Nomenclature

Acronyms

AANN	Autoassociative Artificial Neural Network
ABM	Assumption Based Method
AEGIS	Abnormal Events Guidance and Information System
ANN	Artificial Neural Network
ASM	Abnormal Situation Management
BPN	Backpropagation Artificial Neural Network
DCS	Distributed Control System
EKF	Extended Kalman Filter
F&EI	Fire and Explosion Index
FD	Fault Diagnosis
FDS	Fault Diagnosis System
FL	Fuzzy Logic
FLS	Fuzzy Logic System
FMEA	Failures Modes and Effect Analysis
GDR	Generalized Delta Rule
GUI	Graphical-User-Interface
HAZOP	Hazard and Operability study
IFAC	International Federation of Automatic Control
KB	Knowledge Base
KBES	Knowledge Based Expert System
MF	Membership function
MHI	Material Hazard Index
MPCA	Multiway Principal Component Analysis
MSE	Mean Square Error
NF	Neuro-Fuzzy
NLPCA	Nonlinear Principal Component Analysis
OBM	Observer Based Method
P&ID	Pipìng and Instrument Diagram
PCA	Principal Component Analysis
PCB	Pseudo Continuous Block
PCEG	Possible Cause-Effect Graph
PHA	Preliminary Hazard Analysis
PLS	Partial Least Squares
PNN	Probabilistic Artificial Neural Network

QTA	Qualitative Trend Analysis
RB	Rule Based
RBFN	Radial Basis Function Neural Network
SDG	Signed Directed Graphs
SOM	Self Organising Map
SPC	Statistical Process Control
SPE	Squared Prediction Error

Notation

a	ANN output vector
a_i	Output vector of the ith layer in a BPN
Api	Approximation on the ith decomposition
b	ANN bias vector
b_i	Bias vextor of the ith layer in a BPN
db	Number of nodes in the bottleneck layer of an AANN
Di	Detail of the ith wavelet decomposition
dl	Dilation parameter of a wavelet
E	Residual matrix for a new batch
$\underline{E}$	Residual matrix for historical database
f	Function
F	Fault vector
g	Target vector for ANN training
$H0$	Low pass filter
$H1$	High pass filter
i	Index for batches (or for samples)
j	Index for measurements (sensors)
J	Total number of measurements (sensors)
k	Index for time intervals
K	Total number of time intervals
l	Index for layers in an ANN
m	Index for nodes in an ANN
$M1$	Vector of measurements from the plant that are the ANN's input
$M1K^{nf}$	Matrix with the measurements profiles for the fault nf
$M1'K^{nf}$	Matrix of extrema of the measurements for the fault nf
$m1$	Length of vector M1
$M2$	Vector of measurements from the plant that are part of the FLS's input
$m2$	Total number of measurements that are part of the FLS's input
Md	Number of nodes in the demapping layer of an AANN
Ml	Number of nodes in the mapping layer of an AANN
n_i	Activation status vector of the ith layer in a BPN
$N1$	Output vector of the ANN in the proposed FDS
$n1$	Total number of "pre-faults" diagnosed by the ANN
n	Activation status of a node in an ANN
N	Total number of nodes in a layer of an ANN
Nf	Total number of defined faults
nf	Index for faults
$\%P$	Performance parameter for FDS
$\%P^*$	Modified %P which takes into account cases of false diagnosis
p	Principal components loading vector
P	Principal components loading matrix

P^T	Transpose of matrix P
q	ANN input vector
Q	Sum of squares of the residuals
R	Range of the SPE_{js}% of the set of sensors
rl	Index for rules
Rl	Total number of rules in a FLS
S_i	Total number of nodes of the ith layer of an ANN
S_n	Total number of nodes of the output layer of an ANN
SPE_j	SPE calculated for the measurement j and the corresponding output of the AANN
SPE_{js}	99% upper control limit of SPE_j for a set of correct measurements
$SPE_{js}\%$	Percentage relation between SPE_j of a new measurement and SPE_{js}
SPE_{sup}	99% upper control limit of SPE for a set of correct measurements
t	Principal component scores vector
td	Time spent by a FDS for correct diagnosis
tl	Translation parameter of a wavelet
tss	Time with the plant in non-steady state after a fault occurs
T	Principal component scores matrix
T^2	Overall measure of variability
v	Index for training patterns
W	ANN weight matrix
W_i	Weight matrix of the ith layer in a BPN
X	Bidimensional matrix
$\underline{X}$	Tridimensional matrix
z'_{ct}	Output of the centroid defuzzification method
z'_{ht}	Output of the height defuzzification method
z'_{mn}	Output of the mean of maximum defuzzification method
z'_{mx}	Output of the maximum defuzzification method

Greek symbols

a	Momentum term in the GDR
d	Error signal in the GDR
e	Small number
h	Learning rate for GDR
m	Membership function
σ	Standard deviation
y	Mother wavelet function

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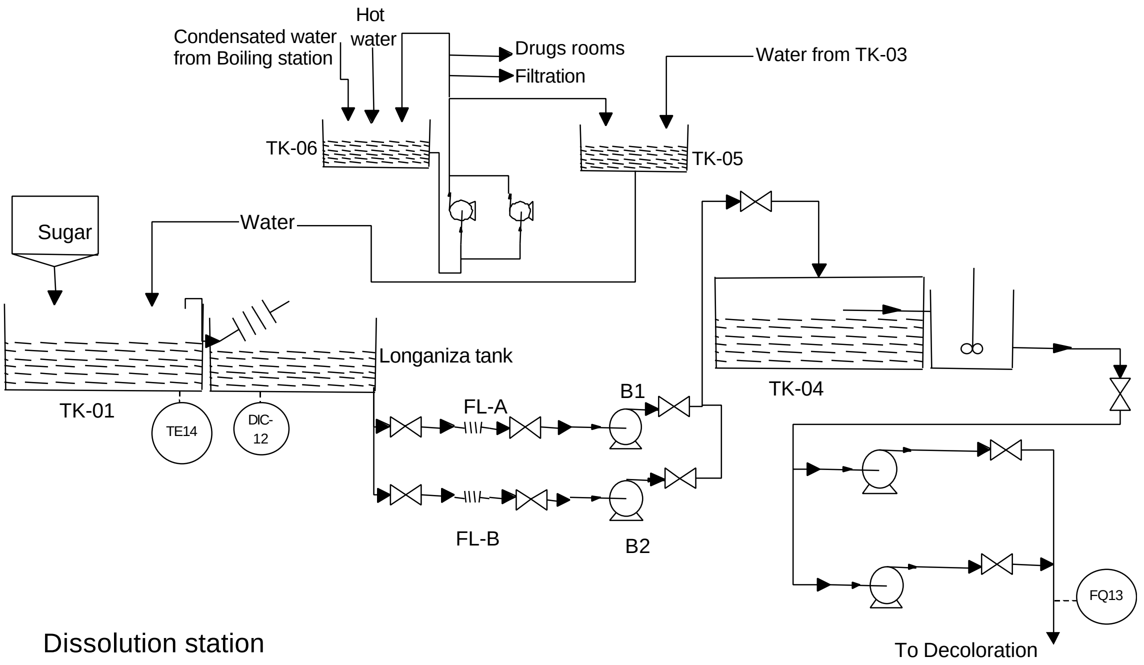
Annex A

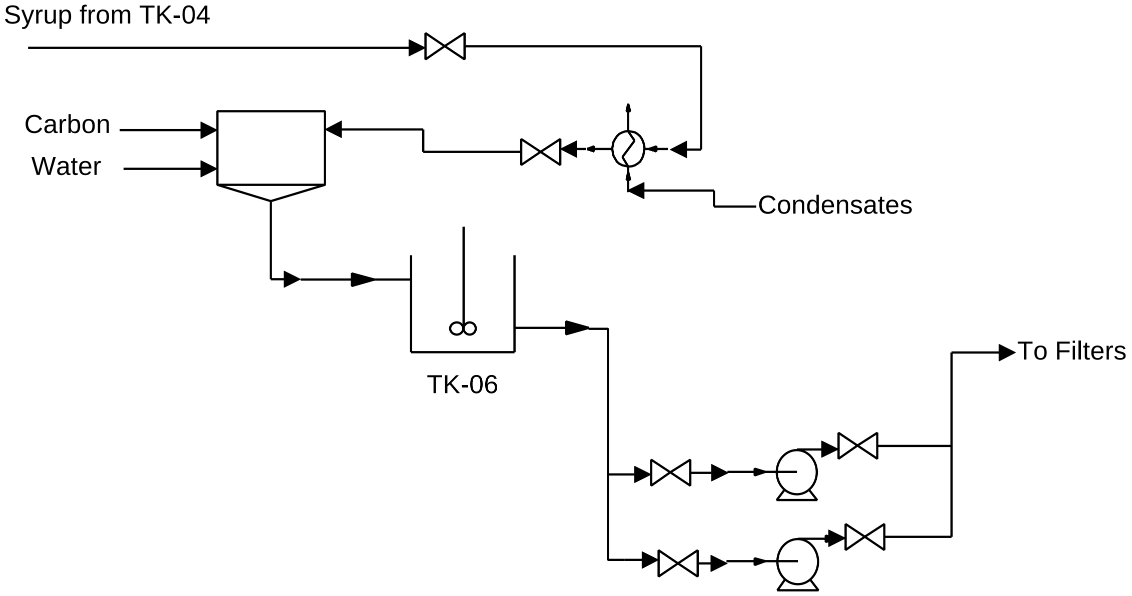
In this appendix, the simplified HAZOP analysis used for the FDS implementation, of the two sugar cane refinery case studies are reported:

- Complejo Azucarera Concepción S.A. (CACSA), with the collaboration of its Technical Office.
- Complejo Agroindustrial Azucarero Camilo Cienfuegos (CAICC), with the collaboration of its plant engineers.

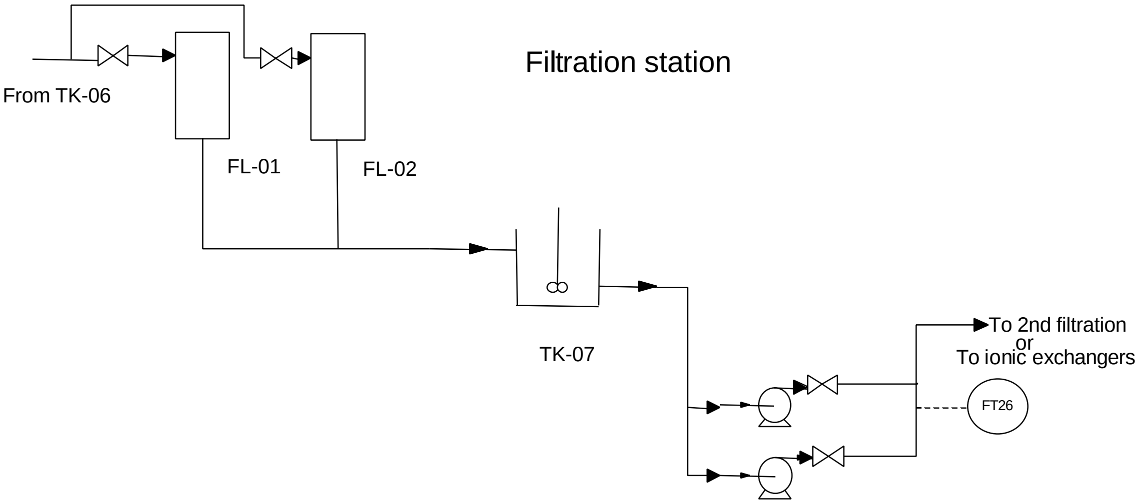
CACSA - HAZOP analysis

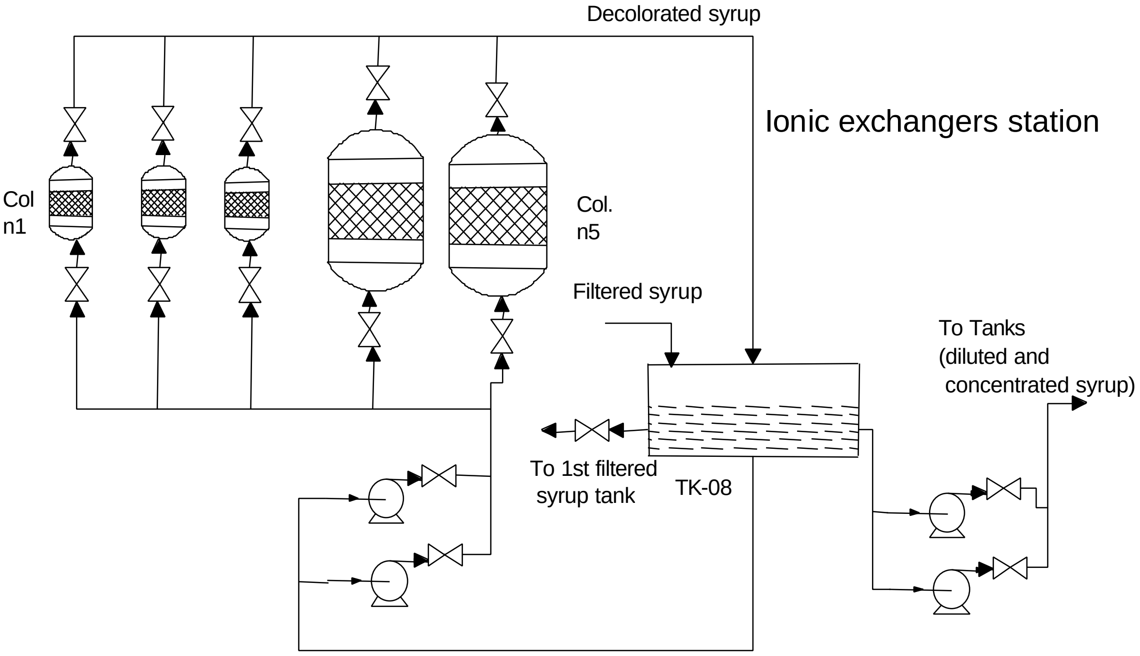


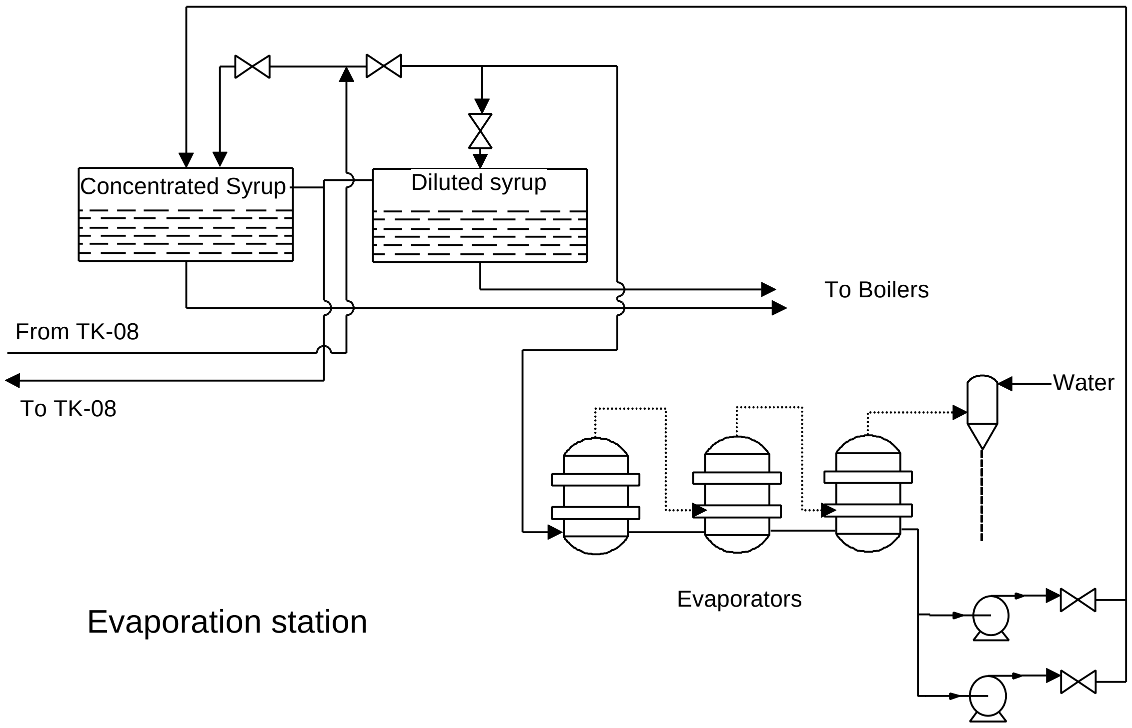
Dissolution station



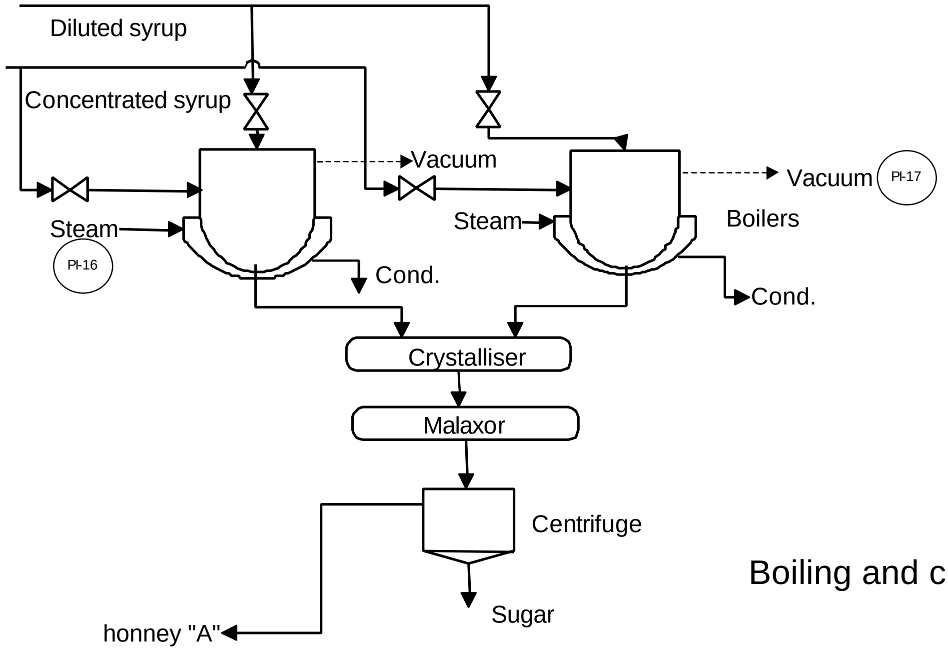
Decoloration station


Filtration station
From TK-06
FL-01
FL-02
TK-07
To 2nd filtration
or
To ionic exchangers
FT26


Decolorated syrup
Ionic exchangers station
Col
n1
Col.
n5
Filtered syrup
To Tanks
(diluted and
concentrated syrup)
To 1st filtered
syrup tank
TK-08



Evaporation station



Boiling and crystallisation

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		Shutdown of pumps B1 & B2	Alternative discharges available
Node: Water discharge to TK01					
Flow	No	Piping broken	High density in dissolution	Cut in the Water supply	Piping preventive maintenance
		Fresh water tank empty	idem	idem	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
Node: Piping from Tank TK01 to pumps					
Flow	Less	Pipe leakage or obstruction	Lack of syrup in tank TK04		Piping preventive maintenance
		Pump malfunctioning		Alternative pump	Pressure sensor in filters
Temperature	More	High temperature in dissolver TK05	Possible pump cavitation	TIC-14	
		Pumps (B1&B2) output valves closed		idem	Proximity sensor in valves
Node: Discharge of the "Longaniza" tank					
Density	Less	Agitator broken (inefficient dissolution)	Major energy conssumption in the concentration process	DIC12 controller	Alternative agitators
	More	Fault in density controller	Decoloration difficulty	DIC12 controller	Redundancy control
			Possible crystalls precipitation	idem	idem

Decoloration station					
Node: Syrup stream to the heat exchanger					
Variable	*Guideword*	*Causes*	*Consequences*	*Safeguards*	*Recommendations*
Flow	Less	Pipe leakage or obstruction	Excessive syrup heating	Operating procedure	Temperature controller in the heat exchanger
		Pump malfunctioning		Shutdown of pumps B1 & B2	To operate having an adequate excess of sugar in stock
	More	Syrup excess in tank TK04	Temperature decrease		Temperature control in the heat exchanger
Node: Syrup to the activated carbon mixer tank					
Flow	Less	Pipe leakage or obstruction	Possible excess of carbon	Operating procedure	Control in carbon adding
	More	Syrup excess in tank TK04	Insufficient amount of carbon	idem	idem
Temperature	Less	Pipe leakage or obstruction	Inadequate decoloration		Temperature controller in the heat exchanger
		Pump malfunctioning	idem		idem
Node: Discharge to TK06					
Flow	No	Mixer tank empty	Lack of syrup with carbon to feed the filters		Low level alarm in TK06
Solids concentration	More	Agitator broken	Pipe obstruction		Shutdown alarm in the agitator
		Carbon excess in the mixer	Solids deposit in pump		Control in carbon adding

Filtration station					
Node: Suspension input to the filters					
Variable	*Guideword*	*Causes*	*Consequences*	*Safeguards*	*Recommendations*
Flow	Less	Pipe leakage or obstruction	Inadequate filtration		Pressure sensor to stop the filtration
		Pump malfunctioning	idem		idem
Node: Input to the tank					
Flow	Less	Pipe leakage or obstruction	Empty tank	Low level alarm	
		Pump malfunctioning	idem	idem	
Node: Output from the tank					
Flow	Less	Pipe leakage or obstruction	Empty tank	Low level alarm	
		Pump malfunctioning	idem	idem	

Ionic exchange station					
Node: Input to the ionic exchangers					
Variable	*Guideword*	*Causes*	*Consequences*	*Safeguards*	*Recommendations*
Flow	Less	Pipe leakage or obstruction	Inadequate operation of a ionic exchange column	Alternative columns	Install flowmeters
		Pump malfunctioning	idem	idem	idem
		Obstruction in a ionic exchanger column	idem	idem	idem
	More	Pump malfunctioning	Deficient decoloration	idem	idem
		Overloading of TK08			Alternative tank for filtered syrup
Temperature	More	Excessive return of concentrated syrup to the TK08	Ionic exchange resins damage		Temperature control in TK08
Node: Decolorated syrup discharge to TK08					
Flow	Less	Pipe leakage or obstruction	Inadequate operation of a ionic exchange column	Alternative columns	Install flowmeters
		Pump malfunctioning	idem	idem	idem
		Obstrucción de una columna de intercambio	idem	idem	idem
	More	Pump malfunctioning	Defficient decoloration	idem	idem
		Overloading of TK08			Alternative tank for filtered syrup
	Reverse	Pumps switch off and valves open		Retention valves	

Evaporation station					
Node: From TK08 to evaporators					
Variable	*Guideword*	*Causes*	*Consequences*	*Safeguards*	*Recommendations*
Flow	No	Pipe leakage or obstruction	Shutdown of evaporation section		Install flowmeters
		Pump malfunctioning	idem		idem
		TK08 empty	idem		idem
	Less	Pipe leakage or obstruction	Do not operate ar a full capacity		Additional diluted syrup supply from an alternative stock tank
		Pump malfunctioning	idem		idem
	Other than	Valve openess in the line to concentrated syrup tank	Dilution of concentrated syrup	Operating procedure	To verify the necesity of this conexion
		Valve openess in the line to the diluted syrup tank	Possible overloading of the tank	High level return	idem
Node: Syrup outputs from each evaporator					
Flow	No	Obstruction in the output	Overloading in the previous evaporator	Maintenance	Flow control
			Low level in the following evaporator	idem	idem
Temperature	Less	Excesive deposit of incrustations in tubes			
		Fat layers in the exterior of the tubes			
		Escape in the base of the calandry			
		Incondensables blocking			
		Water entrance to the steam tube			
		Fault in level sensor			
	More	Evaporator low level	Sugar grains crystallisation		Low level alarm
		Steam at a higher pressure	Syrup coloration		Control in the heating steam pressure

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 vaccum	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 level decrease	Possible sugar coloration due to temperature	Addition of diluted syrup or water	Individual vacuum system
STAGE: Crystallisation					
Node: Vacuum generator					
Seed Humidity	More	Defficient quality control	Bubbles formation	Adequate storage of the seeds	

CAICC - HAZOP analysis

HAZOP ANALYSIS. REFINERY PLANT.

	GUIDE WORD	VARIABLE	DEVIATION	POSSIBLE CAUSES	CONSEQUENCES	RECOMMENDATIONS
NODE # 1: DISCHARGE OF RAW SUGAR TO MINGLER	NO	FLOW	LACK OF SUGAR IN THE MINGLER	LACK OF SUGAR IN STOCK	REFINERY SHUTDOWN	TO HAVE SUFFICIENT STOCK OF SUGAR
	NO	FLOW	LACK OF SUGAR IN THE MINGLER	THICK DISCHARGE OF THE HOPPER	REFINERY SHUTDOWN	TO IMPROVE CURRENT DISCHARGE SYSTEM
	NO	FLOW	LACK OF SUGAR IN THE MINGLER	WEIGHT OF THE BAND FOR THE SUGAR BROKEN	REFINERY SHUTDOWN	PREVENTIVE MAINTENANCE OF EQUIPMENT
	MORE	FLOW	INADEQUATED REGULATION IN THE DISCHARGE	SHUTDOWN OF THE DRIVERS AND ELEVATORS OF SUGAR DUE TO EXTRALOAD	REFINERY SHUTDOWN	TO MODIFY THE SYSTEM OF PROTECTION FOR EXTRALOAD AND THE SUGAR REGULATION

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

HAZOP ANALYSIS. REFINERY PLANT.

	GUIDE WORD	VARIABLE	DEVIATION	POSSIBLE CAUSES	CONSEQUENCES	RECOMMENDATIONS
NODE # 3: CENTRIFUGATION	NO	FLOW	LACK OF MAGMA SUPPLY	LOCKING OF THE VALVE IN LINE THAT FEEDS MIXER	REFINERY SHUTDOWN	TO IMPROVE PREVENTIVE MAINTENANCE TO THE VALVE
			SHUTDOWN CENTRIFUGES	DISCHARGE BLOCKED IN THE CENTRIFUGES DUE TO HIGH LEVEL IN THE PRE DISSOLUTOR	REFINERY SHUTDOWN	TO REVISE AND TO IMPROVE LEVEL CONTROL AT THE PRE DISSOLUTOR. TO IMPROVE MAINTENANCE IN THE PUMP OF THE PRE DISSOLUTOR.
	LESS	POL IN SUGAR	DEFICIENT MAGMA QUALITY	MAGMA NOT FLUENT DUE TO THE LACK OF SYRUP	LOW PRODUCTIVITY OF THE REFINERY	TO EXAMINE THE PREPARATION OF MAGMA
			INSUFFICIENT CLEANING WATER IN CENTRIFUGES	CLEANING CYCLE IN CENTRIFUGES OUT OF CONTROL	LOW PRODUCTIVITY OF THE REFINERY	TO REVISE THE AMOUNT OF CLEANING WATER
			INSUFICCIENT TEMP. IN THE CLEANING WATER OF CENTR.	WATER TEMPERATURE REGULATION OUT OF CONTROL	LOW PRODUCTIVITY OF THE REFINERY	TO INSTALL AN ALARM FOR LOW TEMPERATURE IN WATER
			LOW VELOCITY OF CENTRIFUGATION	INSUFFICIENT TIME OF CENTRIFUGING IN THE CYCLE	LOW PRODUCTIVITY OF THE REFINERY	TO REVISE THE TIME OF CENTRIFUGING

HAZOP ANALYSIS. REFINERY PLANT.

	GUIDE WORD	VARIABLE	DEVIATION	POSSIBLE CAUSES	CONSEQUENCES	RECOMMENDATIONS
NODE # 3: CENTRIFUGATION	MORE	REFINED SUGAR COLOR	DEFICIENT CLEANING IN THE SUGAR	INSUFFICIENT CLEANING IN THE CENTRIFUGES	EFFECTS ON QUALITY OF REFINED SUGAR	TO REVISE THE TIME OF CENTRIFUGING
			DEFICIENT PREPARATION OF THE MAGMA	EXCESS OF DENSITY IN THE MAGMA	EFFECTS ON QUALITY OF REFINED SUGAR	TO REVISE THE QUALITY OF THE MAGMA

HAZOP ANALYSIS. REFINERY PLANT.

	GUIDE WORD	VARIABLE	DEVIATION	POSSIBLE CAUSES	CONSEQUENCES	RECOMMENDATIONS
NODE # 4: DISSOLUTION OF RAW SUGAR	NO	FLOW	LACK OF PRE-DISSOLVED SUGAR	LACK OF SUPPLY OF RAW SUGAR DUE TO INTERRUPTION IN CENTRIFUGES	SHUTDOWN REFINERY	TO REVISE THE PROCESS OF CENTRIFUGATION
			LACK OF PRE-DISSOLVED SUGAR	THICK SUPPLY LINE	SHUTDOWN DISSOLUTION	TO LOOK FOR AN ALTERNATIVE SOLUTION
			LACK OF PRE-DISSOLVED SUGAR	VALVE OF RECIRCULATION BLOCKED	SHUTDOWN DISSOLUTION	TO IMPROVE THE SYSTEM OF FILTERING
			SHUTDOWN OF DISSOLUTION DUE TO HIGH LEVEL IN THE DISSOLUTOR	DEFICIENT PUMPING SYSTEM (23 & 24) OF THE CRUDE LIQUOR	SHUTDOWN DISSOLUTION	TO IMPROVE THE MAINTENANCE SYSTEM TO IMPROVE THE SYSTEM OF FILTERS
			THICK PUMPING SYSTEM	AGITATOR BROKEN	SHUTDOWN DISSOLUTION	TO REVISE AND IMPROVE THE MAINTENANCE OF AGITATORS
			HIGH LEVEL IN THE TANK	PUMPING BLOCKED DUE TO THE FULLNESS OF TANK 200	SHUTDOWN DISSOLUTION	

HAZOP ANALYSIS. REFINERY PLANT.

	GUIDE WORD	VARIABLE	DEVIATION	POSSIBLE CAUSES	CONSEQUENCES	RECOMMENDATIONS
NODE # 4: DISSOLUTION OF RAW SUGAR	LESS	TEMP.	INSUFFICIENT STEAM IN THE DISSOLUTOR	BAD FUNCTIONING OF THE REGULATION SYSTEM FOR THE TEMPERATURE	INSUFFICIENT DISSOLUTION PRESENCE OF CRYSTALS IN THE DISSOLUTION	TO REVISE AND IMPROVE TH MAINTENANCE OF THE REGULATION OF TEMP.
			WATER WITH INSUFFICIENT TEMPERATURE	INSUFFICIENT WATER HEATING IN THE SUPPLY TANK	INSUFFICIENT DISSOLUTION PRESENCE OF CRYSTALS IN THE DISSOLUTION	TO IMPROVE THE HEATING OF WATER AND TO INSTALL AN ALARM FOR LOW WATER TEMPERATURE
	MORE	TEMP.	STEAM EXCESS IN THE DISSOLUTOR	TEMPERATURE REGULATOR OUT OF CONTROL	CARAMELISATION OF THE SUGAR	TO IMPROVE TEMPERATURE CONTROL
	LESS	DENSITY	EXCESS OF WATER	DENSITY REGULATOR OUT OF CONTROL	CLARIFICATION DEFICIENT AND EXCESSIVE STEAM CONSUMPTION	TO IMPROVE DENSITY CONTROL
			PRE-DISSOLUTION WITH LOW DENSITY	DEFICIENT DISSOLUTION OF THE SUGAR IN THE GONDOLAS	CLARIFICATION DEFICIENT AND EXCESSIVE STEAM CONSUMPTION	TO IMPROVE THE MANIPULATION OF THE SYSTEM
	MORE	DENSITY	LACK OF WATER	DENSITY REGULATOR OUT OF CONTROL	THICK FLOW IN LINES AND PUMPS	TO IMPROVE THE SYSTEM OF REGULATION

Publications and Conferences

Control strategies applied to a chemical plant with interacting control loops

Ruiz D., Nougués J.M. and Puigjaner L. (1999).

Journal: *Hungarian Journal of Industrial Chemistry* (HU ISSN: 0133-0276), Vol. **27**, pp 73-79.

Presented at the 4th International Workshop on Mathematical Modelling in Chemical Engineering, in Bad Honnef (Germany), August 10-14, 1998.

Keywords: multivariable control, internal model control structure, neural networks

Abstract

Interaction among control loops in multivariable systems has been the subject of much research in the last decades. Distillation columns that are widely used in the process industries are the typical example of these systems. In this work, Wood and Berry test-bed problem has been used due to the strong interaction among the control variables. Therefore, different control strategies have been applied to this binary distillation column with two interacting control loops. A diagonal controller structure with proportional-integral controllers using several tuning methods has been evaluated. Two Internal Model Control structures have been implemented utilising in one of them a neural network model of the plant. Model identification by neural networks has also been presented.

On-line process fault detection and diagnosis in plants with recycle

Ruiz D., Nougués J.M. and Puigjaner L. (1999).

Journal: *Computers and Chemical Engineering* (ISSN: 0098-1354), Vol. **23S**, pp S219-S222.

Presented at the 9th European Symposium on Computer Aided Process Engineering (ESCAPE 9), in Budapest (Hungary), May 8-11, 1999.

Keywords: fault diagnosis, plants with recycle, artificial neural networks, fuzzy logic

Abstract

A process fault detection and diagnosis system is performed for the complex case of plant-wide control in processes with recycle in which the control system is the inventory control. It is considered an artificial neural network based supplement of a fuzzy system in a block-oriented configuration. A methodology for designing the system is described. As a case study, a

chemical plant with a recycle stream is considered. Faults in the supply of raw materials and in controllers are simulated. The performance of the system in handling simultaneous faults is also analysed. A comparison is made against a classification method (artificial neural networks) and an inference method (knowledge - based system).

Artificial Neural Networks applied to on-line fault diagnosis in chemical plants

Ruiz D., Nougués J.M. and Puigjaner L. (1999).

Proceedings 7th IEEE International Conference on Emerging Technologies and Factory Automation, Editor: J. M. Fuertes, (ISBN 0-7803-5670-5), Vol. **2**, pp 977-986.

Presented at the 7th IEEE International Conference on Emerging Technologies and Factory Automation, Barcelona (Spain), October 18-22, 1999.

Keywords: artificial neural networks, fault diagnosis, chemical plants

Abstract

Different kinds of artificial neural networks are compared regarding with their application to the fault diagnosis in steady state chemical processes. Their performance is studied taking into account the influence of some design parameters. Faults in sensors are considered separately by using auto-associative neural networks and a proposed algorithm. The developments have been applied to two case studies. The first one corresponds to a chemical plant with recycle. The second one has been carried out in a fluidised bed coal gasifier, at a pilot plant scale. In this last case, performance of the selected and optimised neural network approach is compared with a statistical technique: Principal Component Analysis. The methodology of implementation and optimisation of the artificial neural network approach for fault diagnosis shows promising results. This approach can be used to complement a knowledge-based approach for robust fault detection and diagnosis in chemical plants.

Integrated information system for monitoring, scheduling and control applied to batch chemical processes

Canton J., Ruiz D., Benqlilou Ch., Nougués J.M. Puigjaner L. (1999)

Proceedings 7th IEEE International Conference on Emerging Technologies and Factory Automation, Editor: J. M. Fuertes, (ISBN 0-7803-5670-5), Vol. **1**, pp 211-217.

Presented at the 7th IEEE International Conference on Emerging Technologies and Factory Automation, Barcelona (Spain), October 18-22, 1999.

Keywords: batch chemical plants, information system

Abstract

The effective operation of the batch processing based enterprise requires exploitation of computer integrated manufacturing (CIM) developments and the adaptation of these developments for the specific features of batch operations. The aim of this work is to present a general overview of a global methodology which allows to find a practical solution for the control of a multipurpose batch chemical plant. A case study carried out in a pilot plant for the simulation of batch chemical processes is also described.

On-line process fault diagnosis system for chemical process industries

Ruiz D., Nougués J.M. and Puigjaner L. (1999)

Presented at the American Institute of Chemical Engineers Meeting '99 (Paper 208ae), in Dallas (U.S.A.), October 31 - November 5, 1999.

Keywords: fault diagnosis, artificial neural networks, industrial applications

Abstract

A process fault detection and diagnosis (PFD&D) system has been applied to different cases of chemical plants. It considers an artificial neural network (ANN) structure supplemented with a fuzzy system in a block-oriented configuration. The system combines the adaptive learning diagnostic procedure of the ANN and the transparent deep knowledge representation of a structured form of knowledge based expert system. This work is focused on the ANN block. Different ANN architectures have been compared. Back-propagation networks show to be less effective than radial basis function networks in diagnosing process and controllers' faults. Self-organising maps show low resolution but they can be useful to handle unsuspected faults. A performance index for comparison purposes is proposed. False diagnosis is also considered. The ANN is trained with steady state conditions of past faults. Faults in sensors are also contemplated. In this last case Nonlinear Principal Component Analysis is implemented. It uses an auto-associative neural network. Influence of the number of neurons in the bottleneck layer is studied. A comparison against conventional Principal Component Analysis is shown. The features and the performance of the PFD&D system are presented in several scenarios: academic, pilot plant scale and industrial cases. The academic case consists of a chemical plant with a recycle stream The pilot plant scale case consists of a fluidised bed coal gasifier. One industrial case contemplates a real plant of linear alquil benzene. Another industrial case corresponds to a real sugar cane refinery factory. Future work is related to the integration of the PFD&D system to the scheduling and management levels.

Neural computation for abnormal situation management in a cane sugar refinery

Ruiz D., Nougués J.M. and Puigjaner L. (1999)

Presented at the American Institute of Chemical Engineers Meeting '99 (Paper 51g), in Dallas (U.S.A.,), October 31 - November 5, 1999.

Keywords: fault diagnosis, artificial neural networks, sugar industry

Abstract

In this paper, a Fault Diagnosis System (FDS) is applied to a real sugar cane refinery factory. The FDS is composed by an Artificial Neural Network (ANN) structure supplemented with a Knowledge Based Expert System (KBES) in a block-oriented configuration. The system combines the adaptive learning diagnostic procedure of the ANN and the transparent deep knowledge representation of the KBES. The information needed to design and implement the FDS includes a historical database, a Hazard and Operability study (HAZOP) and a model of the plant. The refinery sugar process encloses raw sugar dissolution, syrup treatment, boiling, crystallisation, centrifuging and sugar drying. Some examples of the system performance are shown. They are related to the Boiling step. In this step, the crystallisation of saccharose begins. Its adequate control has strong influence in quality product. Pressure steam to the boilers and the vacuum level must be constants. The ANN block of the FDS shows to be efficient by anticipating faults. It takes advantage of the historical database of past faults. On the other hand, the use of the KBES allows a transparent representation of the knowledge of the plant. In addition, the quick corrective actions implementation is straightforward. By this way the FDS can be robust enough to manage abnormal situations. The development is very important to increase the efficiency in the sugar industry.

Monitoring and fault diagnosis of batch processes using a neuro-fuzzy approach

Ruiz D., Nougués J.M. and Puigjaner L. (1999)

Presented at the 8th Mediterranean Congress of Chemical Engineering (Session: Process systems engineering), in Barcelona (Spain), November 10-12, 1999.

Keywords: batch process, process monitoring, fault diagnosis, neural networks

Abstract

A methodology to design a Fault diagnosis system (FDS) for batch chemical plants is presented. The FDS is composed by an Artificial Neural Network (ANN) structure supplemented with an inference system in a block oriented configuration. The system combines the adaptive learning diagnostic procedure of the ANN and the transparent deep knowledge representation of the expert system. The proposed FDS is also compared with other approach based on multiway Principal Component Analysis. The FDS's potential is illustrated using a pilot plant and an industrial case study.

An integrated architecture for information management in batch chemical processes

Cantón J., Ruiz D., Benqlilou Ch., Nougués J.M. and Puigjaner L. (1999)

Presented at the 8th Mediterranean Congress of Chemical Engineering (Session: Process systems engineering), in Barcelona (Spain), November 10-12, 1999.

Keywords: batch process, process integration, modeling and simulation, process management and control

Abstract

The effective operation of the batch processing based enterprise requires exploitation of computer integrated manufacturing (CIM) developments and the adaptation of these developments for the specific features of batch operations. The aim of this work is to present a general overview of a global methodology which allows to find a practical solution for the control of a multipurpose batch chemical plant.

A Hybrid Neural Network-First Principles Approach for Process Modeling

Benqlilou Ch., Ruiz D., Nougués J.M. and Puigjaner L. (1999)

Presented at the 8th Mediterranean Congress of Chemical Engineering (Session: Process systems engineering), in Barcelona (Spain), November 10-12, 1999.

Keywords: hybrid modelling, neural networks

Abstract

This work is based mainly on the use of Artificial Neural Network (ANN) in collaboration with the a priori knowledge of the process for modelling. The motivation to combine the parametric and non parametric model comes from different properties of two models. While ANN has good approximation and interpolation properties it show limited extrapolation capacity. On the other hand First Principles Model (FPM) is limited to deal with non linearities but often demonstrate more robust extrapolation behaviour. Whereas only modelling of the process is discussed in this work our goal is to proceed in the direction of process control and particularly to a model based predictive control scheme. The structure investigated for the purpose of process modelling is a hybrid parallel model referred to a non-linear error correction. The effective operation of the batch processing based enterprise requires exploitation of computer integrated manufacturing (CIM) developments and the adaptation of these developments for the specific features of batch operations. The aim of this work is to present a general overview of a global methodology which allows to find a practical solution for the control of a multipurpose batch chemical plant.

Teaching the plant-wide control complexity from the beginning

Basualdo M., Ruiz D., Sequeira S. and Pedridio J. (1999)

Presented at the 8th Mediterranean Congress of Chemical Engineering (Session: Process systems engineering), in Barcelona (Spain), November 10-12, 1999.

Keywords plant-wide control, recycles

Abstract

This paper examines the practical use of simulation, within process plant-wide control application areas, and the benefits released by the undergraduate engineering students. In an environment of change, as the control of a chemical process, it offers an attractive tool to teach more efficiently the “real” control problem. The discussion draws on a study of the employment of simulation, which serves as an authentic pilot plant, to design conventional SISO and MIMO feedback controllers implemented over a typical plant which contains both separation and reaction stages. The overall steps from the identification of that system, including the design and tuning of the controllers conform a good practical work. The student can verify, by using dynamic simulation, which is the “cost” of obtaining bad models which drive to bad controller designs. Several proofs, for load and reference changes, are carried out by designing PID and PI for SISO bottom composition control over the separation stage. Then, this design is affected with other loops included in the stripper and finally the effect of including the reactor for conforming the plant is analysed. The need for retuning the controllers in order to improve the overall performance is shown. For SISO case several tuning methodologies are tested including model based statements. For MIMO problem the methodology proposed by Belanger and Luyben (1997) for controlling a plant with recycle is used.

Sistema de diagnosis de fallos en plantas químicas (*Fault diagnosis system in chemical plants*)

Ruiz D., Nougués J.M. and Puigjaner L. (1999).

Proceedings 3th Users Meeting MATLAB 99, Editor: S. Dormido, (ISBN 84-699-1358-1), pp 297-302.

Presented at the 3th Users Meeting MATLAB 99, in Madrid (Spain), November 17-19, 1999.

Keywords: fault diagnosis, neural networks, fuzzy logic, communication via DDE, applications

Abstract

In this work the usefulness of MATLAB for the development of a fault diagnosis system applied to chemical plants is shown. The fault diagnosis system used consists in a combination of an artificial neural network and a fuzzy logic system. An example is shown where the program LABWINDOWS CVI is utilised for the simulation of a chemical plant and the communication via Dynamic Data Exchange (DDE) with the fault diagnosis system programmed in MATLAB is utilised.

Fault diagnosis system support for reactive scheduling in multipurpose batch chemical plants

Ruiz, D., Nougués, J. M., Cantón J., Espuña A. and Puigjaner, L. (2000).

Book chapter: Computer Aided Chemical Engineering Series, Vol. **8** (Editor: S. Pierucci), Elsevier, Amsterdam, ISBN: 0-444-50520-2, pp 745-750.

Presented at the 10th European Symposium on Computer Aided Process Engineering (ESCAPE 10), in Florence (Italy), May 7-10, 2000.

Keywords: fault diagnosis, scheduling, batch plants

Abstract

In this work, a simple strategy for the development and implementation of a Fault Diagnosis System (FDS) that interacts with a schedule optimiser in batch chemical plants is presented. The proposed FDS consists in an Artificial Neural Network (ANN) structure supplemented with a Knowledge Based Expert System (KBES) in a block-oriented configuration. The information needed to implement the FDS includes a historical database of past batches, a Hazard and Operability (HAZOP) analysis and a model of the plant. A motivating case study is presented to show the results of the proposed methodology.

The use of process dynamic simulation for learning to design digital controllers

Basualdo M., Salcedo J.B. and Ruiz, D. (2000)

Book chapter: Computer Aided Chemical Engineering Series, Vol. **8** (Editor: S. Pierucci), Elsevier, Amsterdam, ISBN: 0-444-50520-2, pp 259-264.

Presented at the 10th European Symposium on Computer Aided Process Engineering (ESCAPE 10), in Florence (Italy), May 7-10, 2000.

Keywords: dynamic simulation, digital controllers, education

Abstract

The discussion presented in this paper draws on a comparative study based on several design techniques of digital feedback controllers implemented as SISO structure of a binary distillation column. By using rigorous process models, which serves as an authentic pilot plant, offers an attractive tool to learn more efficiently the “real” control problem. It must be noted that many textbooks have presented several design techniques about this subject but they did not compare over chemical processes. Generally the overall conclusions are based on linear transfer functions only. Chemical processes represent a real challenger for developing efficient digital control design techniques. The overall steps from the identification of the nonlinear, with dead time and inverse response system, including the design and tune of the controllers are presented. Hence, is easier to verify which is the “cost” of obtaining bad models which drive to bad controller designs. Several proofs, for load and reference changes are carried out by designing discrete controllers such as PID, Ragazzini and W transform methodologies by using MATLAB-SIMULINK software. The rigorous model of the distillation column is developed through an S-function of SIMULINK.

Neural network based framework for fault diagnosis in batch chemical plants

Ruiz D., Nougués J.M., Calderón Z., Espuña A. and Puigjaner L. (2000).

Journal: *Computers and Chemical Engineering* (ISSN: 0098-1354), Vol. **24** (2-7), pp 777-784.

Presented at the 7th International Symposium on Process Systems Engineering 2000 (PSE 2000), in Keystone - Colorado (U.S.A.), July 16-21, 2000.

Keywords: fault diagnosis, batch plants, artificial neural networks

Abstract

In this work, an Artificial Neural Network (ANN) based framework for Fault Diagnosis in batch chemical plants is presented. The proposed FDS consists in an Artificial Neural Network (ANN) structure supplemented with a Knowledge Based Expert System (KBES) in a block-oriented configuration. The system combines the adaptive learning diagnostic procedure of the ANN and the transparent deep knowledge representation of the KBES. The information needed to implement the FDS includes a historical database of past batches, a Hazard and Operability (HAZOP) analysis and a model of the batch plant. The historical database that includes information related with normal and abnormal operating conditions is used to train the ANN structure. The deviations of the on-line measurements from a reference profile are processed by a multi-scale wavelet in order to determine the singularities of the transients and to reduce the dimensionality of the data. The processed signals are the inputs of an ANN. The ANN's outputs are the signals of the different suspected faults. The HAZOP analysis is useful to build the process deep knowledge base (KB) of the plant. This base relies on the knowledge of the operators and engineers about the process and allows formulating artificial intelligence algorithms. The case study corresponds to a batch reactor. The FDS performance is demonstrated through the simulation of different process faults. The FDS proposed is also compared with other approach based on multi-way Principal Component Analysis.

Integration of Fault Diagnosis and Reactive Scheduling in Batch Chemical Plants

Ruiz, D., Nougués, J. M., Cantón J., Espuña A. and Puigjaner, L. (2000)

Presented at the 3rd Conference PRES 2000 - Process integration, modelling and optimisation for energy saving and pollution reduction (Ref. H6.4), in Praha (Czech Republic), August 27-31, 2000.

Keywords: fault diagnosis, scheduling, batch plants

Abstract

This paper is a considerable extension of the ideas presented previously (Ruiz et al., 2000a). A simple strategy for the development and implementation of a Fault Diagnosis System (FDS) that interacts with a schedule optimiser in batch chemical plants is shown, taking into account the energy savings. The proposed FDS consists in an Artificial Neural Network (ANN) structure supplemented with a Knowledge Based Expert System (KBES) in a block-oriented configuration. The system combines the adaptive learning diagnostic procedure of the ANN and the transparent deep knowledge representation of the KBES. The information needed to implement the FDS includes a historical database of past batches, a Hazard and Operability (HAZOP) analysis and a model of the plant. Two motivating case studies are presented to show the results of the proposed methodology. The first one corresponds to a fed-batch reactor. In this example, the FDS performance is demonstrated through the simulation of different process faults. The second case study corresponds to a multipurpose batch plant. In this case, the results of the reactive scheduling are shown by simulating different abnormal situations. A performance comparison is made against the traditional scheduling approach without the support of the proposed FDS. Large savings in energy and economic resources can be obtained.

Enhancement of Prediction and Extrapolation Properties By using Hybrid Neural Network Model

Benqlilou Ch., Ruiz D., Espuña A. and Puigjaner L. (2000)

Presented at the 3rd Conference PRES 2000 - Process integration, modelling and optimisation for energy saving and pollution reduction (Ref. H3.7), in Praha (Czech Republic), August 27-31, 2000.

Keywords: dynamic modelling, hybrid neural networks, prediction, extrapolation

Abstract

In this work a comparison between parallel Hybrid Neural Network models (HNN), Artificial Neural Network (ANN) models and a First Principal Models (FPM) is performed in terms of their extrapolation and predictions properties. As motivation example a simple but highly non-linear dynamic process, the dynamic response of pH in a Stirred Continuos Tank Reactor has been chosen.

One experience of teaching the pass from analog to discrete PID designs

Basualdo M., Boselli I. and Ruiz D. (2000)

Proceedings of the the 17th Argentinean Congress on Automatic Control, pp 117-122.

Presented at the 17th Argentinean Congress on Automatic Control, in Buenos Aires (Argentina), September 11-13, 2000.

Keywords: digital controller designs, nonlinear system, dynamic simulation

Abstract

The discussion presented in this paper draws on a study of how to teach more friendly and effectively the pass from analog to digital PID designs. By using rigorous process models, which serves as an authentic pilot plant, offers an attractive tool to learn more efficiently the "real" control problem. It must be noted that many textbooks have presented several design techniques about this subject but they did not compare over chemical processes. Generally, the overall conclusions are based on linear transfer functions only. Chemical processes represent a real challenge for developing efficient digital control design techniques. The overall steps from the identification of the nonlinear, with dead time system, including the design and tuning of the controllers are presented. Hence, it is easy to verify which is the "cost" of obtaining bad models which drive to bad controller designs. Several proofs, for load and reference changes are carried out by designing discrete PID controllers accounting different algorithms and sampling periods. This work is done as a part of series of practical works by using the same plant implemented in MATLAB-SIMULINK software.

A proposal to speed-up the implementation of an Abnormal Situation Management framework into real chemical plants

Ruiz D., Nougués J.M. Benqlilou Ch., Ruiz C. and Puigjaner L. (2000)

Presented at the American Institute of Chemical Engineers Meeting 2000 (Paper 255b), in Los Angeles (U.S.A.), November 12-17, 2000.

Keywords: fault diagnosis, industrial applications, GCO

Abstract

The aim of this work is to present a proposal of implementation in a real industrial plant of a support framework for abnormal situation management. The basic strategy is: to simplify, to automate and to integrate. 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. Based on three sources of information (a historical database, a HAZOP analysis and a regular plant model), the support framework is developed and easily implemented into the real plant. It consists of a pre-processing module which performs a variety of key tasks using plant data such as Trend generation, Principal Component Analysis, Data Reconciliation, filtering and denoising. Some of the outputs of this pre-processing module are the inputs of the Fault Diagnosis System (FDS). This FDS is a combination of a pattern recognition approach based on neural networks and a Fuzzy Logic System (FLS) in a block oriented configuration. The FLS has also the function of alarm handling. The outputs of the FDS can be used by an advanced control module in order to take control actions, or by the operators who are responsible for decision-making or by other levels in the information system as the scheduling system. The case study corresponds to a real petrochemical plant consisting in a train of distillation columns where a group of n-paraphines are separated from kerosene. Fluctuations in pressure of the hot-oil to the reboilers have been considered as suspected faults. The real plant has been simulated with HYSYS, 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. The pattern recognition approach can be developed using NerOnline studio software. This package was useful to perform data analysis, neural network training and validation. Integration of the developed platform with the existing hardware and software in our facilities is underway. Future work includes the application of the presented technology in a sugar cane refinery.

Fault diagnosis support system for complex chemical plants

Ruiz D., Nougués J.M. and Puigjaner L. (2001).

Journal: *Computers and Chemical Engineering* (ISSN: 0098-1354), Vol. **25**, pp 151-160.

Keywords: fault diagnosis, plants with recycle, artificial neural networks, fuzzy logic

Abstract

A process fault detection and diagnosis system (PFD&D) is proposed for complex chemical plants. The system combines an artificial neural network based supplement of a fuzzy system in a block-oriented configuration. A methodology for designing the system is described. As a motivating example, a chemical plant with a recycle stream is considered. Faults in the supply of raw materials and in controllers are simulated. The performance of the system in handling simultaneous faults is also analysed. A comparison of the proposed approach is made with a classification method (artificial neural networks) and inference methods (knowledge - based system). Results of system implementation in a fluidised bed coal gasifier at pilot plant scale are also shown.

On-line fault diagnosis system support for reactive scheduling in multipurpose batch chemical plants

Ruiz, D., Nougués, J. M., Cantón J., Espuña A. and Puigjaner, L. (2001)

Journal: *Computers and Chemical Engineering (in press)*

Keywords: fault diagnosis, scheduling, batch plants

Abstract

In this work, a simple strategy for the development and implementation of a Fault Diagnosis System (FDS) that interacts with a schedule optimiser in batch chemical plants is presented. The proposed FDS consists in an Artificial Neural Network (ANN) structure supplemented with a Knowledge Based Expert System (KBES) in a block-oriented configuration. The system combines the adaptive learning diagnostic procedure of the ANN and the transparent deep knowledge representation of the KBES. The information needed to implement the FDS includes a historical database of past batches, a Hazard and Operability (HAZOP) analysis and a model of the plant. Two motivating case studies are presented to show the results of the proposed methodology. The first one corresponds to a fed-batch reactor. In this example, the FDS performance is demonstrated through the simulation of different process faults. The second case study corresponds to a multipurpose batch plant. In this case, the results of reactive scheduling are shown by simulating different abnormal situations. A performance comparison is made against the traditional scheduling approach without the support of the proposed FDS.

Dynamic Cross-Functional Factory-to-Business Links in the Batch Industry

Badell M., Ruiz D. and Puigjaner L. (2001)

To be presented at the 11th European Symposium on Computer Aided Process Engineering (ESCAPE-11), in Scanticon Comwell Kolding (Denmark), May 27-30, 2001.

Keywords: Enterprise Resource Planning system, short-term planning, financial and production cross-functional link, Web based systems, fault diagnosis system

Abstract

The lack of a cross-functional factory-to-business link between the shop floor and the necessary supply chain relation to e-business creates a gap. In order to bridge this gap a web-business-plant route is developed in a pilot plant using the TicTacToe sequencing algorithm. A web-based order management system is created to generate optimal plans taking into account the factory logistic status and detailed information of the real plant through a fault diagnosis system (FDS) with re-scheduling capabilities.