

Thermal and efficiency analysis of a single phase induction motor with Peltier devices

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(Received 29 July 2011; accepted 26 October 2011)

Abstract

We present the results obtained from the thermal and efficiency analysis of a single phase induction motor with Peltier devices. A single phase induction motor is completely simulated in SolidWorks® and Matlab® Simulink®. The cooling of the induction motor is done by means of Peltier devices and the corresponding power consumption and stator temperature is recorded. From the SolidWorks® simulation results it can be seen that the temperature of the induction motor under normal operating conditions is cooled from 68°C to 35°C. From the Matlab® Simulink® simulation results show that the efficiency of the induction motor is increased by an average of 3.73% from the normal operating condition to the cooled operating condition with the inclusion of the Peltier devices onto the system.

Key words: *Single phase induction motor, Peltier devices, Energy efficiency, Thermal analysis*

1. Introduction

It is estimated that electric motor systems globally consume about 40% of the electricity supplied to the industrial sector and for South Africa it is estimated to be about 60% (Onwunta *et al.*, 2011; Mthombeni *et al.*, 2008). Improving the energy efficiency of electric motors will therefore result in a substantial energy saving. In this paper the energy efficiency of a single phase induction motor is improved by the inclusion of Peltier devices onto the system. The results obtained from the thermal analysis and energy efficiency analysis is presented in section 3. The focus is specifically on single phase induction motors, but the same method (cooling by means of Peltier devices) can be applied to three phase induction motors and other electric motor systems.

Losses in an electric motor can be classified into the following four categories: 1) magnetisation losses, 2) joule effect losses, 3) mechanical losses, and 4) stray load losses (Middelberg, 2011). In this paper we focus specifically on the stator copper losses of the single phase induction motor, but the cooling done by the Peltier devices might also have an influence on some of the other losses. Middelberg, 2011 further provides an explanation on each of these losses.

When a Peltier device is supplied with a dc current it will cool on the one side (cold side) of the device and the opposite side (hot side) of the device will become warm due to the Peltier effect (Morimitsu, 2010; Nelson *et al.*, 1989). A thermoelectric element which can generate a heat transfer is also defined as a Peltier

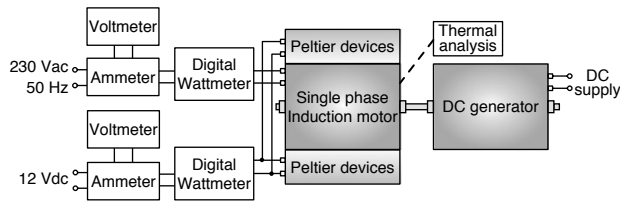


Fig. 1. Overview connection diagram.

device (Maekawa *et al.*, 1998; Nelson *et al.*, 1989). For this project a thermal analysis is performed on the single phase induction motor to determine the exact impact of the Peltier devices. Peltier devices further have relatively fast responses and are therefore considered an ideal tool for transmission of thermal sensation (Morimitsu, 2010). More detail on Peltier modules for commercial use and the use of Peltier devices to control column temperature in high-performance capillary electrophoresis is provided by Maekawa *et al.*, 1998; and Nelson *et al.*, 1989.

Figure 1 shows an overview connection diagram of the single phase induction motor with a dc generator connected to the shaft and the placement of the Peltier devices. For this project the dc generator was used to represent a load on the induction motor. The output of the dc generator could also be used as a dc supply for the Peltier devices. The single phase induction motor is completely simulated in SolidWorks® and a thermal analysis is performed on the single phase induction motor by means of the SolidWorks® Flow Simulation software. More detail on the thermal analysis is provided in the materials and method section (section 2). In order to measure the power consumption and obtain the parameters of the single phase induction motor a digital wattmeter, ammeter and voltmeter is connected to the terminals. The power consumption of the Peltier devices is measured separately with another digital wattmeter. The power consumption and efficiency of the single phase induction motor is calculated by means of a Matlab® Simulink® simulation. More detail and results on the Matlab® Simulink® simulation is provided in the results and discussion section (section 3). More information on thermal cooling and energy efficiency of induction motors is provided by van Jaarsveldt, 2011.

2. Materials and method

This section provides an overview on the single phase induction motor model (simulation done in

SolidWorks®) and the location (placement) of the Peltier devices on the single phase induction motor. A SolidWorks® simulation model was designed for both the single phase induction motor as well as the housing unit for the Peltier devices. The SolidWorks® simulation models are used as basis for the thermal analysis on the stator windings of the single phase induction motor for the normal- and cooled operating conditions. Figure 2 provides a SolidWorks® drawing of the single phase induction motor without the housing unit for the Peltier devices. The different parts of the single phase induction motor were separately simulated before they were combined as one unit. The dimensions of the simulation induction motor correspond with the physical system. More detail on single phase induction motors and simulation of single phase induction motors is provided by Bathunya *et al.*, 2001; Domijan *et al.*, 1994; Gupta, 1998; and Guru *et al.*, 2001.

Figure 3 provides an exploded view of the SolidWorks® induction motor which is used to examine the various parts of the designed SolidWorks® model. The components in the exploded view of the induction motor include the motor body, the rotor of the induction motor, the stator assembly as well as the switching device. All of the above mentioned parts were accurately designed according to the physical single phase induction motor. The stator winding construction is isolated for the purpose of the thermal analysis.

Figure 4 provides a drawing of the SolidWorks® single phase induction motor with the Peltier devices and the housing structure. In this figure the four Peltier devices used to cool the front end side of the stator

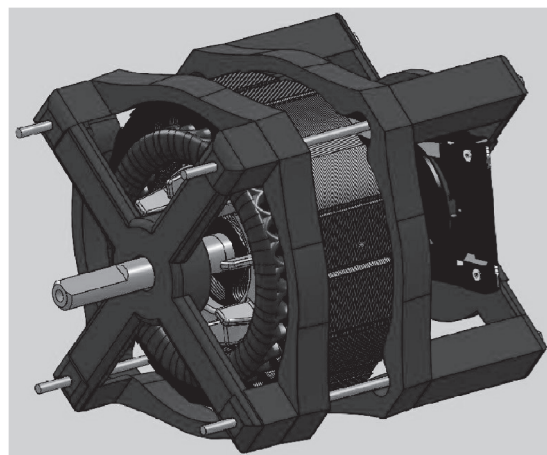


Fig. 2. SolidWorks® single phase induction motor model.

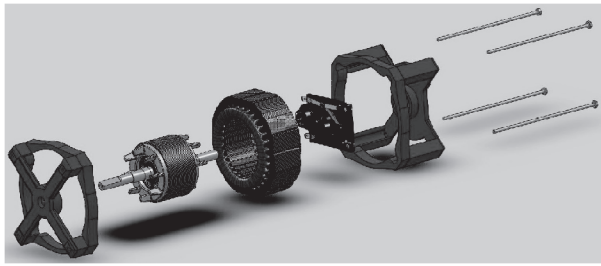


Fig. 3. Exploded view of the SolidWorks® single phase induction motor.

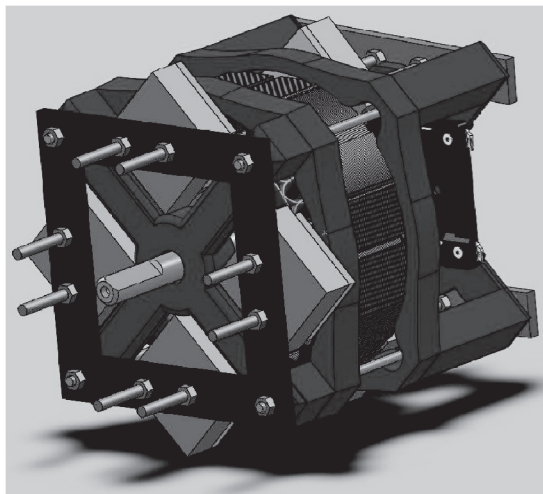


Fig. 4. SolidWorks® single phase induction motor with Peltier devices.

winding is clearly visible. The physical construction of the single phase induction motor constricted the design of the cooling system to a maximum of two Peltier devices at the rear end side of the induction motor. The thermal analysis of the induction motor with the Peltier devices is discussed in section 3.1.

3. Results and discussion

3.1. Thermal analysis results

This section provides the results obtained from the thermal analysis performed in SolidWorks®. To be able to determine the heat transfer within the stator

winding of the induction motor it is necessary to perform a thermal analysis. The thermal analysis also shows the optimum amount of Peltier devices as well as the most effective positions of each. The stator winding assembly of the single phase induction motor is used for the thermal analysis for both the normal and the cooled operating conditions. The thermal analysis is performed by using the SolidWorks® Flow Simulation software. This simulation packet allows for various changes of initial conditions as well as material properties, which allows for more detailed and accurate simulations. The results of the thermal analysis are displayed in numerical format as well as in 3-D thermal analysis plot format. The numerical values are displayed by the use of volume goals as well as surface goals.

The volume goals are the result of the heat transfer throughout the complete body of the stator. The surface goals are bound to a specific face of the stator winding. The surface goal can thus be seen as a typical measurement taken by a thermal probe. The values shown in table 1 are the results obtained for both the volume and surface goal of the thermal analysis under the normal operating conditions of the single phase induction motor. The values obtained from the volume and surface goals are very accurate and are used to evaluate the temperature of the stator winding under normal conditions. This information was also used to aid in the final design of the complete assembly. From this table it can be seen that the average stator temperature for the volume goal and the surface goal is 68.915°C and 68.927°C, respectively.

Figure 5 shows the result obtained from the thermal analysis on the stator winding of the single phase induction motor under normal operating condition. This drawing is used to identify certain “hot spots” on the stator winding. The cooling done by means of the Peltier devices focused on the same areas. From the 3-D thermal analysis plot it can be seen that the areas where the cooling will be focused are both on the front and rear ends of the stator winding. The physical structure of the single phase induction motor allows for relatively easy access to these areas.

Table 1.
Thermal analysis - normal operating condition

Volume goals	Value (°C)	Surface goals	Value (°C)
Minimum stator temperature	68.877	Minimum stator temperature	68.924
Average stator temperature	68.915	Average stator temperature	68.927
Maximum stator temperature	68.936	Maximum stator temperature	68.929

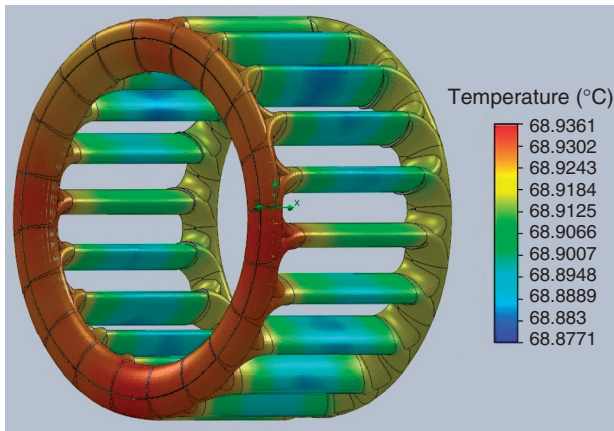


Fig. 5. 3-D thermal analysis plot – normal operation condition.

As with the normal operating conditions, it is also necessary to perform a thermal analysis where the stator winding will be cooled by the Peltier devices. This thermal analysis was used to determine the optimum amount of Peltier devices as well as the most effective positions for the final design. The assembly shown in figure 6 illustrates the model which was used for the thermal analysis of the

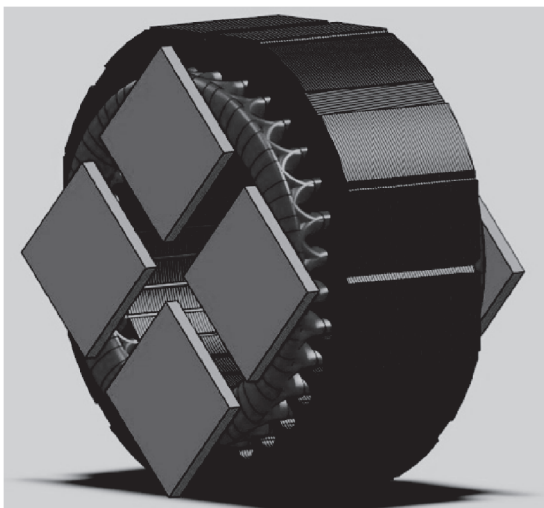


Fig. 6. SolidWorks® stator assembly with Peltier devices.

cooled condition. The grey blocks in the image represent the Peltier devices.

The results obtained for the thermal analysis for the cooled condition is also presented in both numerical form as well as in the 3-D thermal analysis plot form. Table 2 provides results on the thermal analysis with the single phase induction motor under cooled operating condition. From this table it can be seen that the average stator temperature for the volume goal and the surface goal is 35.975°C and 35.885°C, respectively. It is clear from this table that there is a definite decrease in stator temperature when using the designed cooling system.

Figure 7 shows the result obtained from the thermal analysis on the stator winding of the single phase induction motor under cooled operating condition (with the Peltier devices installed). In this figure the cooling effect of the Peltier devices can be clearly seen. The two “hot spots” at the back end side of the stator winding occurred since it was possible to only install two Peltier devices on that side due to the limitation in the available space. Different placements of the Peltier devices were investigated to determine the optimum cooling for the stator winding of the single phase induction

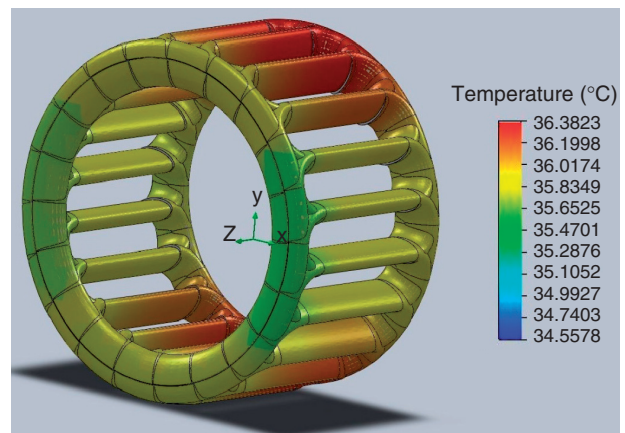


Fig. 7. 3-D thermal analysis plot - cooled operating condition.

Table 2.
Thermal analysis - cooled operating condition

Volume goals	Value (°C)	Surface goals	Value (°C)
Minimum stator temperature	35.636	Minimum stator temperature	35.768
Average stator temperature	35.975	Average stator temperature	35.885
Maximum stator temperature	36.352	Maximum stator temperature	35.943

motor. The placement of the Peltier device shown in figure 6 is regarded as the optimum placement solution for this specific single phase induction motor and type of Peltier devices.

3.2. Efficiency analysis results

This section provides the results obtained from the energy efficiency analysis performed in Matlab® Simulink®. Figure 8 provides the Matlab® Simulink® simulation model of the single phase induction motor with the Peltier devices. In this simulation a capacitor start single phase induction motor was selected and the parameters of the physical single phase induction motor was recorded and used as input for the simulation model. A manual switch provides the induction motor with either a no-load torque or a blocked rotor torque, which is also a representation of the two tests performed on the induction motor. A Peltier system is connected to the input of the motor terminals. The Peltier system has an “OFF” state at port 1 and port 2 and an “ON” state at port 3 and port 4. The Peltier system adjusts the stator winding resistance according to the normal operating condition (averaged at 68°C) and the cooled operating condition (averaged at 35°C) for the single phase induction motor. The corresponding active power demand profiles and rotor speed (mechanical) demand profiles are then calculated and recorded

(saved to the workspace). Gouws, 2011 and van Jaarsveldt, 2011 provides more detail on the Matlab® Simulink® simulation model and parameter allocation for an induction motor and Gupta, 1998 and Guru et al., 2001 provides more detail on the working principle, equivalent circuit, no-load test and blocked rotor test for a single phase induction motor.

Figure 9 provides the Matlab® Simulink® no-load mechanical demand profiles where the single phase induction motor is operated under normal and cooled operating conditions. Under no-load

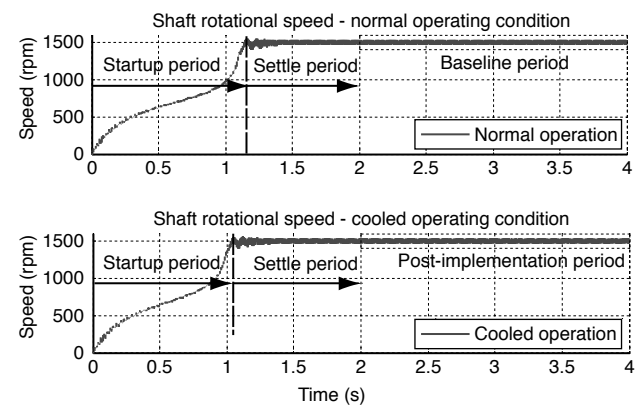


Fig. 9. Matlab® Simulink® no-load mechanical demand profiles.

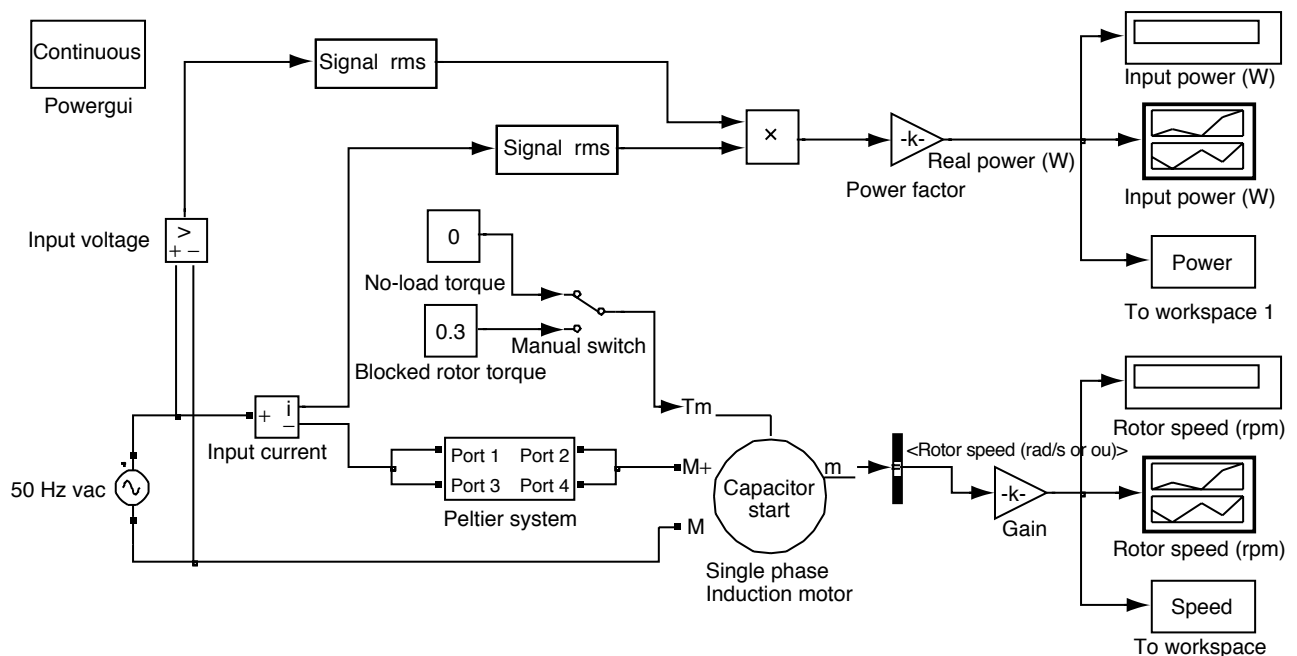


Fig. 8. Matlab® Simulink® model of the single phase induction motor with Peltier devices.

condition the single phase induction motor has a start-up period, a settle period and an operational period. The operational period for the normal operating condition is chosen as the baseline period and the cooled operating condition is chosen as the post-implementation period. From figure 9 it can be seen that the rotor has a slightly faster start-up period under cooled operation than under normal operation.

Figure 10 provides the Matlab® Simulink® no-load power demand profiles where the single phase induction motor is operated under normal and cooled operating conditions. Under no-load condition the single phase induction motor draws a high active power during the start-up period. When comparing the watt/hour of the post-implementation period with the baseline period an average efficiency improvement of 3.73% is calculated.

Figure 11 provides the Matlab® Simulink® blocked rotor power demand profiles where the single phase induction motor is operated under normal and cooled operating conditions. The normal operating condition

was chosen as the baseline period and cooled operating condition was chosen as the post-implementation period. Almost no difference is visible in the power demand profiles of the blocked rotor test; except that the power demand profile for the normal operating condition is slightly higher than that of the cooled operating condition. When comparing the watt/hour of the post-implementation period with the baseline period an average efficiency improvement of again 3.73% is calculated.

4. Conclusion

In this paper the results obtained from the thermal and efficiency analysis of a single phase induction motor with Peltier devices was presented. An induction motor was cooled by means of Peltier devices and the corresponding power consumption and stator temperature was recorded. From the thermal analysis results (performed in SolidWorks®) it can be seen that it is possible to decrease the temperature from the normal operating condition of 68°C to the cooled operating condition of 35°C by means of the Peltier devices. From the no-load mechanical demand profiles a slight increase in the start-up time of the single phase induction motor is visible from the normal operating condition to the cooled operating condition. From the efficiency analysis results (performed in Matlab® Simulink®) it can be seen that it is possible to increase the efficiency of the single phase induction motor by an average of 3.73% (from normal operating condition to cooled operating condition) with the inclusion of the Peltier devices. Detail on transient analysis of induction electric motors with the purpose to improve machine reliability and perform rotor design optimization is provided by Cezario *et al.*, 2005 and Rajagopal *et al.*, 1998. More detail and standards on determining the efficiency of an induction motor is provided by Gouws 2011 and Hameyer *et al.*, 1999.

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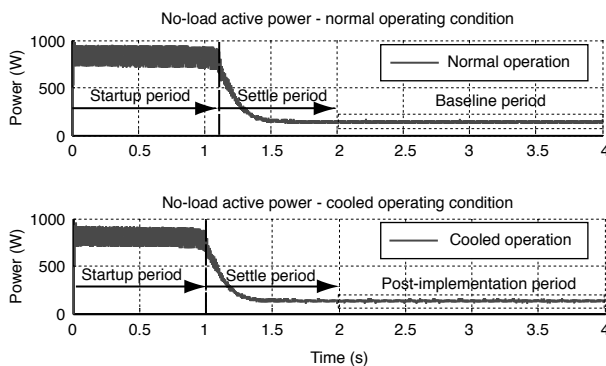


Fig. 10. Matlab® Simulink® no-load power demand profiles.

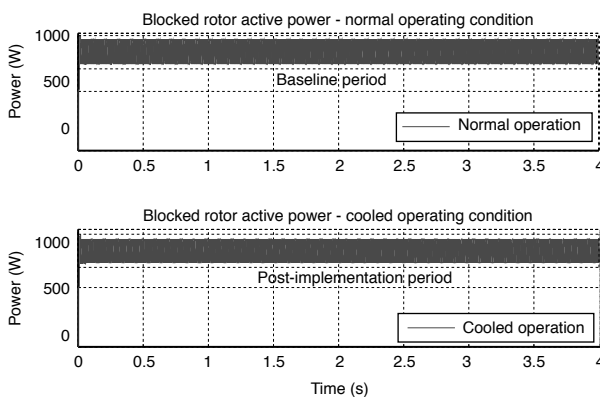


Fig. 11. Matlab® Simulink® blocked rotor power demand profiles.

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