Supervisory Control & Monitoring

Topic - Distributed Control Systems (DCS)

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References

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Elsevier, 2017

G. MAGNANI, G. FERRETTI, P. ROCCO
Tecnologie dei sistemi di controllo - 2a edizione
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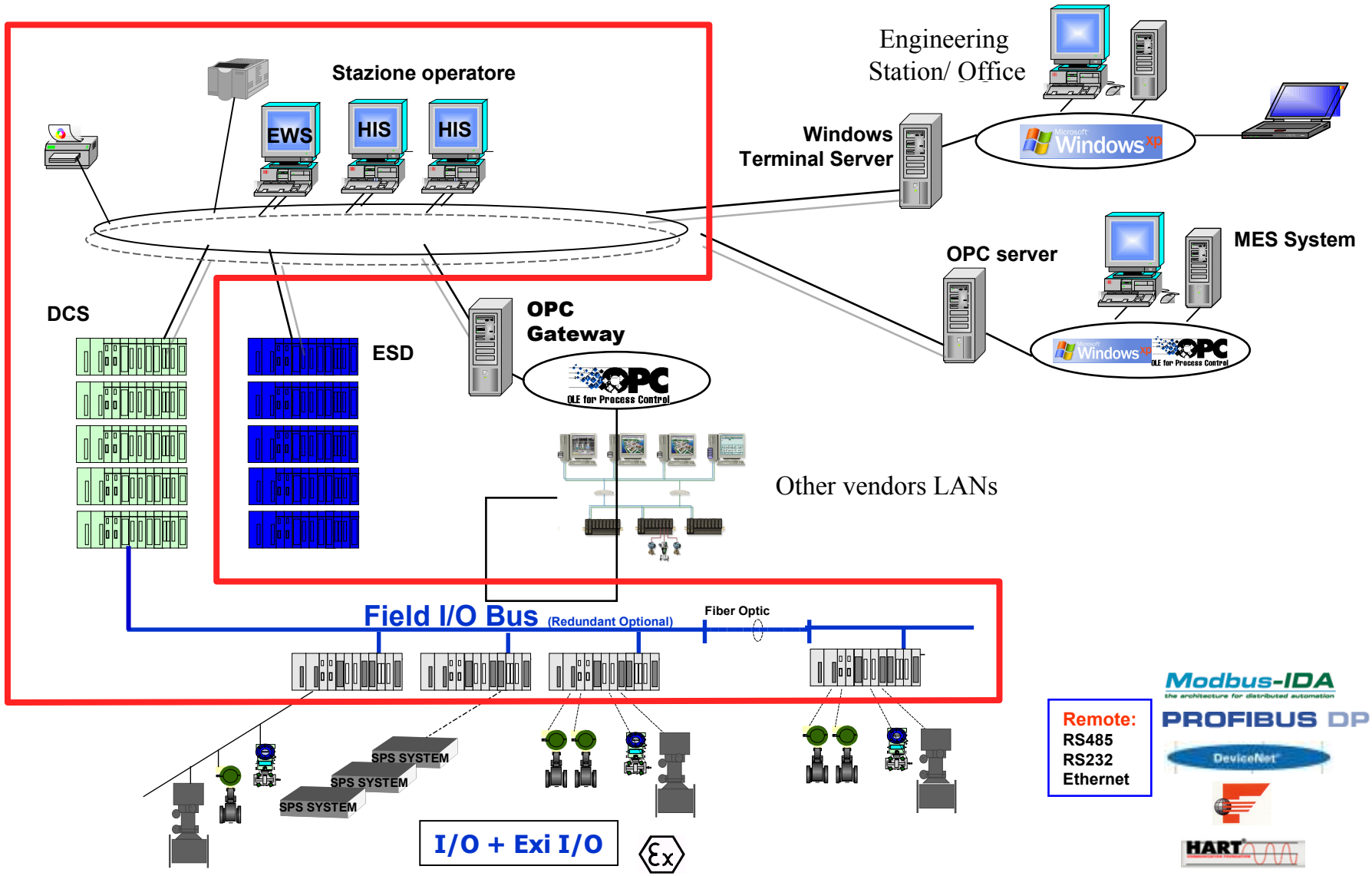
P. Chiacchio
PLC ed automazione industriale
McGraw-Hill Libri Italia, 1996

M. Veronesi
Sistemi di controllo distribuito
Notes

Summary

- Distributed Control Systems (D.C.S.)
- Control function
- Hazard protection function
- Supervision function
- DCS Software

Distributed Control Systems



Distributed Control Systems (DCS)

Distributed Control Systems

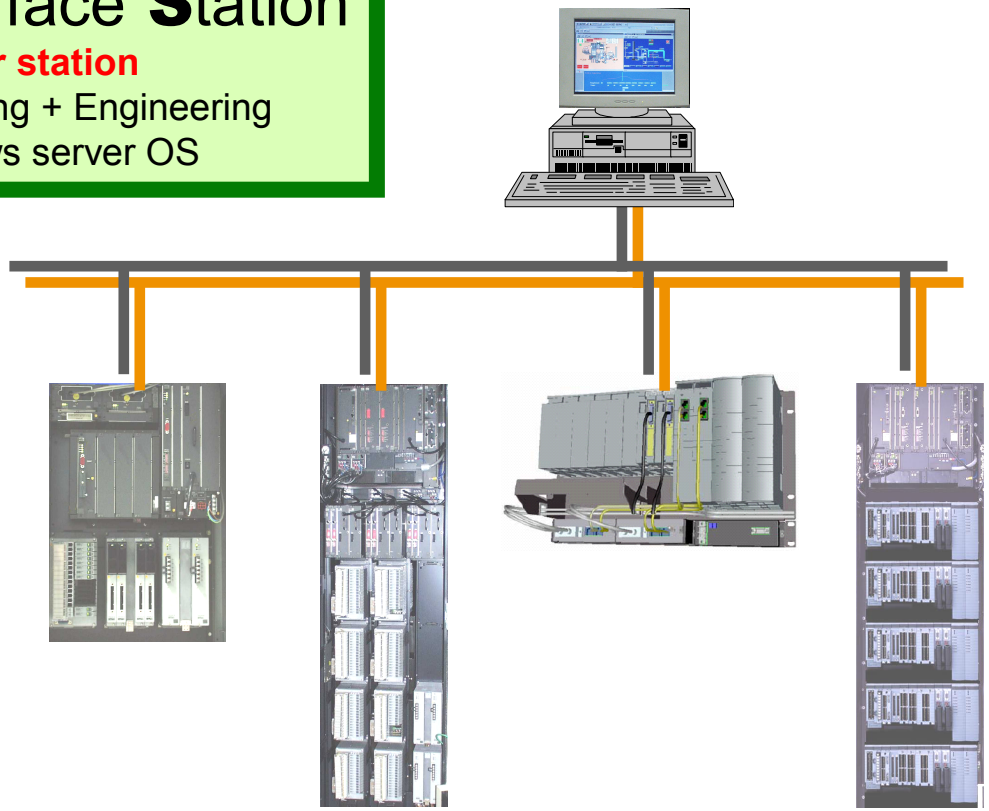
Basic configuration of a DCS

Human Interface Station

Operator station

Control, Monitoring + Engineering

PC + Windows server OS



System Bus

- Token passing
- ★>10 Mb/s
- Redundant
- Coax/optical
- Private

Field Control Station

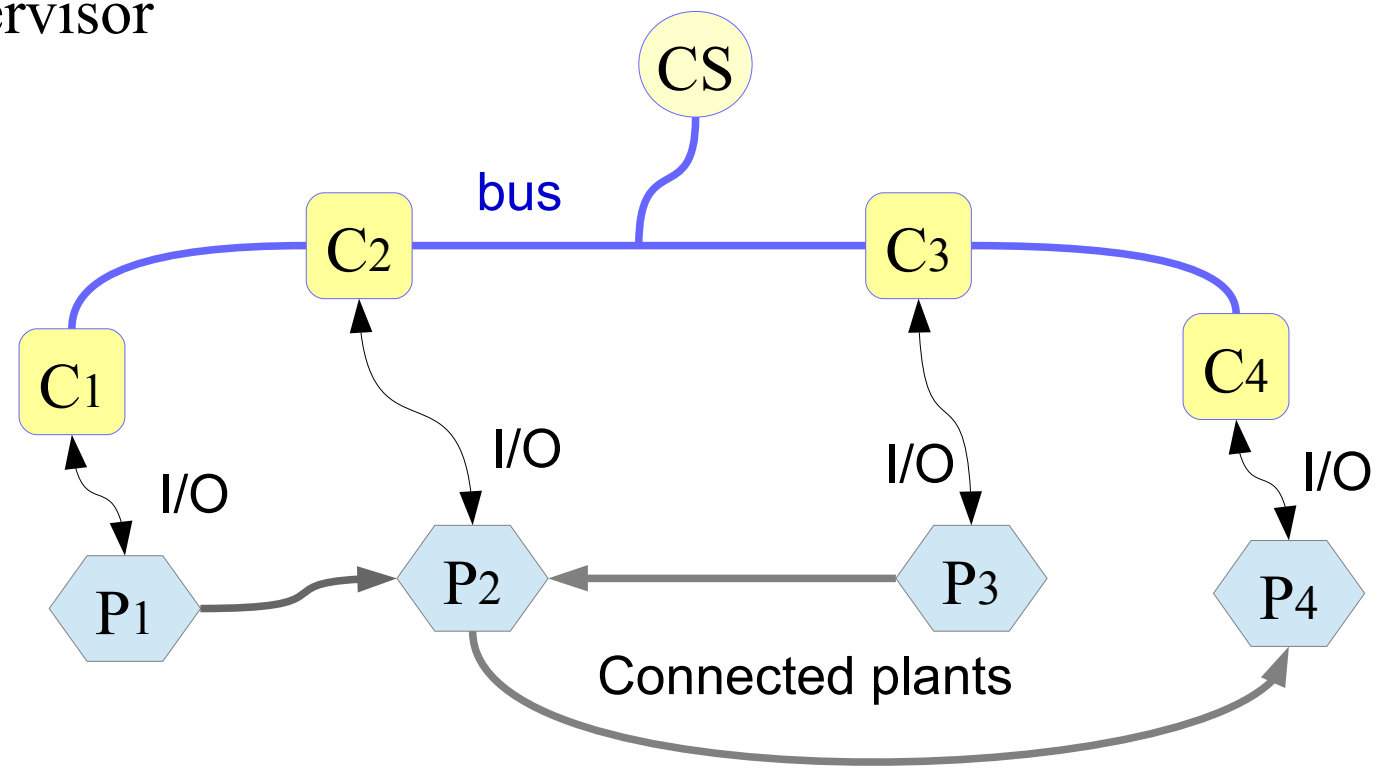
- RISC technology
- Redundant
- Control
- Interblock
- Sequences
- Remore I/O
- Comunication ports

Distributed Control Systems (DCS)

Distributed Control Systems

Systems for the industrial distributed control

Control actions are not exploited by a unique agent but distributed among several autonomous agents, possibly coordinated by a supervisor

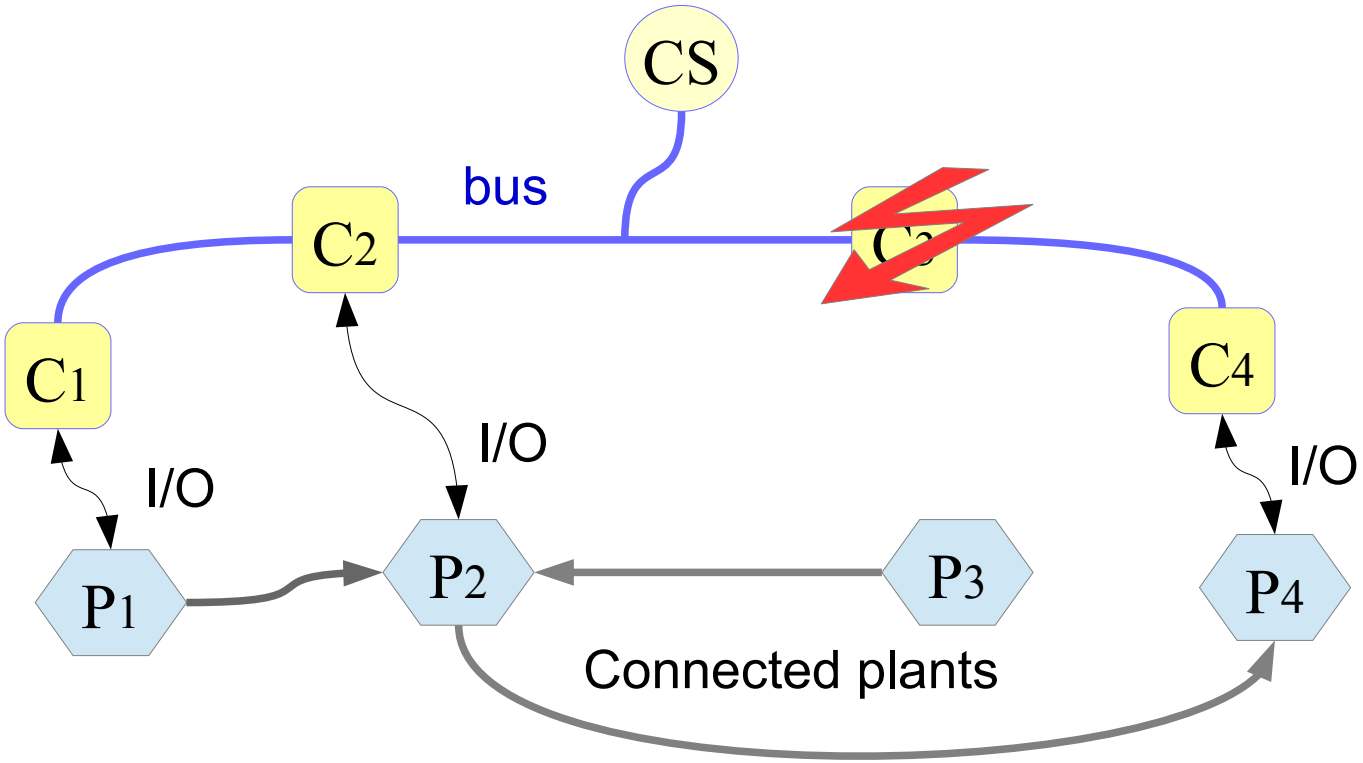


Distributed Control Systems (DCS)

Distributed Control Systems

Systems for the industrial distributed control

A fault or a single agent does not affects the all control system but just a limited part of it

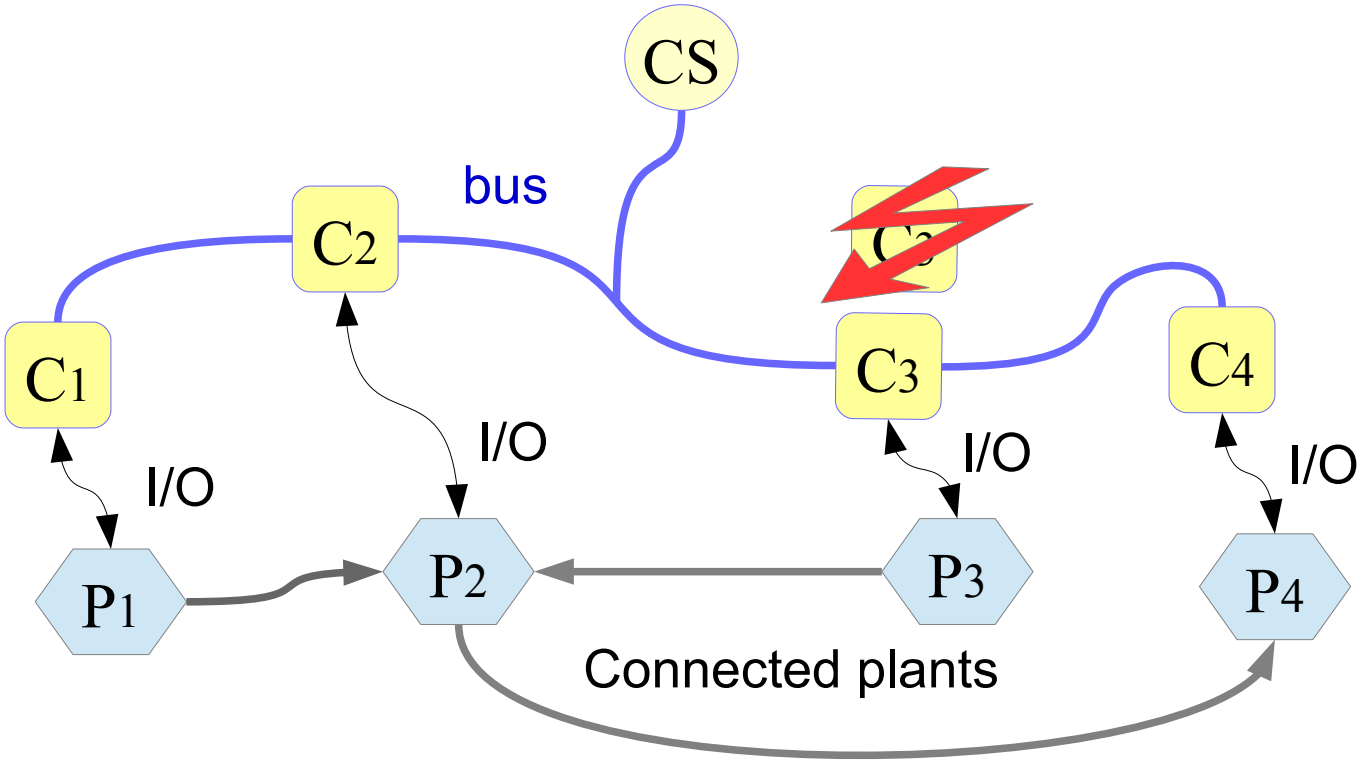


Distributed Control Systems (DCS)

Distributed Control Systems

Systems for the industrial distributed control

Redundancy of critical equipments/devices increases the reliability of the system



Distributed Control Systems (DCS)

Distributed Control Systems

Systems for the industrial distributed control

The supervisor allows for the optimization and proper coordination of the overall production process

Usually they are implemented for process control (*DCS*)

- Control system for which the main aim is to regulate/track continuous variables
- Represented by differential equations

Distributed Control Systems

They are constituted by a number of electronic devices, connected one each other by a network, and connected by proper I/O modules to the field devices (sensors & actuators)

The **modular structure** allows for a great flexibility of the systems and future improvements

Distributed Control Systems

They have a **proper software** that usually includes **object oriented** programming tools

Usually both the hardware and software are **not standard** but specific for each producer. They are "private" systems that can be equiped with **standard interfaces**

Engineering functions are available

Distributed Control Systems

Main class of functions in a DCS

Control

- Continuous and sequential control
- Auto/Self-tuning
- Multivariable Control
- Model Predictive Control
- Fuzzy Logic Control
- Dynamical optimization

F.C.U.
A.C.U.
P.L.C.

Distributed Control Systems

Main class of functions in a DCS

Protection

- Alarm management
- Fault management
- Automatic Shut-down

Supervision function

P.L.C. for safety

Distributed Control Systems

Main class of functions in a DCS

Supervision

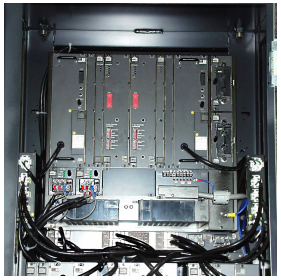
- Alarm management
- Recipes management
- Planning
- Trends and reports
- Human Machine Interface
- Statistical tools
- Maintenance support
- Expert systems
- Communication ports

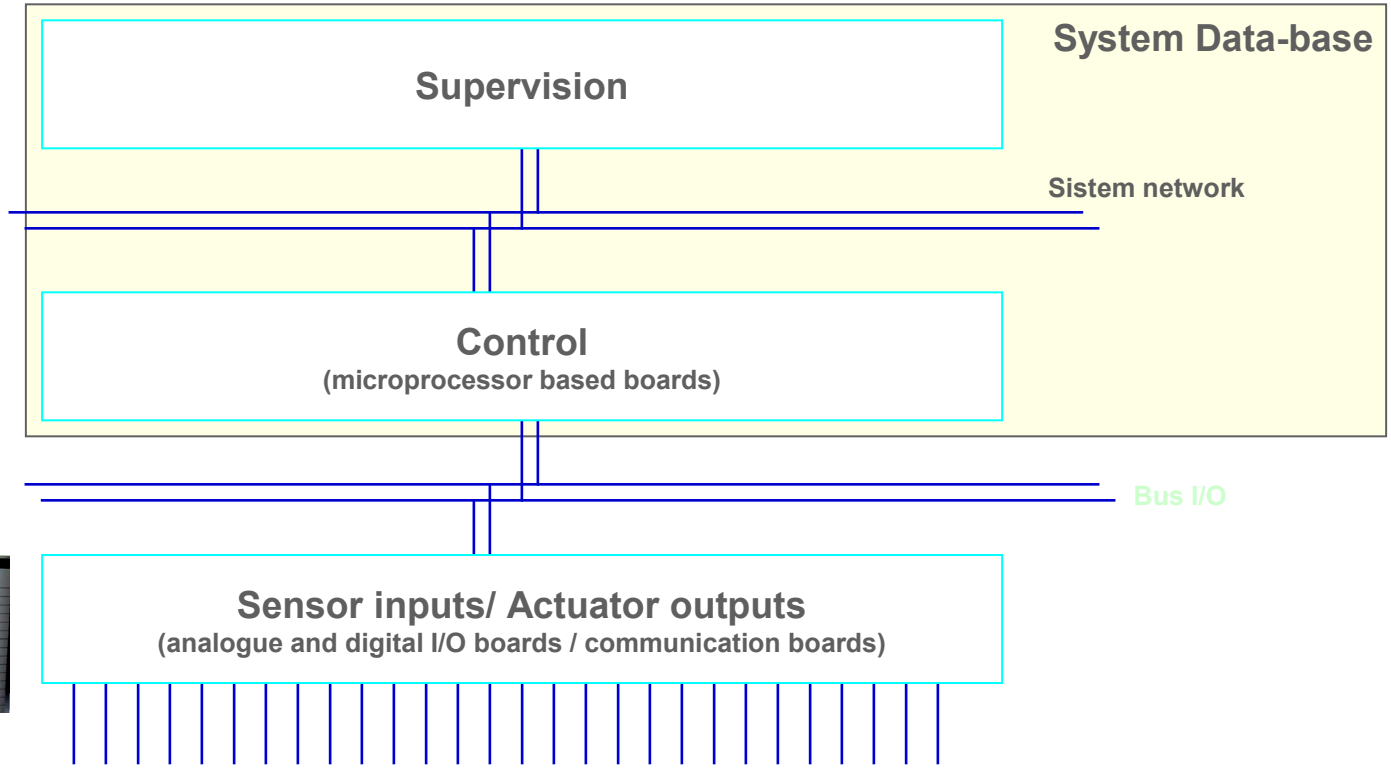
Protection function

S.C.A.D.A.

Distributed Control Systems

Classic architecture of a D.C.S.





Distributed Control Systems (DCS)

The Control Function

- Analogue/digital and sequential control
- Auto/Self-tuning
- Multivariable Control
- Model Predictive Control (MPC)
- Fuzzy Logic Control (FLC)
- Optimal Control (OC)

It is responsible for all control functions

Classic controller - PID, PLC

Advanced controllors - MPC, FLC

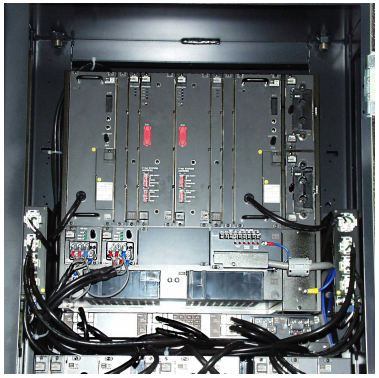
Off-line dynamic programming - OC

Distributed Control Systems (DCS)

The Control Function

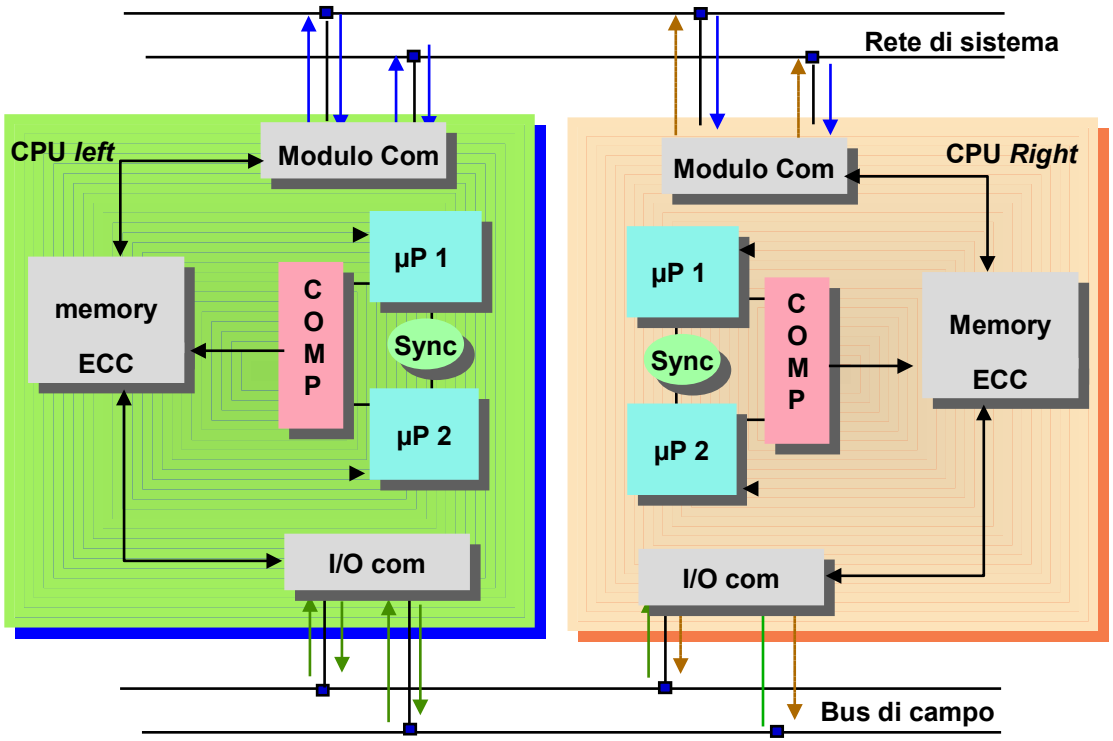
Control units: microprocessor based boards on which all control algorithms can be implemented

- Powerful and reliable microprocessors (es. RISC, 32/64 MB Ram)
- Redundant CPU --> bumpless substitution when in operation
- Redundant power supply
- Redundant communication boards (both with the field and the control room)
- All control functions are implemented (both continuous and batch)



The Control Function

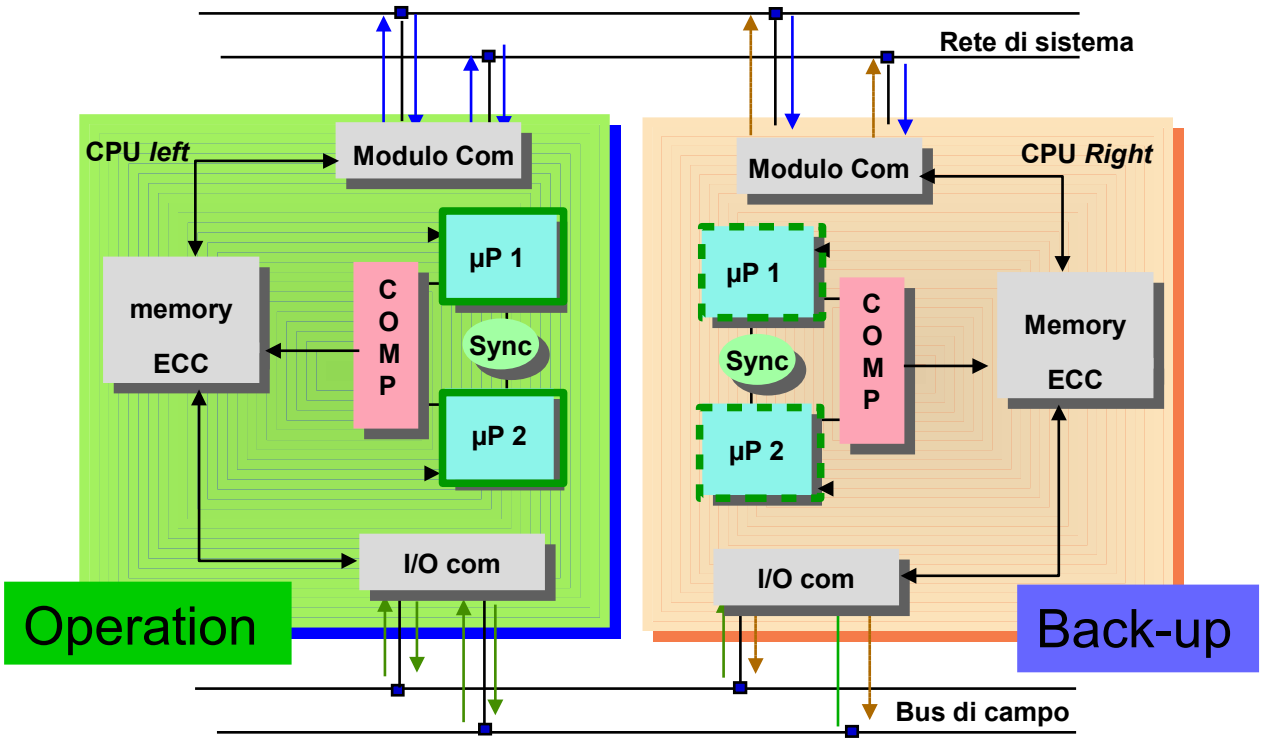
CPU Pair & Spare



- Both CPU treat the same set of signals

The Control Function

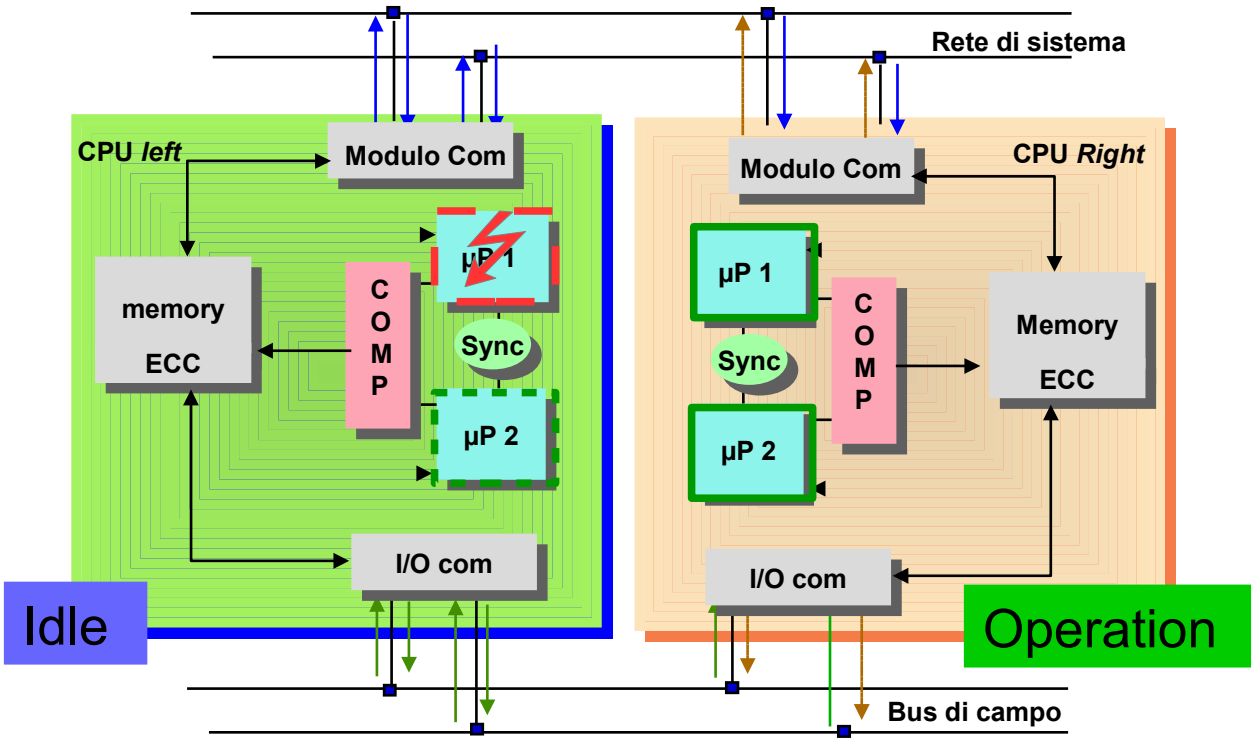
CPU Pair & Spare



- Both CPU treat the same set of signals
- Any CPU has 2 micro-processors working in parallel and synchro-nized (**PAIR**)

The Control Function

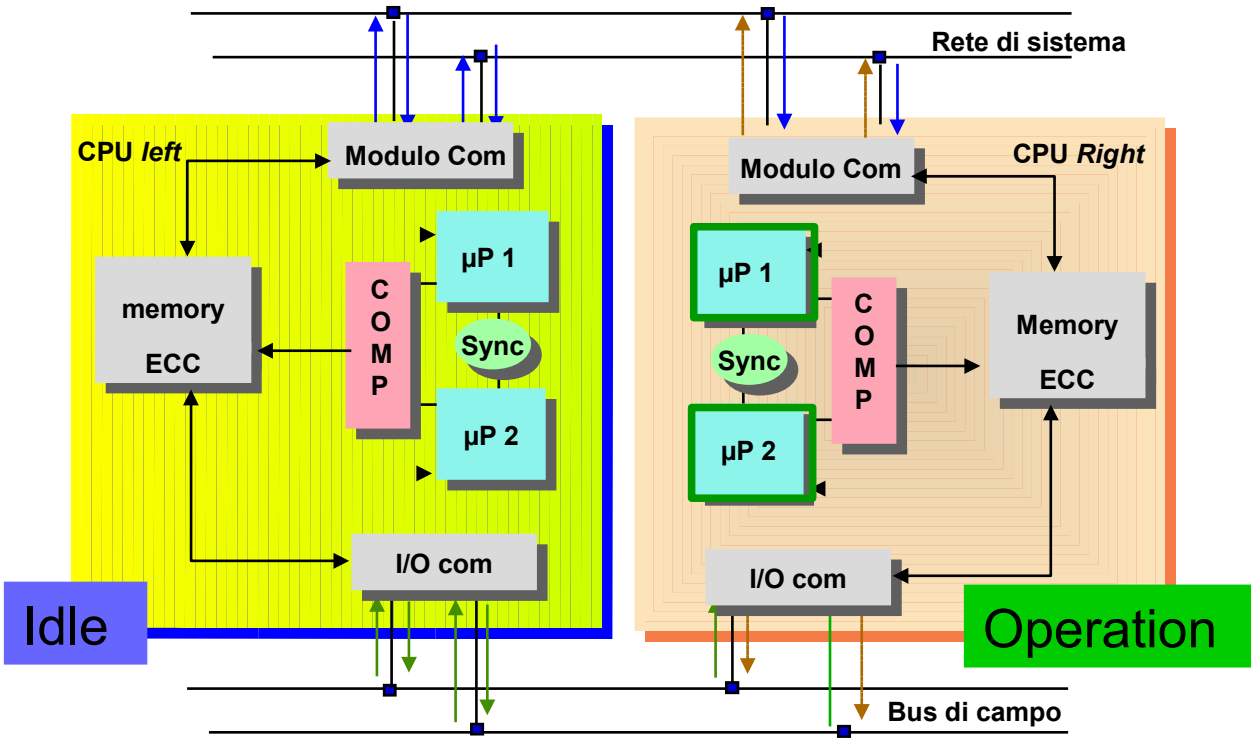
CPU Pair & Spare



- Both CPU treat the same set of signals
- Any CPU has 2 micro-processors working in parallel and synchro-nized (**PAIR**)
- When a fault is detected the spare CPU goes on full operation (**SPARE**)

The Control Function

CPU Pair & Spare



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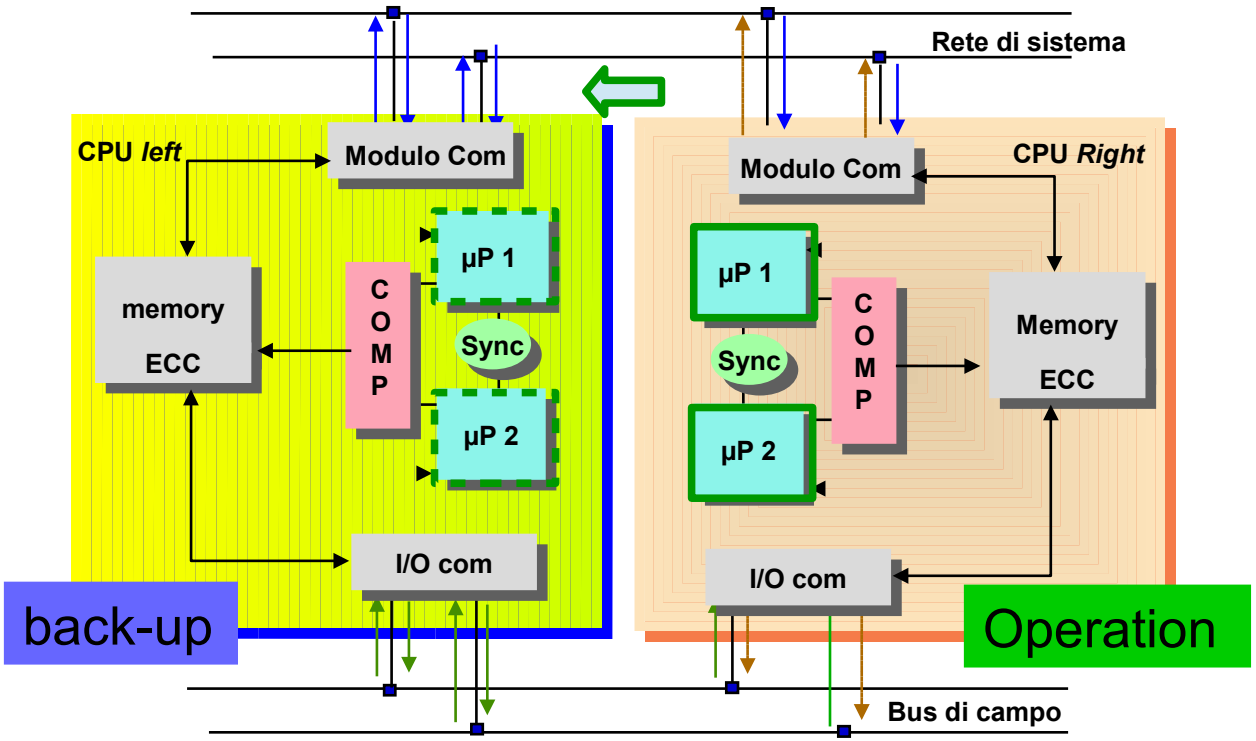
- When a fault is detected the spare CPU goes on full operation (**SPARE**)
- The faulty CPU can be substituted without turning off the board

The Control Function

CPU Pair & Spare



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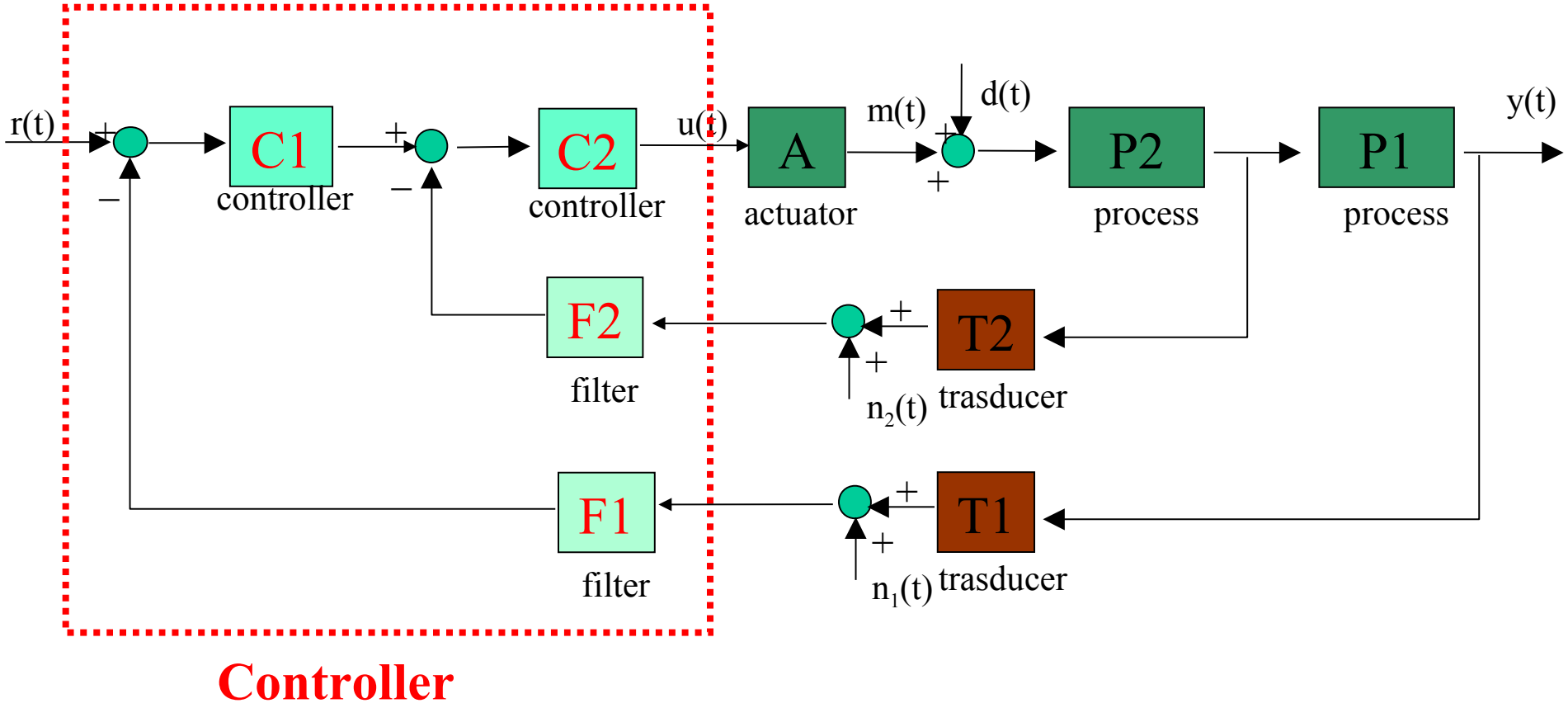
- Any CPU has 2 micro-processors working in parallel and synchro-nized (**PAIR**)
- When a fault is detected the spare CPU goes on full operation (**SPARE**)
- The faulty CPU can be substituted without turning off the board
- The control program is uploaded to the new CPU

The Control Function

Configuration of continuous control loops



The Control Function

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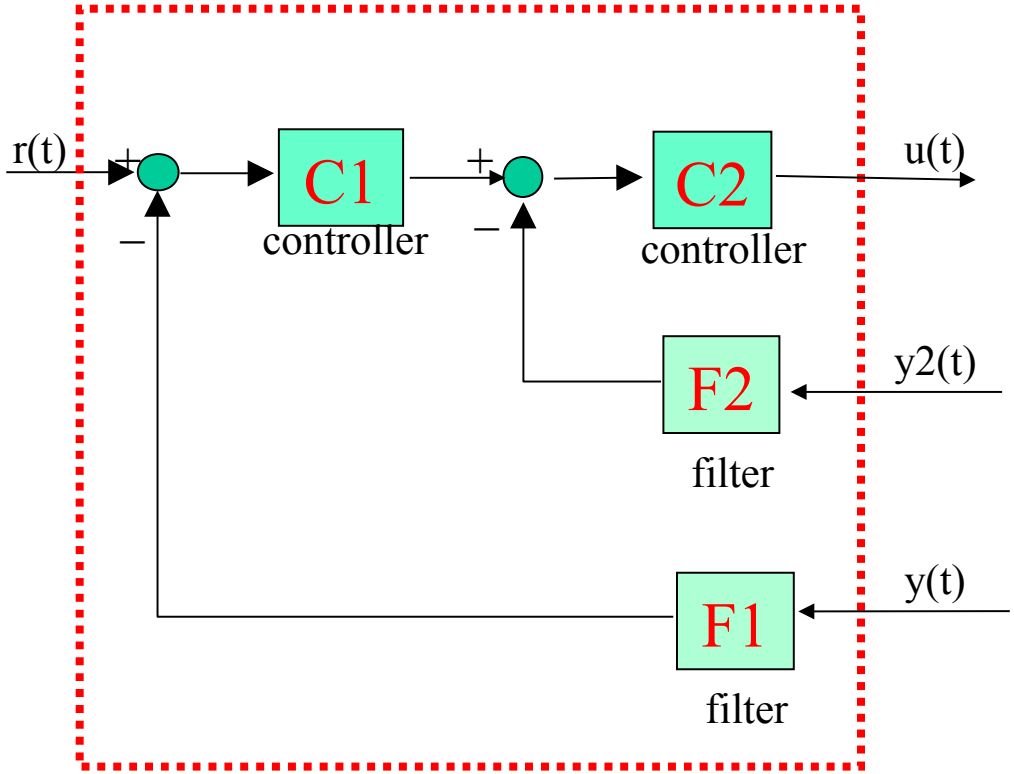

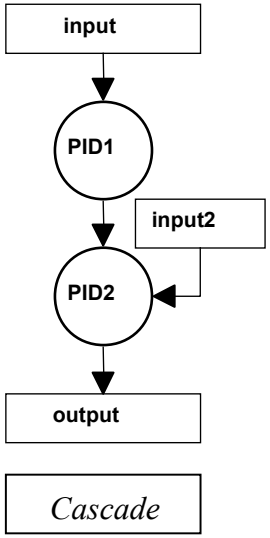

The Control Function

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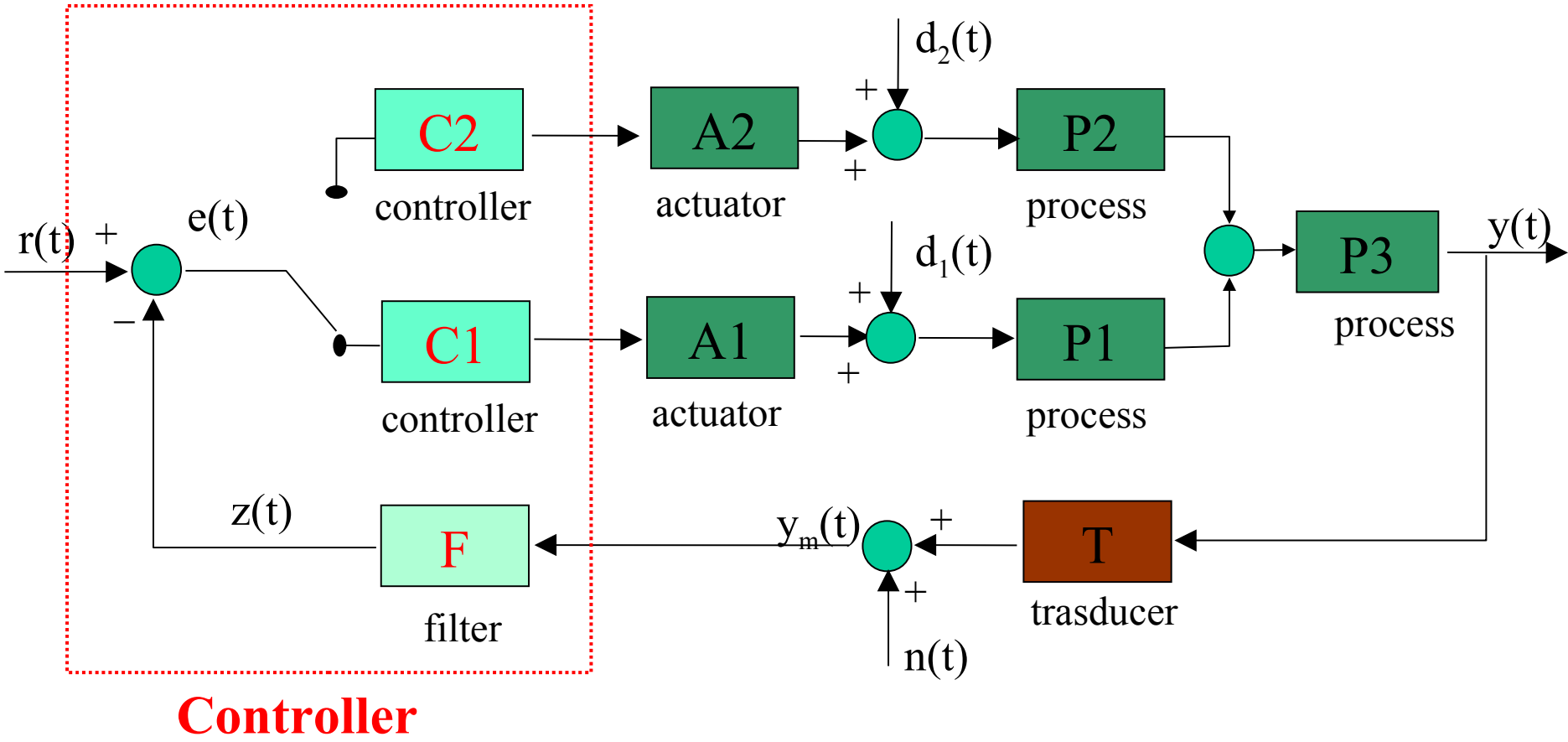

The Control Function

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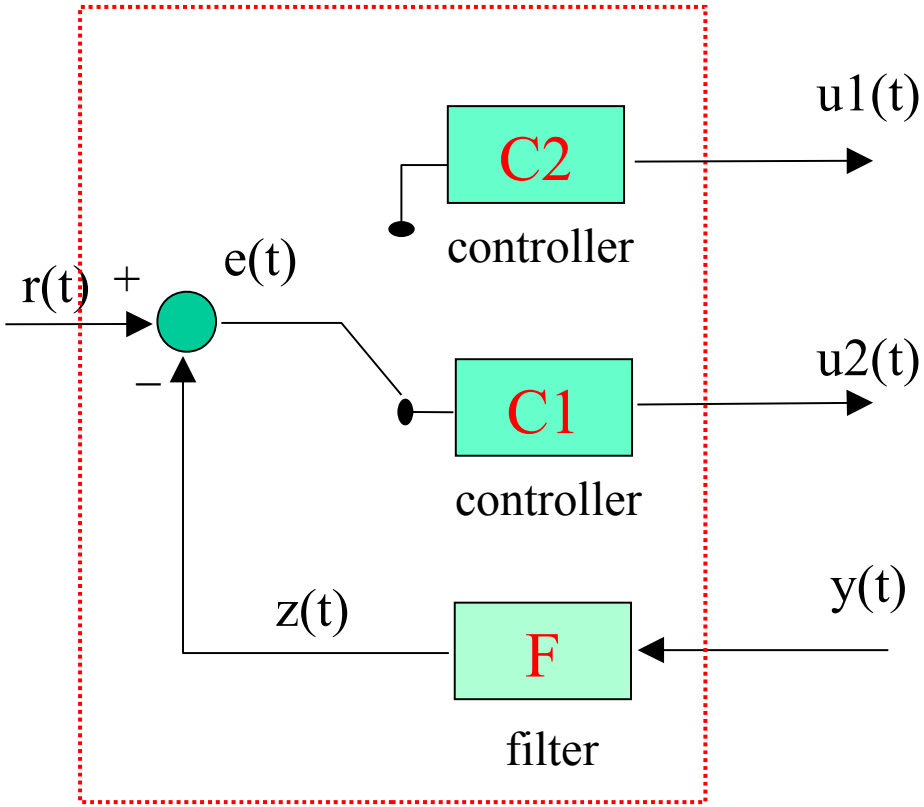

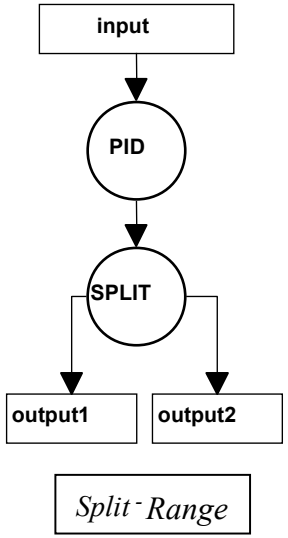

The Control Function

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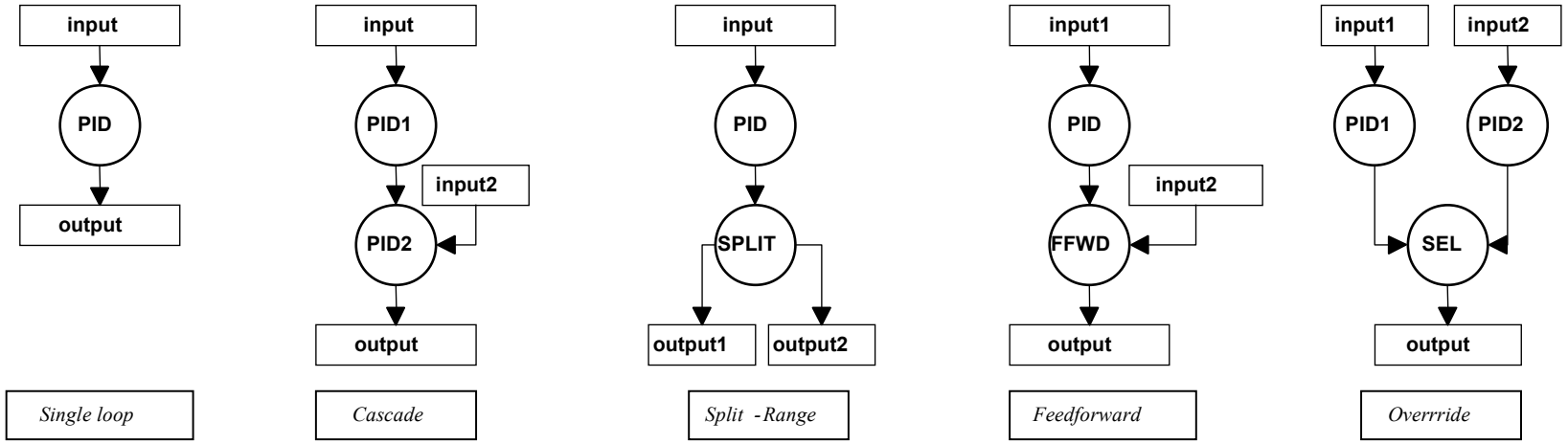


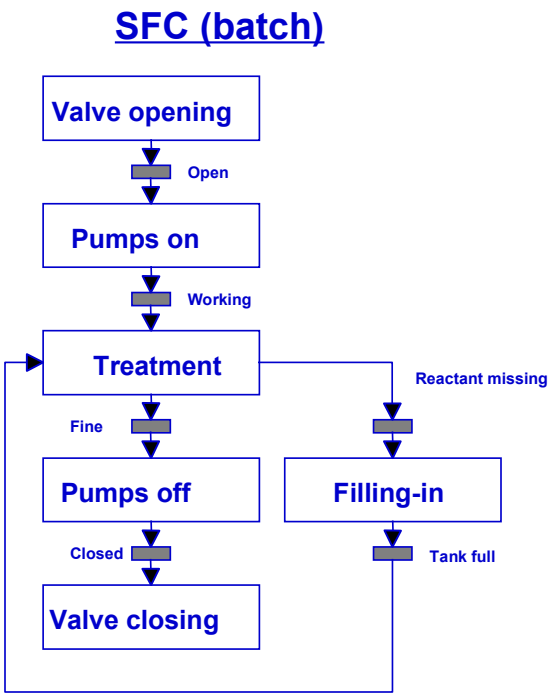
Configuration can be designed using Function Blocks

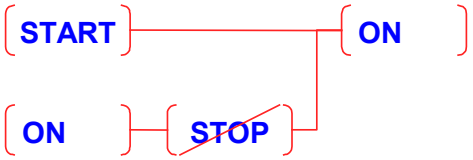
(Rich library with function blocks, e.g., Lag Delay, LeadLag, etc.)

The Control Function

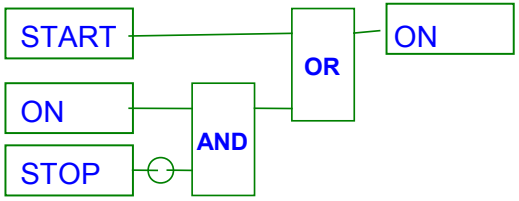
Programming event-driven control loops

IEC 1131-3 progamming languages are available





Ladder Diagram



Logic Chart

Load ON
Load STOP
not
and
Load START
or
Store ON

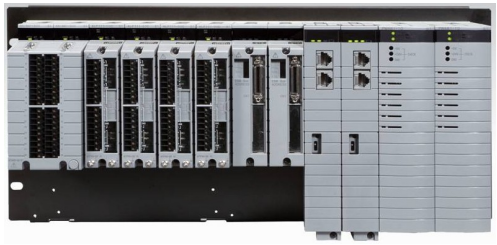
Structured language

Distributed Control Systems (DCS)

The Control Function

Multi-protocol communication modules are connected to a sensors network and a process network

All communication modules have an interface with the measurement and the control devices



PROFINET

MODBUS TCP
(Ethernet)

MODBUS
(RS-485, 422, 232C)

Hart

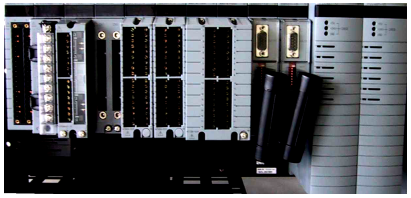
FOUNDATION Fieldbus
FOUNDATION HSE

PROFIBUS-DP

Distributed Control Systems (DCS)

The Control Function

Remote Measurement Units to acquire the field data and send them to the Control Unit



- I/O boards with 8 or 16 analougue channels
- I/O bourds with just one signal for critical control loops
- Boards with 16, 32 or 64 digital inputs
- Boards with 16, 32 or 64 digitaloutputs (transistor or relays)
- Communication boards:
  - RS232, private/standard protocols (es. Modbus)
  - RS422A/485, private/standard protocols (es. Modbus, Profibus)
  - Foundation Fieldbus (with field control loops)
  - Ethernet
- Communication to the control unit via local bus (private or stanbdard) that can be short and fast (es. 185 Mb/sec, < 10m) or long and slow (es. 10 Mb/sec, < 180 m)

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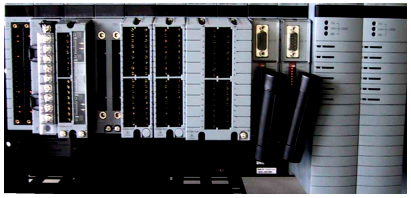

I / O modules

Are the interface between the process and the control system

while guaranteing the isolation with the field deviced

Galvanic decoupling

Relays
Optoisolators
High isolation trasformers

Functional decoupling

Voltage follower

Distributed Control Systems (DCS)

The Control Function

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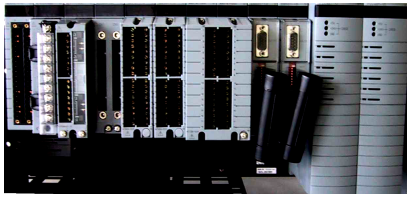

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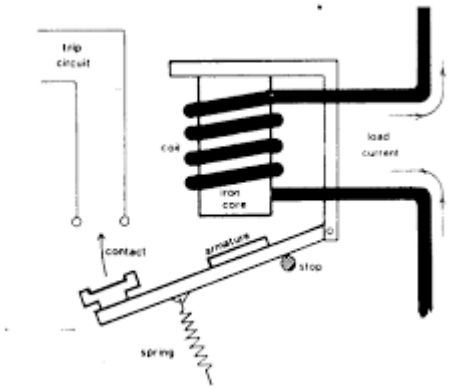

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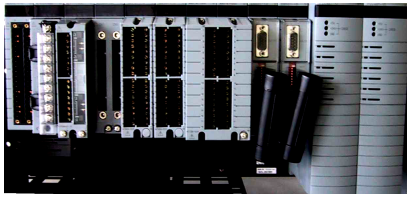

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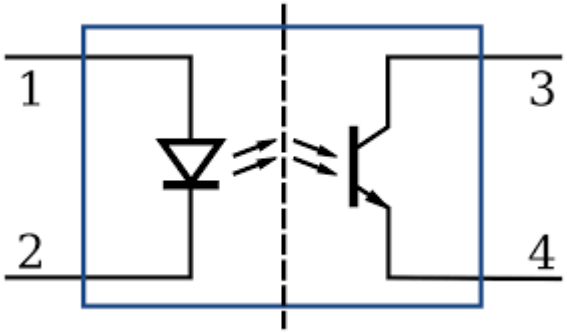

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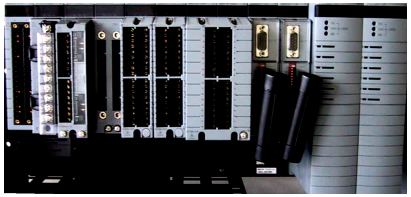

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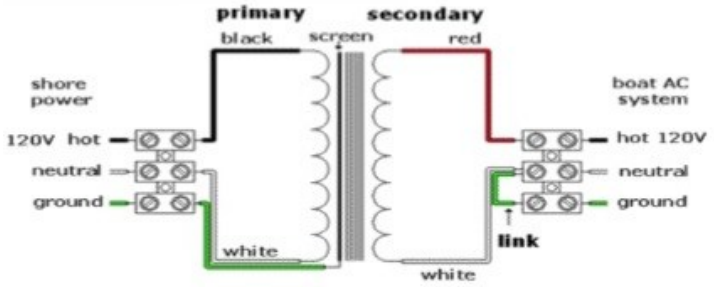

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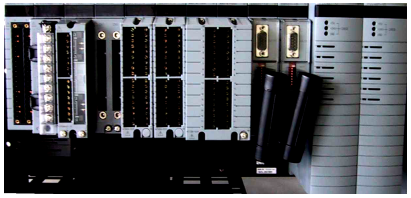

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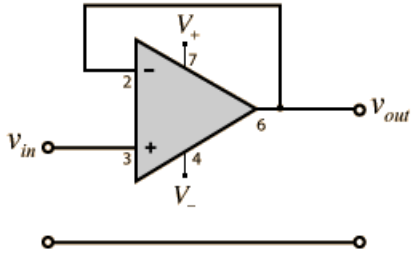

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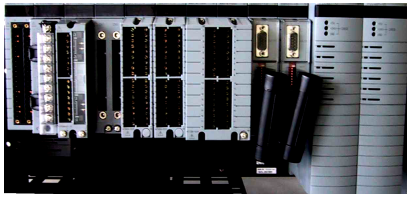
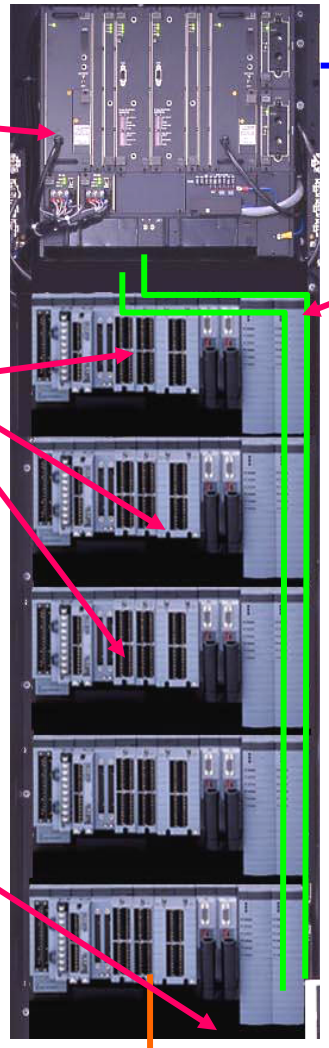


Digital I/O	0÷24 V d.c. 0÷230 V a.c. 50 Hz
Relay I/O	0÷24 V d.c. 0÷230 V a.c. 50 Hz
Analogue I/O	± 5 V, ± 10 V, 0÷10 V, 4÷20 mA for temperature measurements A/D converter (minimum 1) D/A converters (≥ 1)

Distributed Control Systems (DCS)

The Control Function

FCU rack look

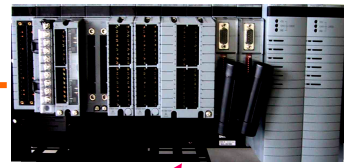


Redundant network

Single or redundant CPU
- RISC µ processor
- Memory 16 MB (with ECC)

Internal bus
- **Simple or redundant**
- **128 Mb/s**
- **10 m**

Rack I/O
- Single or redundant power supply
- 8 I/O slots
- max 15 Racks per KFCS
- 19 "x 5 U (22cm)



Remote I/O
- Single or dual power supply
- 8 I/O slots
- max 14 remote racks
- Option G3 at 70°C
- 19 "x 5 U (22cm)

Remote connection bus
- Simple or redundant
- 10Mb/s
- ~180 m max
- ~ 2km with optical fiber

Hazard Protection Function

- Fault management
- Automatic shut-down

- It allows for the management of dangerous operating conditions that constitute a possible risk for people and equipments

It is essential to decrease the safety risk

Decreases the probability that a damage follows an event

$$R_i = \sum_j c_j * d_{ji} * p_i$$

Hazard Protection Function

- Fault management
- Automatic shut-down

- It supports the operator in his task
- Sometime it is integrated with Expert Systems

Gives the operator "the picture" of the situation

Mathematical models and AI algorithms can be used to suggest the operator the causes of a fault with some probability

Hazard Protection Function

- Fault management
- Automatic shut-down

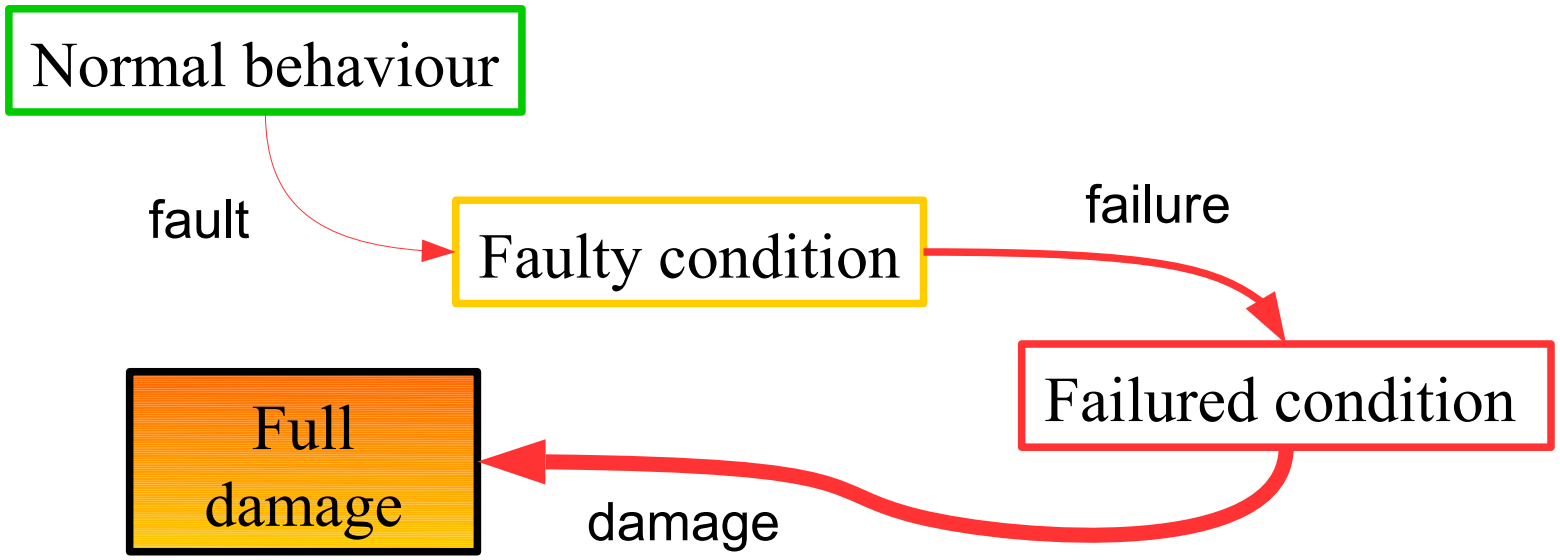
- High reliability characteristics
- Fully dedicated electronic systems

The probability of occurence of a fault in a hazard protection system should be much less than that of the dangerous event from which it should protect

Hazard Protection Function

- Fault management
- Automatic shut-down

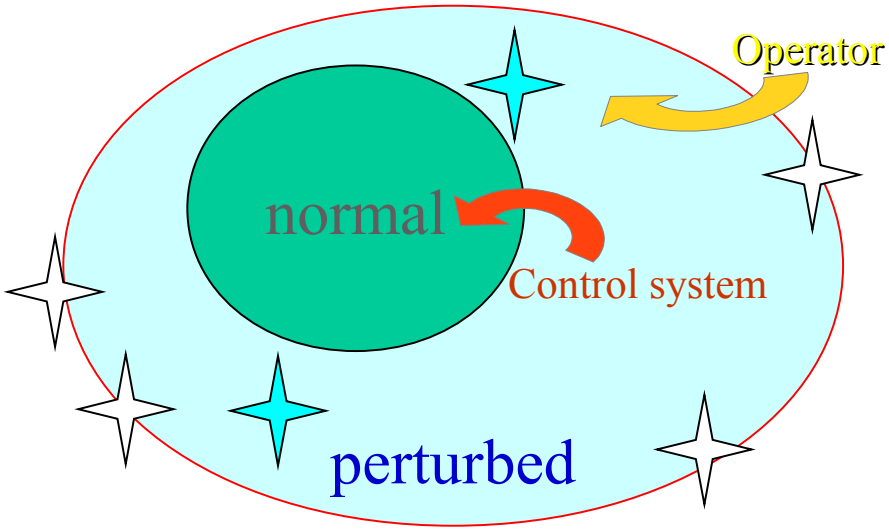
The alarme should be able to track the dangerous sequence



Hazard Protection Function

The control systems should be able to compensate for perturbations

Not effective alarms reduce the operators' attention



Not effective alarms

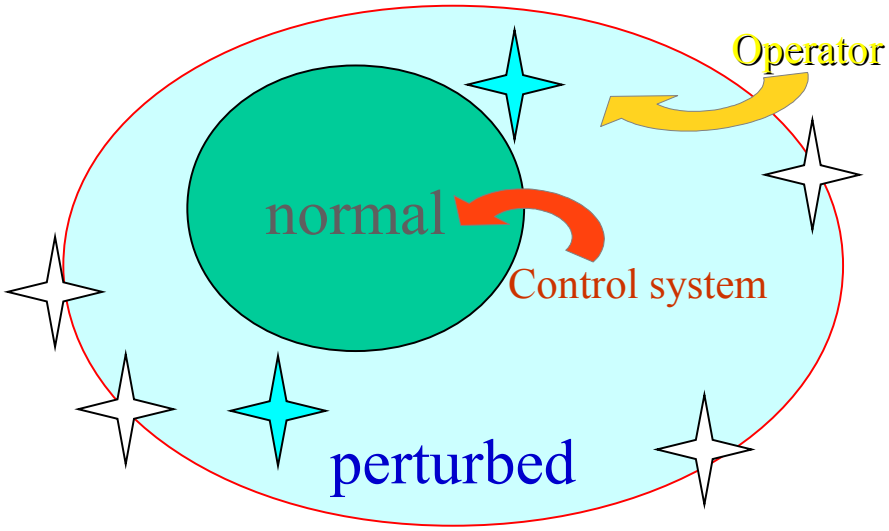
Effective alarms

Distributed Control Systems (DCS)

Hazard Protection Function

The control systems should be able to compensate for perturbations

The control system is redunded to decrease the probability that a perturbation evolves into a fault

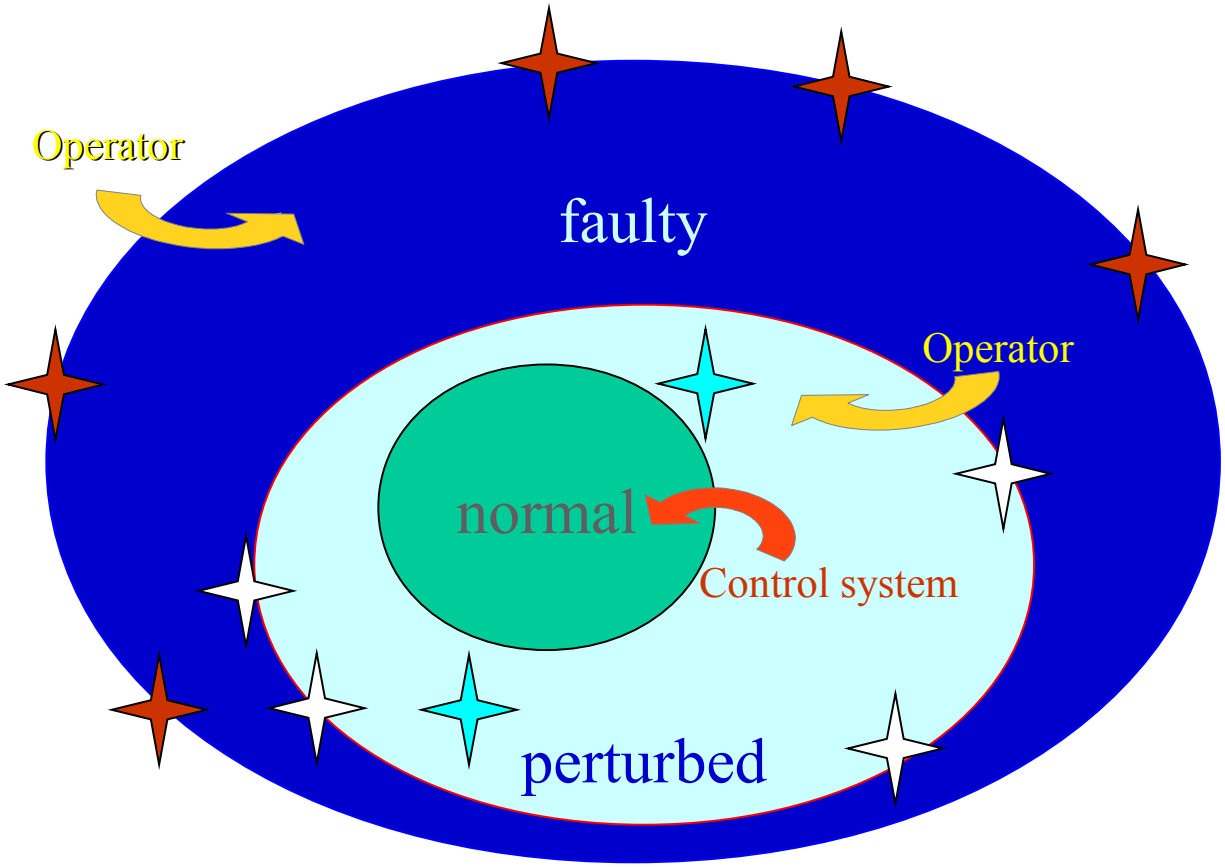


Not effective alarms

Effective alarms

Hazard Protection Function

Operators act to recover from faults

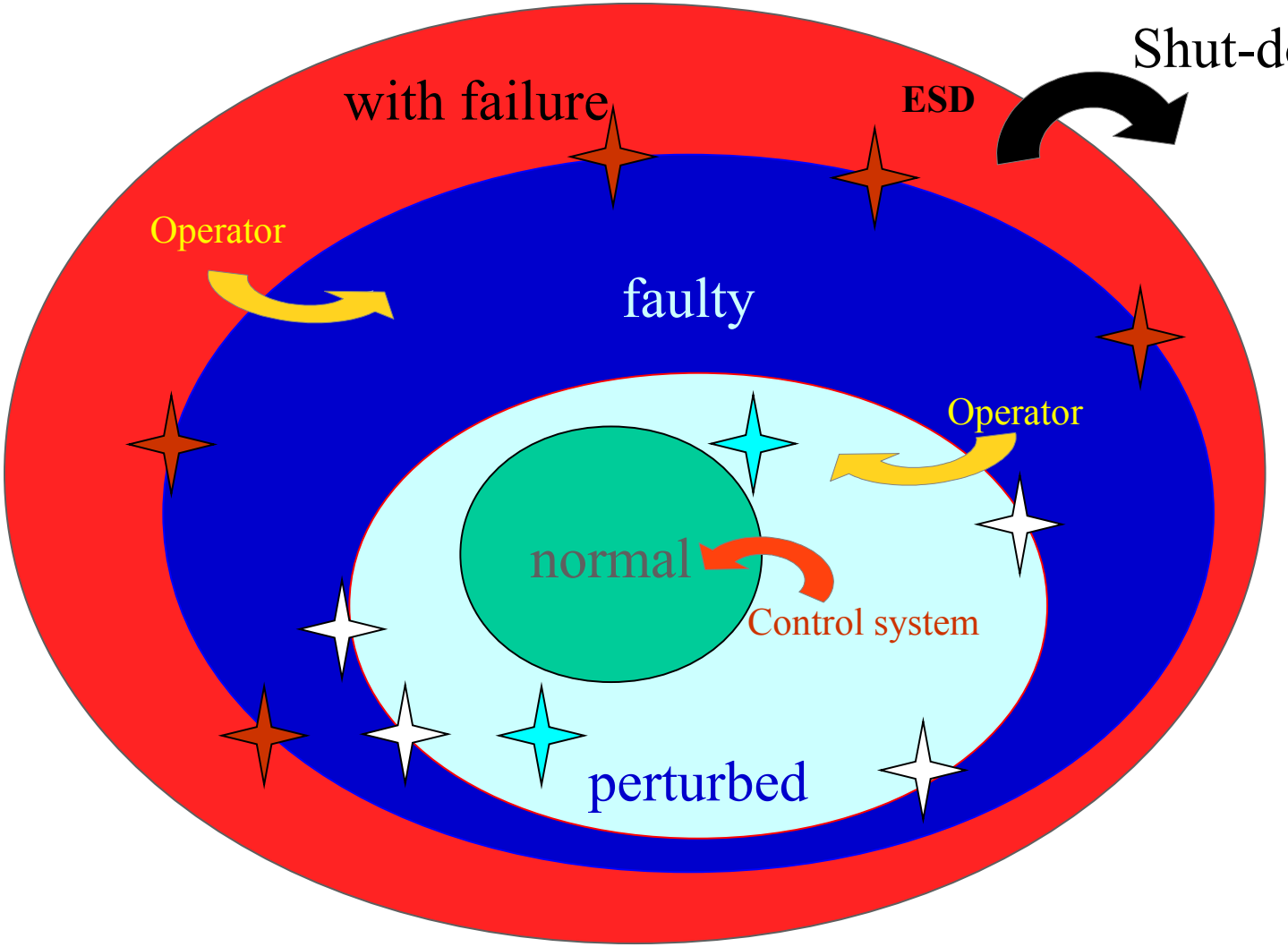


Not effective alarms

Effective alarms

Distributed Control Systems (DCS)

Hazard Protection Function



Not effective alarms

Effective alarms

Distributed Control Systems (DCS)

Supervision Function

- Expert system
- Alarm management

The Expert System can support the operator in making the correct manouvres and operative choices

It is used when large deviations from the nominal operating conditions occur, specially when high priority alarms and blocks are switched on

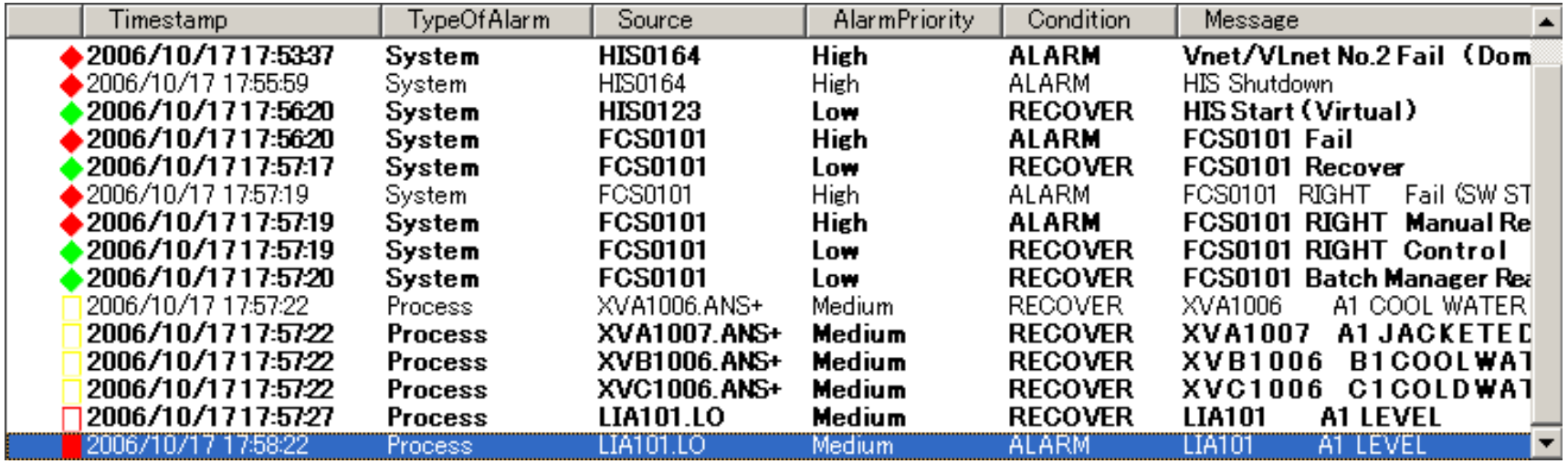
The alarm management is critical with respect to the reactiveness of the operator:

- Repeated not significant alarms
- Alarm shower

Supervision Function

- Alarm Management

  - Repeated alarms must be highlighted
  - A priority level must be associated to each alarm
  - Some filter can be implemented to better associate different faults
  - The statistical analysis of the alarm history helps in the alarm classification
  - Less meaningful alarms must be well distinguished



Timestamp	TypeOfAlarm	Source	AlarmPriority	Condition	Message
2006/10/17 17:53:37	System	HIS0164	High	ALARM	Vnet/VLnet No.2 Fail (Dom
2006/10/17 17:55:59	System	HIS0164	High	ALARM	HIS Shutdown
2006/10/17 17:56:20	System	HIS0123	Low	RECOVER	HIS Start (Virtual)
2006/10/17 17:56:20	System	FCS0101	High	ALARM	FCS0101 Fail
2006/10/17 17:57:17	System	FCS0101	Low	RECOVER	FCS0101 Recover
2006/10/17 17:57:19	System	FCS0101	High	ALARM	FCS0101 RIGHT Fail (SW ST
2006/10/17 17:57:19	System	FCS0101	High	ALARM	FCS0101 RIGHT Manual Re
2006/10/17 17:57:19	System	FCS0101	Low	RECOVER	FCS0101 RIGHT Control
2006/10/17 17:57:20	System	FCS0101	Low	RECOVER	FCS0101 Batch Manager Rea
2006/10/17 17:57:22	Process	XVA1006.ANS+	Medium	RECOVER	XVA1006 A1 COOL WATER
2006/10/17 17:57:22	Process	XVA1007.ANS+	Medium	RECOVER	XVA1007 A1 JACKETED
2006/10/17 17:57:22	Process	XVB1006.ANS+	Medium	RECOVER	XVB1006 B1COOLWAT
2006/10/17 17:57:22	Process	XVC1006.ANS+	Medium	RECOVER	XVC1006 C1COLDWAT
2006/10/17 17:57:27	Process	LIA101.LO	Medium	RECOVER	LIA101 A1 LEVEL
2006/10/17 17:58:22	Process	LIA101.LO	Medium	ALARM	LIA101 A1 LEVEL

Supervision Function

- Trends e reports
- Statitical tools for process analysis

The data from the plant are acquired and stored to make possible the analysis of the production efficiency and effectiveness (Trends, repors, statistical analysis)

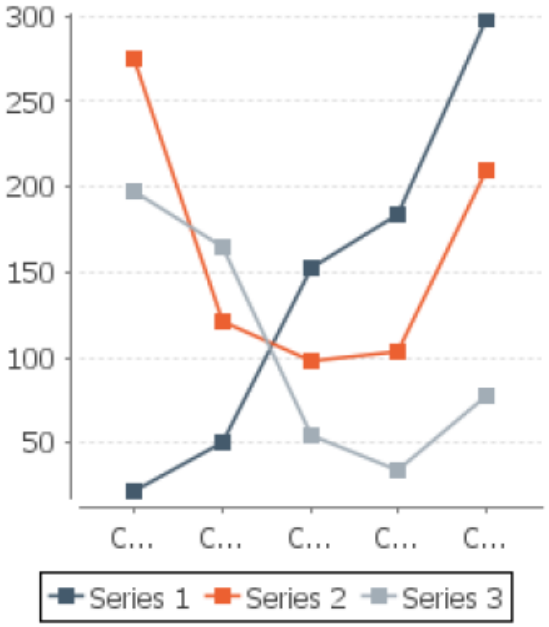
Effective tools that are useful to identify anomalies and faults and to suggest possible action to improve the process performance

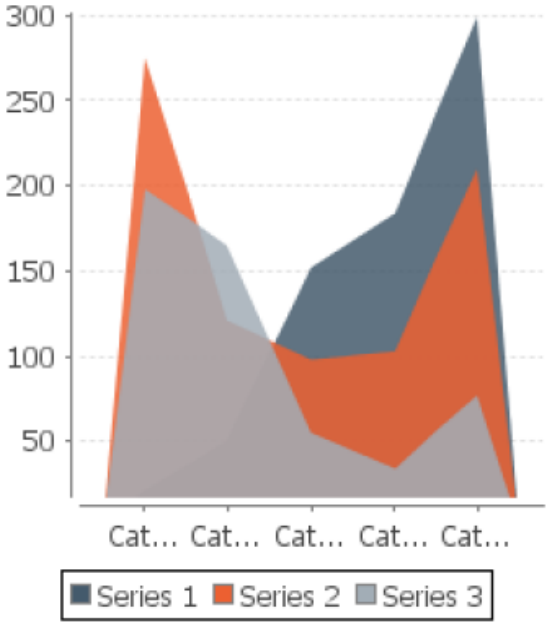
A centralised complete data-base of the process variables and parameters

Distributed Control Systems (DCS)

Supervision Function

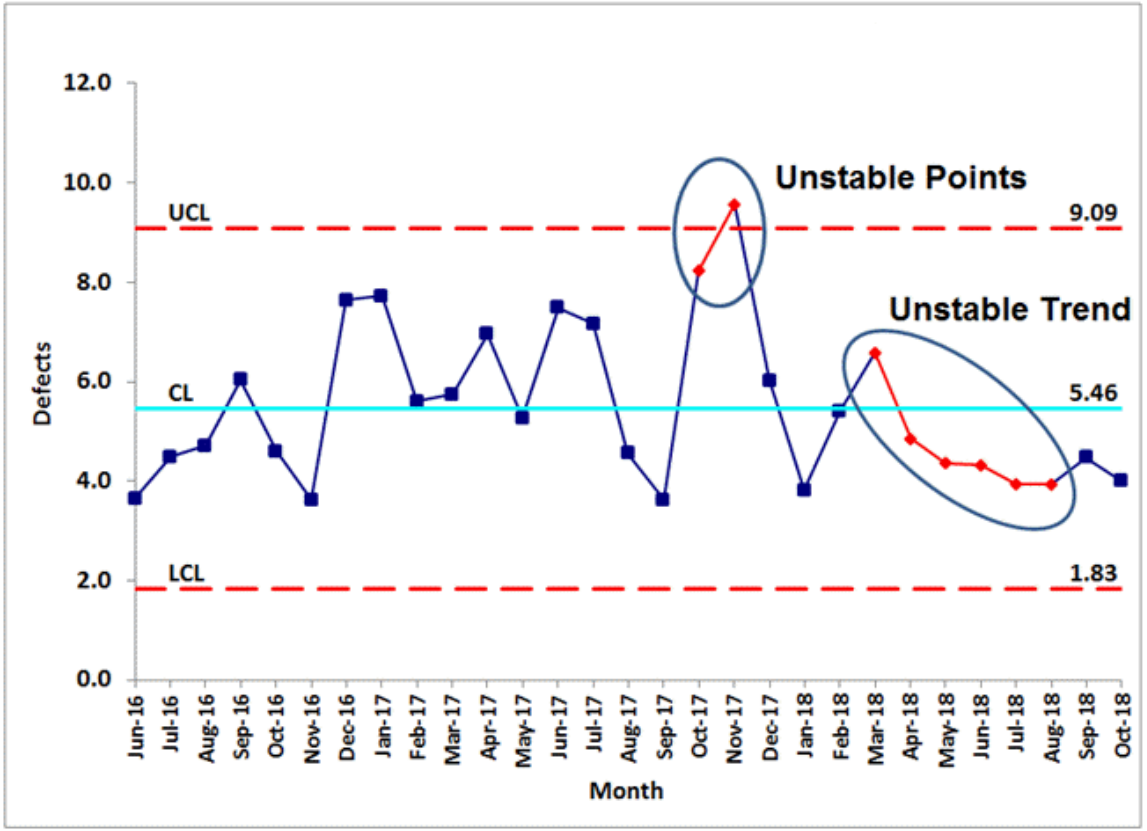
- Trends e reports





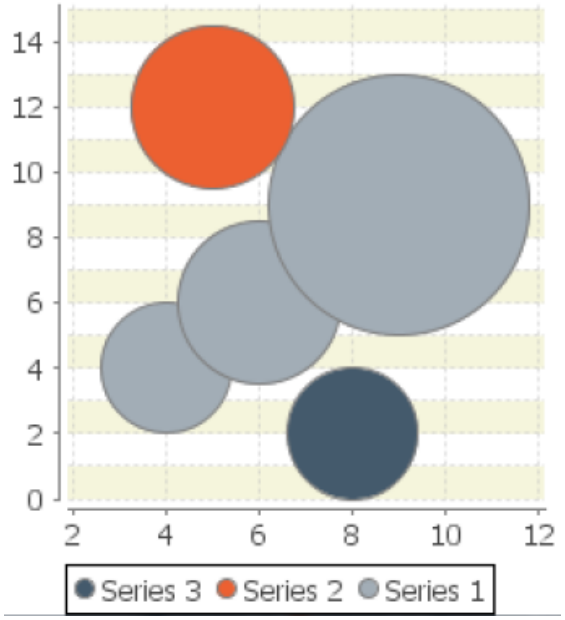
Supervision Function

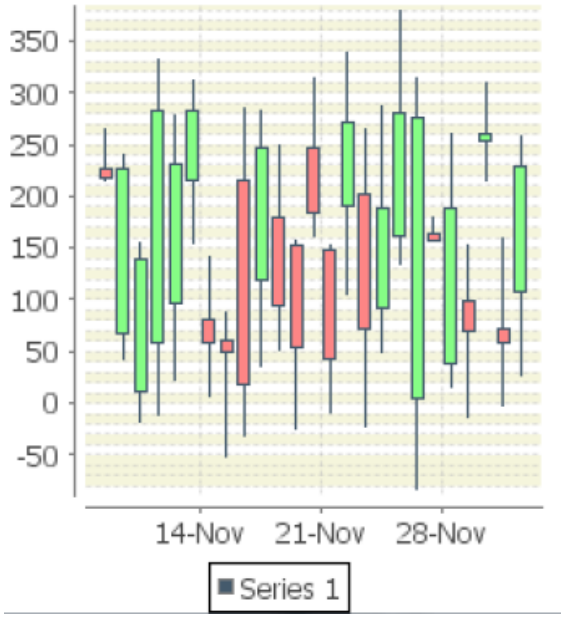
- Trends e reports



Supervision Function

- Statitical tools for process analysis





Supervision Function

Human Machine Interface

Nowadays, it is mostly based on Windows technology

Control room changes to Improve the operators' comfort

Distributed Control Systems (DCS)

Supervision Function

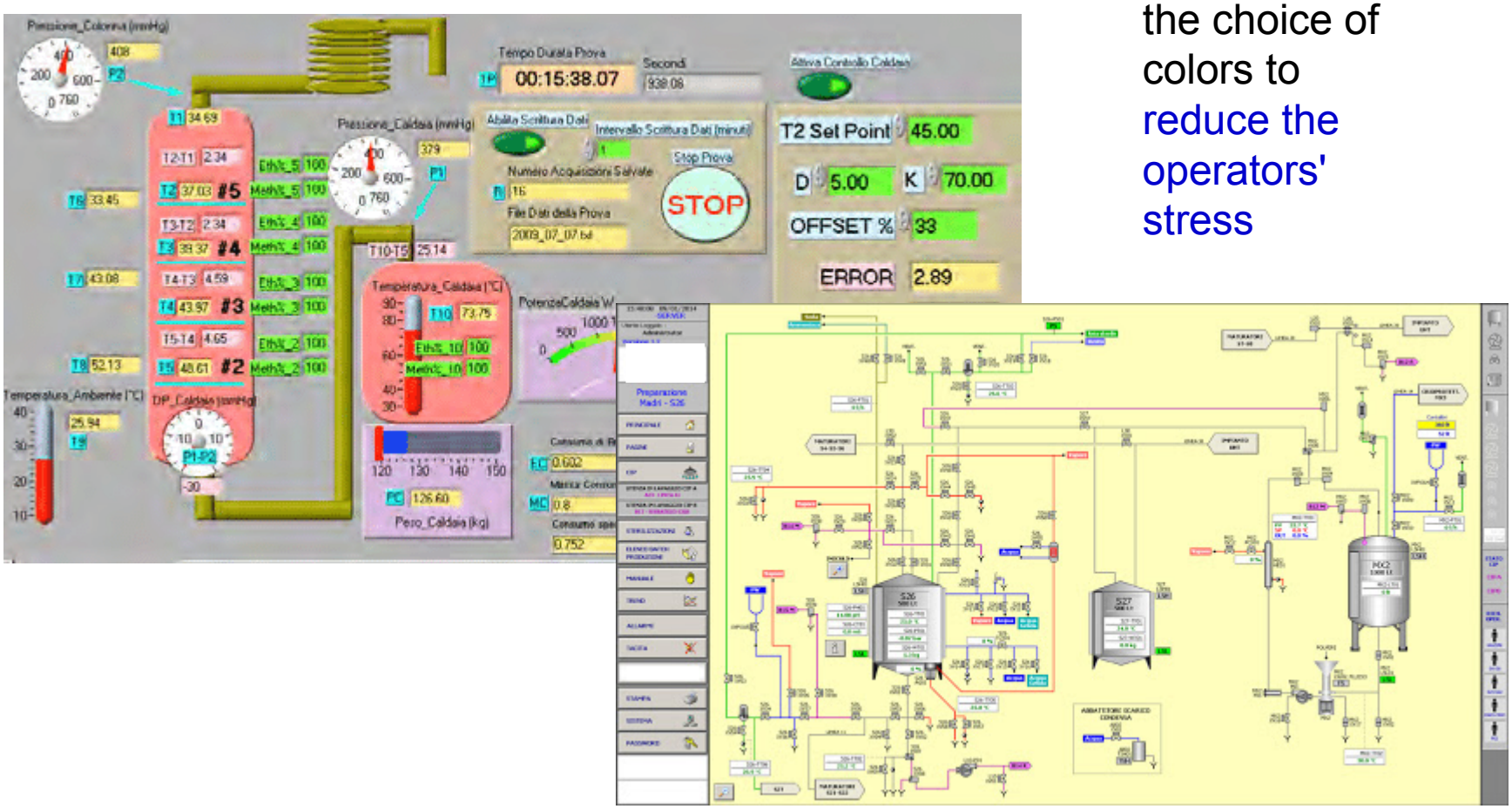
Human Machine Interface

Synoptic panel of a gas network.

Donated by SNAM to the Science and technology museum in Milan

Supervision Function

Human Machine Interface

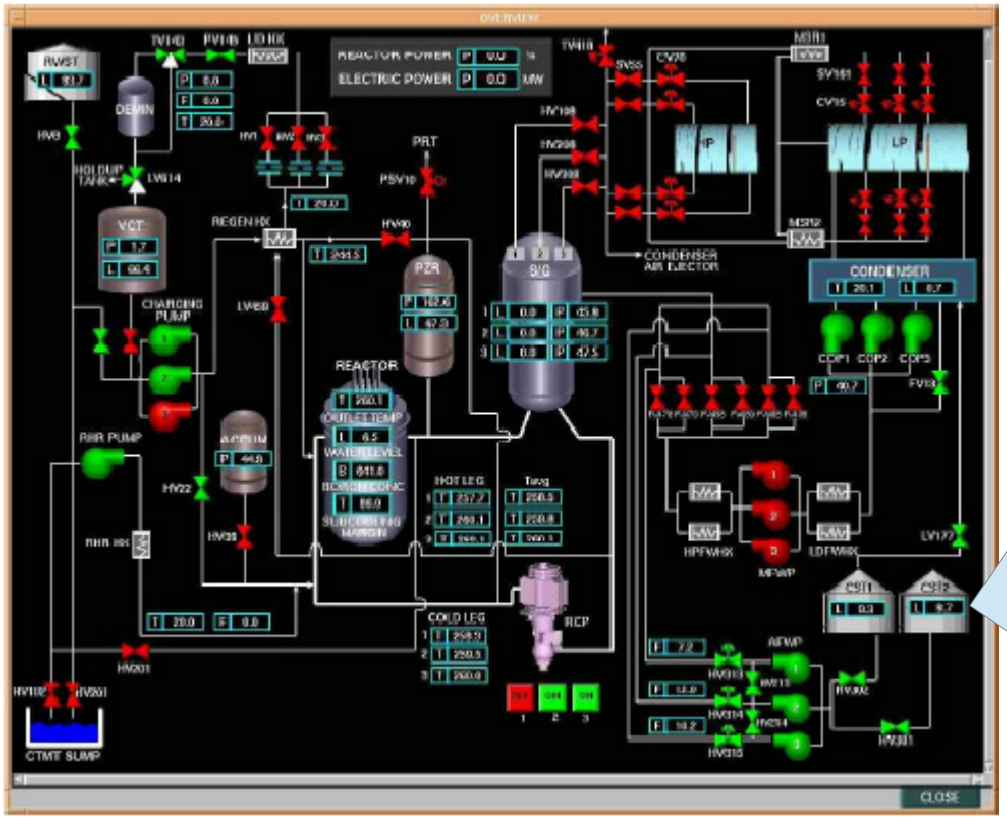


More care in the choice of colors to reduce the operators' stress

Distributed Control Systems (DCS)

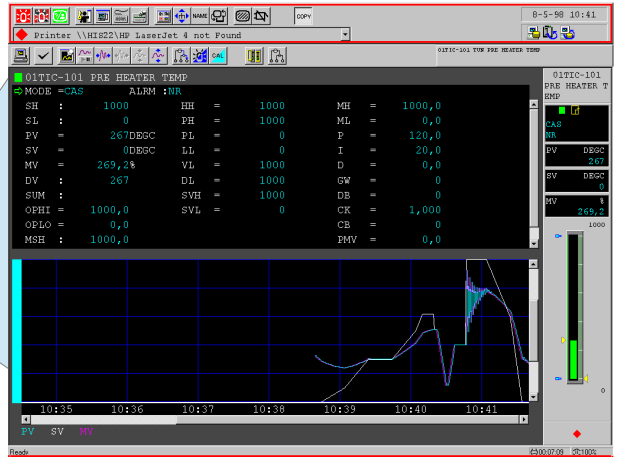
Supervision Function

Human Machine Interface



Specific information can be obtained by zooming

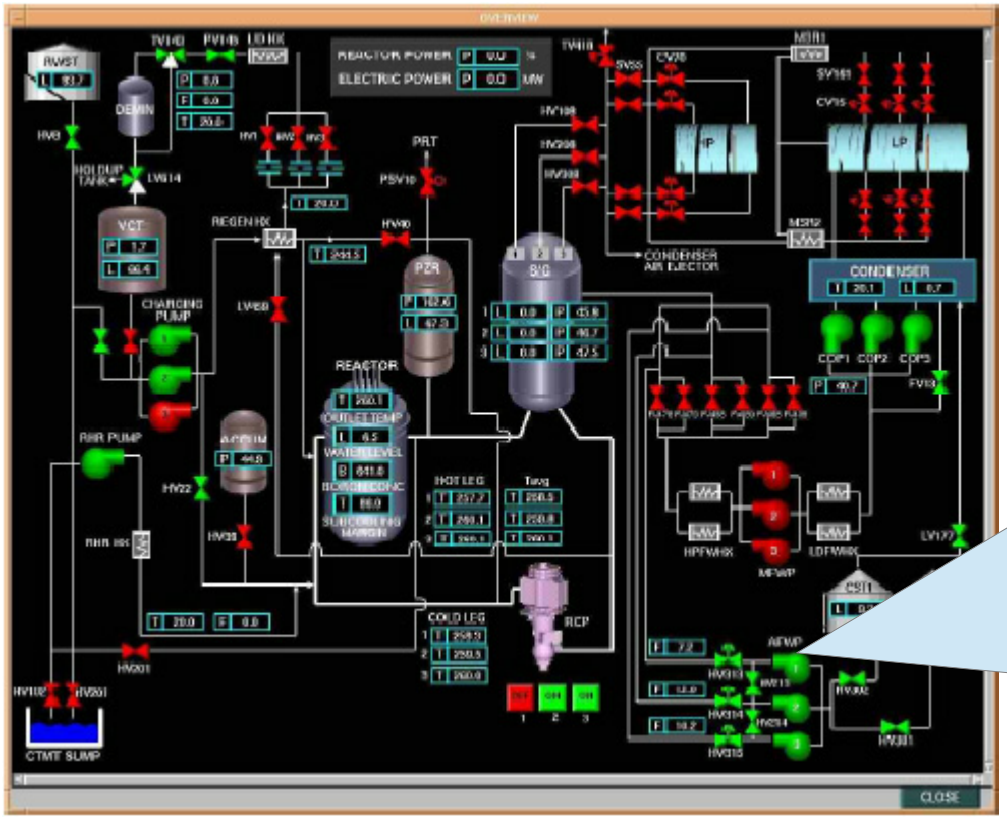
trends



Distributed Control Systems (DCS)

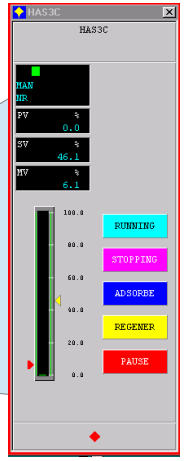
Supervision Function

Human Machine Interface



Specific information can be obtained by zooming

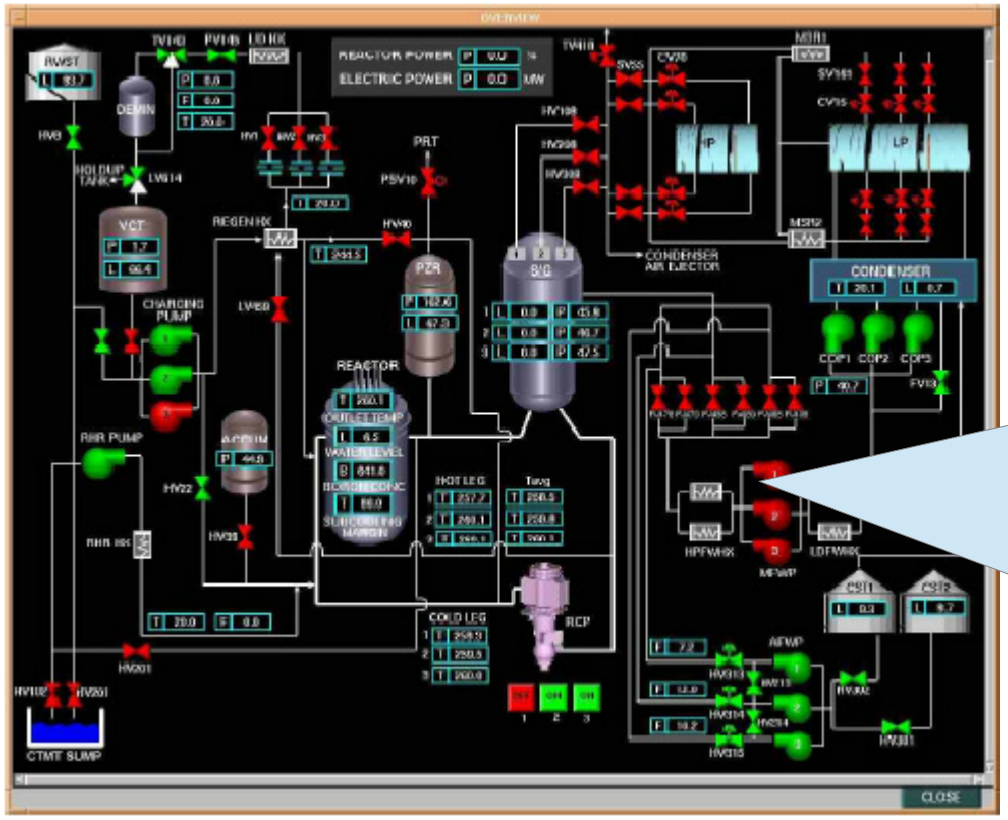
control values



Distributed Control Systems (DCS)

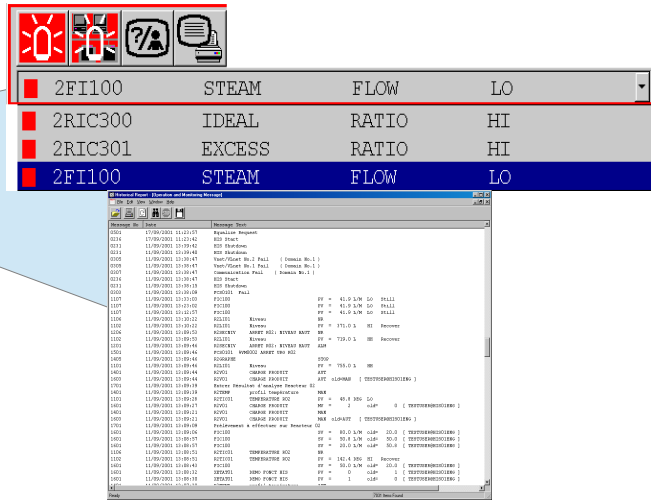
Supervision Function

Human Machine Interface



Specific information can be obtained by zooming

alarms



Distributed Control Systems (DCS)

Supervision Function

- Human Machine Interface

It is the equipement that allows the operators to monitor the working conditions of the process and to act on the plant

Ergonomicity of the site must be well taken into account

- Talking synoptic representations
- Printers
- Acustic signals
- Proper light signals
- Keyboard, track-ball, touch membrane
- Touch-screen

Careful use of colours

Supervision Function

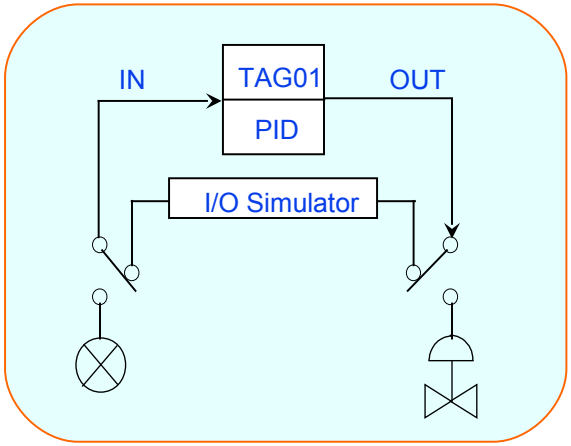
Engineering station

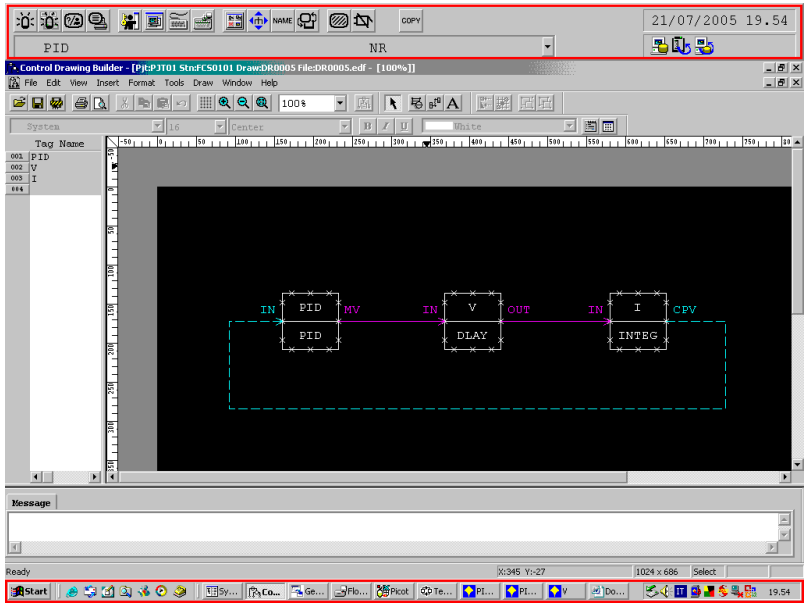
- Hardware configuration of the control stations
- Software configuration of the control stations
- Configuration of the pages for plant supervision, monitoring and control
- Simulation software for design test and personell training (without the Field Control Station)
- Design by means of advanced tools and software, often object-oriented
- Simplified configuration of the DCS functions by means of dedicated pages
- A number of pre-defined functions
- Possibility of user-defined function by means of standard languages (e.g., C+)

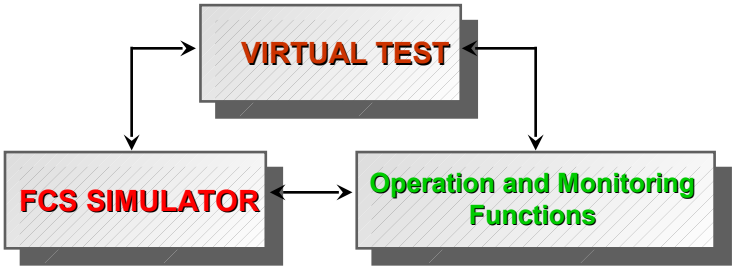
Supervision Function

Engineering station

- Automatic documentation of the engineering activities and design
- Allows for import/export of previous projects and data-bases







Supervision Function

- Communication

Data acquisition and system integration

- ✓ High level networks for external connections (Ethernet)
- ✓ Private networks for the connection of the system devices
- ✓ Redundant buses to increse the system reliability
- ✓ Standard devices as switches and routers for connecting the different branches of the network

Supervision Function

- Recipes management
- Planning
- Maintenance support

These tools allow for the complete management of the plant

They are connected to the plant/factory/company management system to implement the Computer Integrated Manifactory paradigm using specific tools such as the **M**anufactoring **E**xecution **S**ystem and the **P**lant **I**nformation **M**anagement **S**ystem

Allow for the extension of the Industrial Control System

Distributed Control Systems (DCS)

Software

Software

- Excution software
- Operating System software
- Applicative software
- Communication applicatives
- Configuration software
- User ID and password access

Software

System access control and registration is the base for the system security

- Usually 4 groups can be identified on the basis of their role:
  - Operators
    - Command, monitoring, execution of configuation actions, reporting
  - Maintenance engineers
    - System configuration for changing and tuning the control logic, sequences, drawingg, etc
  - Production and process enginers
    - Recipes update.
  - System administration
    - Access control to DCS, configuration, etc

Software

Any operator logins the system by his own User ID and Password

The UserID is strictly related to role of the user and the functions that he can exploit on the system

The password should be changed periodically

An intrusion detection tool should be implemented

When a certain time with no access is elapsed:

- the password is automatically required to be changed
- the user has to be registered again
- the system interface access is blocked to that user

For peculiar operation double authorization can be required (e.g., alarm by-pass)