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Modeling of Hot Resistance for Switched Reluctance Machine Using Regression Techniques

KEYWORDS: Switched Reluctance Machine ,hot resistance , temperature rise and Regression

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ABSTRACT *To design a energy saving electrical machine, it is important to fully understand its thermal behaviour of the which is a key component in lifetime expectance analysis. Rise in the winding temperature can be determined from the estimated values of winding resistance, both cold and hot. In this paper the hot resistance was modeled using linear regression technique. The modeled hot resistance helps to find out the load losses at any load situation. This technique estimates hot resistance of the winding in the case of 6/4 Switched Reluctance Machine using the input variables as cold resistance, ambient temperature and temperature rise. The estimated values of hot resistance show a good agreement between the computed values obtained using regression technique. Hence this model proves to be well suited for the estimation of temperature using resistance method.*

I. Introduction

In the last decades, the Switched Reluctance Machine (SRM) has become an important alternative in various applications both within the industrial and domestic markets, namely as a motor showing good mechanical reliability, high torque – volume ratio and high efficiency, plus low cost. The machine is robust and is appropriate for both high speed operation and operation in harsh environments due to the absence of windings on the rotor which simplifies the machine assembly. Furthermore it is convenient for heat management in this singly excited machine since the majority of the losses are within this stator [1]. The SRM operates on the principle of torque production through the tendency of the machines rotor to align itself to a position where the inductance is at its maximum.

The Electric currents and friction in an electrical machine generate heat. Hence temperature of different parts of the machine rise which could cause deterioration of insulation in windings [2], thermal stress, efficiency reduction which leads to motor failure. The life time of insulation, bearings of the machine shortens exponentially with the temperature rise of the machine. Also under high loads, temperature rise influences the machine electrical and magnetic parameters [3]. It is therefore necessary to maintain the temperature of the machine components within permissible limits for safety operation [4]. So the temperature rise estimation in SRM using regression techniques is presented in this paper. Section II discusses about the methods of temperature rise measurements. Modeling of hot resistance using linear regression is discussed in section III. Results and discussions are presented in section IV and concluded in section V.

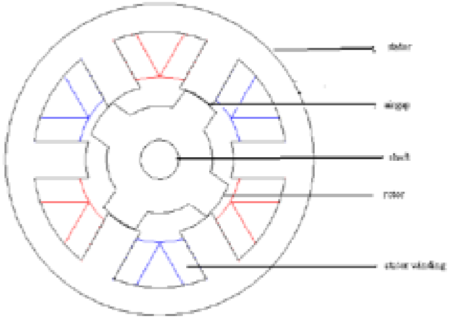

Figure. 1. Geometrical model of 6/4 SRM

II. Review on the methods of measurement of temperature rise.

The two main components of electromagnetic losses in Switched reluctance Machine are core losses in the laminations and copper losses in the windings. These losses are the heat source in a thermal analysis [5]. For any motor the copper losses can be calculated from the I2R products, where R is the effective resistance of one phase winding. Due to Skin and proximity effects, the value of R is greater than the DC resistance. Core losses in switched reluctance machine are relatively low but in high speed applications they become the dominant component of the total losses.

In an electrical machine heat flow is complex due to materials having different conductivities and heat transfer coefficients. Hence calculation of temperature rise is not simple [6]. To ascertain sufficient cooling ,heat runs are done to record temperature rises against time.

Three methods are widely used to determine the temperature rise in electrical machines namely

A) Thermometer method
B) Embedded temperature detector method
C) Resistance method

In the thermometer method, thermometer indicates the temperature of the surface at one point only. Embedded temperature detectors indicate the temperature of one internal point only. This method is rarely used due to the difficulties[7] faced in mounting as well as in its maintenance.

In the resistance method, temperature of winding is determined based on the increase in the winding resistance. It involves the measurement of cold and hot resistance and estimating the average temperature rise by the temperature coefficient of resistance. Temperature rise can be obtained using the formula for the ratio of resistance as

$$\frac{R_2}{R_1} = \frac{\theta_2 + 235}{\theta_1 + 235}$$

Where R_2= Resistance of the winding at the end of the test

R_1= Initial resistance of the winding(cold)

Θ_2= Temperature of the winding at the end of the test

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Θ_1= Temperature of the winding at the moment of initial resistance measurement

Θ_a= ambient air temperature at the end of the test

Thus temperature rise can be found as

$\Theta = \Theta_2 - \Theta_a = ((R_2-R_1)(235+\Theta_1))/R_1 + \Theta_1 - \Theta_a$

This formula is applicable if the windings are made of copper. The present study suggests a method for the determination of hot winding resistance in switched reluctance machine using a statistical method called Multiple variable regression.

III. Modeling Of Hot Resistance Using Multiple variable regression (MVR)

One way to model a system is to make use of simple and multiple linear regression analysis. A continuous response variable is explained in terms of various input factors. Regression analysis[8] is widely used for prediction and forecasting. It includes many techniques for modeling and analyzing several variables. Its focus is on the relationship between a dependent variable and one or more independent variable . Regression analysis helps to understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. The estimation target is a function of the independent variables called the regression function. For carrying out regression analysis many techniques such as linear regression and ordinary least square have been developed. Regression models involve the following variables namely the unknown parameters, denoted as β, which may represent a scalar and vector, the independent variables, X and the dependent variable, Y.

Regression models involve the following variables:

- The unknown parameters, denoted as β, which may represent a scalar or a vector.
- The independent variables, X.
- The dependent variable, Y.

A regression model relates Y to a function of X and β.

$Y \approx f(\mathbf{X}, \boldsymbol{\beta})$, the approximation is usually formalized as E(Y | X) = f(X, β). To carry out regression analysis, the form of the function f is based on knowledge or convenient form for f is chosen. Assume now that the vector of unknown parameters β is of length k. To perform a regression analysis one must provide information about the dependent variable Y:

- If N data points of the form (Y,X) are observed, where N < k, since the system defining the regression model is underdetermined most classical approaches to regression analysis cannot be performed.
- If exactly N = k data points are observed, and the function f is linear, the equations Y = f(X, β) can be solved exactly rather than approximately.. If f is nonlinear, a solution may or may not exist,
- The most common situation is where N > k data points are observed, there is enough information in the data to estimate a unique value for β that best fits the data. In this case, the regression analysis provides the tool to find a solution for unknown parameters β so that the distance between the measured and predicted values of the dependent variable Y can be minimized as per the method of least squares.

IV. Results and Discussions

The hot resistance values are obtained from the thermal analysis carried out on a 6/4 switched reluctance machine for various values of ambient temperature and are listed in Table I. Resistance of the winding at ambient temperature represents cold resistance and hot resistance is calculated as per heat run test.

Table I. Estimation of hot resistance

Temperature rise_c_1	Cold Resist ance- C_2	Ambient temperature-C_3	Hot resistance-C_4
6.628	0.4981	30	0.5355
10.765	0.4992	30	0.5378
19.845	0.5017	30	0.5418
19.855	0.5022	30	0.5422
20.449	0.5034	30	0.5423
5.521	0.395	20	0.497
9.745	0.4	20	0.499
16.184	0.418	20	0.5
19.981	0.438	20	0.508
20.01	0.43	20	0.51
20.245	0.45	20	0.515
20.449	0.48	20	0.518
5.521	0.52	45	0.5629
9.745	0.523	45	0.5635
16.184	0.5235	45	0.565
18.245	0.525	45	0.569
19.845	0.527	45	0.57
19.981	0.529	45	0.572
20.01	0.53	45	0.5735
20.245	0.532	45	0.574
20.449	0.535	45	0.579

In order to validate our model done using regression technique, residual plots are analysed. Regression residuals are actual estimates of true error. If the modeling is done correctly then the residuals should be centered on zero throughout the range of the fitted values. Hence residuals fall in a symmetrical pattern and have a constant spread throughout the range.

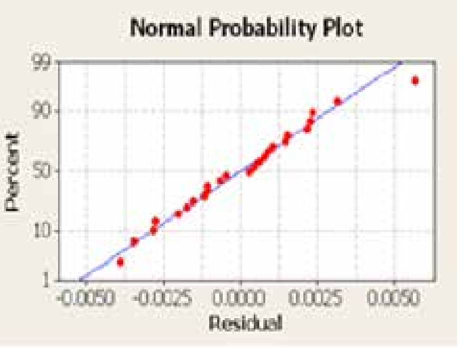

Fig.2. Normal Probability Plot

The assumption of normality in error terms is validated in fig.2. Most of the output values are clustered around central line indicating that error terms are approximately normal.

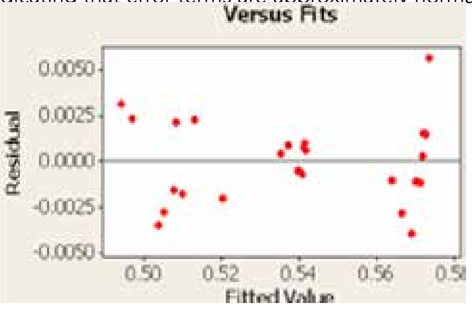

Fig.3. Residual Vs Fitted value

In fig.3. the error terms are approximately half above and half

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below the zero line indicating that our assumption of error terms

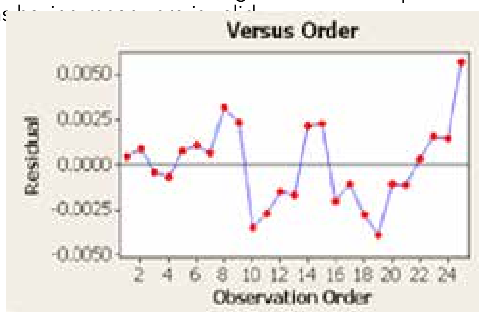

Fig.4. Residual Vs Observation order

A clear cyclic pattern as shown in Fig.4.indicates that error terms are dependent on the time variable. The (MVR)regression equation for hot resistance modeling is found to be

C4 = 0.365 + 0.000387 C1 + 0.240 C2 +0.00161 C3

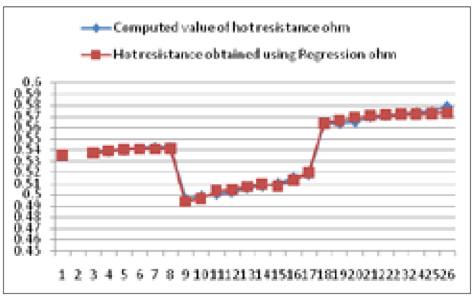

Fig.6. Comparison between computed and regression results in estimating hot resistance

From the above results, it is clear that the predicted values using MVR are very close with the computed values. It is observed from the mathematical modeling that regression technique predicts the hot resistance with much less error. Hence it is proved that this Multiple Variable Regression technique is capable of accurately predicting hot resistance for electrical machines which will help to find the losses and the temperature rise in them without any complicated experimental set up.

V. CONCLUSION

This paper has discussed about the effects of temperature rise in electrical machines and the methods of estimating the same. In this work the measurement of temperature rise in switched reluctance machine using hot resistance estimation method has been used and is implemented using Multiple Variable Regression.. From the results it is clear that the results of hot resistance values of SRM from the proposed technique is very close with the actual computed values .Thereby this method is highly suitable for such estimations in real time applications.

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