POTENTIALITIES OF FUZZY LOGIC CONTROL APPLIED TO SMALL VAPOR COMPRESSION REFRIGERATION SYSTEMS

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Abstract

This work shows the potentialities of fuzzy logic blocks built in Matlab® packages in control of electronic expansion valves for small refrigeration systems. The control law, developed using Matlab® package, was based on conditions and decision rules freely elaborated by authors. The potentialities of this type of control were verified in a 298 watts, vapor compression refrigeration system, using R134a as working fluid. Supply and exhaust temperatures and pressures at the condenser, evaporator, compressor and expansion valve were monitored by means of a A/D interface card, properly adapted in a PC. It was used a commercial expansion valve properly adapted to be operated by stepper motor, and the control law was developed in order to keep the degree of superheating constant (10 ºC). Experimental results show good stability, precision, easy implementation and possibilities of use with multiple variables, beside the facility to change time constant. Performance of this type of control show advantages with respect to conventional thermostatic expansion valves, and the facility to implement the control law show a clear path to increment the use of this control methodology.

Keywords: Fuzzy Logic, Control, Refrigeration Systems and Electronic Expansion Valves.

1. INTRODUCTION

One of the main goals in refrigeration systems is to keep cooling capacity in evaporators as high as possible, commercially the simples way to do this is using an on/off compressor control and degree of superheating controlled by expansion valve. These type of controls produces low refrigeration efficiency (Junior *et al.*, 1995) mainly because heat exchangers do not work in optimal conditions (Pederson *et al.*, 1999). Modern control of refrigeration systems deals mainly with control of two parameters "degree of superheating" and "compressor speed". This paper deals with "degree of superheat" control using the development of a fuzzy logic technique, applied on a semi-electronic expansion valve, (EEV) in order to keep degree of superheating as constant as possible and stable (Fredsted, 1999).

2. WHY FUZZY LOGIC CONTROL ?

Most of work found in literature related with fuzzy logic applied to HVAC systems, are at simulation level. Shavit *et al.*, 1999, concentrated in the control loop and performance throughout the HVAC load range, and suggest the use of *PID* control with automatic compensation. One example of this technique is the Adaptive Neural Network *PID* control algorithm developed by Zhou *et al.*, 1999, who made an adaptive control applied to an electronic expansion valve using *PID* control laws, modified in real time to keep degree of superheating constant and concluded that fuzzy logic is highly recommended for real control of EEV used in refrigeration systems.

Our work deals with the operation of a commercial expansion valve properly adapted, using fuzzy logic controls type *PD*, *ID*, with output commands properly *modified* to obtain minimal feedback error (<1 ºC) and stable operation within the whole operation range of a small size refrigeration system. The change in signal to valve (actuator) – control output – is based in evaporator gain (EG) change, defined as the relation between the total temperature change, and the change in cooling capacity (CC), the control gain (CG) obtained by change of EG is the signal used to operate the system.

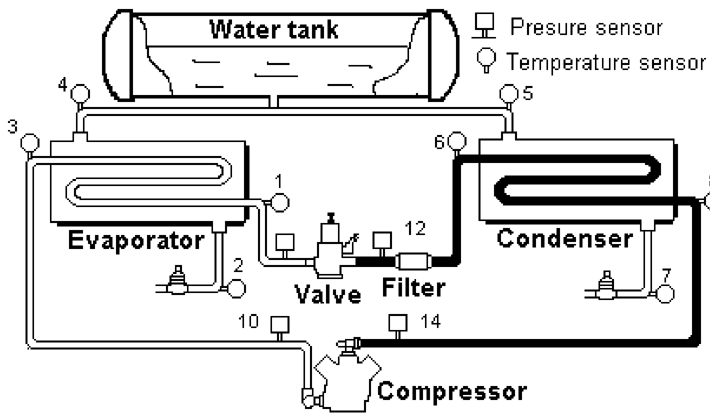

Figure 1. Refrigeration system prototype.

The control was tuned in real time with the refrigeration system in operation, by changing cooling capacity (CC).

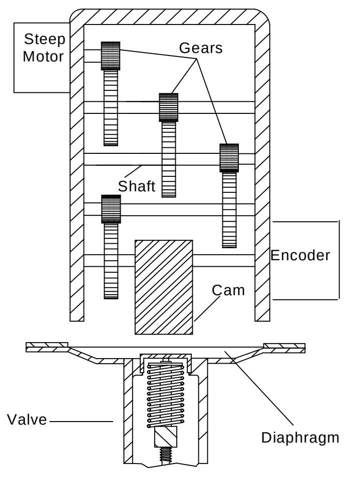

Figure 2. Expansion valve actuator.

It was built a refrigeration system prototype shown in Figure 1, totally instrumented, to operate between –5 ^{o}C (evaporator temperature) and 60 ºC (condensation temperature), using annuli type heat exchangers and a hermetic compressor (298 watts), a commercial expansion valve properly adapted to use a mechanic actuator designed by authors as shown in Figure 2.

The fuzzy logic commands use the Mandani interference strategy graphically shown in Figure 3, this strategy is ready to use in fuzzy Matlab® packages.

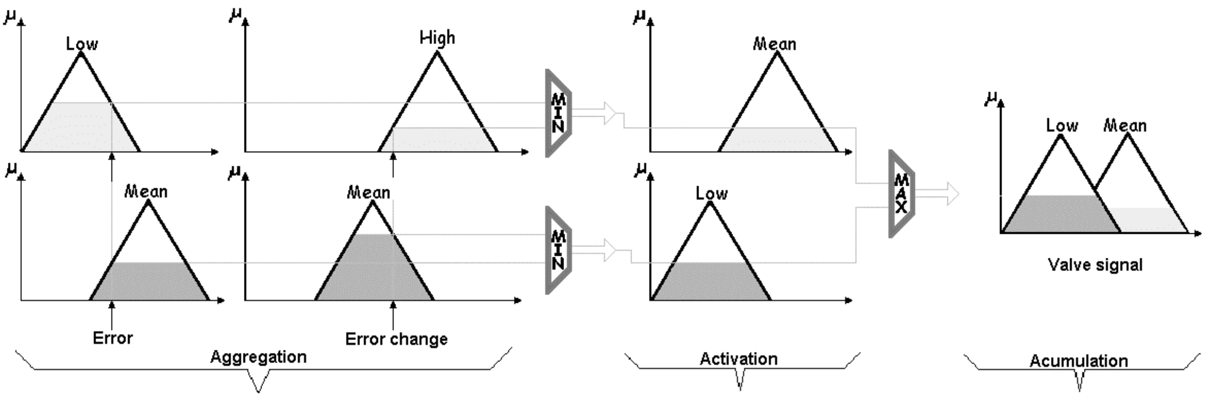

Figure 3. Mandani inference strategy.

2. BASIC CONCEPTS OF THE CONTROL

The control used to actuate on the steeper motor shown in Figure 2, is schematically shown in Figure 4 and it is composed of three block.

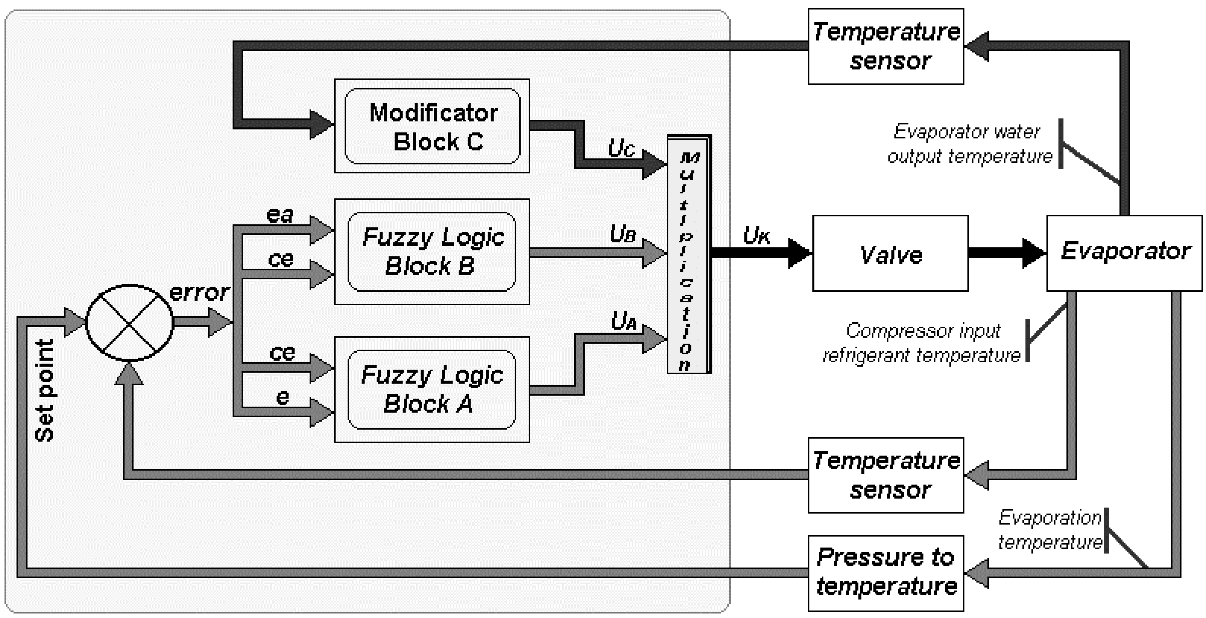

Figure 4. Developed Fuzzy Logic Control.

The block A has two inputs: error *e* and change of error *ce* relatives to a reference temperature. The block B has two inputs: accumulated error *ea* and *ce*. These two blocks give an output U_A and U_B. The last block (C) is a *modificator* actuating in parallel to the other two blocks using T_{ex} as input and gives a signal output according to function show below:

$U_C = 100.(1{,}01 - 0{,}0032.T_{ex} + 0{,}0226.T_{ex}^2)$ (1)

Where:

U_c – Signal output from *modificator* and

T_{ex} – Output temperature of the water in the evaporator.

The steeper motor (actuator) receives a signal (U_K), in millivolts, which is a multiplication series of the blocks shown in Figure 4.

$U_K = U_A * U_B * U_C$ (2)

The signal (U_K) denominated control gain (CG), is affected by the water evaporator output temperature, reference temperature and refrigerant compressor input temperature.

2.1 Characteristic of block A

The Block A is a Proportional Derivative (*PD*) fuzzy controller with two inputs:

$e(k) = T_{s10} - T_{ev}$ (3)

$ce(k) = e(k-1) - e(k)$ (4)

where:

T_{s10} - reference temperature (evaporation temperature plus 10 ºC)
T_{ev} - evaporation temperature
k - actual time
k-1 - previous time

This block uses seven triangular membership functions, for each one of the inputs and outputs (*e*, *ce*), defined as shown in Figure 5.

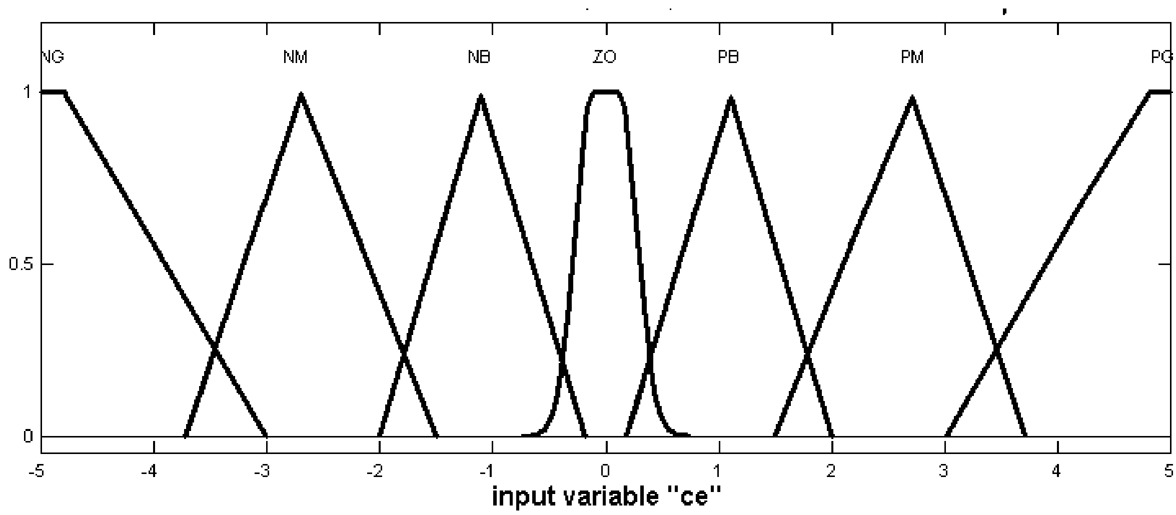

Figure 5. Membership functions used for change of error input (c*e*).

Where:

NG	-	big negative
NM	-	mean negative
NB	-	low negative
ZO	-	Zero
PB	-	low positive
PM	-	mean positive
PG	-	big positive

2.2 Characteristics of block B

The Block B is a Integral Derivative (*ID*) fuzzy controller with two inputs:

$$ea(k) = e(k-1) + e(k) \quad (5)$$

$$ce(k) = e(k-1) - e(k) \quad (6)$$

The block B uses two inputs *ea* and *ce*, with seven triangular membership functions for each one of the inputs defined in similar way to those shown in Figure 5 (see Carvajal, 2000) using different universe of discourse, and four membership functions for the output (U_B) as shown in Figure 6.

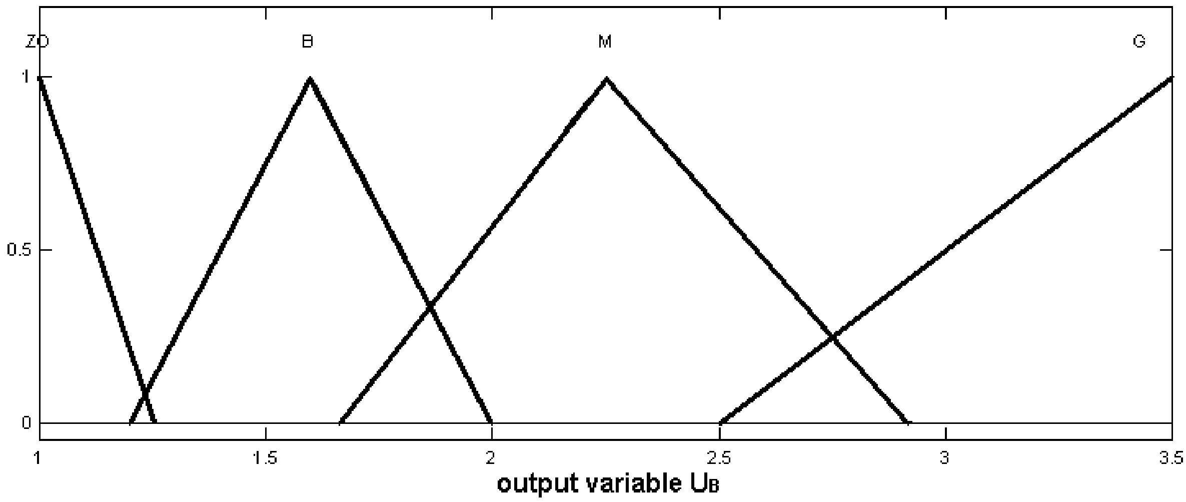

Figure 6. Membership functions used for output variable U_B.

Where:

ZO : zero
B : low
M : mean
G : big.

3. EXPERIMENTAL RESULTS

One of the main problems to control degree of superheating in refrigeration systems are instabilities mainly at lower refrigerant mass flow rate, this is due to not well established boiling in evaporator, according to Silva *et al*., 1994, Schmidt, 1999 and Hittle, 1999. For above reasons it is necessary a good tuning and the first step for a good tuning is to analyze the system behavior operating in open loop under extreme operational conditions.

Initially, our system was tested working in open loop, and the expansion valve was open or closed suddenly in order to analyze the time evolution of temperatures and pressures; when the valve was closed, it was observed a time constant of 60 seconds, with error about 7 ºC, and degree of superheating about 17 ºC. When the expansion valve was opened, the time constant was 45 seconds, the error was about 10 ºC., and the degree of superheating was about 0 ºC in both cases answer was unstable, the same behavior was registered by Silva, 1994.

In order to control temperature evolution within the range desired, was implemented a fuzzy *PD* control (Carvajal, 2000), operating in closed loop as shown in Figure 7, this fuzzy *PD* control caused a damping effect for high and low refrigerant charge (RC) into the system, and it was observed a high static error about 3°C. When the system charge is high the behavior is very unstable mainly when the RC is above recommended levels. When the system charge is below recomended level, the fuzzy *PD* control works well for the whole range of operation.

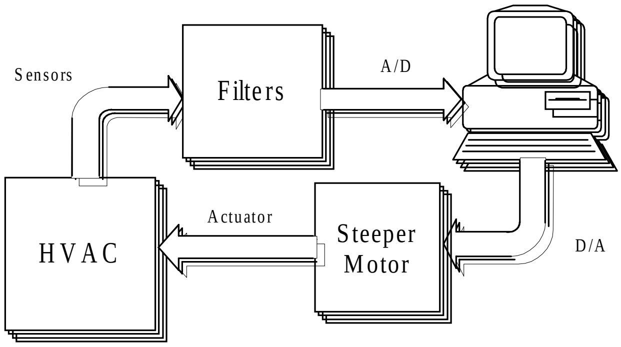

Figure 7. Closed Loop Control.

In order to improve the *PD* controllers for low and high RC, it was implemented the non fuzzy *gain modificator*. The system lowered the error in about 1.5 ºC, but the time constant was incremented from approximately 100 seconds (*PD*) to 400 seconds (*PD*modificator*) (Carvajal, 2000). In order to decrease the time constant was implemented the fuzzy control *ID*, that avoids big overshoots, bringing the system faster to stability as shown in Figure 8. The time constant observed in Figure 8 for high and low RC was less than 50 seconds.

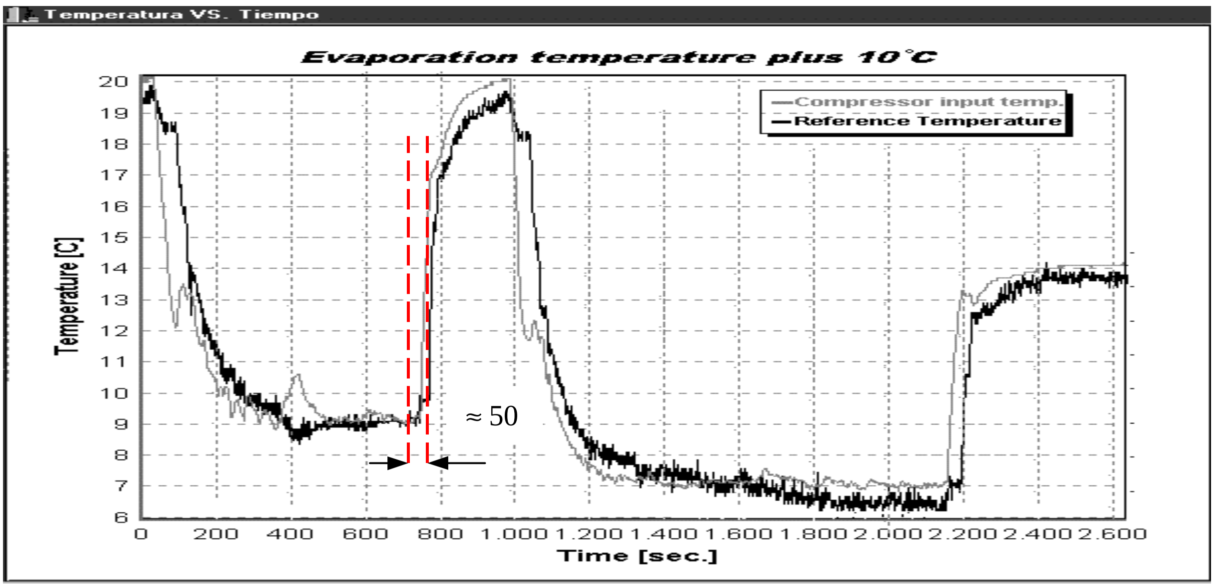

Figure 8. Temporal evolution of control parameters using *PD*ID*modificator*.

The behavior of the fuzzy control developed in this work (*PD*ID*modificator*) (Carvajal, 2000), is compared with the non fuzzy *PID* control used by Silva *et al.*, 1994 with behavior shown in Figure 9. We can see that the controller developed is faster (<50 seconds), instead of more that 300 seconds needed by non fuzzy *PID* control, it is also observed good stability and error inside of tolerance allowed (<1 ºC).

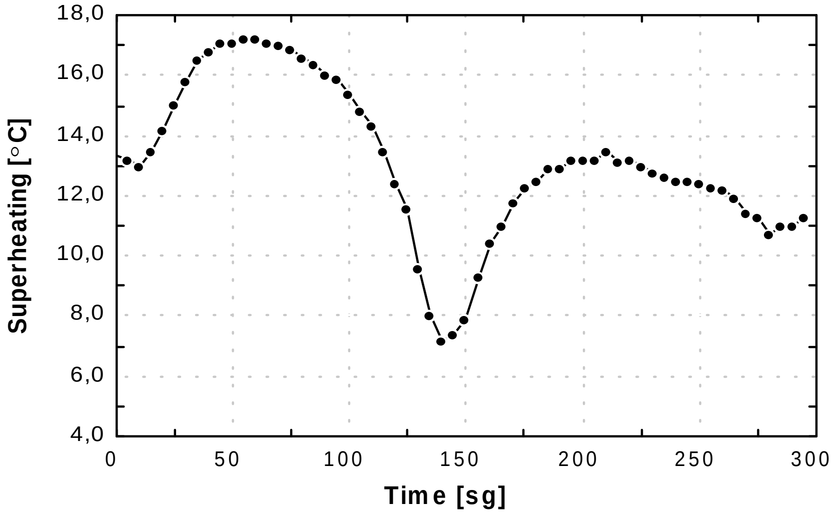

Figure 9. *PID* control without fuzzy logic.

4. CONCLUSIONS

We can say that the *PD*ID*modificator* fuzzy controller developed in this work, showed good behavior in the sense that keeps error below 1 ºC, and presents good stability throughout the full operation range of refrigeration system for low and high system refrigerant charge. It requires initially a good knowledge of the system behavior, in all operating range of the system. It is a new type of controller that is not found in actual literature. We believe that this type of control can be implemented to optimize refrigeration systems performance, using multiples variables and micro-controllers can be developed using this methodology to control refrigeration systems.

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