STATIC AND TRANSIENT THERMAL ANALYSIS OF POWER FACTOR CONVERTERS IN SWITCHED RELUCTANCE MOTOR DRIVE

Dr. G.Venkatesan , Dr. K.Nithiyananthan
Department of Electrical and Electronics Engineering,
Karpagam College of Engineering, Coimbatore, INDIA
geevee76@gmail.com, nithiieee@yahoo.co.in

Abstract: *Switched Reluctance Motor (SRM) drives are gaining popularity due to their simple construction, easy of control and reduced maintenance requirements. Power electronic converters are used to switch currents into the windings of SRM for their operation. The input current waveforms of the power controllers are distorted due to switching operation, which results in poor input power factor in the supply side. Input Power factor controllers are implemented along with the power converters, thereby improving the input power factor. The switching devices of the input power factor controller and power converter devices are mounted on the same base of a heat sink. In this paper an attempt is made to investigate the temperature distribution in the power factor controller and converter devices under steady state and transient condition of operation. The thermal analysis is performed using ANSYS software and the results are reported. The real time temperature of the hardware circuit also measured for various load current and the relation between the temperature and load current tabulated and compared.*

Key words: *Switched Reluctance motor, Power factor correction, Static and transient thermal analysis*

1. Introduction

Switched Reluctance Motor (SRM) drives have been used for aerospace systems, linear and mining drives, hand held tools and home utility applications. SRM is suitable for variable speed as well as servo type applications. The main advantages of using SRM are, simple in construction, robust structure, high efficiency, controllability and high ratio of torque to rotor volume. SRM drives are normally supplied from a stable dc link voltage. The switching of voltage into the phase winding is done by power converter, in which the input current is distorted. The distortion of input current waveform reduces the power factor of the system. In the view point of energy saving and to improve the power factor, researchers have introduced different power factor improvement methods. Due to the implementation of the power factor controller along with the power converter, the total number of devices used is increased. It leads to more amount of heat generation in the power devices and the temperature of the devices to be observed.

The development of microelectronic devices and reduction in the size of devices, the thermal management which deals with the dissipation of heat has become vital issue in designing the electronic circuits. The performance and life of the electronic equipment are directly related to the temperature of the equipment. It is necessary to maintain the device operating temperature within the limit specified in the manufacture’s specifications. When the device temperature is more than the specified limits, heat sinks are used to dissipate from a hot surface to a cooler medium. The three basic methods by which heat can be dissipated are radiation, conduction, and convection. The large amount of heat is dissipated by forced convection as the cooling air passes over the individual electronic components.

Chan-Ki Kim and Kee-Man Nho [1] discussed about the heat sink design for the high power converter with air cooling method. Chyi-Tsong Chen et al [2] discussed the optimal plate fin design and control for the central processing unit (CPU) heat sink processes. Finite element method was used to investigate the heat transfer in heat sink. Emre Ozturk [3] explained the modeling and analysis of complete computer chasis model with heat sinks and fans. ANSYS Icepak software was used for pre processing and FLUENT software was used for solution and post processing of the solution.

Lee [4] developed the analytical simulation model for predicting and optimizing the thermal performance of bidirectional fin heat sinks. Walker and Williams [5] described the heat management in converter design and application. The thermal effects of converter PCB design and package materials were also discussed. Xiaoni Xin and Jianhong Zeng et al [6] analyzed the PFC design for the high power density applications. The switching frequency effects on PFC choke, heat sink and EMI filter were discussed.

Cova et.al [7] analysed the thermal modeling and design of power converters with various thermal constraints. A.G.Alshaer et.al [8] discussed the thermal management of electronic devices using carbon foma and PCM/ nano-composite. Ui- Min Choi et.al [9] explained the study and handling methods of Power IGBT module failures in the power electronics converter systems.

In the references cited above, the thermal analyses are done for various applications, devices using different software. In this paper, the devices employed for the power factor correction and power converters for the Switched Reluctance Motor are taken and their thermal analyses are performed and the temperature distributions in the heat sink are also obtained.

2.Modeling of Digital PFC

A Digital PFC circuit employing Rectifier Bridge, Power MOSFET's and diodes is modeled using ANSYS. In the PFC of SRM the various converter used are rectifier, power factor corrector (boost converter device) and asymmetric bridge converter. The MOSFET (IRFP 460) is chosen as the boost converter device and the asymmetric power converter switching device. The Diode (MUR 3060) is chosen for the asymmetric power converter and rectifier. All the dimensions of the devices are taken from the data sheet and placed in the heat sink.

The operating temperatures at the device junction have a major impact on the device reliability and device operation. The main reason for the heat generation is the switching of the devices. The temperature of devices is dependent on device spacing due to thermal interaction between the devices. The temperature distribution of the devices should be as uniform as possible. The temperature of a particular device is more, it leads to the thermal stress of the device and the device may be burn out.

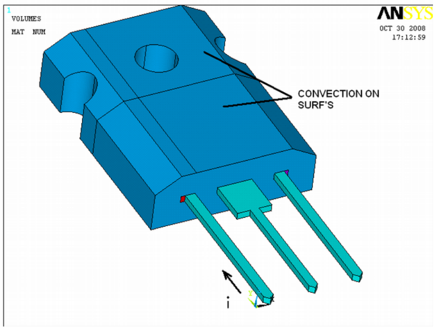

Fig. 1. MOSFET model

In the modeling process, the three leads of the MOSFET are placed in a plastic cap as shown in the Fig. 1. The dimensions of the heat sinks and fin dimensions are given in Table 1.

Table 1 Dimensions of heat sink

Properties	**Heat sink 1**
Height of heat sink	100 mm
Width of heat sink	276.75 mm
Thickness of heat sink	10 mm
Number of fins	11
Fin length	50 mm
Fin thickness	2.5 mm
Distance between the fins	22.725 mm

3. Steady state thermal analysis of Single Device

The steady state thermal analysis is performed on the single device for various currents from 1 A to 10 A insteps of 1 A. The temperature distribution for 5A is shown in the Fig. 2. The relationship between the temperature and the current is given in the Table 2. The temperature is higher in the leads of the device when current is flowing through it and the plastic cap top portion the temperature is lesser one as compared to the other parts of the device. The temperature at initial stage of 1 Ampere current is 28.8 ° C and the temperature gradually increases with increase in the current rating. When the current is 10 Amps, the temperature is 110 ° C.

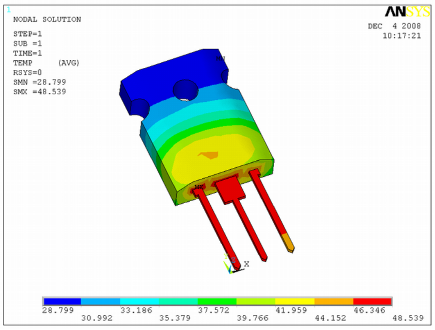

Fig. 2. Thermal analysis of Single MOSFET for a current of 5 Amps

Table 2 Current Vs Temperature

S.No	**Current (Amps)**	**Temperature (°C)**
1.	1	28.8
2.	2	31.3
3.	3	35.4
4.	4	41.1
5.	5	48.5
6.	6	57.6
7.	7	68.3
8.	8	80.6
9.	9	94.5
10.	10	110.2

4. Steady state thermal analysis of Multiple devices

The various converters used are rectifier, boost converter, inverter and SRM power converter. The various converters used for the analysis and the devices used are tabulated in table 3. The devices 7,8,9,10 forms the first phase of SRM, the devices 11,12,13,14 forms the second phase of SRM, the devices 15,16,17,18 forms the third phase of SRM.

Fig. 3. shows the placement of the devices on the heat sink with fins. Fig. 4. shows the thermal distribution of the devices and heat sink when all the SRM converter switches are in OFF condition for a current of 5A. The temperature of the SRM converters are minimum and the input side device temperature are high. Fig. 5. shows the 1st set of SRM converter is ON and the 2nd and 3rd sets are OFF for a current of 5A. Fig. 6. shows the 2nd set of SRM converter is ON and the 1st and 3rd sets are OFF for a current of 5A. Fig. 7. shows the 3rd set of SRM converter is ON and the 1st and 2nd sets are OFF for a current of 5A.

The phase windings are switched on in a cyclic manner and the temperature of the particular phases are more as compared to other two phase winding devices. The temperature during the steady state operation of SRM are within the temperature specified in the data sheet of the devices. The design of heat sink and spacing between the devices also take part in the temperature distribution of power converter circuits.

Table 3 Device number and Devices used

S.No	**Device number**	**Converter**	**Device used**
1	1	Rectifier	Diodes
2	2	Boost converter	MOSFET
3	3,4	Inverter	MOSFET
4	5,6	Rectifier	Diodes
5	7,8,11, 12,15,16	SRM converter	MOSFET
6	9,10,13, 14,17,18	SRM converter	Diodes

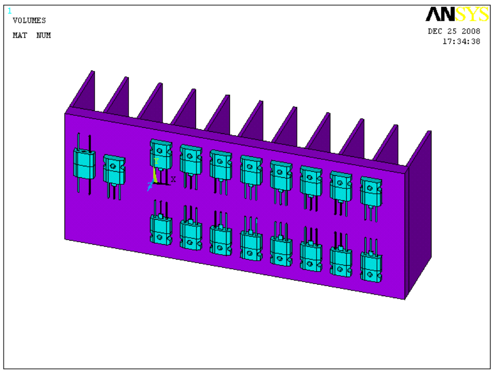

Fig. 3. Placement of devices in heat sink with fins

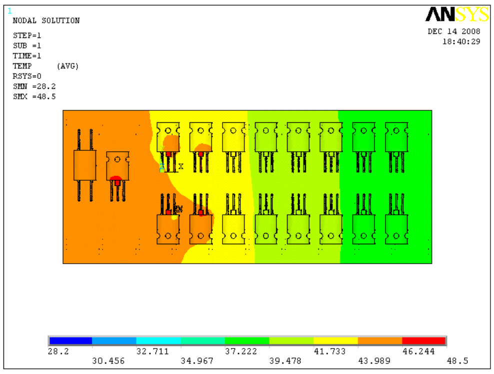

Fig. 4. Temperature plot when all switches of SRM converter is OFF for 5A

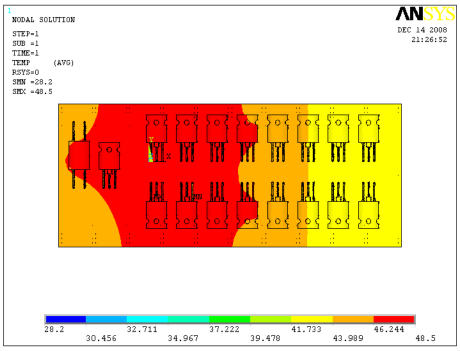

Fig. 5. Temperature plot when 1^{st} phase of SRM converter is ON for 5A

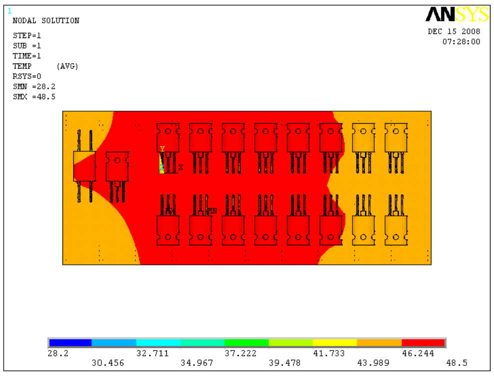

Fig. 6. Temperature plot when 2^{nd} phase of SRM converter is ON for 5A

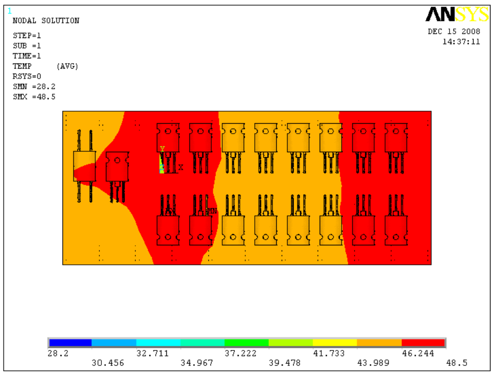

Fig. 7. Temperature plot when 3^{rd} phase of SRM converter is ON for 5A

5. Transient state thermal analysis of Multiple devices

The transient analysis of converters are made in a manner that each and every SRM converter is operating for a period of 0.02 seconds. The switching ON and OFF of the converters are given in table 4.

Fig. 8. shows the temperature distribution for a transient operation of the converters for a current of 1A to 2A as shown in the table 4. Fig. 9. shows the temperature distribution for a transient operation of the converters for a current of 1A to 3A in steps of 1A. Fig. 10. shows the temperature distribution for a transient operation of the converters for a current of 1A to 4A in steps of 1A.

Table 4 Transient operation of SRM converter

S. No	SRM converter ON	SRM converter OFF	Time (sec)	Current
1	1^{st} set	2^{nd} & 3^{rd} set	0 to 0.02	1 A
2	2^{nd} set	1^{st} & 3^{rd} set	0.02 to 0.04	1 A
3	3^{rd} set	1^{st} & 2^{nd} set	0.04 to 0.06	1 A
4	1^{st} set	2^{nd} & 3^{rd} set	0.06 to 0.08	2 A
5	2^{nd} set	1^{st} & 3^{rd} set	0.08 to 0.1	2 A
6	3^{rd} set	1^{st} & 2^{nd} set	0.1 to 0.12	2 A

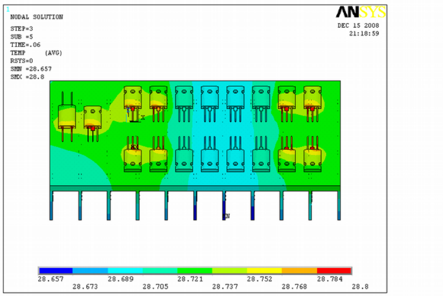

Fig. 8. Temperature plot for transient operation of converters for a current 1A to 2A in steps of 1A with time duration of 0.02 sec for a set

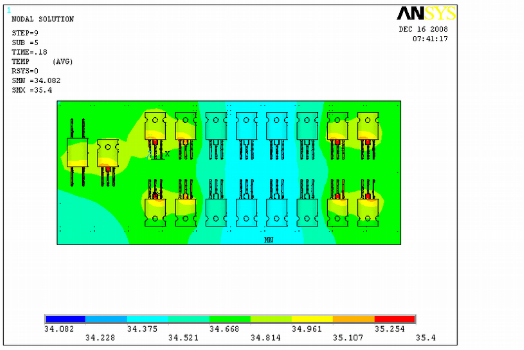

Fig. 9. Temperature plot for transient operation of converters for a current 1A to 3A in steps of 1A with time duration of 0.02 sec for a set

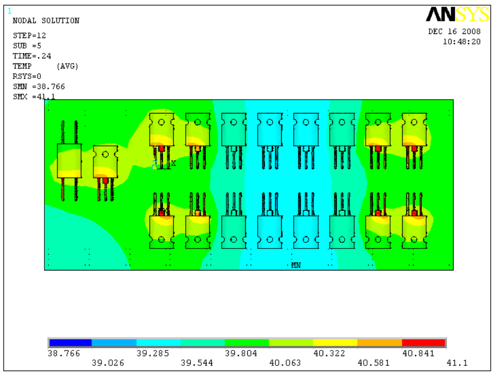

Fig. 10. Temperature plot for transient operation of converters for a current 1A to 4A in steps of 1A with time duration of 0.02 sec for a set

In these analysis, the combination of rectifier, boost converter and asymmetric bridge converter devices are modeled and the temperature distribution is obtained.

6. Real time measurement of Temperature:

The real time measurement of temperature is found by using Infrared thermometer. As the temperature goes up, the amount of infrared radiation increases. An infrared device is like a camera, and finds the temperature at a particular point. By using the infrared temperature measurement kit, at room temperature (35 ° C) the temperatures of the devices are measured.

During the initial conditions the temperature of the device is around 35° C and increases to the maximum of 85° C for a maximum load current of 6Amps. The maximum temperature for the measurement is limited to 85° C, beyond the range the device may fail due to over temperature.

Table 5 shows the temperature for various load currents of 2A, 4A and 6 A. The load current of 2 A reaches its steady state temperature value of 45° C after 9 minutes of motor operation. For a load current of 4A, it reaches the steady state value of 58 °C after 18 minutes. For a load current of 6 A, it reaches the value of 85° C after 15 minutes. The devices are heated for a higher current at a earlier time.

Time (Sec)	Load Current (Amps)		
	2 A	4A	6A
INITIAL	30° C	30° C	30° C
AFTER 1 MIN	35° C	35° C	35° C
5 MIN	41° C	42° C	46° C
10 MIN	45° C	50° C	72° C
15 MIN	45° C	55° C	85° C
20 MIN	45° C	58° C	> 85° C

Conclusion

This paper discusses the prediction of the temperature distribution at various points in the power converters of SRM using the ANSYS software package. The various converters used in the SRM are bridge rectifier, boost converter and classic bridge converter. Static and transient thermal analysis is performed and results were post processed. It is observed that the temperature of static and transient thermal analysis is less than the temperature specified in the manufacturer data sheet. By using the results, the power converters were designed and same was suggested to use in real time implementation. The real time temperature are also measured for various load currents.

References:

1.Chan-Ki Kim., and Kee-Man Nho. (1998), 'Heat sink design of high power converter' , Power Electronics Specialists Conference, Vol 2, PP 2122-2130.2

2.Chyi-Tsong Chen, Ching-Kuo Wu., and Chyi Hwang, (2008),'Optimal Design and Control of CPU Heat sink processes', IEEE Transactions on components and Packaging Technologies, vol 31, PP.184-195

3.Emre Ozturk and Ilker Tari (2007), 'CFD Modeling of Forced Cooling of Computer Chassis', Engineering applications of computational fluid mechanics, Vol. 1, No. 4, pp. 304-313.4

4..Lee S. (1995), 'Optimal design and selection of heat sinks' , IEEE Transactions on components, Packaging, and Manufacturing Technology, vol.18, Issue 4, pp 812-817

5.Walker A.D., and Williams D (1996), ' Thermal design considerations in the design and application of DC-DC converters', Applied Power Electronics Conference and Exposition, Vol.2 , PP 990-996.

6.Xiaoni Xin., Jianhong Zeng., Haoyi ye and Aibinquiu (2006), ‘ PFC Design for High Power Density Application’, International Telecommunications Energy conference, PP 1-5.

7. P. Cova, N. Delmonte (2012) , ‘Thermal modeling and design of power converters with tight thermal constraints’,Microelectronics Reliability, Elesvier publications, pp. 2391–2396.

8..G. Alshaer, S.A. Nada, M.A. Rady et.al., (2015) , ‘Thermal management of electronic devices using carbon foam and PCM/nano-composite’, International Journal of Thermal Sciences, 79-86.

9. Ui-Min Choi, Frede Blaabjerg, Kyo-Beum Lee (2015), ‘Study and Handling Methods of Power IGBT Module Failures in Power Electronic Converter Systems’ , IEEE Transactions on Power Electronics, Vol. 30, No. 5, May 2015, pp. 2517 -2533.