

Real Time Temperature Measurement for the Thermal protection of Switched Reluctance Machine

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Abstract—Heat transfer is a critical aspect related to Electrical machine design. To insure a successful design of the electrical machine, special attention has to be given to thermal aspects in parallel with the traditional Electromagnetic design. For calculating the temperature rise in electrical systems such as electrical machines or power electronic systems it is important to measure the temperature rise in the motor winding .The common method has many shortcomings, therefore a new method for measuring the temperature rise is proposed in this paper. Rise in the winding temperature in an electrical machine namely Switched Reluctance Machine can be determined from the estimated values of winding resistance calculated during the heat run test . The results obtained for a 2 H.P Switched Reluctance Machine is validated with the temperature measured using Resistance temperature detector and Infra-red Camera.

Keyword- Regression, Switched Reluctance Machine ,hot resistance and temperature rise.

1. INTRODUCTION

Thermal Protection is one of the most important aspect to monitor the proper condition of an electric motor. Thirty percent of motor failure occurs due to the damage in stator winding insulation. It is commonly assumed that for every 10°C increase above its stator winding temperature limit , the motor's life is reduced by 50%/. Therefore accurate monitoring of the stator winding temperature is crucial against thermal protection.[1]. Generally the heat generated by the electric currents and friction in an electrical machine increase its temperature. This could cause deterioration of insulation in windings [2], thermal stress, efficiency reduction and 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]. Hence the temperature rise estimation is implemented using resistance method in this paper for a 8/6 Switched Reluctance Machine.

The Switched Reluctance Machine (SRM) has become an important alternative in various applications both within the industrial and domestic markets, that require good mechanical reliability, high torque –volume ratio, wide speed range, fast dynamic response, high efficiency, plus low manufacturing cost. The machine is robust and is appropriate for both high speed operation and operation in harsh environments. The absence of windings and permanent magnets on the rotor simplifies the machine assembly as shown in Figure.1[5].Because of these characteristics, the SRM may be used as a Motor/Generator in many applications where a robust machine is required [6]. With the increasing pressure on the design of energy saving electrical machines, a new trend has come to carry out thermal analysis along with the traditional Electromagnetic field analysis. Knowledge of thermal behaviour in different operating conditions can prevent the damages caused by breakdown of stator winding insulation, over heating and can also improve the utilisation of the system[7]. Therefore to achieve a useful operational lifetime of the motor, the temperature of the motor components must be maintained below allowable limits[8].This paper is organized as follows. Section II discusses about the various methods to measure the temperature rise. The experimental set up along with results and validation are presented in section III and concluded in section IV.



1.(b) Rotor



1.(a) Stator

Fig.1. View of 8/6 Switched reluctance machine

2. 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 [9]. Temperature is one of the most important thermodynamic properties which determines the state[10] of a material and appears in many physical laws. It is so important in a temperature field to know the basic methods of heat measurement that cannot be measured directly. For this purpose, three methods discussed here are namely

- 1) Resistance method
- 2) Resistance temperature detector(RTDs)
- 3) Infra-red (IR) thermometry

1. Resistance method

In the resistance method, average stator winding temperature can be estimated based on the increase in the winding resistance [11]. It involves the measurement of cold and hot resistance and estimating the average temperature rise by the temperature coefficient of resistance of copper. Temperature rise can be obtained using the formula[12] 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

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

$$\begin{aligned} \Theta &= \theta_2 - \theta_a \\ &= ((R_2 - R_1) (235 + \theta_1)) / R_1 + \theta_1 - \theta_a \end{aligned}$$

This formula is applicable if the windings are made of copper. In case of materials other than copper, reciprocal of resistance temperature co-efficient at 0°C should be used instead of 235.

Thermal testing includes the measurement of ambient temperature which is the room temperature in the vicinity of the motor. It is the temperature that the entire motor would assume when it is shut off and completely cool. If the motor is operated in a ambient temperature lower than 40° C, then motor life will be extended. The Cold resistance of the winding is measured by acquiring the D.C voltage and current across the stator winding when the machine is stationary. Then the machine is operated at a particular loaded condition until the temperature indicated by the RTD reach their steady state value. That is when the temperature change is less than 2°C per hour [13], then the resistance of the stator winding is measured which forms the Hot resistance.

2. Resistance temperature detector(RTDs)

The two most common methods used to measure industrial temperatures are with sensors namely resistance temperature detectors (RTDs) and thermocouples. Choice between them is usually determined depending on temperature range, response time, size, accuracy and stability requirements. Resistance thermometers are constructed in a number of forms and offer greater stability, accuracy and repeatability in some cases than thermocouples. Thermocouples use the Seebeck effect to generate a voltage where as resistance

thermometers use electrical resistance and require a power source to operate. These sensors measure temperature by correlating the resistance of the RTD element with temperature. This resistance ideally varies linearly with temperature. The RTD element is made from a pure material, platinum, nickel or copper. The element is usually quite fragile hence it is often placed inside a sheathed probe to protect it. Due to higher accuracy and repeatability, they can slowly replace the use of thermocouples in many industrial applications below 600 °C,

RTDs [14] are active devices which require an electrical current to produce a voltage drop across the sensor that can be then measured by a calibrated read-out device to measure its resistance. Its advantages are stable output for long period of time, ease of recalibration and accurate readings over relatively narrow temperature spans. When compared to the thermocouples, they have smaller overall temperature range, higher initial cost and less rugged in high vibration environments. But mechanical strain and resistive heating on the resistance thermometer also causes inaccuracy.

3. Infra-red (IR) thermometry

A robust method of characterizing thermal behavior which has gained popularity is the Infra-red (IR) thermometry. It provides good resolution and accuracy. It can be used in studying the dynamic thermal management techniques. Its external nature also helps in locating the thermal sensors at temperature-critical portions. It is one of the noncontact temperature measurements type. Measurement of the body's surface temperature is done by the electromagnetic radiation emitted from the body and received by the camera sensor. The electromagnetic waves originating from mechanical movement of particles can be characterized by their intensities and wavelengths. These characteristics are then related to the temperature (the hotter object, the shorter wavelength). However, there are a few limitations of using IR imaging since IR rays cannot pass through metal.

3. RESULTS AND DISCUSSIONS

A 2 H.P four phase 8/6 SRM was tested in the laboratory to observe the temperature rise in stator winding. RTDs were inserted into selected parts of the machine to measure the temperature. The experimental setup is shown in Fig.2.

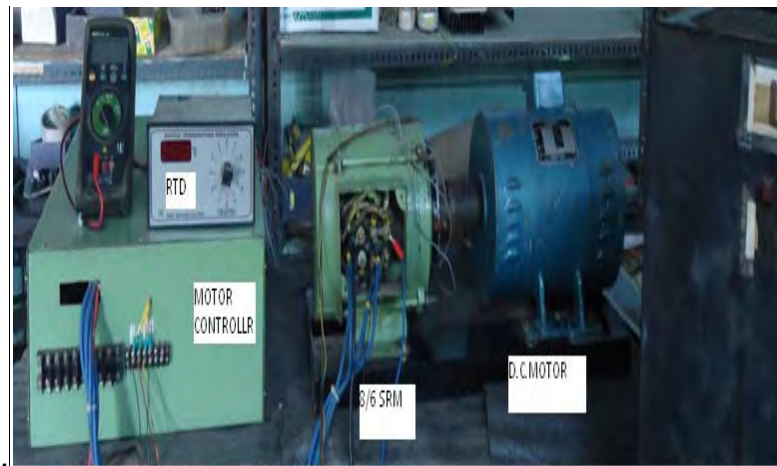


Fig.2. Experimental setup for the SRM thermal measurement

The hot resistance, cold resistance and ambient Temperature values are measured on a 8/6 switched reluctance machine using the above setup and are listed in Table I. Resistance of the winding at ambient temperature represents cold resistance and hot resistance is resistance of the winding calculated at the end of the Test as per heat run test. Based on the resistance method, temperature of the winding is calculated to be 67.9 °C.

TABLE I
Results from Resistance method

Ambient Temperature in °C	33
Cold Resistance in Ω	0.023
Hot Resistance in Ω	0.026
Temperature of the winding at the end of the Test in °C	67.9

The above result is validated using Resistance temperature detector and Infra-red thermometry. The machine is operated at full load until the temperature indicated by the RTD reach their steady state value .RTDs are inserted into selected parts of the machine to measure the temperature and are listed in Table.2.

TABLE.II
Temperature measurement by Resistance temperature detector

Time in minutes	Temperature of the Stator winding measured by the RTD in °C (Resistance Temperature Detectors)
Initial	33
20	40.8
30	49.6
35	53.2
45	58.1
60	63.4
70	68

The measurement is done using IR camera at different times at t=10, 30, 60 min and soon with full load. The measurement period is considered till the temperature reaches the steady state value. The areas are coloured according to its temperature as shown in figure.3 which depends on the wavelength of the radiation that the camera sensor received. The measurement error is due to the uncertainty of the correct values of emissivity of the body surface.

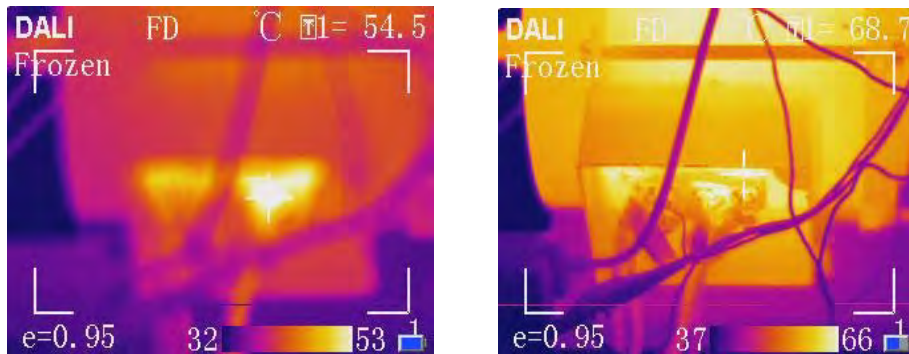


Fig.3. Temperature measurement by IR camera after 20 and 100 minutes

Table .III
Comparison Table

Method	Temperature of the Winding at the end of the test in °C
Resistance method	67.9
RTD	68
IR Camera	68.7

From the table, it was clear that temperature measured using resistance method is close with the results obtained using RTD and IR camera. Thus temperature of the winding can be calculated easily without any complicated and costly arrangement. Thus the hot resistance helps to find the load losses at any load situation without using complicated measurement set –up. These losses from the heat source which should be analysed to maintain the temperature rise within the limits.

4. CONCLUSION

The effects of temperature rise in electrical machines and the methods of estimating the same are discussed in this paper. In this work the measurement of temperature rise in switched reluctance machine using hot resistance estimation method has been implemented . The results are compared with the actual measured values obtained using Resistance temperature detector and IR camera. Thereby it is concluded that this method is highly effective and suitable for temperature rise measurement in real time applications.

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