

## Smart Defrost Control for Refrigeration System

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### Abstract

In this paper, a smarter way of deciding the defrost interval based on the usage pattern has been developed. A new intelligent logic of triggering the defrost at appropriate time has been designed thus continuously maintaining the frost level in the evaporator. In this paper defrost pattern is decided by monitoring the factors that lead to frost formation rather than monitoring the effects of frost formed. A separate adaptive algorithm is also been designed which changes the defrost interval with respect to the change of usage pattern as well as climatic changes.

**Keywords:** Defrost, Humidity, Adaptive tuning, Heat transfer, Refrigeration.

### INTRODUCTION

As refrigeration has an important role not only in domestic usage but also shares equal importance in industries as well, so it is highly required to have an efficient system both in terms of performance and energy consumption. Keeping this necessity in mind, a change is needed in the present defrost system such that the process becomes more adaptive with respect to usage. The whole purpose of refrigeration is to maintain the cabinet temperature, as this is achieved by transferring of heat between cabinet and evaporator, thus it becomes major criteria to keep the evaporator surface free of frost [6][9]. During the process heat exchange, the moisture in the cabinet air gets solidified and deposits on the surface of the evaporator coil. When the amount of frost been deposited increases, this layer acts as a Thermal barrier thereby decreasing the heat exchange. Hence to maintain the cabinet temperature the compressor has to run for more duration thereby increasing the energy consumption.

To avoid this frost formation, after a particular interval defrosts has is triggered, this removes these ice layers and makes the evaporator clean. At the same time frequent defrost is also not appreciable as every time defrost is triggered a lot of energy is been consumed for heating the coil and also once defrost is complete, the compressor has to run for more time to bring down the temperature to the set point. Hence, logic has to be designed which activates defrost once the frost layer exceeds the allowable depth.

This paper is organized as follows. In Section 2 back ground of the application is discussed. In section 3, the logic development and adaptive algorithm is presented and section 4 is dedicated for methodology. The experimented results are presented and analyzed in section 5. Finally the proposed work is concluded in section 6.

### LITERATURE SURVEY

In parallel to the development of refrigeration techniques, methods of defrosting have also evolved from Manual-Trigger to Auto-Trigger with various methods [1,3,7].

Evolution in Defrost Interval:-

- 1) Manual-Trigger: User switches the defrost manually when he feels the frost level has increased.
- 2) Auto-Trigger: There are several ways in which the present Auto-Defrost working principle [2]:
  - a) Defrost after fixed periodic interval (say 4 hrs., 6hrs or 8hrs).
  - b) Defrost after fixed compressor run time.
  - c) Defrost once evaporator goes below a fixed Temperature value [11]

Evolution In Defrosting Methods:-

- 1) Manual Defrost: Letting the door been opened and melting the ice.
- 2) Auto-Defrost
  - a) Natural (only fan): the only fan is switched on and compressor switched off.
  - b) Electrical Heating: A heater is coiled along the evaporator which is switched on, thus making the defrost faster.
  - c) Hot Gas: The heat which is released from the condenser is collected and is made to flow through the evaporator thus melting the frost formed over there.

## LOGIC AND ADAPTIVE ALGORITHM

A Defrost is said to be efficient if the defrost is switched ON and OFF at an appropriate instant. Two important factors which are been considered for an efficient defrost are:

- 1) Defrost interval: The time interval between two defrost cycles.
- 2) Defrost time: Duration of defrosting in a defrost cycle.

### Logic Development

A dynamic defrosts process is been designed which changes the defrost interval with respect to usage. On the other words, a defrost system which works based on monitoring the factors that lead to frost formation is developed [5].

The depth (amount) of frost formed can be sensed by using an optical sensor or a frost sensor. But none of these methods is not economical when it has to be used for a larger number of products.

As there is no direct, economical method available to find the amount of frost formed, an indirect measurement of frost depth is calculated. Frost is formed from the moisture present in the cabinet, it is been observed that the factors leading to increasing the moisture content in a cabinet are [4]:

1. Accumulated amount of time the Door remains open.
2. No. of times the Door been opened (and closed)
3. Accumulated Compressor run time.
4. Ambient room temperature and Humidity.
5. Cabinet temperature.
6. Evaporator temperature.
7. Fan operating pattern.
8. The moisture content of the food products present.

Various tests and studies have been performed to determine the contribution of each factor in frost formation, it was found that the factors which play the major role in frost formation are [8]:

- 1) Accumulated amount of time the Door remains open.
- 2) No. of times the Door been opened (and closed).

These are the factors which increase the moisture content in the cabinet to a larger extent. Due to the difference in temperature between a cabinet and an ambient lot of heat (air) exchange takes place and every time the door is closed ambient air is pushed into the cabinet at a faster rate. Thereby increasing the moisture content in the cabinet hence more frost is formed. The usage pattern is decided based on the door activities. By monitoring these two factors the defrost pattern is calculated using an adaptive algorithm [11,12]. Thus the more the door opening the higher is the frost formed thus sooner should be the corresponding defrost and similarly

lesser the door usage extending the defrost thereby making the process more efficient.

### Adaptive Algorithm

#### Adaptive Defrost Logic

A dynamic defrosts interval which varies with the door usage pattern is developed. An algorithm which delays the triggering of defrost when the usage is less. Thus,

$$\text{Defrost Interval } a \text{ (1/Door usage)} \quad (1)$$

$$DEf \geq ((\text{maxdef time}) - (\text{dot} * x) - (\text{Adt} * y)) \quad (2)$$

Where,

*DEf* - Time elapsed since previous defrost has to end

*maxdef time* - the Maximum interval between two defrost allowed (fixed by the user)

*dot* - Counter for the number of times door been opened after every defrost.

*Adt* - Counts accumulated time the door has been kept opened.

*x* - Weigthing factor for a number of door openings

*y* - Weigthing factor for accumulated door open time.

In other words, *x* and *y* are the duration of time that has to reduce from the maximum defrost interval for each single door opening and for a unit amount of time door is been kept opened respectively. With this logic, an indirect monitoring of frost is achieved. The maximum defrost interval initially set is very large (ex. 30 to 40 hours) thus delaying the defrost at low usage situations especially at night times and holidays.

The value of *x* and *y* will be depending on the climatic conditions. The contribution of these factors on frost formation will vary with parameters like temperature, humidity etc. Thus, it is not appropriate to generalise a particular value for *x* and *y*, as this has to be changing with variation in climatic conditions and the type of food materials the user generally stores in the cabinet.

### Adaptive Weighting Factors

The whole process of cooling is based on the transfer of heat from a hotter substance to a cooler substance in the case of refrigeration the heat is transferred from cabinet to evaporator. Hence ideally every refrigerator maintains the evaporator at a fixed temperature lesser than cabinet to maintain proper cooling. During this process of cooling, moisture present in the cabinet gets deposited on the evaporator in the form of frost, and the thickness of this layer keeps on increasing.

This layer of frost on evaporator starts behaving like a thermal barrier and restricts the heat transfer between evaporator and cabinet. This makes the compressor to run continuously for more duration as the rate of cooling decreases and the compressor has to run for more time.

Hence, by monitoring the compressor run time duration the amount of frost formed can be determined and this measurement is used to update the weighting factors. These weighting factors are updated such that the factors are suitable for current climate and place.

**METHODOLOGY**

The first Defrost after power up is triggered based on the door activity with the weighting factors values as initialized (default value). Once this defrost is completed and as the first compressor cycle is completed, the first three compressor cycles with no door activities have happened are monitored and the corresponding three compressor run times are recorded

Say;

- C1 - First compressor run time with no door activities
- C2 - Second compressor run time with no door activities
- C3 - Third compressor run time with no door activities

The reason behind this logic is; if there has been no door open or door activity it implies that there were no load changes. So the temperature of the cabinet does not affect due to any new loads. Thus the rate of cooling which is based on the compressor run time solely depends on the type and size of a refrigerator. As just after defrosting the evaporator are clean without any frosts.

These three values are recorded after every defrosts cycles, and the average of these values is calculated as:

$$C_{avg} = (C1 + C2 + C3) / 3 \tag{3}$$

Similarly, last compressor run (without any door activity) time just before the trigger of defrosting is recorded.

CL - last compressor run time with no door activities before the trigger of defrosting.

The difference between *Cavg* and *CL* is calculated and is compared. Compressor run time increases with increase in frost level because as frost gets built on the surface of evaporator the heat exchange rate decreases thus compressor has to run for more time to reach the desired set point. Hence this difference is proportional to the amount of frost formed.

This comparison is performed just before the start of every

defrost cycle and the run-time variation in compressor cycle at frost-free condition (initial compressor cut out) and at maximum frost (latest compressor cut out) is studied and the weighting factors are changed accordingly as follows:

if (CL – *Cavg*)

Case 1. Less than 3: Very less frost is formed thus Defrost interval has to be increased;

*x* and *y* Decrements by (-1)

Case 2. More than or equal to 6: More frost is formed thus Defrost interval has to be decreased;

*x* and *y* Increments (+1)

Case 3. Between 3 to 6 : an Allowable amount of frost is formed thus Defrost interval is proper.

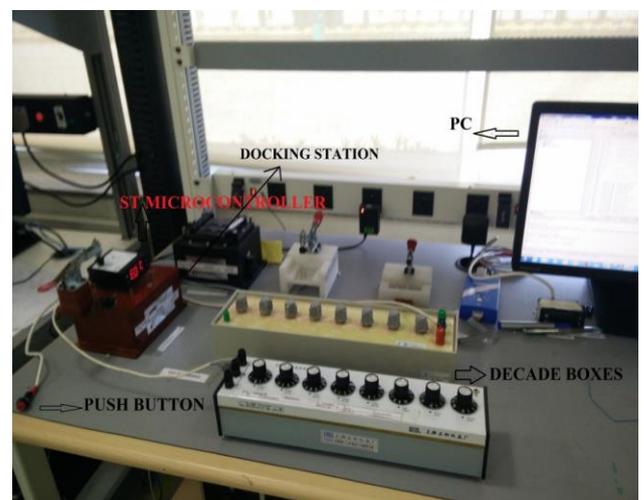
*x* and *y* Remain same.

This method helps to tune the factors within few defrost cycles with respect to ambient climatic conditions.

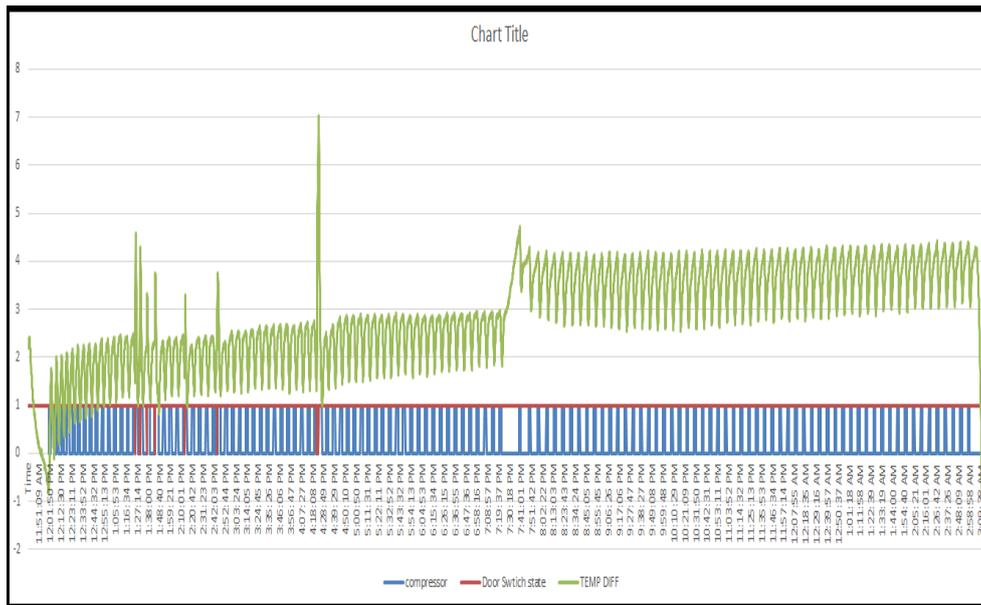
**RESULTS AND DISCUSSION**

The smart logic proposed is developed and is tested at bench level shown in Figure 1 followed by real-time environment and the performance of this logic is compared with that of the previous existing logics. As mentioned above the previous defrost logic pattern is decided based on factors like accumulated compressor run time, minimum evaporator temperature cutout and maximum defrost interval. The effect in frost formation in both the logics are performed under same circumstances is recorded and compared.

In this test the current smart logic, where the defrost is based on logic given by eqn. (2).



**Figure 1:** Bench Test of smart defrost logic



**Figure 2:** The graph plotted between compressor state, door switch and temperature

Here,

- *Def* is the time (in minutes) since the last defrost has occurred.
- *maxdef time* is given as 2880 (48 hrs\*60) hrs.
- *dot* is the number of times door is opened.
- *x* is initialized as 5 (in minutes)
- *Adt* is the accumulated time door has been kept opened (in minutes).
- *y* is initialized as 10.

This test is performed on ST microcontroller with the help of all required hardware components. Here a push button acts as door switch and the decade boxes are used for temperature adjustments.

The controller is programmed using Source insight and tested at bench level using ST Visual Tool which helps in monitoring and recording of various parameters in progress[9]. As shown in Figure 2. The graph here plots the corresponding change in evaporator temperature with frost formation. In these tests, the number of time door been opened and closed is noted and the same is calculated with the smart logic. The parameters after One of such a test where the door was opened for 45 times and total door opened time accumulated is 3665 seconds (approximately 60 minutes) was recorded, and defrost is triggered using new prescribed smart defrost algorithm is explained here;



**Figure 3:** Real Time Test



**Figure 4:** Monitoring parameters on Kool Prog PC tool

The average of first three compressor run time is recorded as  
 $C1 = 5$  minutes  
 $C2 = 5$  minutes  
 $C3 = 4$  minutes

Thus,  $C_{avg} = 5$  minutes and the last compressor run time before defrost has been recorded as  $CL = 11$  minutes. Thus on the basis the adaptive logic for weighting factors  $A_s$ ;  $(-C_{avg}) \geq 6$ . The  $x$  any  $y$  factors increments to  $x = 6$  and  $y = 11$ . This indicates more frost has formed than allowed. And thus the factor adapts itself to the future process. This result proves the defrost interval changes with door usage.

And followed by this bench test a real-time test shown in Figure 3 is also performed and the

performance is monitored by koolprog software. It is presented in Figure 4.

This test was aimed especially to know the efficiency benefit of smart logic over conventional old logic. Also here various tests were performed with varying the factors like load, Ambient climatic conditions, usage etc. both the logic cases were performed under identical scenario and corresponding results and parametric changes were studied and analysed. One of such case results is shown in this paper.

Both the refrigerator were opened twice every hour for about 30 seconds, the one with old logic shown in Figure 5 triggered defrost after 7 hrs (max def time.) even though there was no frost in the evaporator, thus leading inefficient use of energy. But in Figure 6, the system with new logic with similar door activity



**Figure 5:** With old logic



**Figure 6:** With smart defrost logic

rn triggered defrost after 30 hrs (max def time) and the frost was also under limits. Thus this proves the efficiency of new smart logic.

## CONCLUSION

The efficiency of the developed smart defrost logic in maintaining the frost level in the refrigerator is compared with that of the old defrost logic. And it is evident from the performed test results the new proposed logic is more efficient than the conventional method. The new smart logic always maintains the amount of frost formed and ensures the frost formed does not exceed the allowable limit. As the frost formed in the fins at evaporator amount is always maintained a proper heat flow between evaporator and cabinet is ensured thus making the whole system more energy efficient.

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