DANFOSS A/S
REFRIGERATION AND A/C CONTROLS

Part of the dissemination of the work done in the ESO2

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Preface

The report is created at part of the dissemination of the work done in the ESO2 project. This report covers some of the essential contribution to the project from Danfoss.

The project participants from Danfoss where: Refrigeration specialist Frede Schmidt and research engineer Torben Green.

1 Introduction

The operational performance of the refrigeration plant is connected with the ability to avoid unnecessary oscillation of the various actuators in the plant. One way of achiving this is by ensuring that the compressores switch frequency is minimized. Decreasing the switch frequency of the compressor rack can be pursue in many different ways. The approach in this report has been to manipulate the display cases to match the current load on the compressor rack.

2 Description of the proposed method

The method is implemented as a supervisor controller which uses the thermostat controllers in the display cases to assist the pack controller in maintaining the suction pressure. This is achieved by offsetting the cutin and cutout temperatures and then simply testing the thermostats against the offset of the cutin or cutout limits. If the current temperature is above the offset cutin limit the state of the thermostat will be changed from OFF to ON and the display case will then start producing gas to the suction manifold and thereby postpone a compressor switch. This is all done without changing the actual cutin and cutout limits of the thermostat controller, the offsetting of the limits and the testing is only done in the supervisor controller and thus the temperature safety is inherited from the thermostat controller. In addition the switching of the controller state is only allowed within the cutin and cutout limits originating from the thermostat controller, and it is therefore not possible to compromise the food safety with this method,

The general idea behind the proposed method is illustrated in Fig. 1. The top plot is the suction pressure, Po, and the suction pressure reference is denoted by Po_{ref}. The middle plot is the temperature in a display case. The bottom plot illustrates the state of the thermostat. Fig. 1 it can be seen that when the suction pressure goes down it will reach a thermostat supervisor neutral zone before it reaches the neutral zone of the compressor controller. By following the dotted line to the middle plot it can be seen that the supervisor controller will then start to offset the cutin limit in an effort to get more display cases to produce gas into the suction manifold and thereby raise the suction pressure. As the suction pressure keeps decreasing and the temperature in the display case increases the cutin limit set by the supervisor controller will keep decreasing and eventually the temperature will get above the offset cutin temperature which will trigger a state change of the thermostat which can be seen on the bottom plot.

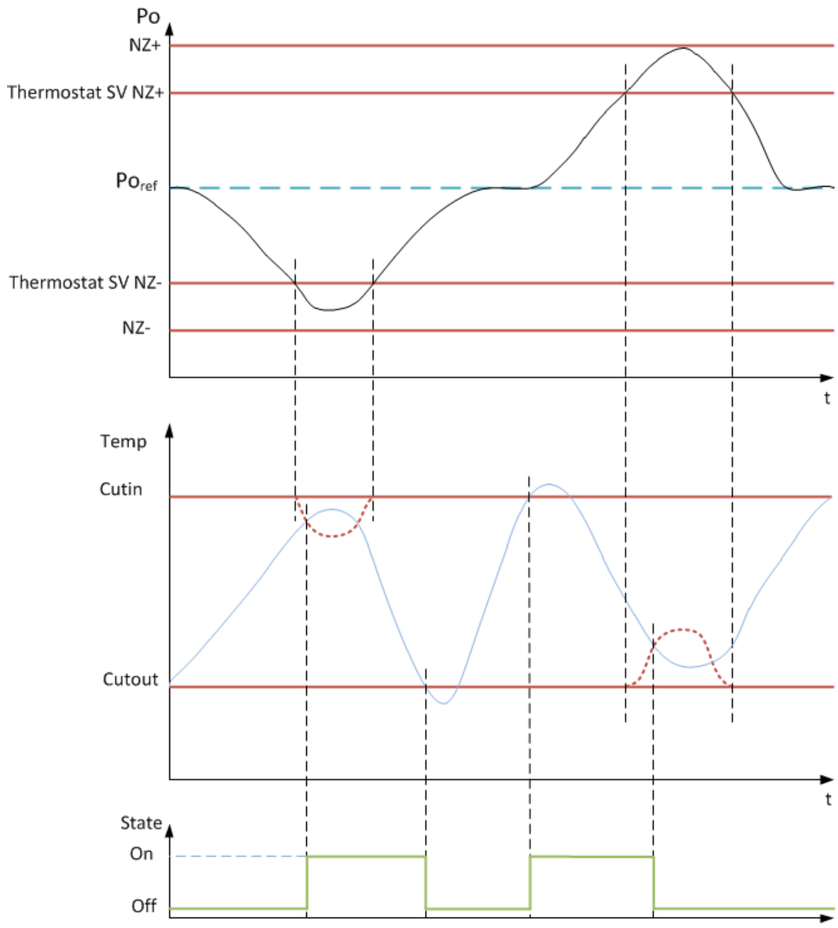

Figure 1: Description of the algorithm

3 Test setup

The proposed method was tested in the supermarket Fakta in the town Otterup in Denmark. The test was conducted using a setup where the proposed method was implemented as a supervisor controller running on a pc connected to the display case controllers and the pack controllers via the lon bus. The method was only tested on the medium temperature display cases and the medium temperature pack, however, the display case used for storing meat was not included in the test. The test was conducted while the refrigeration system was in operation. The test was conducted with a sample rate of 20 seconds and therefore a baseline dataset was collected with the same sample rate to enable better data background for evaluation of the test results. The standard sample time for the data logging in the supermarket system is 1 minute and the logged data would therefore not be able to provide the optimal background for the analysis of the results.

The baseline dataset and the dataset from the test covers a number of days. The data that has been compared are from two different night from 23:00 in the evening to 06:00 in the morning. The reason is that to be able to conclude something based on the available data, the refrigeration system has to be subjected to similar conditions in both the test dataset and the baseline dataset. Night operation was chosen to avoid the influence of created by the human interaction with the system during the opening hours of the supermarket. For example customers opening and closing the doors in the sales area to the dairy cooler and the staff opening and closing the door to the dairy cooler.

4 Results

In this section the results from the test of the proposed algorithm will be presented.

The top plot of Fig. 2 shows the running capacity of the medium temperature compressor rack and the bottom plot show the corresponding suction temperature. From the top plot it can be seen that only one of the compressors are running and it is the frequency controlled compressor. On the bottom plot it can be seen that there is a significant fluctuation on the suction pressure which causes the compressor to pump down, and switch OFF which is undesirable. This is an undesirable form of operation of the refrigeration plant, because the pump downs are unnecessary and they use superfluous energy. By comparing the results from the baseline shown in Fig. 2 against the results show in Fig. 3 it is clear to see that the proposed algorithm has a significant impact on the operation of the refrigeration plant during night operation.

Figure 2: Compressor capacity and suction pressure from the test baseline

The top plot of Fig. 4 shows the power consumption of the medium temperature compressor rack during the baseline and the bottom plot shows the outdoor temperature during the baseline. When comparing the plots from Fig. 4 against the plots from Fig. 5 it can be verified that the average outdoor temperatures of the baseline and the test i are close and comparing the test results against the baseline seems reasonable. In addition, the average power consumption is a bit lover on the results from the test compared against the baseline.

The results can also be view in table 1, where it can be seen that the proposed algorithm contributes with significant improvement on a couple of evaluation parameters. The switch frequency of is reduced and therefore also the number of stops. Since the reducing the number of stops is the same as reducing the number of pump down there is also an improvement on the energy consumption during the night operation compared to the baseline. This energy consumption improvement is achieved despite the fact the average outdoor temperature is a bit higher in the test. The overall energy consumption savning amounts to 9.31 % compared to the energy consumption in the baseline.

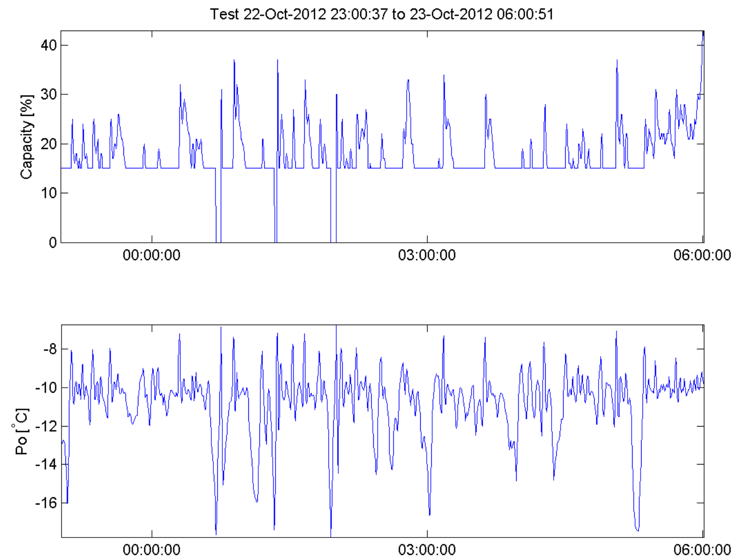

Figure 3: Compressor capacity and suction pressure from the test data

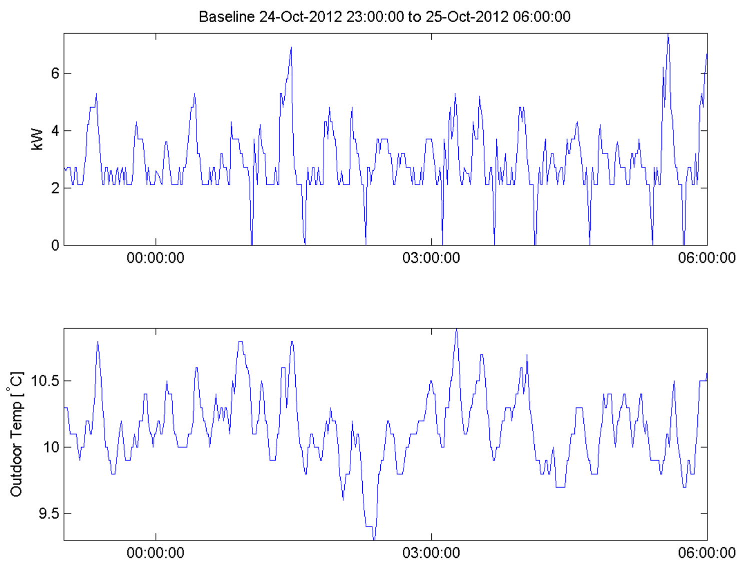

Figure 4: Power consumption of the cooling compressors and the outdoor temperature in the baseline

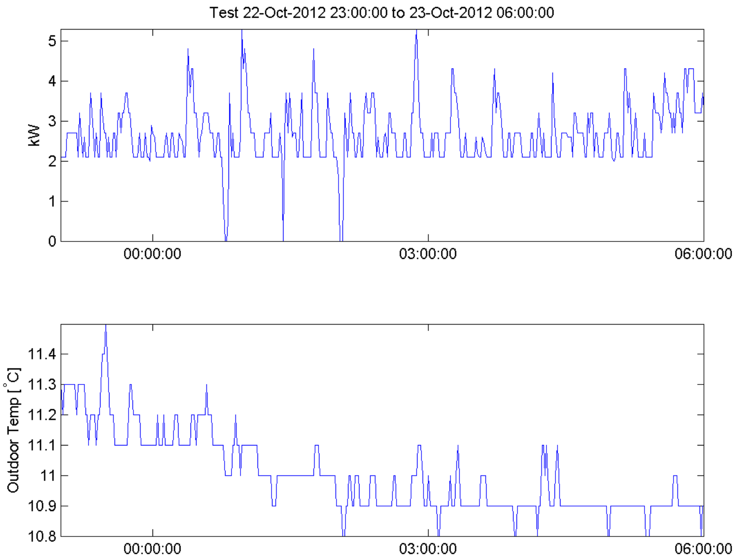

Figure 5: Power consumption of the cooling compressors and the outdoor temperature in the test

	Baseline	Test
Time period:	Wed 24-10-2012 23:00 to Thu 25-10-2012 06:00	Mon 22-10-2012 23:00 to Tue 23-10-2012 06:00
Switch frequency [Switches/hour]	0.0044	0.0013
Number of stops	9	3
Average power consumption	2.91 kW	2.65 kW
Energy consumption	20.4 kWh	18.5 kWh
Average outdoor temperature	10.14 °C	11.00 °C

Table 1: Results from the baseline and the test

5 Future work

The presented result is from the first trial of the proposed method and further investigation of the algorithm is recommended. First of all the algorithm needs to be tested for a longer time period and secondly it would be interesting to test the algorithm on an entire supermarket instead of only on the medium temperature display cases and compressors. One of the benefits of the algorithm is that it is able to lower the amount of compressor stops, and there by pump downs, and it would therefore be very interesting to test the algorithm on the low temperature cabinets and compressors.

Further tests are also needed to investigate if the algorithm also can provide an increase in the system performance during day operation. Due to the relatively small data set from the test and the baseline it has not been possible to find two similar day in both data sets to compare. In addition, due to the amount of noise in the data during day operation it will also be necessary to use an average over a number of day in both the test and the baseline data.

6 Conclusion

The proposed algorithm was described in section 2 and the results from the test on the refrigeration system in Fakta in Otterup, Denmark was presented in section 4. The results are clearly promising however, some future work is needed to help mature the algorithm as mentioned in section 5. During night operation a significant energy reduction of 9.31 % was achieved in the first test of the algorithm, and the robustness of the design of the algorithm was also proven during the test period.