may be highlighted by polynomial function[19]. Spline is often used in simulation model of the switched reluctance machine because it does not deteriorate the shape of the experimentally obtained curves or data. Further that the new generated point passes through the data points obtained through the experiments.

3. Simulation Model using Different Interpolation Techniques

Simulation of the SR motor is carried out in Matlab software. For the intension of observing the effect of different interpolation techniques on static characteristics of the drive which are starting step to compute the performance of the machine in different operating modes e.g. single pulse mode, current chopping mode and voltage PWM (Pulse Width Modulation) mode shown in Figure 7 respectively, the model is updated with required data tables. Figure 9 and Figure 10 are obtained as result of linear interpolation; the area is encircled in Figure 9 in particular to show the need of proper curve fitting whereas; Figure 10 if compared to Figure 5 and Figure 6 pose a clear difference if proper interpolation is not applied.

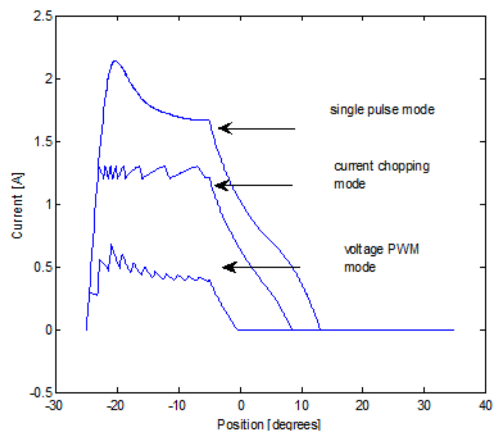

Figure 7. Phase current versus rotor position in different operating modes of the switched reluctance motor using spline data interpolation[1].

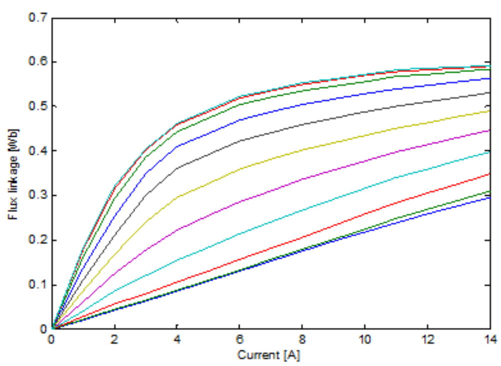

Figure 8. Flux linkage characteristics $\Psi(\theta,i)$ computed through linear interpolation[20].

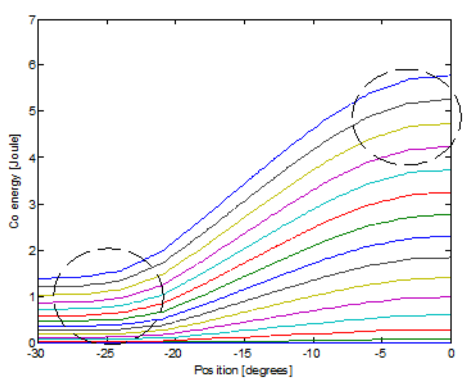

Figure 9. Co energy $W'(\theta,i)$ characteristics, obtained using linear interpolation[1].

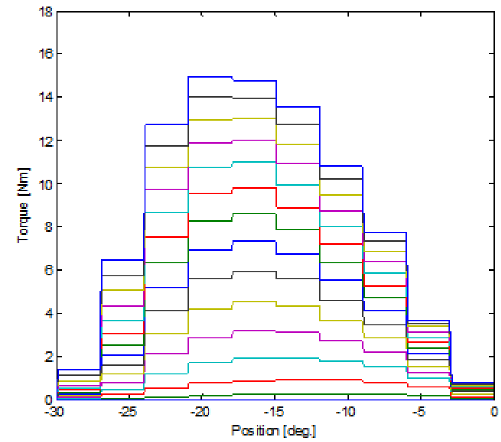

Figure 10. Torque versus rotor position obtained using linear interpolation[20].

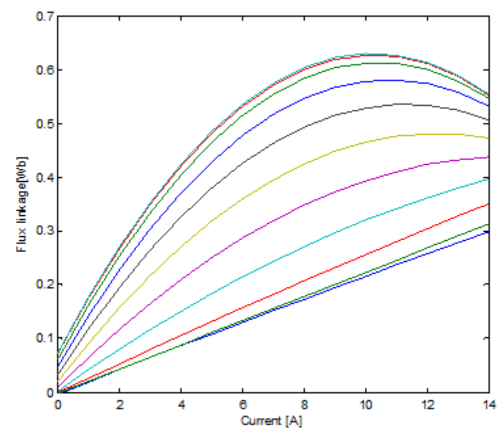

Figure 11. Flux linkage characteristics $\Psi(\theta,i)$, computed through polynomial first order interpolation[20].

An ample well-defined difference in the magnetization characteristics of the drive for range of current from 1A-14A can be seen from Figures 2 obtained using spline interpolation, Figure 8 obtained by linear interpolation and Figure 11 when model used polynomial interpolation separately. The actual trend of flux linkage curves is obvious in Figure 2 once other findings are compared.

If spline, linear and polynomial data interpolation techniques are used separately in the simulation model of the drive, the resulting instantaneous phase current of the machine looks like Figure 7, Figure 12 and Figure 13.

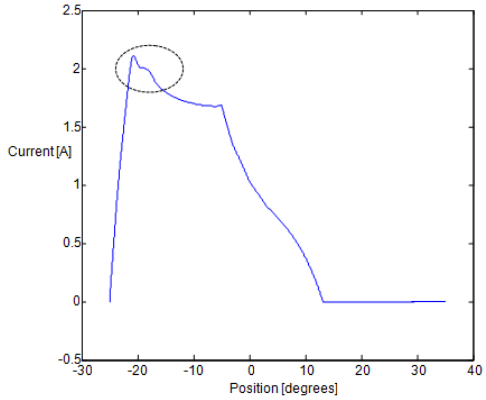

Figure 12. Phase current versus rotor position in different operating modes of the switched reluctance motor using linear data interpolation[1].

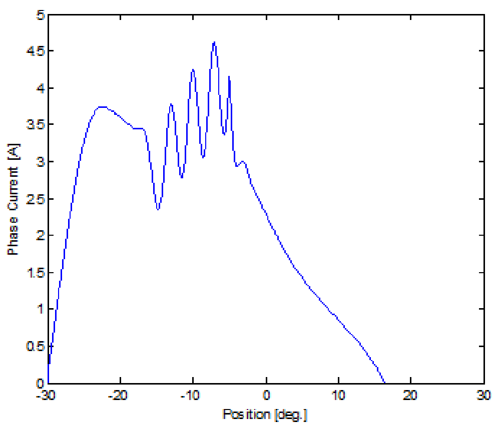

Figure 13. Phase current versus rotor position in different operating modes of the switched reluctance motor using polynomial data interpolation[20].

4. Conclusions

An investigation has been made on basis of different interpolation techniques in the simulation model of the drive. The obtained graphs of current profile which correspond to the input data tables of static characteristics of the machine show clear difference. This research is helpful in developing accurate model of the motor if the experimental data of magnetization characteristics is available. Furthermore, this work can be extended to see the effect of these interpolations on torque profile of the drive.

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