

Industrial applications

In this chapter, the implementation of the proposed FDS in different real industrial scenarios is reported. Industrial cases have been described in Chapter 6 (section 6.3).

When applying the proposed methodology of design and implementation, following the presented guidelines in Chapter 5, some limitations usually appear. For example, some sources of information like historical data are not available. In each industrial case, the limitations and the way they are overcome are commented.

First, the two cases of sugar cane refineries are treated. Then, the petrochemical case is considered.

8.1. CACSA Sugar cane refinery

In this case, the process flowsheets, a HAZOP analysis and the historical data from 1998 have been available. The work has been focused on the Boiling and Crystallisation section due its importance in relationship with product quality (Ruiz et al., 1999f; Ruiz et al., 2001d).

First, the handling of the available sources of information is commented. Then the implementation of the ANN and its integration with the FLS in the proposed FDS is shown.

8.1.1. Sources of information

The behaviour of the plant under normal operating conditions as well as under deviations occurred in the past is available. This information is required to develop the pattern recognition block of the FDS (step 4, section 5.2).

Profiles of the measured variables have been plotted. These profiles have been studied taking into account the abnormal situations. The relationship among variables when process faults occur has been considered. From the point of view of process monitoring and fault diagnosis, more than the existing sensors are needed. However, the proposed FDS will be useful because it takes advantage of the available historical data and the process knowledge.

From the partial Piping and Instrument Diagram (P&ID) supplied by CACSA the plant has been divided in sectors. These sectors have been represented by simple schemes as can be seen in Figure 8.1 (dissolution station). Each node has been analysed in order to perform the HAZOP analysis.

The partial scheme of the HAZOP analysis of the dissolution station is shown in Table 8.1. The Deviations considered as more relevant have been analysed and then reported to the plant engineers. The report has been reviewed by the Technical Office (CACSA) and positively evaluated. In the Annex A the HAZOP analysis is shown for the different sectors.

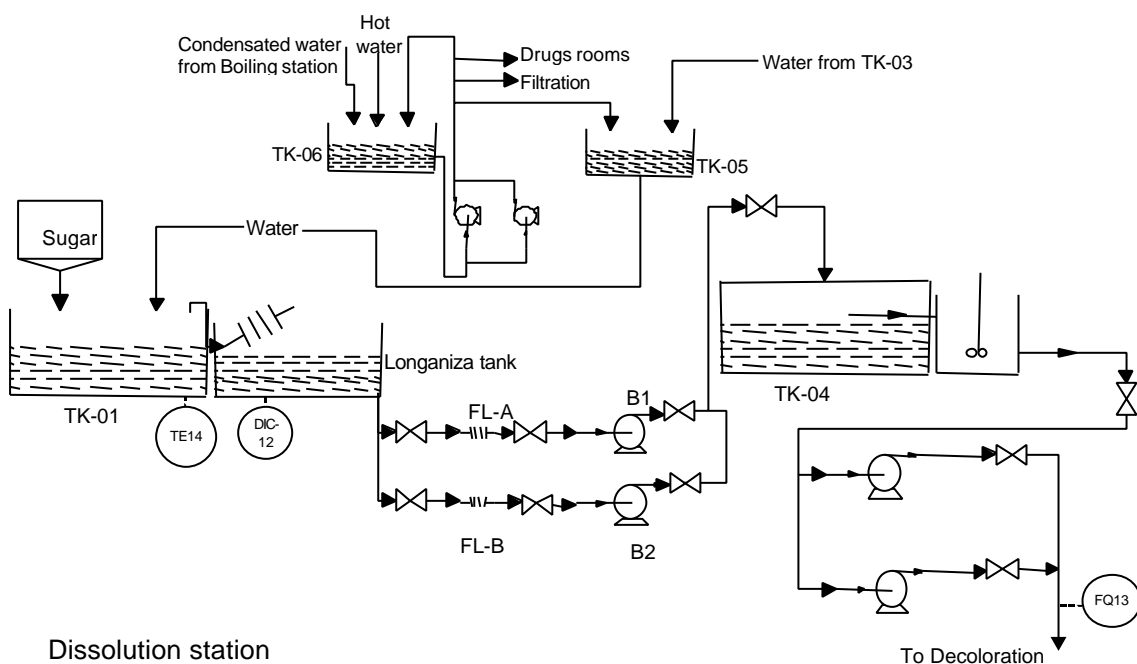


Figure 8.1. P&ID of the dissolution station

Table 8.1. Partial HAZOP analysis (dissolution station)

Dissolution station					
Node: Sugar discharge to TK01					
Variable	Guideword	Causes	Consequences	Safeguards	Recommendations
Flow	No	Raw sugar unavailable	Refinery shutdown	Cut in the Water supply	To operate having an adequate excess of sugar in stock
		Obstruction in the discharge system		Shutdown of pumps B1 & B2	Alternative discharges available
Node: Water discharge to TK01					
Flow	No	Piping broken Fresh water tank empty	High density in dissolution idem	Cut in the Water supply idem	Piping preventive maintenance Low level alarm in tank TK-05 (Fresh water tank)
Temperature	Less	Water temperature decrease in tank TK05 due to low water supply from tank TK03	Difficulties in sugar dissolution	Temperature controller in tank TK01 (TIC-14)	
	More	Water temperature increase in tank TK05 due to low water supply from tank TK06	Possible sugar caramelisation	idem	To install safety cold water stream

From the HAZOP analysis a set of general faults has been recorded. These faults are common in the different sectors of the sugar cane refinery:

- Piping obstruction / leakage
- Pump malfunctioning
- Agitator broken
- Faults in sensors
- Faults in controllers
- Empty tanks
- Tank overloading

On the other hand, some faults are specific of some sectors. The following list summarises them:

- Unavailability of raw sugar
- Water supply high / low
- Excess of syrup
- Excess of activated carbon

- Obstruction in the ionic exchange column

In the following sections, two important faults that correspond to the Boiling and Crystallisation section are considered. They are the following:

- Fault 1: Steam pressure low
- Fault 2: Vacuum level low

These two abnormal deviations affect product quality as can be observed in the partial HAZOP analysis shown in Table 8.2.

Table 8.2. Partial HAZOP analysis of Boiling Station

Boiling station					
STAGE: Loading					
Node: Input of concentrated syrup					
Variable	Guideword	Causes	Consequences	Safeguards	Recommendations
Flow	Less	Low level in the concentrated syrup deposit			
		Insufficient addition of syrup by the operator	Caramelisation of the splashing of small drops on the heating surface	Operating procedure that indicates that the heating surface has to be covered	Level control
STAGE: Grain growth					
Node: Input of heating steam					
Pressure	Less	High steam demand from the plant which generates a sudden decrease in steam pressure	False grain formation	Temperature increase by the reduction of vacuum	Adequate scheduling
Node: Vacuum generator					
Vacuum level	More	Vacuum level increase	idem	Addition of diluted syrup or water	Individual vacuum system
Vacuum level	Less	Vacuum decrease level	Possible sugar coloration due to temperature	Addition of diluted syrup or water	Individual vacuum system
STAGE: Crystallisation					
Node: Vacuum generator					
Seed Humidity	More	Deficient quality control	Bubbles formation	Adequate storage of the seeds	

8.1.2. ANN development

A BPN was trained using the Levenberg-Marquardt method. The inputs are the steam pressure and vacuum level, considering a moving window of six seconds (Figure 8.2). The outputs are the faults: Fault 1 corresponds to low steam pressure and Fault 2 corresponds to low vacuum level. A total of 360 data from one day of operation have been considered. After 50 epochs the Mean square Error (MSE) obtained was 10^{-6}

(Figure 8.3). The faults have been defined as follows: a steam pressure lower than 0.20 kg/cm^2 was considered not permitted (Fault 1=1). A value of 0.45 kg/cm^2 was considered the normal operating condition (Fault 1=0). A vacuum level less than 500 mmHg was considered not permitted (Fault 2 =1). A value of 600 mmHg was considered the normal operating condition (Fault 2=0). Using the trained ANN, it was tested with experimental data.

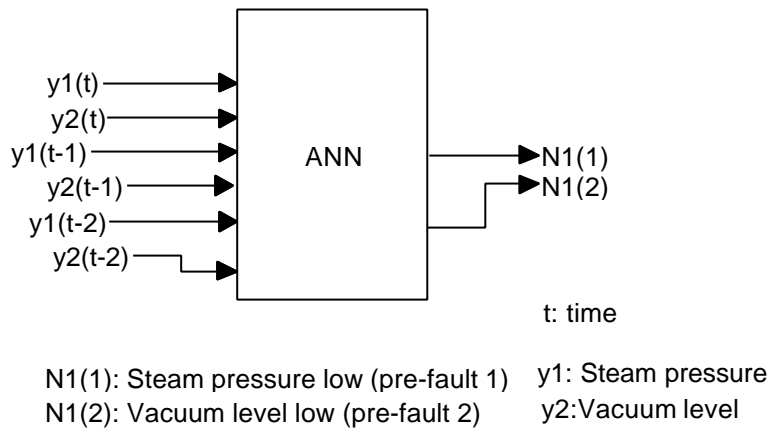


Figure 8.2. ANN scheme

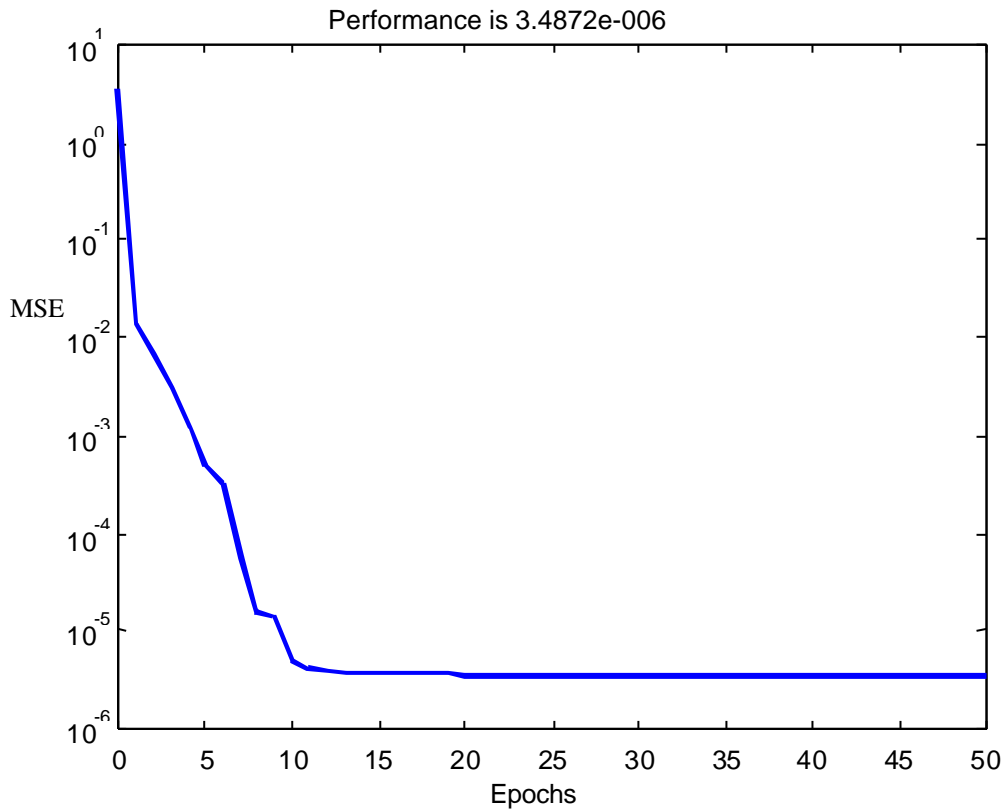
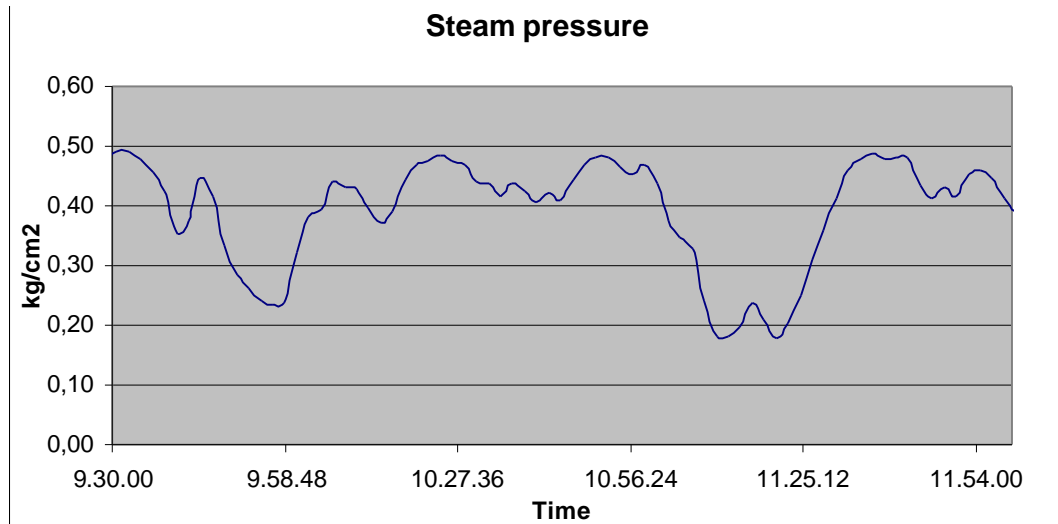
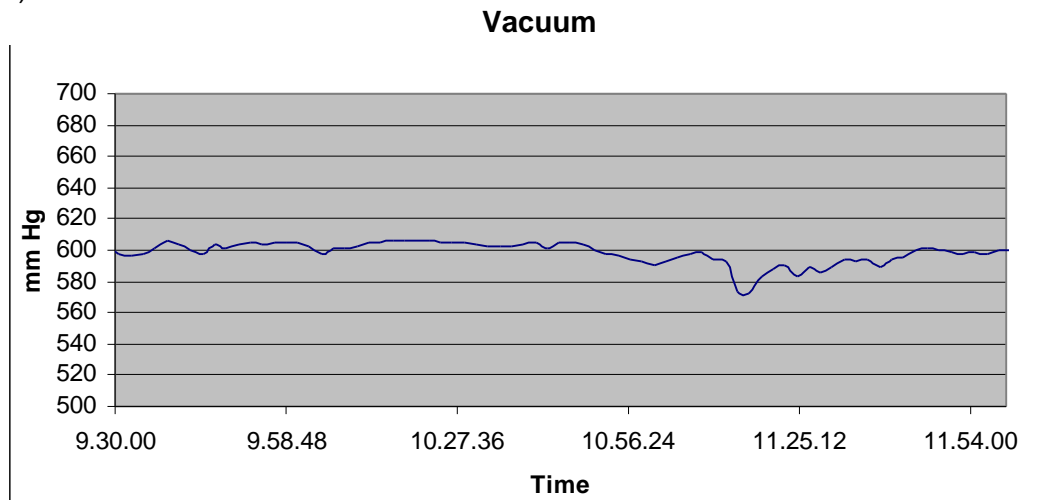


Figure 8.3. ANN training

a)



b)

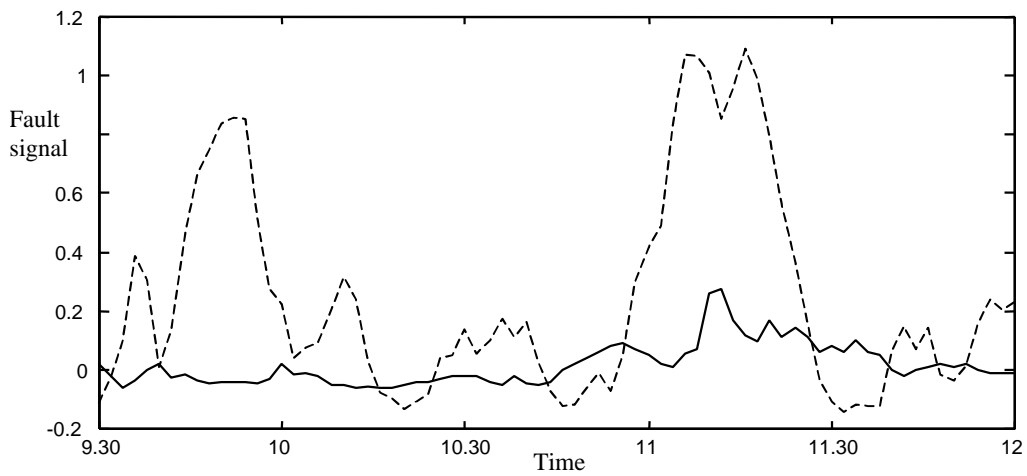


Figure 8.4. Example of Fault 1 occurrence; a) Steam pressure and vacuum profiles. b) ANN response; Fault 1: - - - , Fault 2: _____

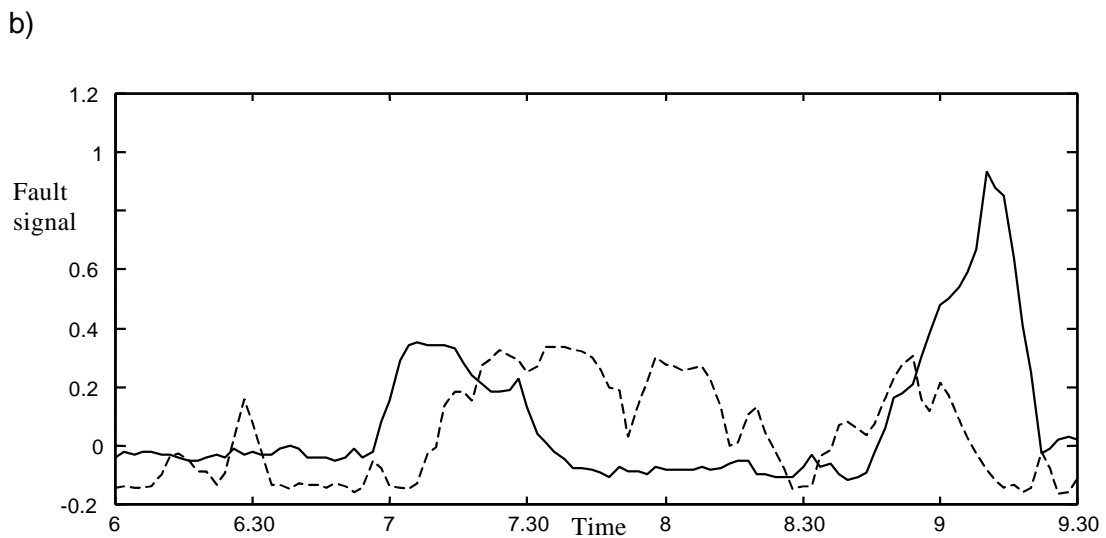
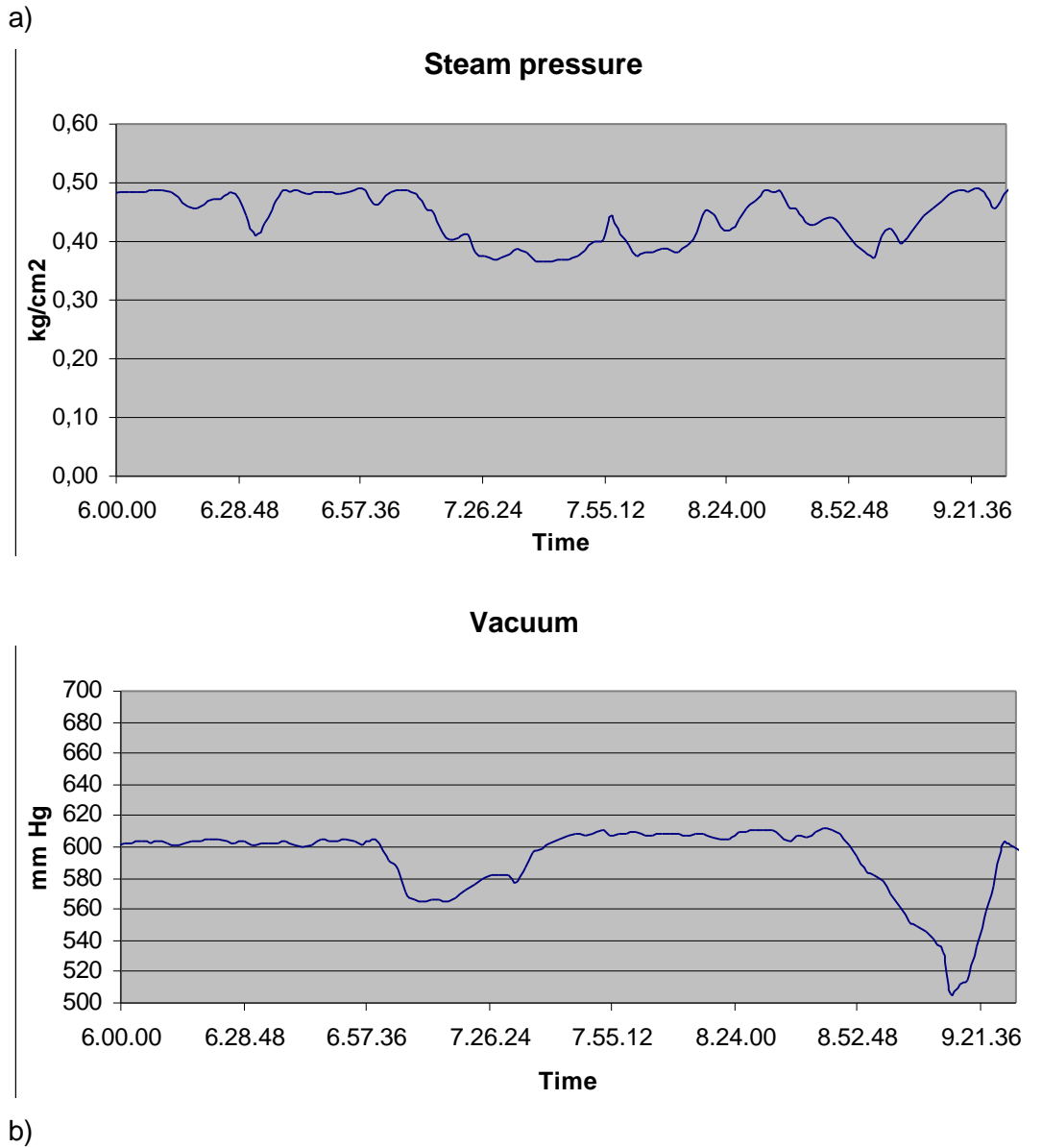


Figure 8.5. Example of Fault 2 occurrence; a) Steam pressure and vacuum profiles. b) ANN response; Fault 1: _ _ _ _ , Fault 2: _____

Figure 8.4 shows the evolution of a) vacuum level and steam pressure and b) the response of the ANN when Fault 1 occurred at time 9.50. The ANN correctly diagnosed the deviation in steam pressure. The consideration of more than one variable helps in obtaining an anticipated signal of the fault. The same Figure 8.4 shows that Fault 1 occurred again at time 11.10 and the ANN anticipated correctly the fault signal.

Figure 8.5 shows the evolution of a) steam pressure and vacuum level and b) the response of the ANN when Fault 2 occurred, at time 9.15. It can be seen how the ANN identified the fault signal in advance.

8.1.3. FLS development

The FLS system has been structured in the following way. Each Fault has a sub FLS. In the following paragraphs the sub-FLS for the diagnosis of Fault 1 is explained. The sub-FLS for the diagnosis of Fault 2 has a similar structure.

In order to diagnose Fault 1, two inputs and one output are considered. The inputs are the ANN output and the steam pressure. The FLS properties are the following. It is a Sugeno type FLS. It has trapezoidal membership functions for the inputs and "product" inference procedure. Membership functions (μ) for the output Fault are "high" (parameter 1, constant) and "low" (parameter zero, constant). The overall output is obtained via weighted average. Figure 8.6 shows the Graphical User Interface (GUI) of the explained sub-FLS. It has been built using Matlab/Fuzzy Logic Toolbox.

For each input the membership functions (μ) have been defined in the following way. The range of normal operating conditions for steam pressure has been defined with the term "normal" ($\mu = 1$). The μ plots are shown in Figure 8.7 for this input. As can be seen the term "low" has been used for pressures levels lower than the abnormal operating condition of 0.2 kg/cm^2 .

Eight rules have been defined in relation to Fault1. They have been extracted from the HAZOP analysis, the ANN results and the experience with the plant. Figure 8.8 shows the GUI.

Figure 8.9a and 8.9b show the fuzzy reasoning when Fault 1 has been simulated. The first two columns correspond to the inputs to the FLS (the ANN output for the Fault1 and the steam pressure value). The third column corresponds to the FLS output (Fault 1). The eight rows correspond to the eight if-then rules. The activated MF in each if-then rule is greyed for the inputs. For the output, as it is a Sugeno FLS, the

contribution to the weighted average of each if-then rule can be observed (the black thick line indicates that the corresponding if-then rule is activated). In Figure 8.9a, the ANN output has a value of 1 and the steam pressure has the value of 0.2 kg/cm² (a non permissible low value for steam pressure). The FLS output, that is, the weighted average, has a value of 1. It is important to point out that in practice the Fault 1 is diagnosed even if the ANN output is lower than 1 and the steam pressure is higher than 0.2 kg/cm² (over the non permitted limit), anticipating the fault adequately (Figure 8.9b). In this last case, the FLS output has a value of 0.9.

Figure 8.10 and Figure 8.11 show the response of the FDS during a day of operation of the plant (May 23th 1998). Fault 1 (low steam pressure level) has been successfully diagnosed several times. On the other hand, Fault 1 (low vacuum level) has been diagnosed in advance at time 9.15.

8.1.4. Check list for the operators

One of the main problems in relation with the implementation and adequate maintenance of the proposed FDS is the correct follow-up of the faults that are occurring.

A checklist has been proposed to the plant managers. By this way, the operators can report adequately the deviations. Furthermore, the expert system can be updated. The checklist has been built following the HazOp analysis scheme because the operators should have training and also should participate in plant hazard analysis. Table 8.3 shows an example of the proposed checklist. In the case of repetitive incidences, the checklist can be improved with schemes of the type "multiple choice". For example:

Pump malfunctioning		TAG: P01
Piping leakage		
Empty tank		

Table 8.3. Proposed checklist for the operators

Equipment Boiling tank n° 26

Plant section Boiling & crystallisation section

Begins Date/time	Reported by	Ends Date/Time	Reported by	Description of the deviation	Possible causes	Consequences observed	Corrective actions	Comments
10/12/99: 14:55	Pablo Galetti	10/12/99; 16:30	José Pérez	Syrup is not circulating during tank loading	Shutdown pump P1 due to cavitation	Boiling delayed	Change of configuration to work with	Automation of the change is proposed

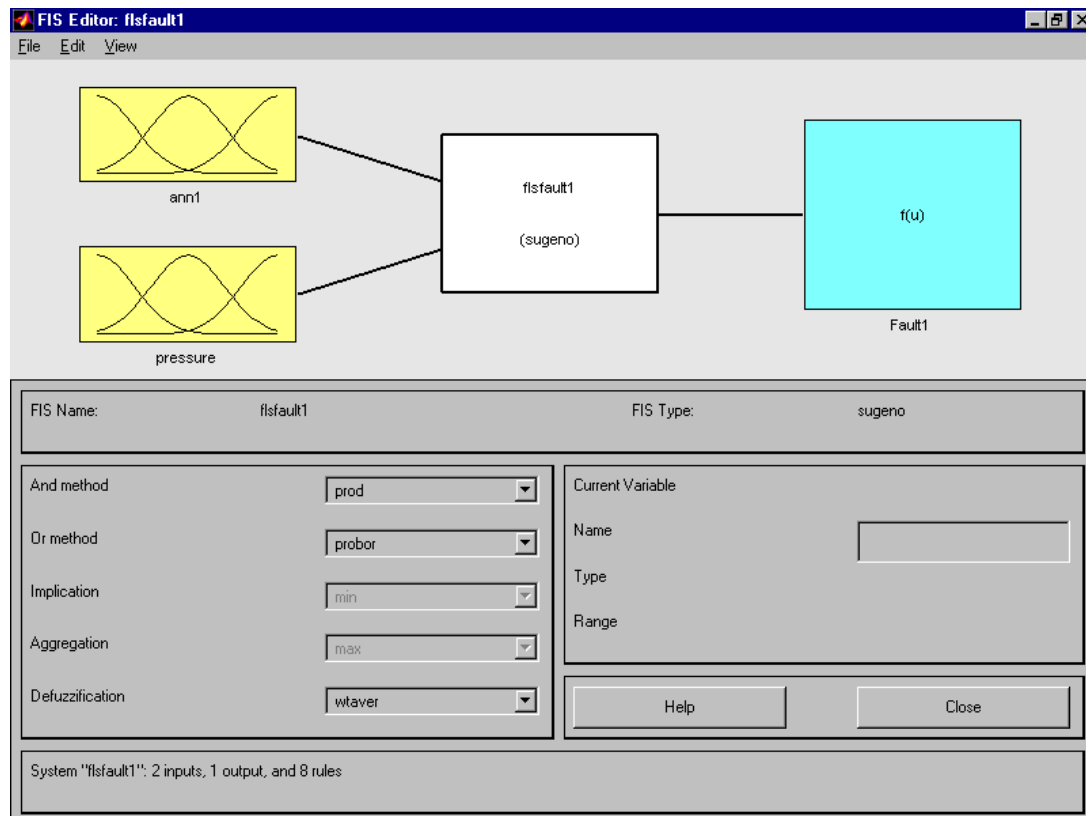


Figure 8.6. GUI of the subFLS for the diagnosis of Fault 1

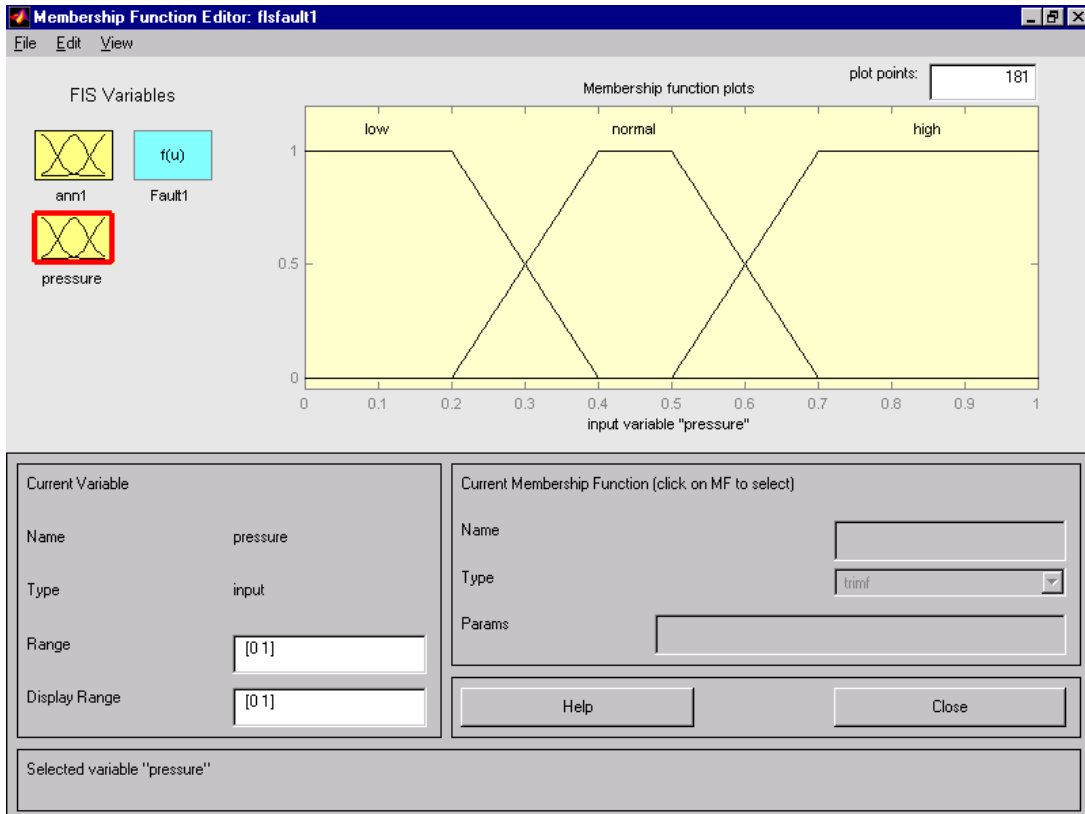


Figure 8.7. Membership function plots for the input steam pressure (sub FLS, Fault 1)

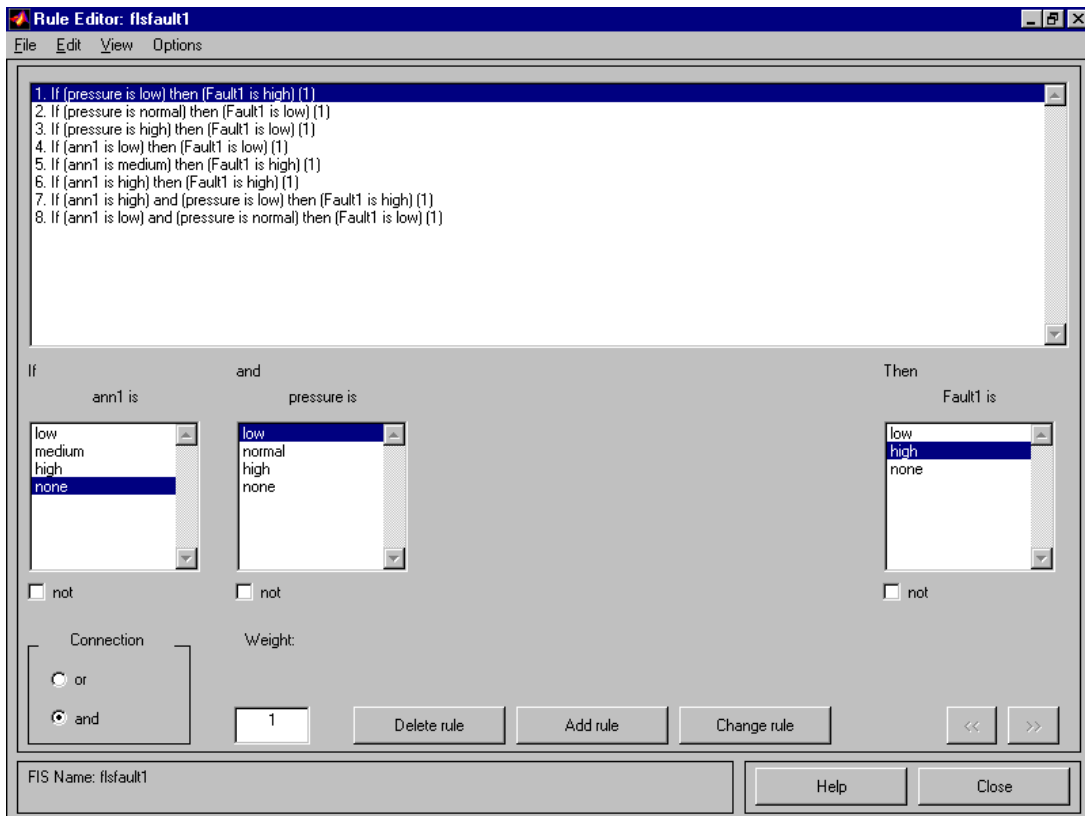
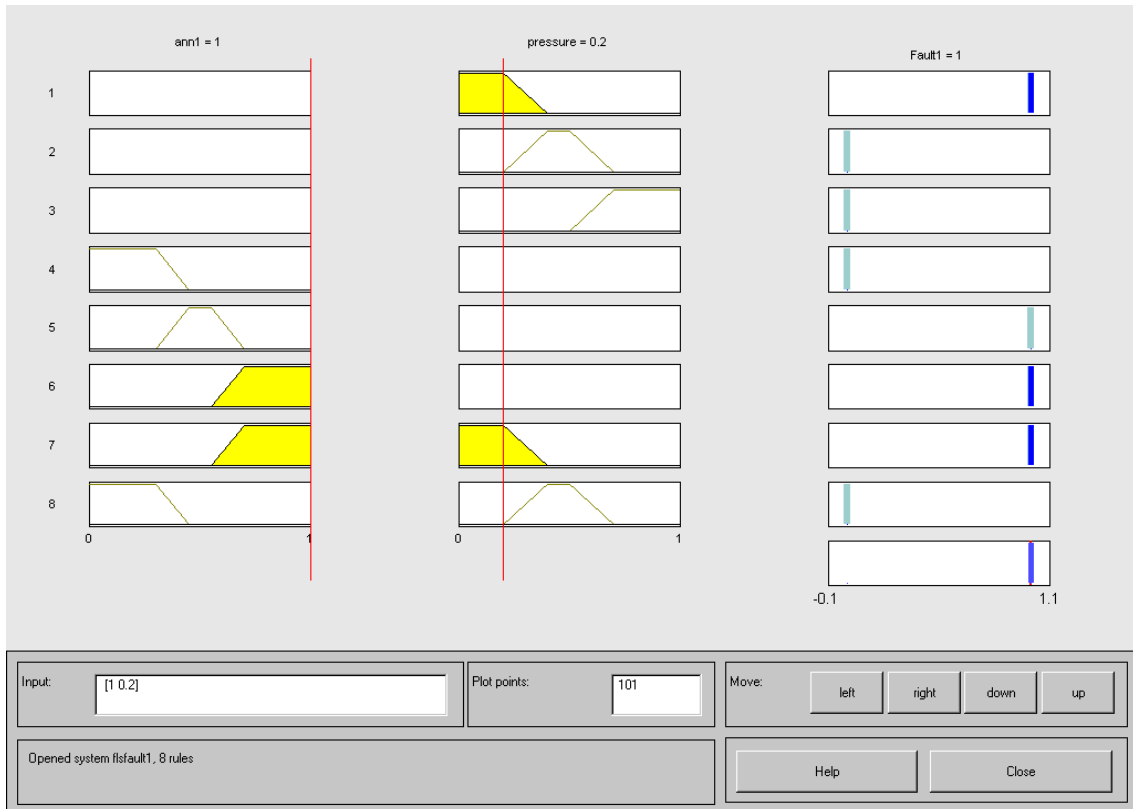


Figure 8.8. Set of rules of the sub-FLS for Fault 1 diagnosis

a)



b)

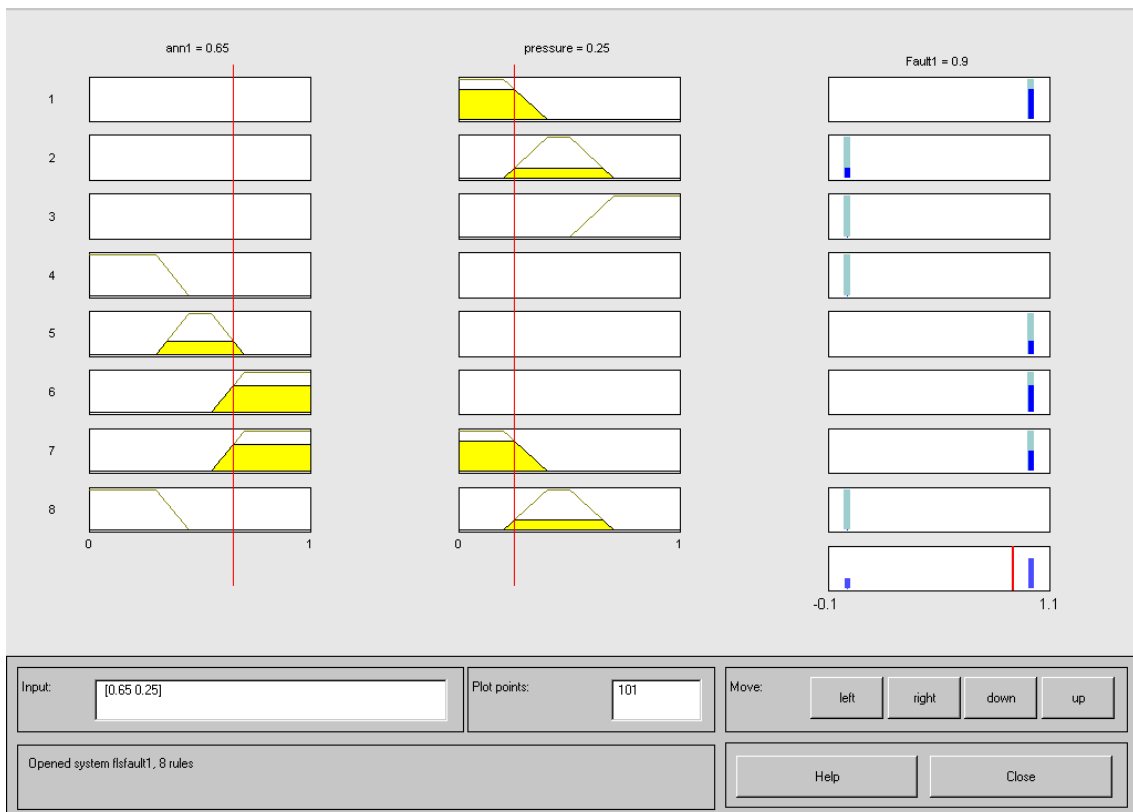


Figure 8.9. Fuzzy reasoning when Fault 1 is simulated; a) FD; b) Incipient FD

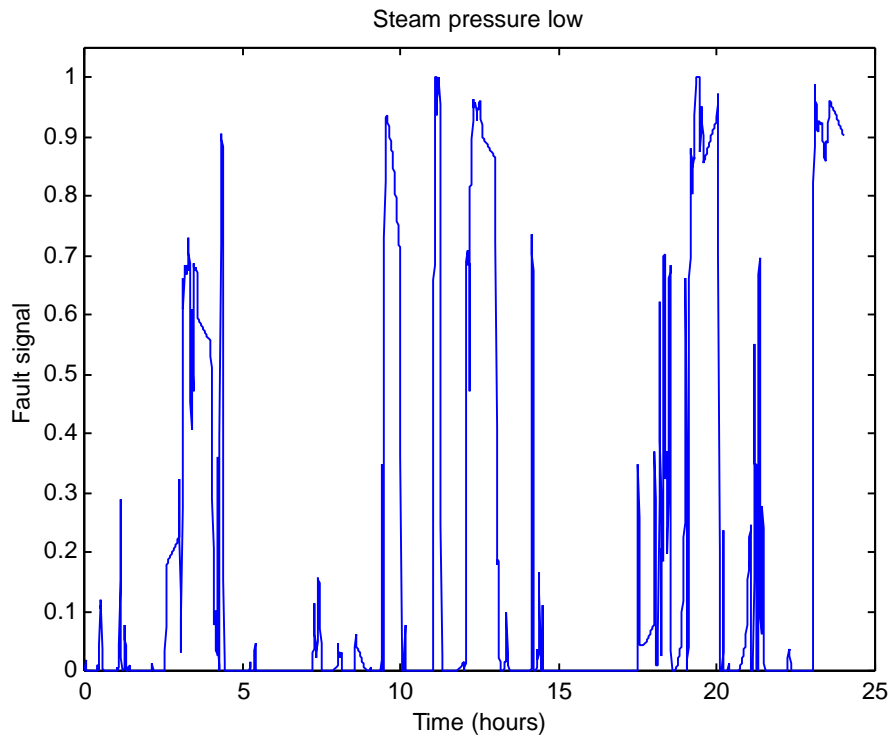


Figure 8.10. FDS response during May23th 1998. Fault 1 occurred several times

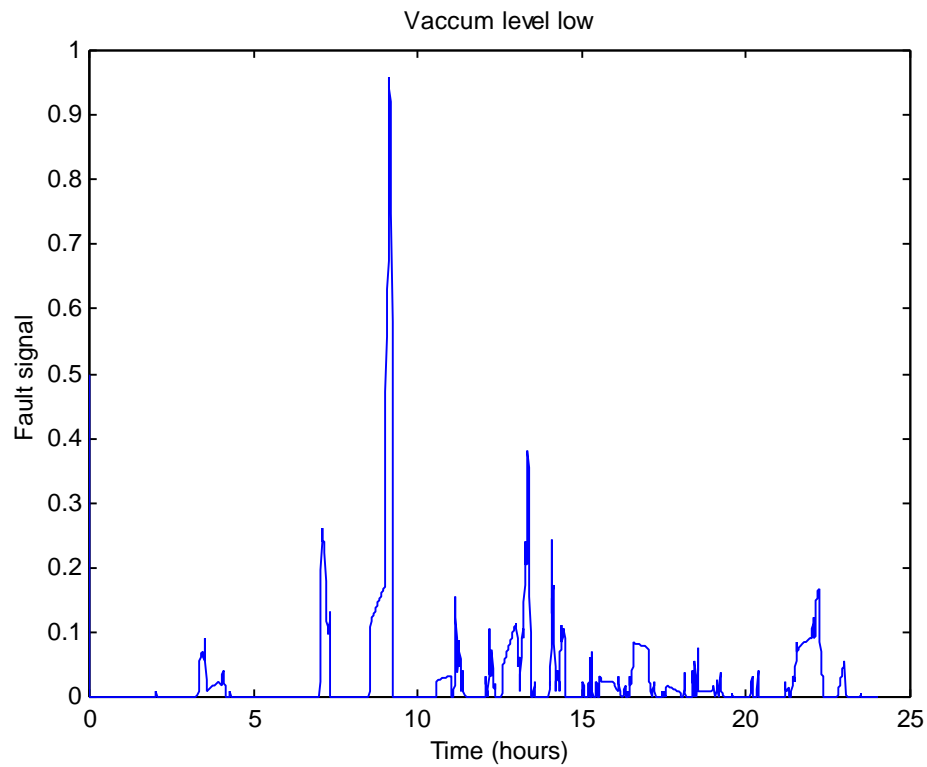


Figure 8.11. FDS response during May23th, 1998. Fault 2 diagnosed at time 9.15

8.1.5. Discussion

Promising results have been shown in the diagnosis of abnormal deviations. The Boiling and crystallisation sector of the cane sugar refinery was chosen to show these results.

One important and useful task performed is the HAZOP analysis in the sugar cane refinery. The conclusions of that analysis can lead to the implementation of safeguards that improve the plant safety and also the optimal operation.

In this case study, it has been shown the development of the FLS from the HAZOP analysis. A main feature of the novel approach is the ease of implementation.

A checklist for the operators has been proposed in order to improve system performance by successive updating.

The proposed FDS shows to be robust enough to manage abnormal situations in complex plants. The development made is very important to increase the efficiency in the sugar industry. It has strategic importance in most countries, especially in selected specific regions where it represents a large amount of the total sugar produced by the respective countries.

8.2. CAICC sugar cane refinery

In the case of CAICC, the FDS has been developed based only on the HAZOP analysis and off-line measurements because there is not an on-line data acquisition system installed (Ruiz et al., 2001f). A detailed flowsheet was developed and a complete HAZOP analysis of the preparation of the syrup for the refinery has been provided by plant engineers (Annex A).

From HAZOP analysis the following set of faults has been extracted which correspond to "possible causes":

- Lack of sugar supply
- Insufficient cleaning in the centrifuges
- Thick discharge of hopper
- Excess of density in the magma
- Weight of band for the sugar broken
- Shutdown of centrifuges
- Shutdown of the drivers and elevators
- Thick supply line
- Insufficient steam to the syrup tank
- Valve of recirculation blocked
- Excess of steam in the syrup tank
- Deficient pumping of the liquor
- Fault in density controller (in the mingler)
- Agitator broken
- Syrup tank empty
- Tank of dissolved sugar full
- Locking of the valve in the line that feed the mixer
- Fault in the sugar solution temperature controller
- High level in the pre-dissolutor
- Water heating insufficient
- Cleaning cycle in centrifuges out of control
- Fault in density controller
- Fault in water temperature controller
- Deficient dissolution of the sugar in the gondolas
- Time of centrifuging low

Table 8.4 shows the HAZOP analysis of node "mingled of raw sugar". It is highlighted one line in order to show the construction of the if-then rule from HAZOP analysis. The rule is:

If "Temperature" is High Then "Excess of Steam to refinery" is High.

The range of normal conditions of each observable variable has been provided by the plant engineers, together with the corresponding limits for the unpermitted deviations. With such information, the MF of each observable variable has been defined by using trapezoidal ones. For example, the temperature of the mingled of raw sugar has a range of normal values of 46-48 °C. A value of 1 is given for the MF of the fuzzy set Normal in that range. A value of 50°C is considered a non-permissive higher limit. Therefore, the value of 1 is given for the MF of the fuzzy set High in the range of 50°C and higher. A value of zero is given for that MF at the value of 48°C as well as for the MF of the fuzzy set Normal at the value of 50°C. In the same way, a value of 44°C is considered a non-permissive lower limit. Therefore, the value of 1 is given for the MF of the fuzzy set Low in the range of 44°C and lower. A value of zero is given for that MF at the value of 46°C, as well as for the MF of the fuzzy set Normal at the value of 44°C.

Table 8.4. Partial scheme of HAZOP analysis - CAICC- "Raw sugar mingled"

HAZOP ANALYSIS. REFINERY PLANT.						
	GUIDE WORD	VARIABLE	DEVIATION	POSSIBLE CAUSES	CONSEQUENCES	RECOMMENDATIONS
NODE # 2: MINGLED OF RAW SUGAR	NO	FLOW	LACK OF SUGAR	LACK OF SUGAR SUPPLY	REFINERY SHUTDOWN	TO HAVE SUFFICIENT STOCK OF SUGAR
	LESS	TEMP.	LOW TEMPERATURE IN THE SYRUP	INSUFFICIENT STEAM OF HEATING FOR THE REFINERY SYRUP	LOW QUALITY IN REFINED SUGAR	TO IMPROVE THE REGULATION OF TEMPERATURE IN THE SYRUP TANK TO INCREASE TIME OF CENTRIFUGATION
	MORE	TEMP.	HIGH TEMPERATURE IN THE SYRUP	EXCESS OF STEAM TO REFINERY	DISSOLVED SUGAR IN EXCESS IN THE REFINERY PROCESS	TO IMPROVE THE REGULATION OF TEMPERATURE AND TO ADD LESS SYRUP
	LESS	DENSITY	EXCESS OF SYRUP IN THE SYSTEM	DENSITY REGULATION OUT OF CONTROL	DISSOLVED SUGAR IN EXCESS IN THE REFINERY PROCESS	TO IMPROVE THE REGULATION OF THE DENSITY CONTROL LOOP
	MORE	DENSITY	LACK OF SYRUP IN THE SYSTEM	LACK OF SYRUP IN THE SUPPLY TANK AND FAULT IN THE DENSITY CONTROL SYSTEM	MINGLER BROKEN	TO IMPROVE THE REGULATION OF THE DENSITY CONTROL LOOP TO INSTALL LOW LEVEL ALARM IN THE SYRUP TANK

Figure 8.12 shows the fuzzy reasoning when that fault is simulated in the explained node "mingled of raw sugar". There are three observed variables: discharge of syrup

flowrate (ton/day), mingled of raw sugar temperature (°C) and mingled of raw sugar density (°Brix). Six rules has been defined. The third one (above described) has been fired in this example. The output, the fault "Excess of steam to refinery" coded as F22, has a value of 1.



Figure 8.12. Fuzzy reasoning when Fault "Excess of steam to the refinery" has been simulated.

Some nodes have the same suspected fault. For example, the fault "lack of sugar supply" can be diagnosed in two nodes: "Discharge section" and "Mingled section". In such cases, the response of the FDS is chosen as the major output value from the two considered FLSs.

Figure 8.13 shows the Graphical- User - Interface (GUI) done with Matlab-Simulink of the FDS that can be used by the operators as a support for decision-making. The measurements from the plant (off-line) are inserted in the developed program and as a result the signals of the suspected faults are obtained. On the left, the cells of the observed variables are displayed. In the centre, the four blocks corresponding to the four considered nodes are located. On the right, the display of each suspected fault is

shown. In this case, a value of zero (no fault) can be observed for all the suspected faults.

The updating of the system can be easily carried out through editing the if-then rules. The edition can be performed when the corresponding HAZOP analysis is revised or when new unsuspected faults appear. The proposed checklist for the operators (section 8.1.4) can be used for such purpose.

The proposed FDS has been tested with hypothetical situations and has responded well. It is now being used at CAICC.

FDS implementation in this industrial case has not the brightness of the other industrial applications presented in this thesis since it is not an on-line application. However, the active and interested participation of plant personnel has allowed obtaining an important tool that is satisfying their expectations. Furthermore, they want to extend the application to other sectors of the plant.

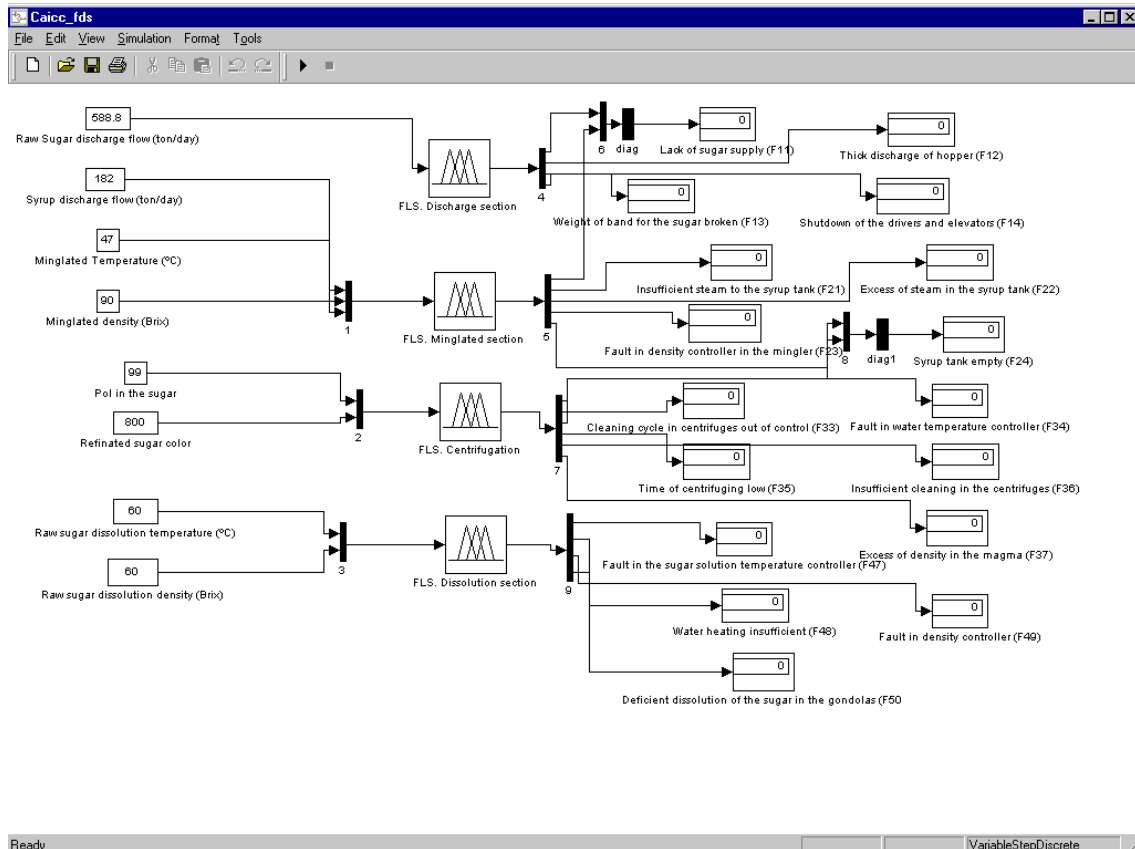


Figure 8.13. GUI of the FDS support for operators at CAICC plant.

8.3. Petrochemical plant

The aim of this section is to present a proposal of implementation of the proposed FDS in a real industrial plant, already described in section 6.3.2. The focus of this section is to highlight that the developed technology can take advantage of existing software packages that are familiar to plant engineers (e.g. Plant Information System) and a commercial process simulator (Ruiz et al., 2000d; Ruiz et al., 2001e).

First, the use of the available sources of information are described (historical data, plant model and HAZOP analysis). Then, implementation results are shown.

8.3.1. Historical data

Data was collected using Plant Information (PI) historian Excel Data Link interface. A total of 50 operating variables were collected during the period December 1998-February 1999. After data screening, inspection to identify unstable operating conditions or sensor malfunction, a 5 days period was selected as training set.

NeuroOnline Studio software can be used off-line or on-line. It is a tool for analysis of processes. Typically, the source of data is a data historian or other data archive. Here, it has been used as a visualisation tool for Principal Component Analysis (PCA) plots. Figure 8.14 shows the plot of the two first Principal Components. Three points can be distinguished corresponding to an identified deviation (highlighted with white boxes).

Using the step-by-step guidance provided by NeuroOnline Studio, an ANN has been trained and tested to predict the identified upset. Figure 8.15 shows the output of the ANN model which gives the value of 1 when the fault occurs. The predicted values practically overwrite the actual ones.

In order to show a more general applicability of the proposed FDS another kind of ANN, programmed with Matlab, was utilised in the section 8.3.4 (Implementation Results).

8.3.2. Plant model

The plant has been simulated using HYSYS.Plant. Perfect pressure control of both columns has been assumed. Reboilers and accumulators levels are controlled with Proportional-only controllers. A Proportional Integral controller controls the feed to the plant flow-rate. Cascade control is used for Stage 9 temperature at the Re-distillation column, which is related to product composition, by controlling the reflux to the column.

Comparing the available historical data and simulation results some differences have been found. This is a typical situation when simulating chemical plants. The usefulness of a simulator is characterised by the ability to predict the trend of the real plant behaviour.

8.3.3. HAZOP analysis

Table 8.5 shows a simplified sample of the plant HAZOP analysis which has as cause the considered fault "High hot oil to the reboiler". The set of variables considered are only the on-line measurements from the plant.

Table 8.5. Fragments of the HAZOP analysis

Variable	Guideword	Causes	Consequences
Reboiler level - Stripper column (LREB1)	High	High Hot-oil to Reboiler (re-distillation column)	Fluctuation in Product compositions
Reboiler level - Re-distillation column (LREB3)	Low	idem	idem
Temperature - top stripper column (TTOP1)	High	idem	idem
Temperature - top Re-distillation column (TTOP3)	High	idem	idem
Temperature - bottom stripper column (TBOT1)	High	idem	idem

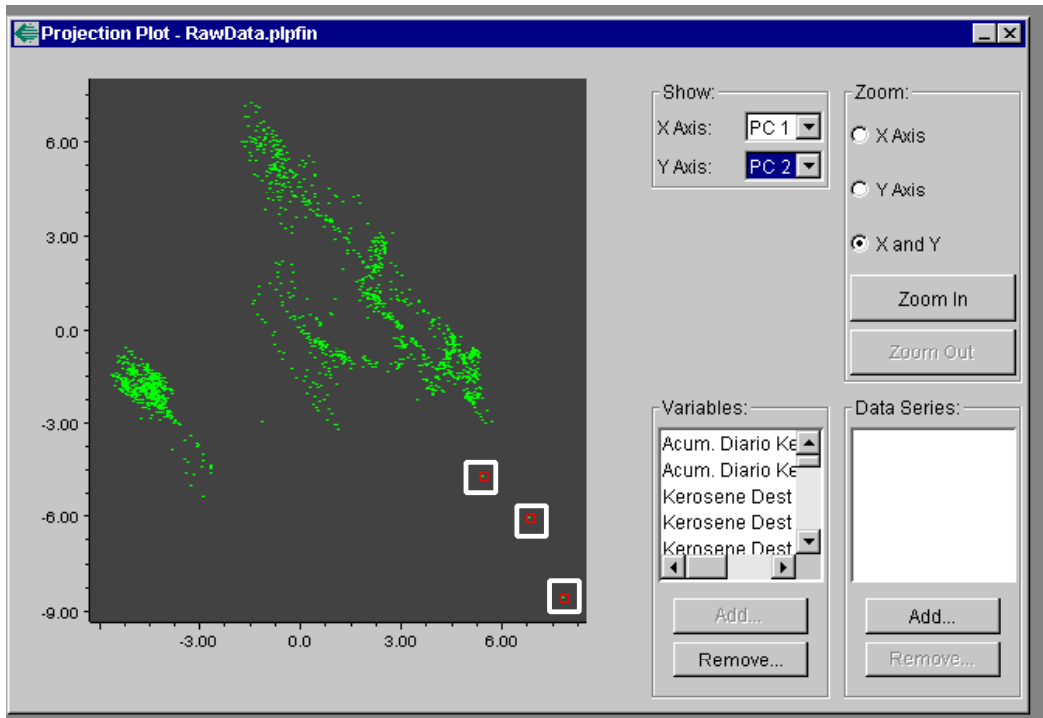


Figure 8.14. PCA plot indicating a plant upset

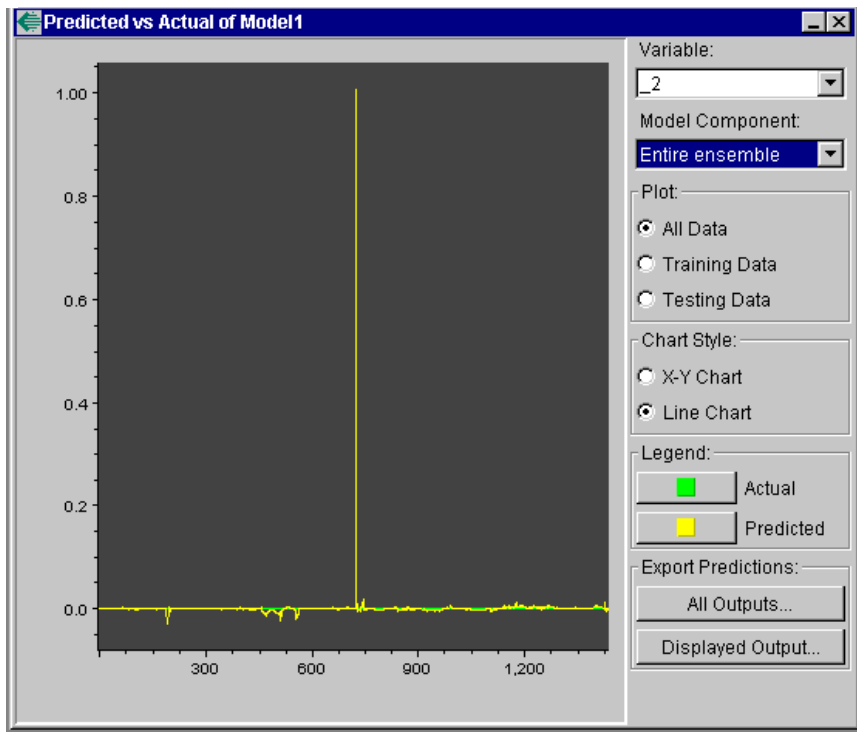


Figure 8.15. Neural model response to the identified upset

8.3.4. Implementation results

The implementation test was focused on a specific problem which consists in a fluctuation in the pressure of hot oil utilised for the reboiler's heating at the Re-distillation column. This fault was simulated and the variable profiles were saved.

The different signals were processed by a multilevel 1-D wavelet using a specific wavelet filter. An eight-coefficient Daubechies wavelet was used as a filter. As the noise components are reduced and then disappeared as the scale increases, the detail of scale 5 was considered sufficient. Then, the extrema of the processed signals was determined for each signal (section 5.4.2).

The following measured process variables show special features corresponding to the fault studied: feed to the stripper flow rate; stage 35 temperature in the stripper column; Boilup and stage 38 temperatures in the Re-distillation column; and Reflux to Re-distillation column flow rate. These patterns were used as inputs to the ANN classifier. Figure 8.16 shows the patterns corresponding to the signal of the extrema determination from wavelet decomposition of the signal Feed Flow rate to the stripper. It can be seen how the frequency of the extrema is increased with the size of the fault. The ANN architecture used as a classifier in this study was a PNN.

The development of the rules was carried out from the HAZOP analysis. The set of if-then Rules extracted from the HAZOP analysis shown in Table 8.5 is the following (the considered fault "High hot oil to the reboiler" is coded as FAULT 1):

IF LREB1 IS HIGH THEN FAULT1 IS HIGH

IF LREB3 IS LOW THEN FAULT1 IS HIGH

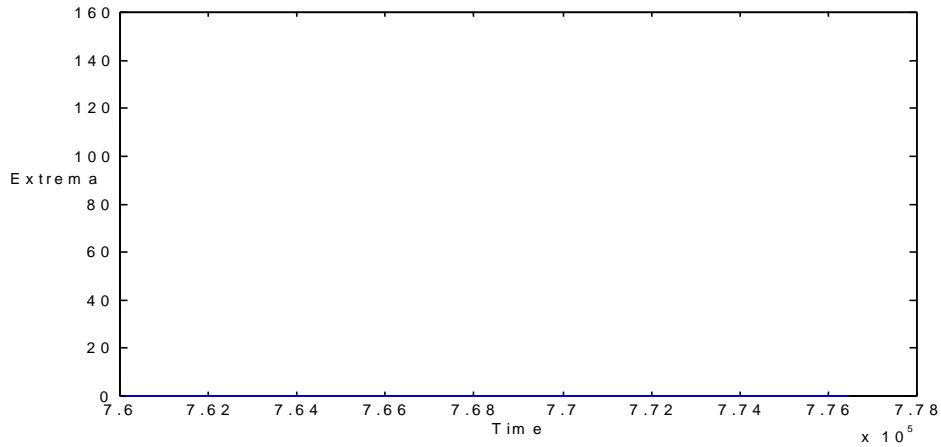
IF TTOP1 IS HIGH THEN FAULT1 IS HIGH

IF TTOP3 IS HIGH THEN FAULT1 IS HIGH

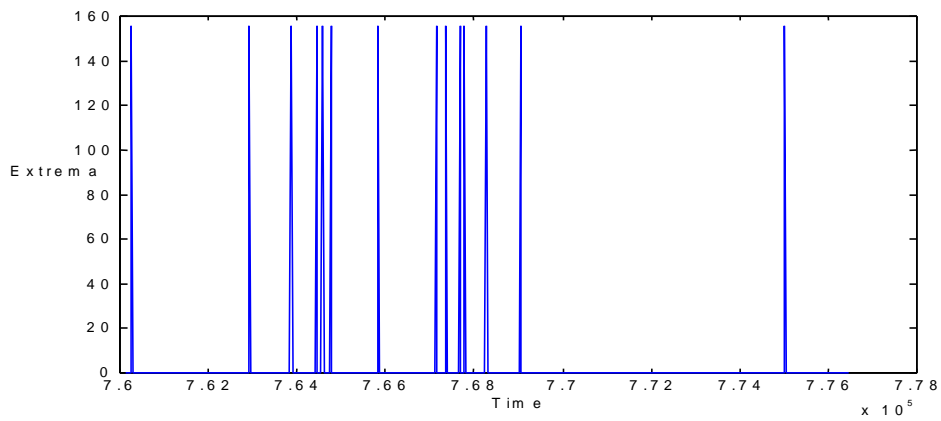
IF TBOT3 IS HIGH THEN FAULT1 IS HIGH

The previous set must be complemented by considering the opposite changes with the consequent "FAULT1 IS LOW", and by the if-then rules which include the neural classifier information (e.g. "IF $N1(1)$ IS HIGH THEN *FAULT1 IS HIGH*").

a)



b)



c)

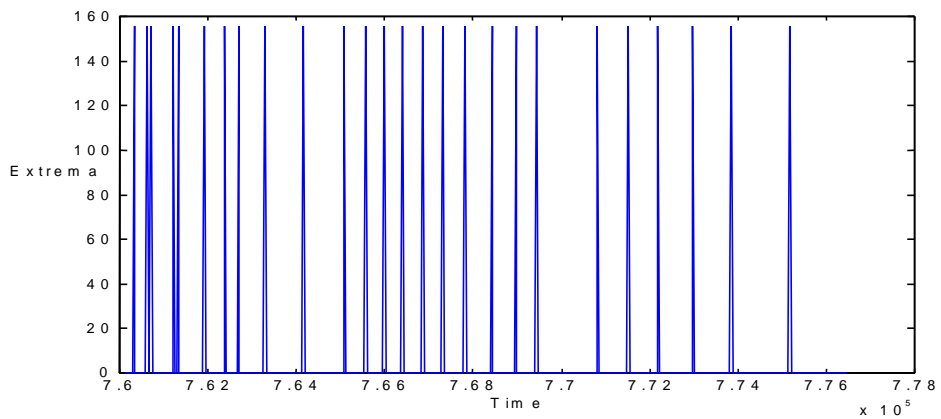


Figure 8.16. Extrema Determination from wavelet decomposition of signal Feed Flow rate to the stripper. a) No fault; b) High flowrate of Hot-oil to Reboiler Re-distillation column (+1%); c) High flowrate of Hot-oil to the Reboiler Re-distillation column (+2%).

The real plant has been simulated with HYSYS.Plant, using the DCS driver to allow communication with other applications. In this case, the other application is MATLAB, where the pre-processing system and the FDS are run.

Figure 8.17 shows the Graphical User Interface of HYSYS.Plant with the strip charts of the measured variables and the fault signal in the top-right corner, during the simulation of the fault studied. The fault signal jumps from zero to one. On the other hand, the strip charts with the process measurements show the profiles of the tank levels (reboiler, condenser and accumulator corresponding to both columns "FRV1" and "FRV3"), the flowrates (feed, reflux, top and bottom corresponding to both columns) and the product composition (molar fraction of the hydrocarbons). Slight changes in process measurements are observed. At the bottom, a portion of the process flow diagram is shown and, above it, a part of the spreadsheet with the process variables that are sent to the FDS program.

The fault isolation shows to be fast enough to take actions onto the plant.

8.3.5. Discussion

A proposal to speed-up the implementation of a support framework for Abnormal Situation Management in a real petrochemical plant has been shown through the petrochemical case study.

The main feature of the technology developed is that it takes advantage of existing software packages that are familiar to plant engineers (e.g. Plant Information System) and a commercial process simulator.

8.4. Conclusions

The proposed FDS has been implemented in three industrial cases. The motivation has been to illustrate that the FDS is flexible enough to handle the lack of information, sometimes usual in real industrial plants.

By this way, the testing and validation of the proposed FDS has been completed. The results obtained in case studies with increasing complexity (academic and pilot plant scenarios, in Chapter 7) has been complemented with the implementation of the proposed FDS in scenarios ^oat industrial scale.

Furthermore, some considerations has been made looking for the reduction of the gap between academia developments and industrial applications. By this way, the use of

the existing software packages that are familiar to plant engineers has been suggested to speed-up the implementation of the FDS.

A checklist for the operators has also been proposed for the adequate maintenance of the FDS.

Finally, it is important to note that the good results obtained promise a good future to the presented technology.

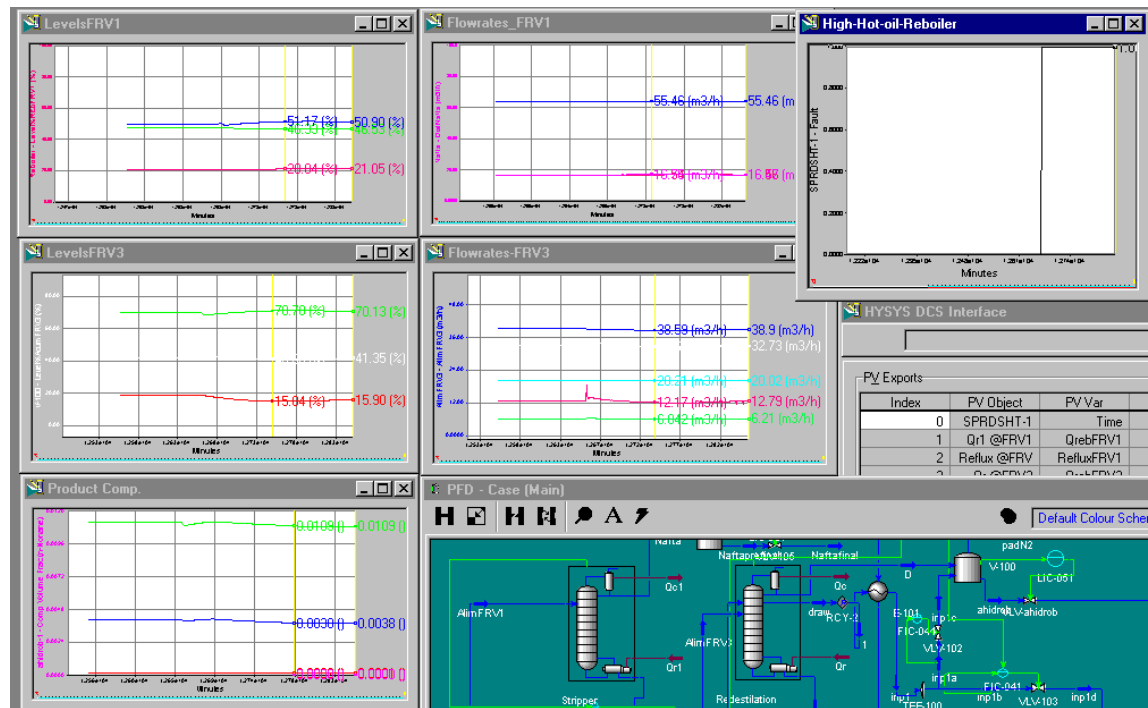


Figure 8.17. HYSYS.Plant Graphical user interface. Fault "High Hot oil to Reboiler" simulated

Acronyms

ANN	Artificial Neural Network
BPN	Backpropagation ANN
DCS	Distributed Control System
FDS	Fault Diagnosis System
FLS	Fuzzy Logic System
GUI	Graphical-User-Interface
HAZOP	Hazard and Operability study
MSE	Mean Square Error
PCA	Principal Component Analysis
PNN	Probabilistic Artificial Neural Network
P&ID	Piping and Instrument Diagram

Notation

F	Fault vector
$N1$	Output vector of the ANN in the proposed FDS

Greek symbols

m	Membership function
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