ISSN: 0975-766X
CODEN: IJPTFI
Available Online through **Research Article**
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MODELING OF SWITCHED RELUCTANCE MOTOR FOR PHARMACEUTICAL INDUSTRIES

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Received on 10-05-2016 *Accepted on 09-06-2016*

Abstract

In the past few decades, switched reluctance machine (SRM) has become the subject of interest among the researchers in the field of electrical machines. This is owing to the fact that SRM has proved to be a valid alternative to conventional electrical machines in almost all industrial sectors. Especially, SRM finds its vital application in the pharmaceutical packaging industries. The performance and control accuracy of SRM extensively relies on the precision of its machine modeling. This paper presents the fuzzy logic based inductance modeling technique for switched reluctance machine. The main objective of this work is to determine the suitable dedfuzzification technique for SRM inductance modeling. The various types of dedfuzzification techniques available in fuzzy logic such as centroid, bisector, middle of maximum (MOM), largest of maximum(LOM) and smallest of maximum(SOM) are used to develop the SRM inductance model. The inductance curves modeled from all these techniques are compared. The results of these comparisons are analyzed and presented in detail. From the analysis of results, it has been proved that the centroid dedfuzzification technique has developed a good SRM model compared with the other models. The kind of non-linearity exhibited by SRM is well handled by centroid method. The developed SRM model is a prospective applicant in real time control application in pharmaceutical filling and packaging industries.

Index Terms: Fuzzy logic, Non-linear inductance model, Pharma industries, Switched Reluctance machine (SRM).

I. Introduction

Accurate inductance modeling L (I, θ) of SRM is the major requirement for its real time control [1,2]. Many publications have developed nonlinear models for the machine. Analytical models are discussed in [3] and [4]. Model based on magnetic theory is done in [5]. Both these models are time consuming. Finite element method which provides precise results is employed in [6], but it requires complicated mathematical calculations and computational effort. Artificial neural network algorithms are used in [7] and [8] that need numerous data for training. Adaptive neuro fuzzy inference system and statistical regression are implemented in [9-11]. In this paper, inductance model for SRM is built using fuzzy logic method from the fuzzy logic toolbox in MATLAB. Fuzzy Inference System (FIS) for SRM inductance model has been developed using various dedfuzzification techniques. The accuracy of all these models is compared. This paper has been organized as follows. The magnetization characteristics of SRM is discussed in section 2. Section 3 presents the SRM inductance model using various dedfuzzification techniques. The inductance model based on bisector function is presented in section 3.1. The inductance model based on middle of maximum function is presented in section 3.2. The inductance model based on largest of maximum function is presented in section 3.3. The inductance model based on smallest of maximum function is presented in section 3.4. The inductance model based on centroid function is presented in section 3.5. The comparison between the individual dedfuzzification function models and actual magnetization model from SRDaS is discussed in each section. Comparison of all these models are presented in section 4 and the conclusive remarks are discussed in section 5.

II. Magnetization Characteristics of SRM

Fig. 1 shows the highly non-linear inductance curves of a 6/4 pole SRM from SRDaS [12]. It shows the relation between the inductance with the current and rotor position. The curve is linear up to saturation after which the correlation between L and i is highly non-linear as θ moves from unaligned (0 deg) to aligned position (45 deg). The parameters current, rotor position and inductance are extracted from these curves and utilized in building fuzzy inductance model based on various dedfuzzification techniques.

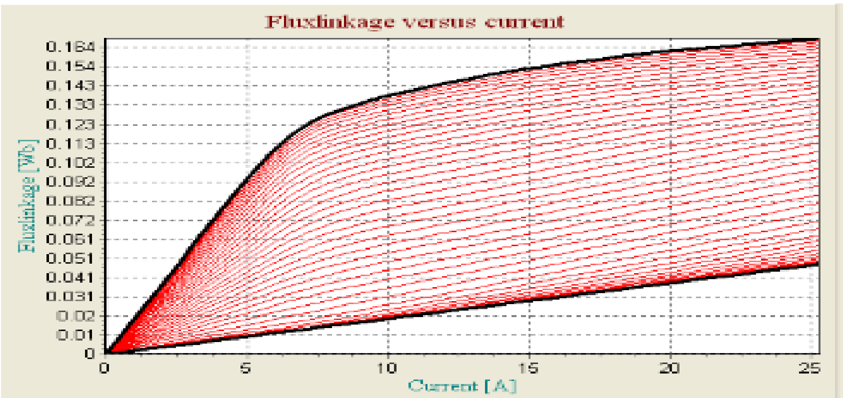

Fig. 1. Inductance curves of SRM.

III. Fuzzy Logic Based Inductance Modelling of SRM Using Various Dedfuzzification Techniques

The fuzzy inference system (Mamadani model) based inductance model for SRM is developed using fuzzy logic toolbox in MATLAB. There are two inputs to the, current and rotor position. The output of the model is L (I,θ). The magnetization data for SRM are taken from [12] for one electrical cycle with the ranges of $0 \leq I \leq 25$ A , $0 \leq \theta \leq 45$ deg and $0.0014 \leq L \leq 0.02$ H.

A. Inductance model of SRM using bisector method

The comparison between the actual inductance values and the values predicted from bisector based FIS model is shown in Fig. 2. The results are analysed based the statistical error measures such as maximum absolute error(MAVE), Mean Absolute Error (MAE), sum of squared error (SSE) and Root Mean Square Error (RMSE).

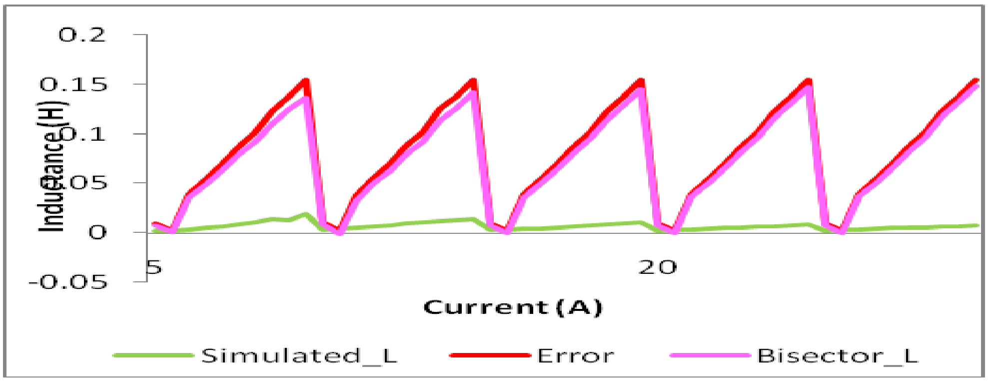

Fig.2. Comparison of actual and modeled L (I, θ).

These errors are shown in Fig.3 and presented in Table.1. With the careful examination of errors, it is obvious that the FIS model using bisector function is not in good concurrence with the actual data and hence is non suitable for modelling the inductance parameters for SRM.

The maximum absolute error obtained in this model is 0.08128.

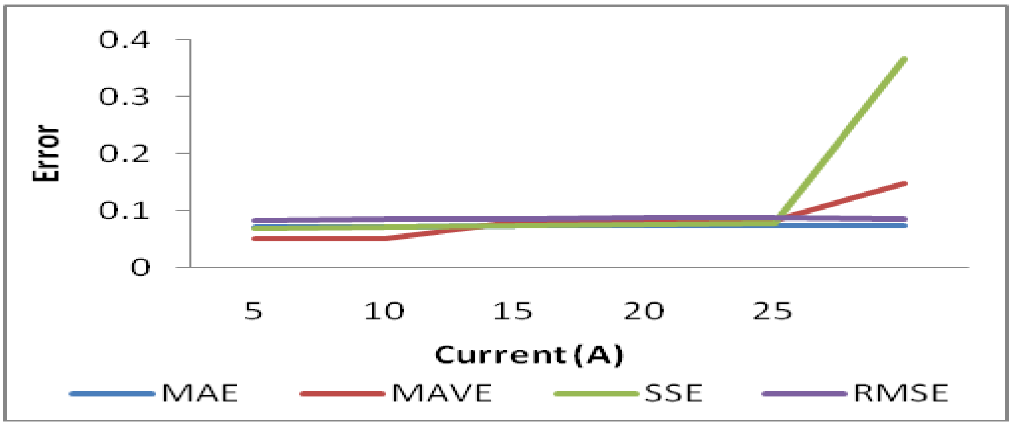

Fig.3. Errors at various operating currents.

Table-1: Various errors in L (I, θ) using bisector model.

Inductance Errors	RMSE	SSE	MAE	MAVE
5A	0.082874	0.068681358	0.069904	0.0494
10 A	0.084159	0.07082813	0.07067	0.0497
15A	0.086066	0.074073031	0.072133	0.07987
20A	0.087383	0.076357148	0.073185	0.08105
25A	0.087914	0.077288482	0.073556	0.08128

B. Inductance model of SRM using middle of maximum method

The comparison between the actual inductance values and the values predicted from MOM based FIS model is shown in Fig. 4. The various errors are shown in Fig.5 and presented in Table.2. With the careful examination of errors , it is obvious that the FIS model using MOM function is not in good agreement with the actual data and hence is non suitable for modelling the inductance parameters for SRM.

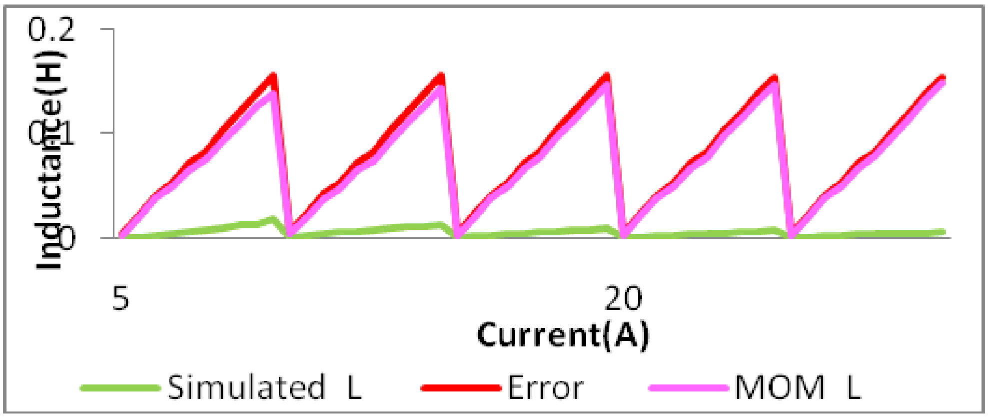

Fig.4. Comparison of actual and modeled L (I, θ).

Table-2: Various errors in L (I, θ) using MOM model.

Inductance Errors	RMSE	SSE	MAE	MAVE
5A	0.082962	0.06882637	0.071344	0.0486
10 A	0.083811	0.07024241	0.07165	0.0473
15A	0.086152	0.07422143	0.073587	0.076667
20A	0.087169	0.07598429	0.074475	0.07785
25A	0.087566	0.07667889	0.07464	0.07808

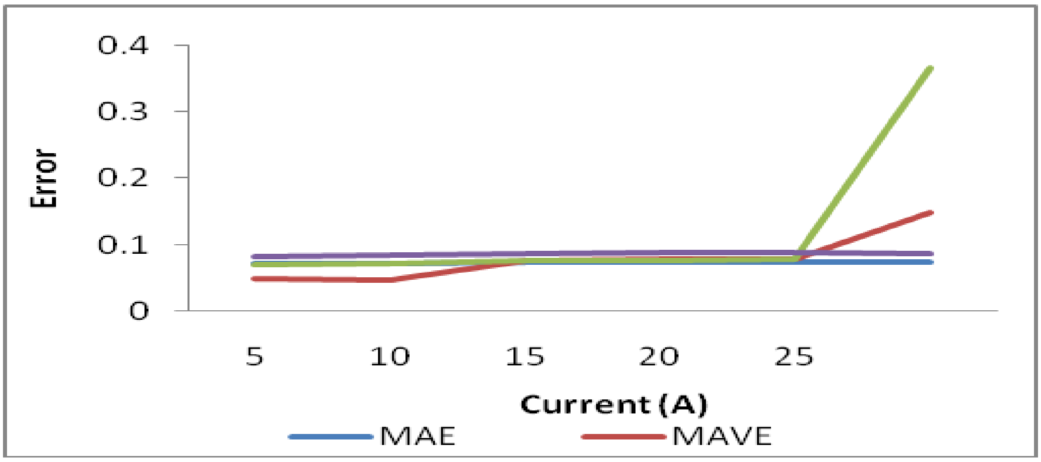

Fig.5. Errors at various operating currents

With the careful observation from the comparison charts and error values , it is evident that the FIS model using MOM function is not showing any agreement with the actual results and proves to be non suitable for modelling the non-linear SRM parameters. The maximum absolute error obtained in this model is 0.07808.

C. Inductance model of SRM using largest of maximum method

The comparison between the actual inductance values and the values predicted from LOM based FIS model is shown in Fig. 6. The various errors are shown in Fig.7 and presented in Table.3. With the careful examination of errors, it is obvious that the FIS model using LOM function is not in concurrence with the actual data and hence is non suitable for modelling the inductance parameters for SRM. The maximum absolute error obtained in this model is 0.08288.

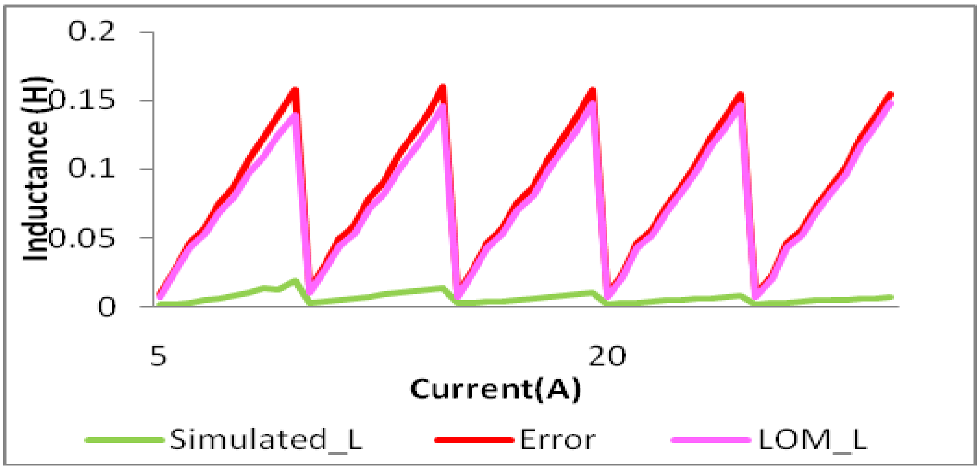

Fig.6. Comparison of actual and modeled L(I, θ).

Table-3: Various errors in L (I, θ) using LOM model.

Inductance Errors	RMSE	SSE	MAE	MAVE
5A	0.085477	0.073062638	0.074884	0.0526
10 A	0.088366	0.07808533	0.07753	0.0529
15A	0.088611	0.078519151	0.077047	0.081467
20A	0.088642	0.078573748	0.076795	0.08265
25A	0.088908	0.079046242	0.07678	0.08288

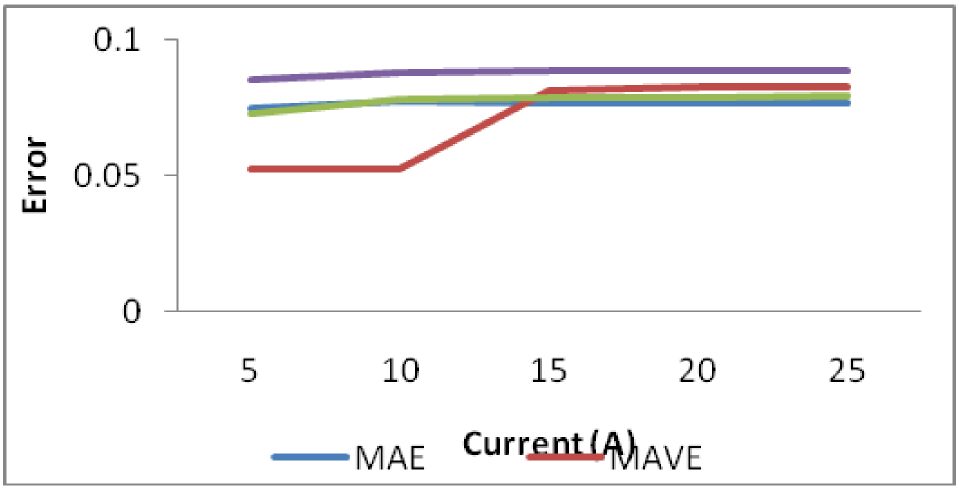

Fig.7. Errors at various operating currents.

D. Inductance model of SRM using smallest of maximum method

The comparison between the actual inductance values and the values predicted from SOM based FIS model is shown in Fig. 8. The various errors are shown in Fig.9 and presented in Table.4. With the careful examination of errors, it is obvious that the FIS model using SOM function is not in concurrence with the actual data and hence is non suitable for modelling the inductance parameters for SRM. The maximum absolute error obtained in this model is 0.07328.

Table-4: Various errors in L (I, θ) using SOM model.

Inductance Errors	RMSE	SSE	MAE	MAVE
5A	0.080154	0.06424715	0.067896	0.0446
10 A	0.079308	0.06289741	0.06615	0.0417
15A	0.083391	0.06954016	0.070327	0.071867
20A	0.085774	0.07357099	0.072605	0.07305
25A	0.086304	0.07448442	0.072948	0.07328

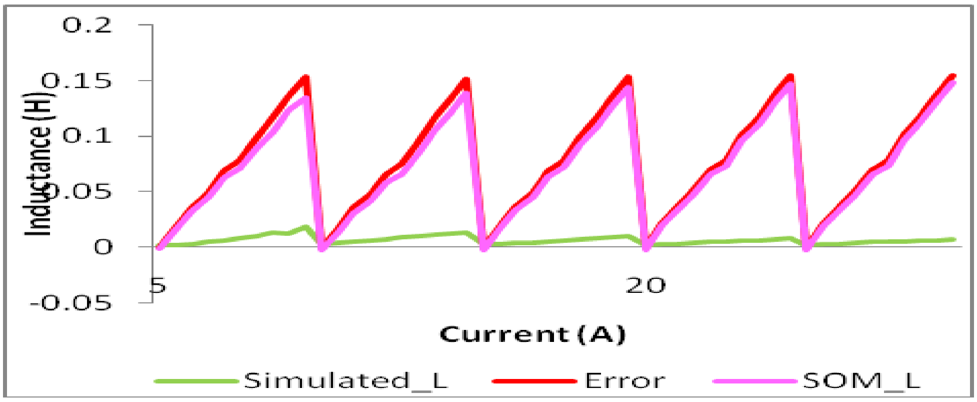

Fig.8 Comparison of actual and modeled L (I, θ)

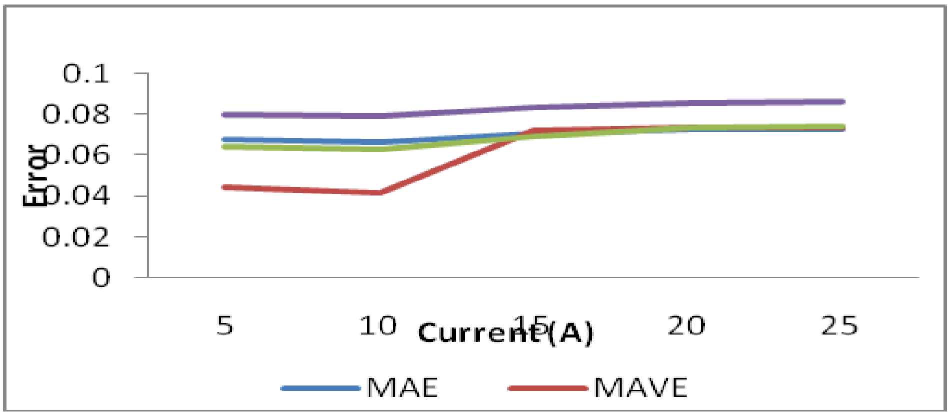

Fig.9. Errors at various operating currents.

E. Inductance model of SRM using centroid method.

The comparison between the actual inductance values and the values predicted from centroid based FIS model is shown in Fig. 10. From this figure, it is observed that there exists fair concurrence between the modelled and actual inductance values.

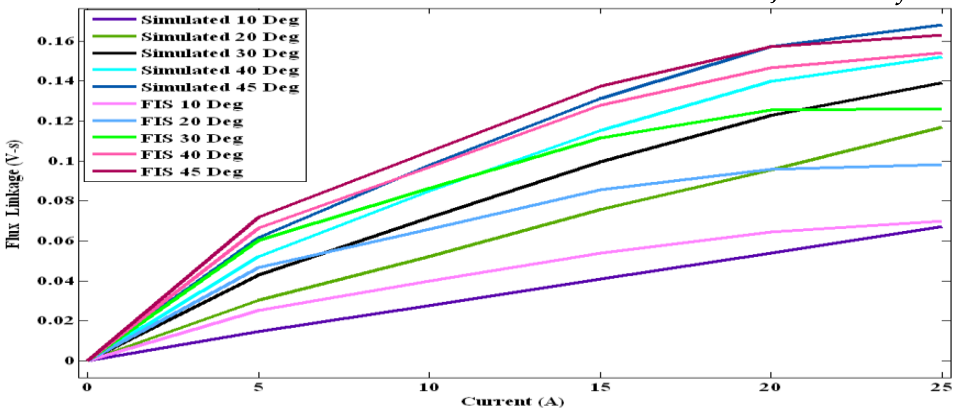

Fig. 10. Simulated Vs FIS inductance profiles.

The errors are shown in Fig.11 and presented in Table.5. With the careful examination of errors, it is obvious that the FIS model using centroid function is in fair agreement with the actual results and proves to be the suitable for developing SRM model with lesser errors for the entire set of data range. The maximum absolute error obtained in this model is 0.00608.

Table-5: Various errors in L(I, θ).

Inductance Errors	RMSE	SSE	MAE	MAVE
5A	0.008373	0.000701127	0.006768	0.00364
10 A	0.00816	0.00066579	0.0074477	0.00566
15A	0.006188	0.000382911	0.005667333	0.00608
20A	0.005056	0.000255585	0.004726	0.00507
25A	0.004665	0.000217612	0.0044512	0.00492

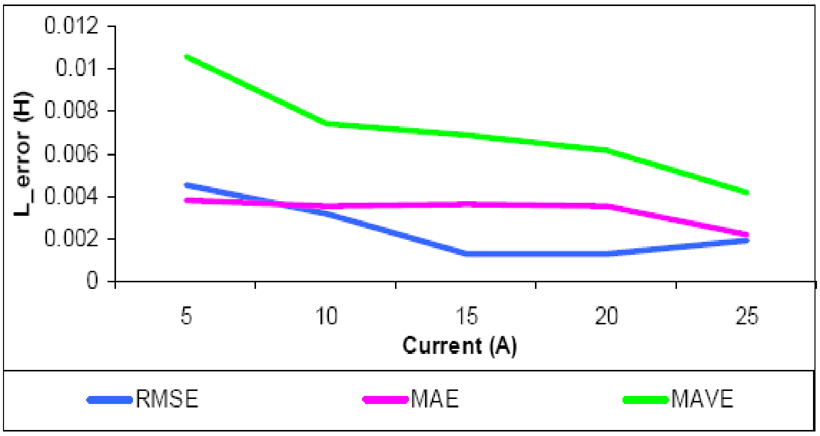

Fig. 11. FIS errors at various operating currents.

IV. Comparison of SRM Inductance Models Using Various Membership Functions

In this section, an overall comparison of the L (I,θ) models developed from various FIS Defuzzification techniques is presented. Fig.12 shows the graphical representation of different types of errors occurred from various Defuzzification techniques. The nonlinear mapping surface of L(I,θ) is shown in Fig.13.

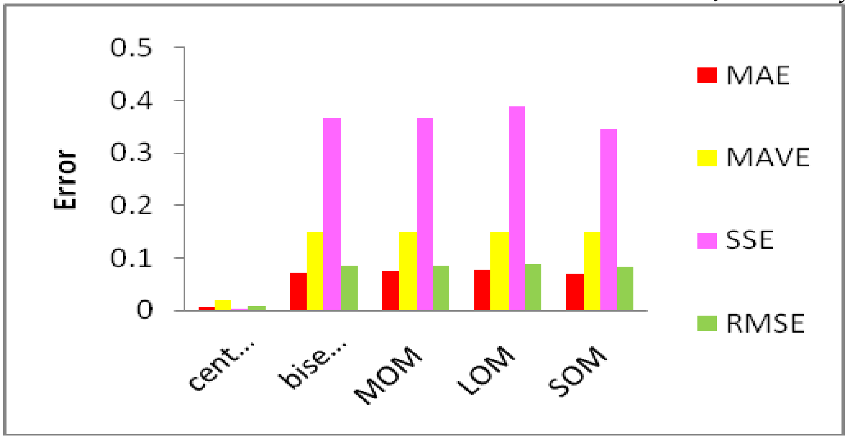

Fig.12. Errors at various operating currents.

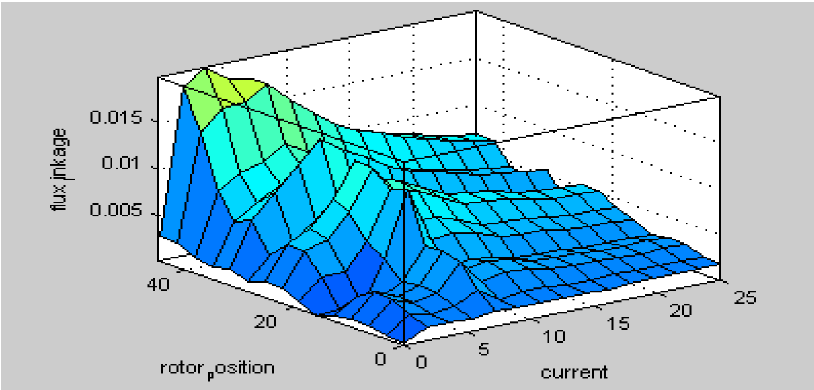

Fig.13. Nonlinear mapping surface of L(I, θ).

Apart from graphical representation, The quantity of errors from various Defuzzification techniques are tabulated in Table-6. From the comparison charts and error table, it is observed that the errors in LOM, MOM and bisector are very high. Compared to this, the errors in SOM is lesser. But still these errors are not within tolerant accuracy limits. From the overall observation, it is inferred that the centroid based SRM model has the least errors. Compared with all the other models, this L (I,θ) model of SRM is tested to be in fair agreement with the training data used for modeling. The error values are well within the tolerance limits.

Table-6: Comparison of L (I,θ) errors from various Defuzzification techniques.

Types of Errors	For θ varying from 0 to 45 deg at each phase current 1 to 25A				
	Bisector	MOM	LOM	SOM	Centroid
RMSE	0.0857	0.085552	0.08801	0.083035	0.006668
SSE	0.367228	0.365953	0.3872871	0.3447401	0.00222302
MAE	0.071889	0.073139	0.0766071	0.0699851	0.0058120
MAVE	0.14828	0.14828	0.14828	0.14828	0.01826

V. Conclusion

In this paper, a inductance model for a 3 phase, 6/4 pole switched reluctance machine is developed. The main objective of this work to determine the suitable defuzzification function for SRM modelling has been met. The FIS based SRM inductance models using various fuzzy defuzzification techniques such as bisector, MOM, LOM, SOM and centroid are built. The developed inductance models are tested with the actual inductance values obtained from SRDaS. The comparative analysis is discussed. From the performed analysis on all the inductance models, it is noted that the model built from centroid based defuzzification function is in fair concurrence in accordance to the actual set of magnetization data. The developed FIS based SRM inductance model using centroid function has a very simple structure, fast computational speed and characteristic of robustness and presents a good performance when applied to modeling, prediction and real time control across all industrial sectors especially in pharma industries.

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