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Significant improvements in valve maintenance by the adoption of a closed loop performance monitoring system

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Outline

➢ Introduction
- ❑ Control Loop Performance Monitoring
- ❑ Valve Stiction: from modeling to smart diagnosis

➢ The PCU Monitoring system
- ❑ The structure
- ❑ Standard vs. Advanced diagnosis

➢ Applications for valve state assessment
- ❑ Operator Check for threshold definition
- ❑ Valve maintenance scheduling
- ❑ (Improvement by smart diagnosis)

➢ Cloud Monitoring
- ❑ The project IdroLab 4.0 (technological demo)

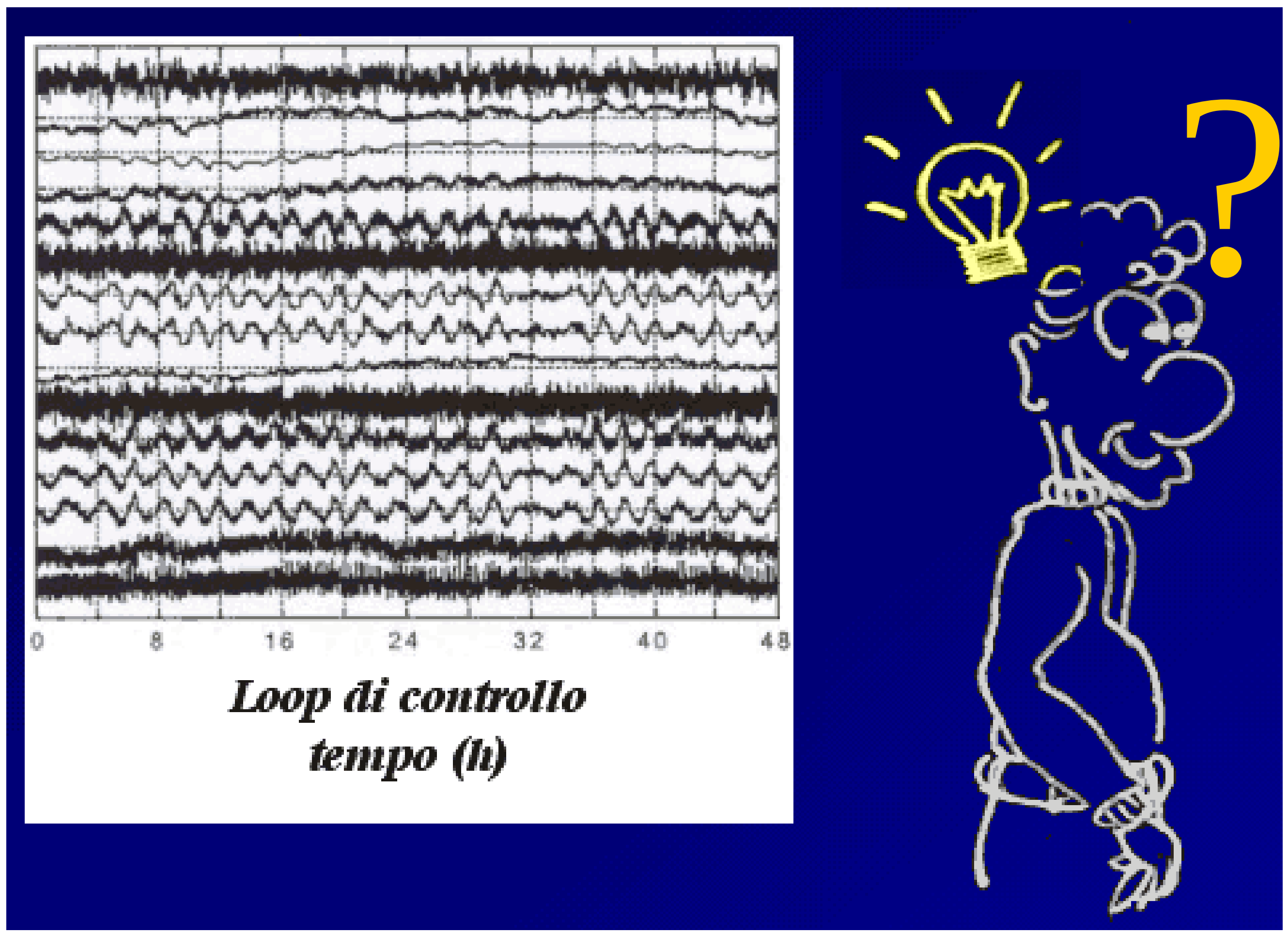
Performance Monitoring & the PCU (Plant Check-Up) System

Motivations:

Importance of performance assessment and malfunction noticing

- Hundreds of control loop ←→ too heavy burden
- Oscillations of different origin → different causes and actions

Valves play a very important role...



PCU scope

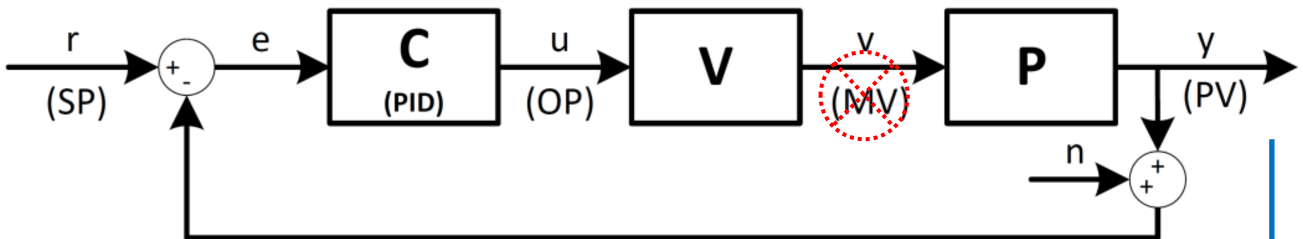
To assist operator

- **Plant status**
- **Actions to do**

Standard Diagnostics vs. Advanced Diagnostics

Standard Diagnostics

- ➢ For old industrial plants (*e.g., petrochemical*)
- ➢ Only 3 variables (measurements) available:
- • Set Point (SP)
- • Controlled Variable (PV)
- • Controller Output (OP)
- ➢ Valve Position (**MV**) is **not** available
- ➢ Signals transmitted in 4-20 mA current



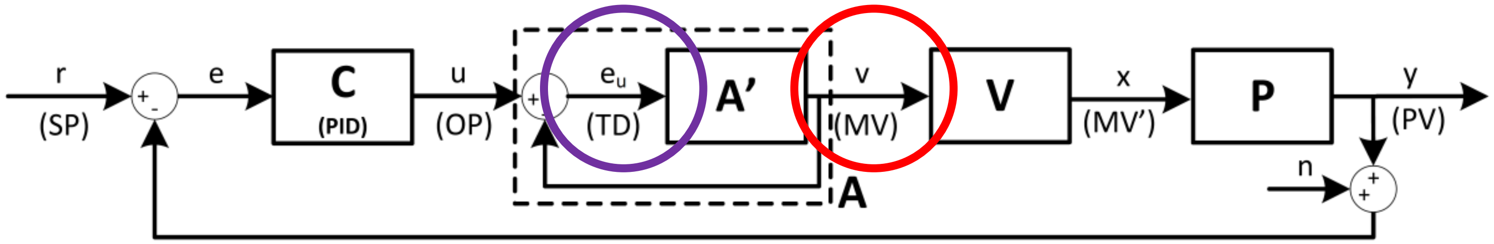
PCU Developed

@ CPC Lab Uni-PI

Advanced Diagnostics

- ➢ In new-design plants (*e.g., power*)
- ➢ Use of intelligent instrumentation and smart valves
- ➢ Adoption of field bus communication
- ➢ Additional variables to acquire and analyze:

→ **MV** (Valve Position), **TD** (position error)



➢ MV allows better diagnosis of loop and valve problems:

- **stiction** (static-friction) - most common cause of degradation
- related problems: *dead band, hysteresis, backslash*
- other faults for <u>pneumatic valves</u>:

changes in spring elasticity, membrane wear or rupture, leakage in the air supply system, I/P malfunction

Friction in control valves

STICTION (static-friction): one of the most common issue

Definition: blockage of valve stem due to (high) static friction between mechanical components

Effects: jerky movements (stick-slip) of the stem; persistent oscillations in loop variables

Lasting Research Activity …
Review Paper:
Bacci di Capaci & Scali, 2018

I. Stiction Modeling

Consolidated Research
Physical Models (first-principle)
Empirical Models (data-driven)

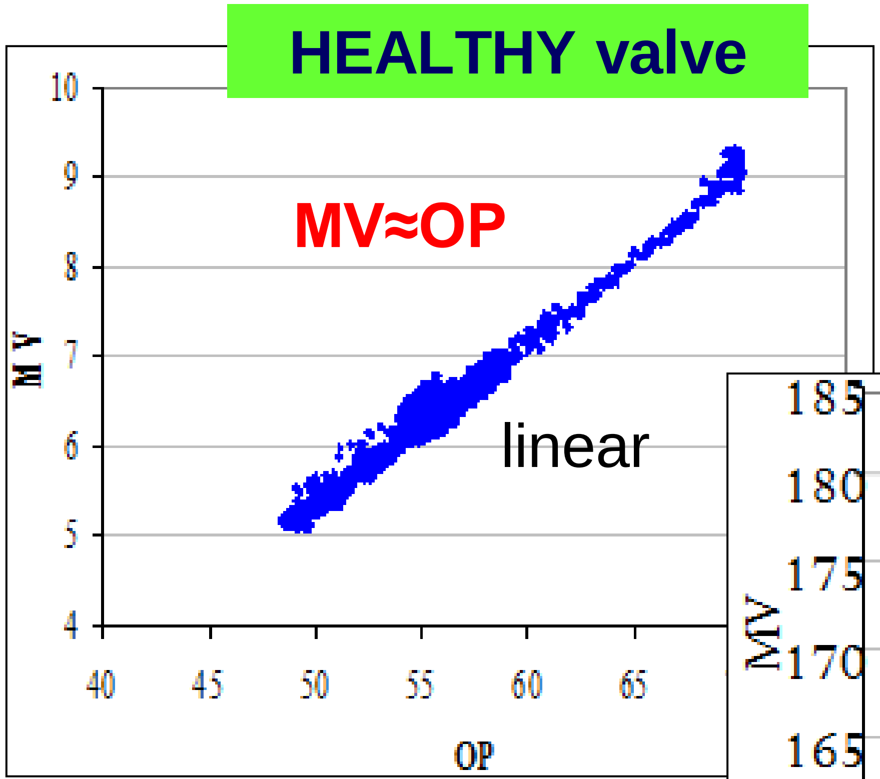
II. Stiction Detection

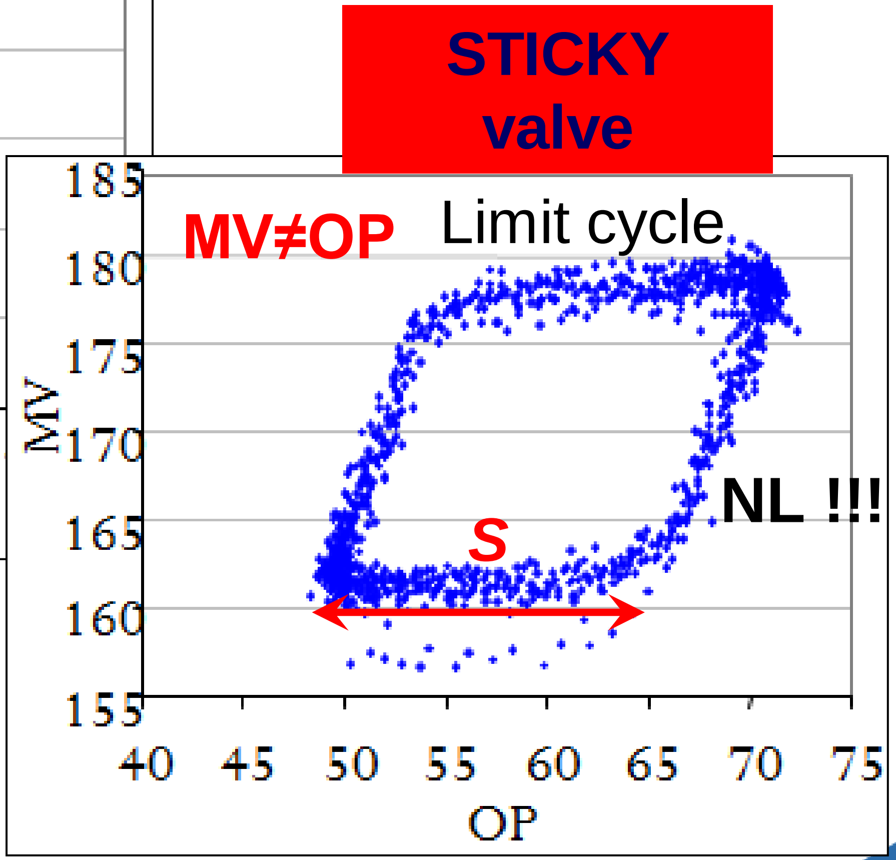
Consolidated Techniques to detect stiction from routine data

III. Stiction Quantification & IV. Compensation

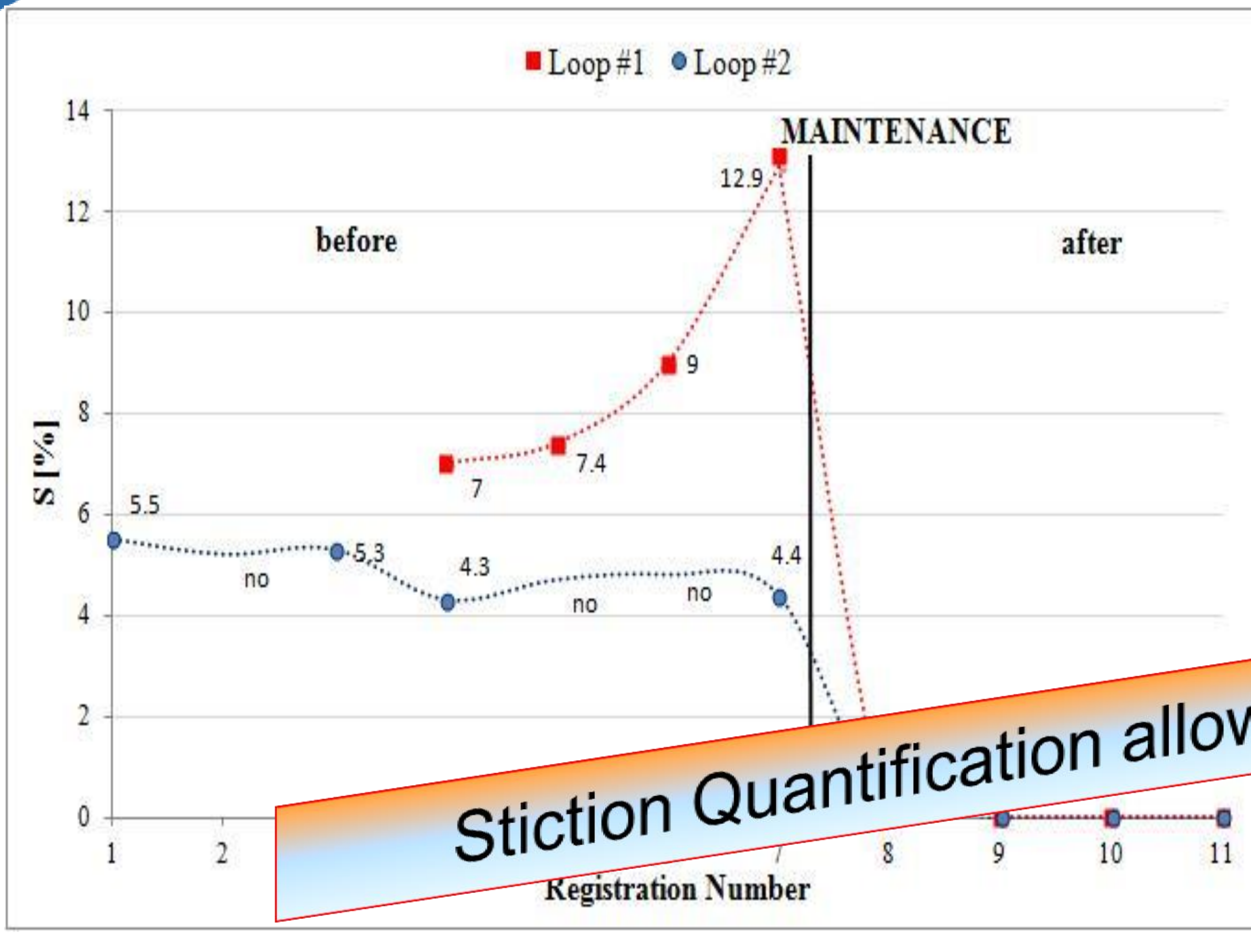
Techniques to estimate stiction amount (***S*** parameter) and then remove (reduce) induced oscillations

MV(OP) diagram
flow rate vs. valve input



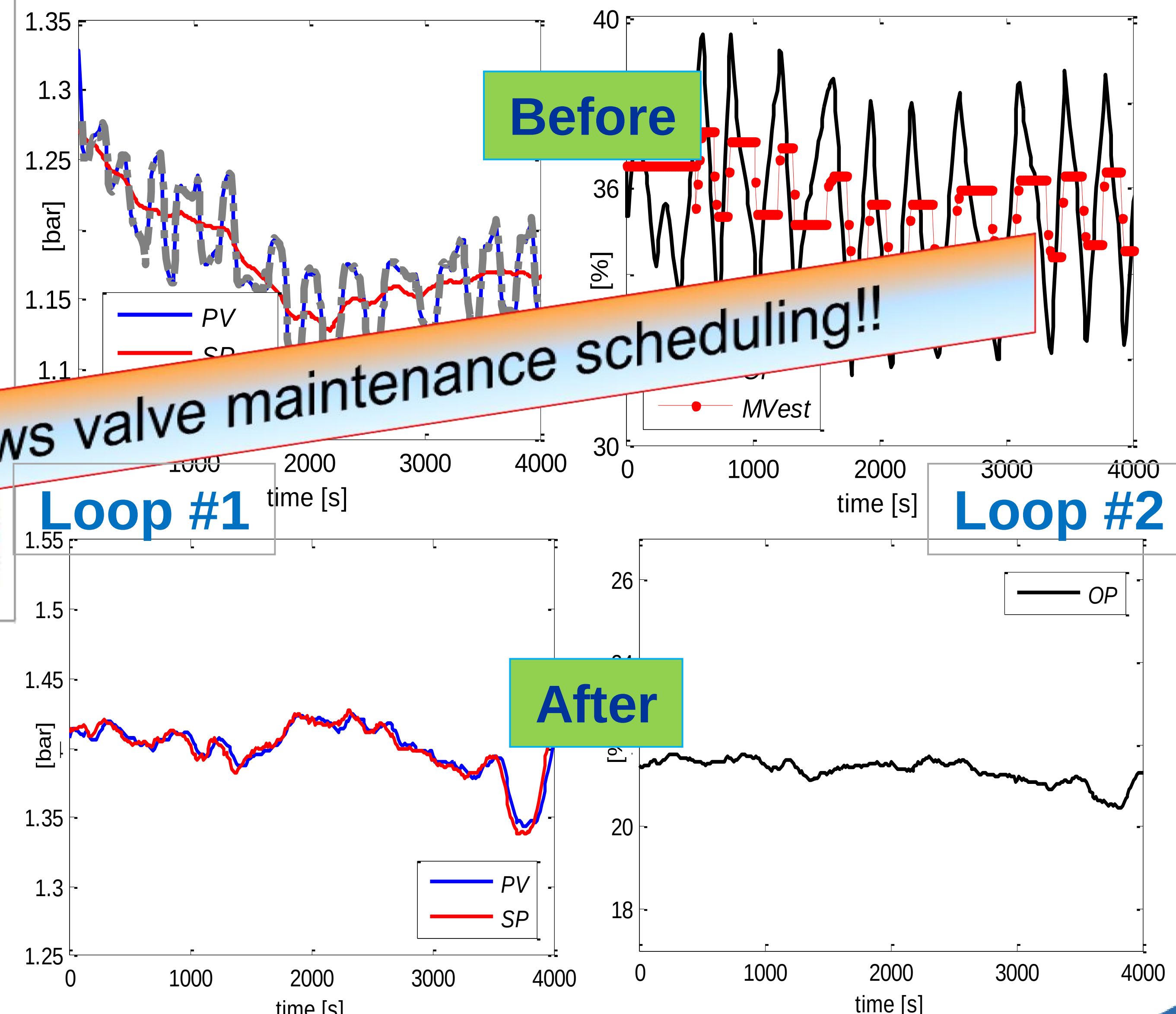


Stiction Quantification:
open issue & new feature implemented in PCU



Time evolution (*S* parameter):

2 loops: typical trends observed from process data



Stiction Quantification allows valve maintenance scheduling!!

Before maintenance:

Loop #1 → increasing trend of ***S***

Loop #2 → ~ constant values of ***S***

After:

Loop #1 & #2 → non significant oscillation and negligible stiction (*S≈0*)

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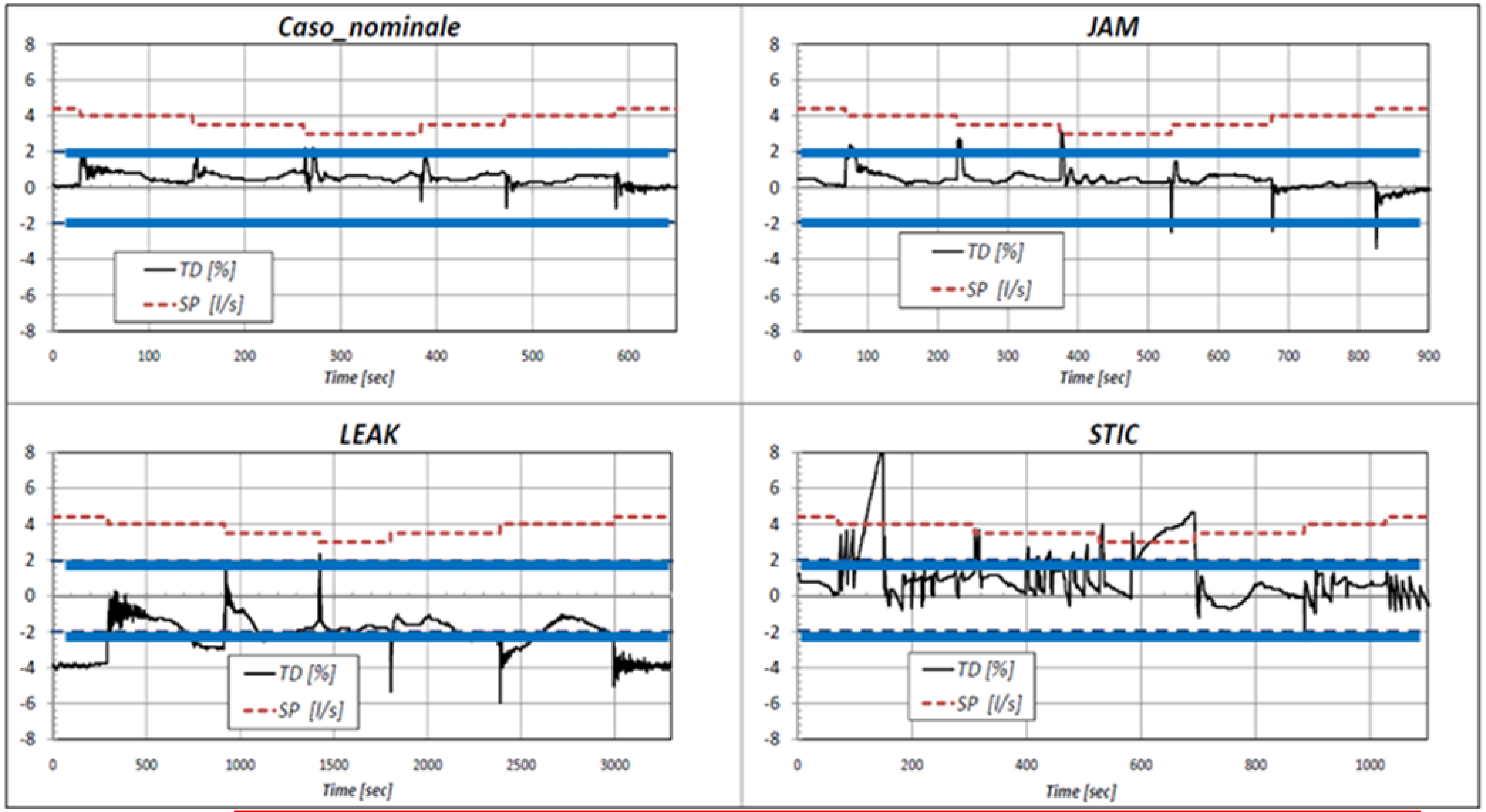
Development of the new PCU⁺ logics

TD = MV - OP is the key variable: __ ←→ **MV!!!**

- Modest amplitude (oscillations and peaks) in the nominal case (do not exceed 2%)
- Larger deviations and shapes in the presence of various anomalies



Definition of 6 indexes for valve evaluation

PCU^{+} : Thresholds and Actuator Status

Index	I_i,$_{low}$	I_i,$_{high}$
I_1	3	6
I_2	5	10
I_3	±0,7	±1,5
I_4	±2100	±3000
I_5	3000	5000
I_6	10	20

Proposed thresholds for actuator **diagnosis**
Choice not unique, depending also on user (field calibration)

Proposed Indexes Values and Actuator Status

Status Evaluation	Conditions	
GOOD	All indexes under low threshold	
ALE[illegible]	[illegible] ...old [illegible] ...x exceeds high threshold	*i : I_i > I_i,low* & *I_i < I_i,high , i=1,…,6*
BAD	At least one index above high threshold	*i : I_i > I_i,high*

Status (Good – Alert – Alarm) depends on THRESHOLDS
→ Calibration on Plant Data

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PCU+ & competitors (13) ..

Table 13: Synthesis of Performance Assessment Software.

Software	Organization	Features of Stiction Analysis				
		Modeling	Detection	Quantification	Compensation	Smart Diagnosis
Control Performance Assessment [176]	Petroleum University of Technology, Iran	✗	✓	✗	✗	✗
Plant Check–Up (PCU) [112, 174, 175]	University of Pisa, Italy	✓	✓	✓	✗	✓
Process Assessment Technologies and Solutions (PATS) [177]	University of Alberta, Canada	✓	✓	✓	✓	✗
Aspen Watch Performance Monitor [178]	AspenTech	✗	✓	✗	✗	✗
Asset Condition & Performance Monitoring [179]	Flowserve	✗	✓	✗	✗	✗
ControlMonitor [180]	Control Arts, Inc.	✗	✓	✗	[illegible]	[illegible]
Control Performance Monitor CX (ex Process Doctor & Loop Scout) [181]	Honeywell	✗	✗	[illegible]	[illegible]	[illegible]
ControlWizard & TuneWizard [182]	PAS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EnTech Toolkit & DeltaV InSight [183]	Emerso[illegible] Manage[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	✗
INTUNE+ [184]	Contro[illegible]	[illegible]	[illegible]	✓	✗	✗
Loop Performance Manager (LPM) [185] [186] [187]	ABB	✗	✓	✗	✗	✗
Loop Tuning - TuneVP [188]	Yokogawa	✗	✗	✗	✗	✗
Plantstreamer Portal - Multiverse [189]	Ciengis	✗	✓	✓	✗	✗
Plant Triage [190]	Metso (Expertune)	✗	✓	✓	✗	✗

Symbols: "✗", no; "✓", YES

Last Year → Review Paper:
only PCU+ includes Smart Diagnosis
In some cases: embedded / distributed

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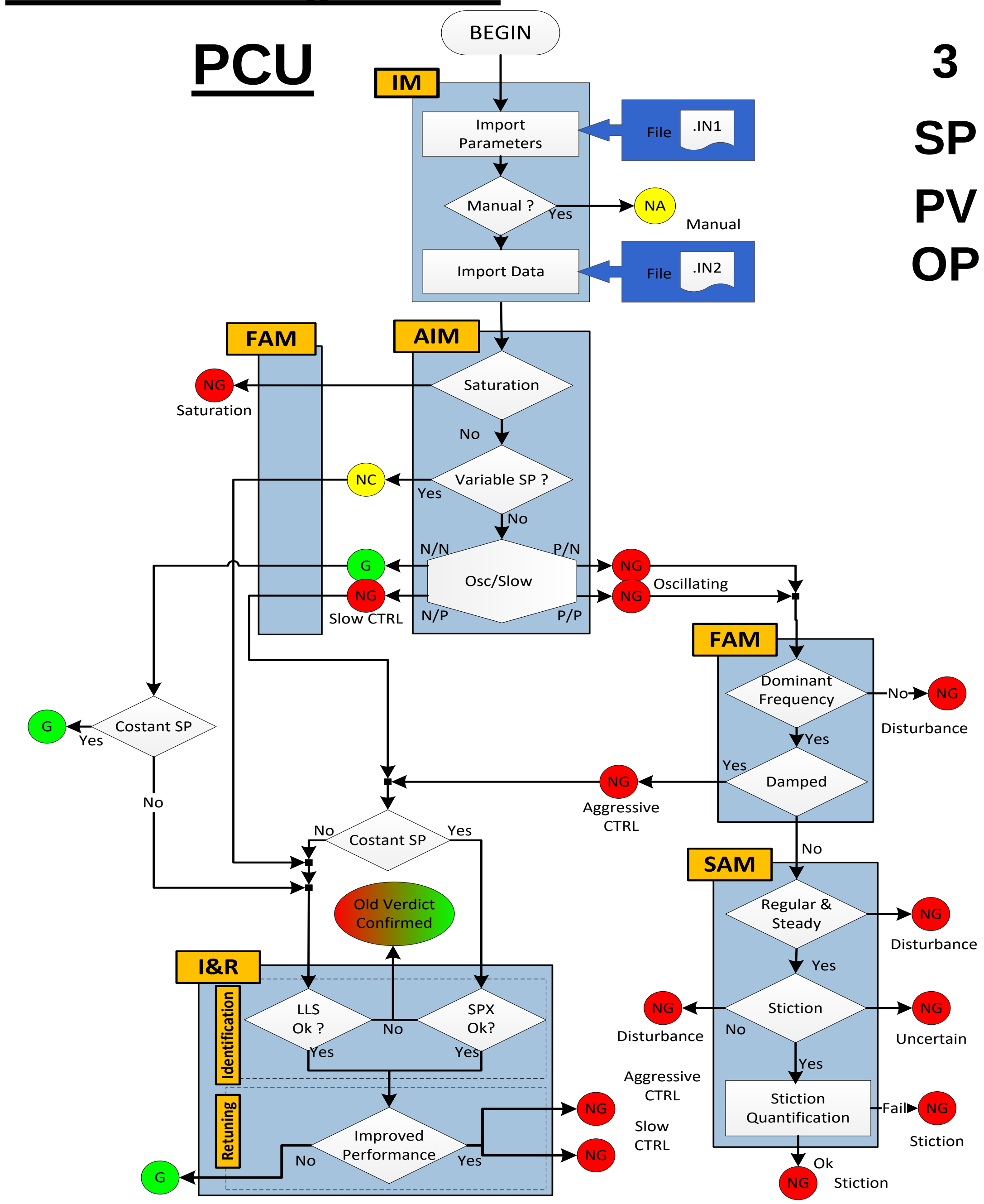
PCU systems structure (implemented in ENI, ENEL, CLUI AS …)

Standard Diagnostics

PCU



3	N° variables	4
SP		SP
PV		PV
OP		OP
		MV (TD)

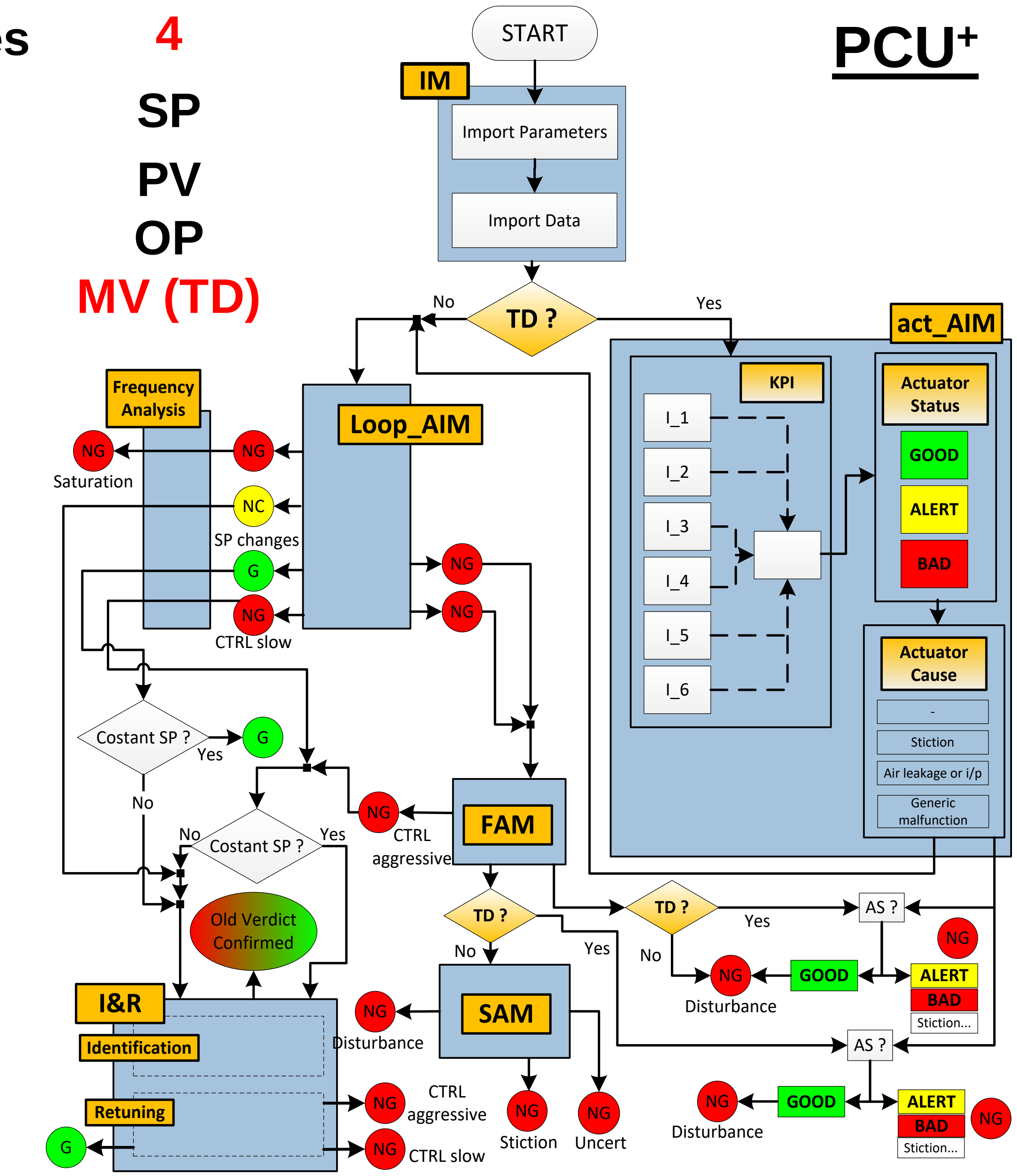
PCU Developed @

CPC Lab

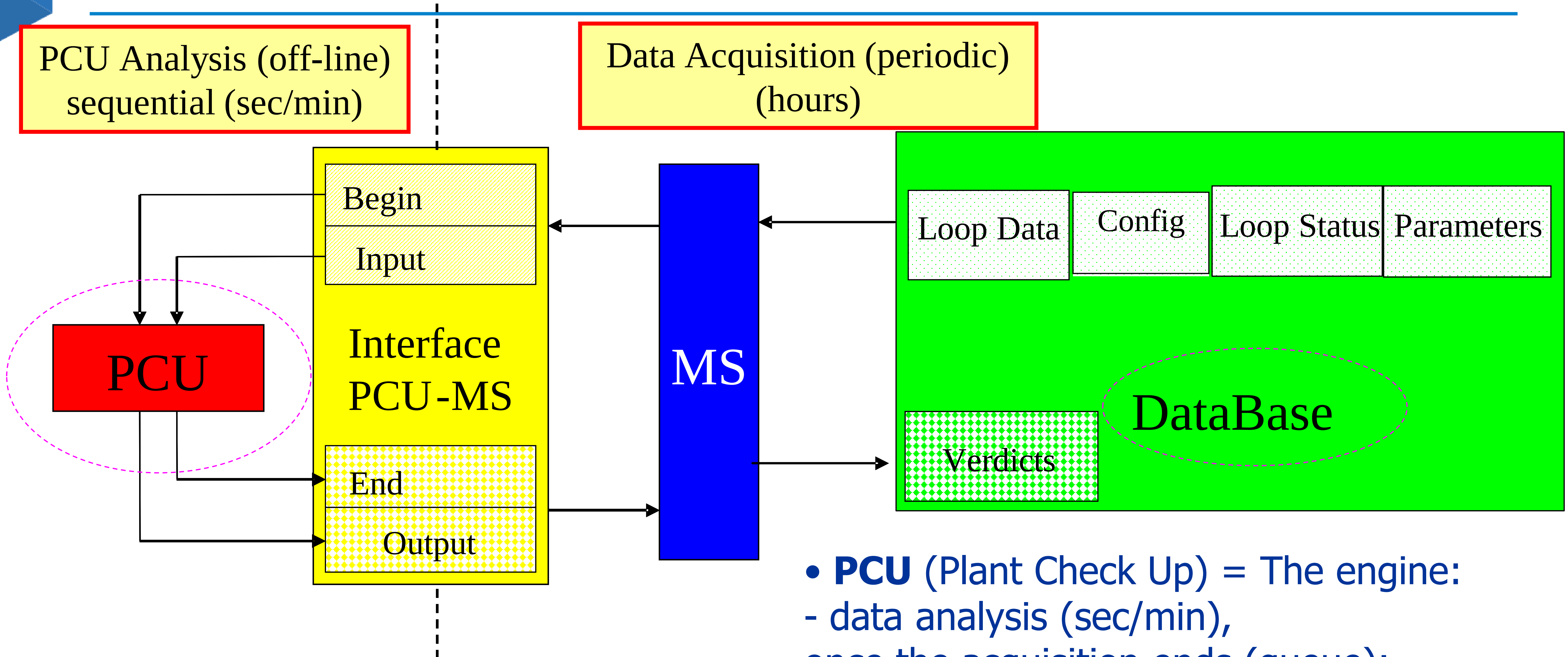
Uni-PI

Advanced Diagnostics

PCU+



Global System Architecture



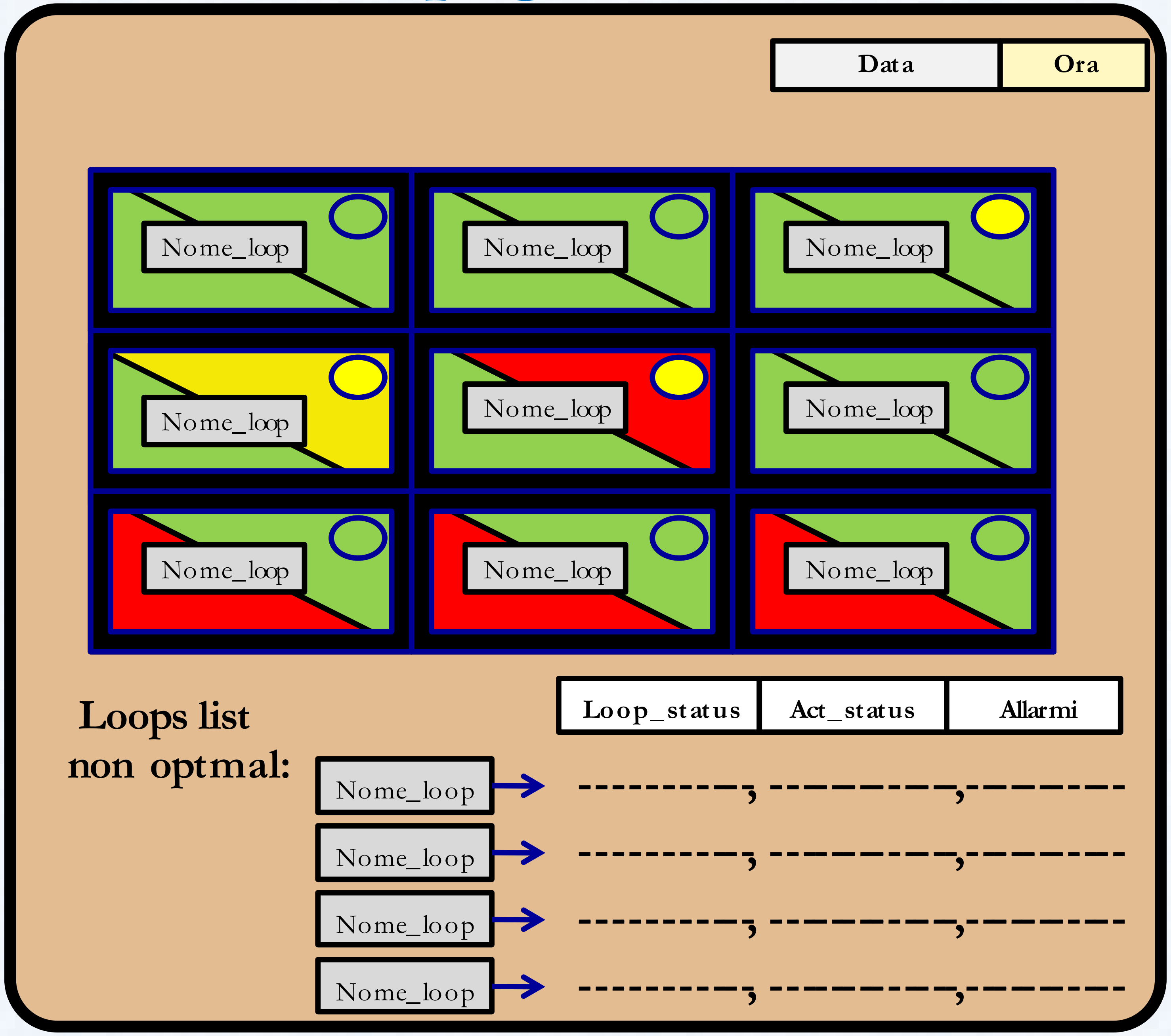
• **PCU** (Plant Check Up) = The engine:
- data analysis (sec/min),
once the acquisition ends (queue);
- performance assessment (verdicts)..

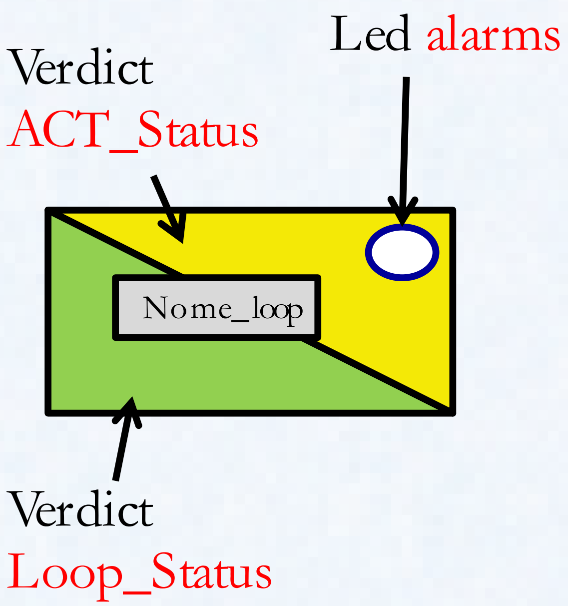
•**DB** (DataBase) = All Info
- loops data & parameters and,
after PCU analysis, also verdicts.. → Visualization & Reporting **(User)**

Begin: User ≡ End: User

PCU⁺ : Alarms, Viewer e & Verdicts

Main initial page





- ❑ Actual status with three levels: **Good – Alert – Bad**
- ❑ Alarms: in real time
- ❑ Verdict: after peridical analysis
- ❑ **Click** Nome_loop

→ **Hystory**

→ **Details & Trends**

Hints for a successful application

<u>Features to be included:</u>

- Completely unattended operation (continuous / **periodic** acquisitions)
- **Automatic** Emissions of final reports about plant status
- **Avoid False Alarm**
- **Off-line Re-Analysis** of historical data
- **Easy** implementation of changes

KEY ROLE of OPERATORS

The global **Performance Monitoring System** which includes **PCU** as tool for detection and assessment of malfunctioning causes (**valves** included):

- Developed in close contact with control room and software operators,
- **Periodic campaigns of parameter calibration**
- **Ex-post evaluation and check of results**
- Assistance and maintenance (new releases of PCU)

Treshold calibration: PCU vs Operators verdicts

About 1200 loops supervised…
- "too many" NG (Not Good) verdicts issued by PCU (most caused by valves)
- "felt" by the operator as False Alarms

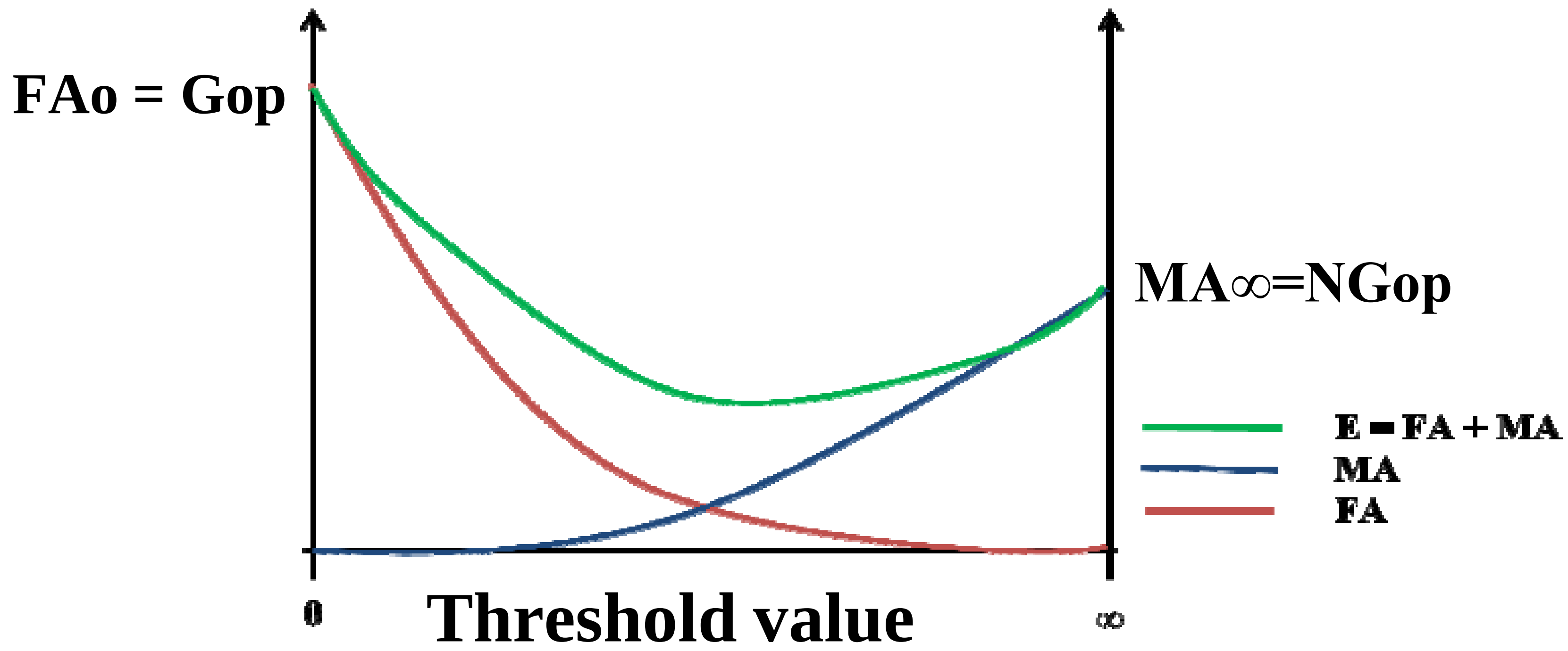
NOTE: In the initial stage of the project calibration runs were carried out with agreement on threshold values

Loop type	PCU NG loops	Operators NG loops	Operators G loops
FC	48	18	30
PC	42	11	31
LC	26	3	23
TC	49	15	34

Note:
- **All loops reported at least 2 consecutive NG verdicts**
- **Operator indications for FC,PC,TC : Good/Total = 60-70%; (for LC: 88%)**
- **All these loops appear as oscillating (almost no mismatch for Slow loops)**

The action:
Filtering NG verdicts to decrease the number of False Alarm

This will happen at the expenses of increasing the number of Missing Alarm (MA): Total errors E = FA + MA



Ideal situation…
NO errors in a range of the threshold value

Actions:
- Define new performance indices
- Act on the threshold value

Increasing threshold (of any performance index)
- The number of FAs decreases from Gop to zero
- The number of MAs increases from zero to NGop
- Total number of errors E = MA + FA is to be minimize …

Detection of (significant) oscillations

In AIM(odule) of PCU:

PV oscillations are classified as anomalous, adopting the **Oscillation Detection Technique** (Hägglund'95).

<u>**ODT**: An oscillation is significant if:</u>

- IAE > IAE_{lim}
- For a certain number of times N > N_{min}
- In the assumed supervision time T_{sup}

$$IAE = \int_{t_{i-1}}^{t_i} |e(t)| \cdot dt \quad con \; |e(t)| = SP - PV$$

$$IAE_{\lim} = \frac{2 \cdot a \cdot RangePV}{\omega^*} \qquad \omega^* = \omega_u, \ldots, \omega_I = \frac{2 \cdot \pi}{\tau_I}$$

- Reasonable criterion (IAE based), to focus on oscillation in the low-medium range
- Several parameters have subjective/unknown values: IAE_{lim}, N_{min}, T_{sup}, a (default values suggested)
- Other criteria (Thornhill&Hägglund'97, Thornhill et al. '03) …

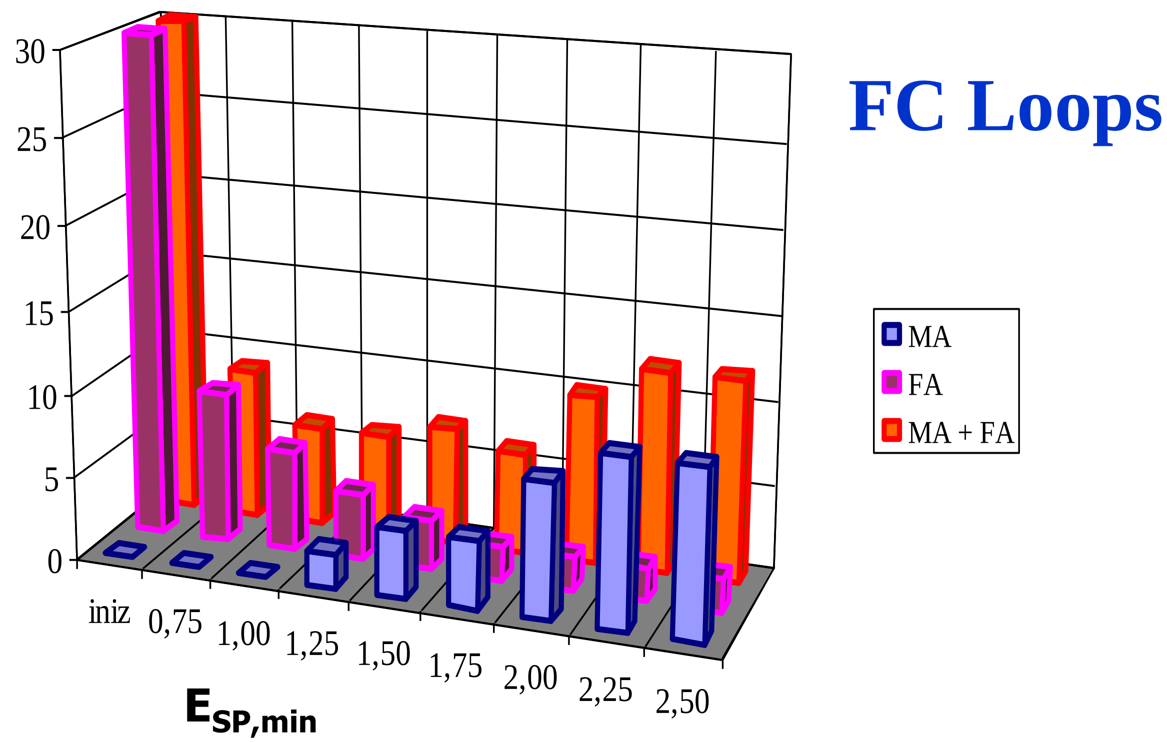
→ room for proposing new criteria / parameters / thresholds

<u>New metrics proposed:</u> Amplitude of oscillation compared with SP and PV range

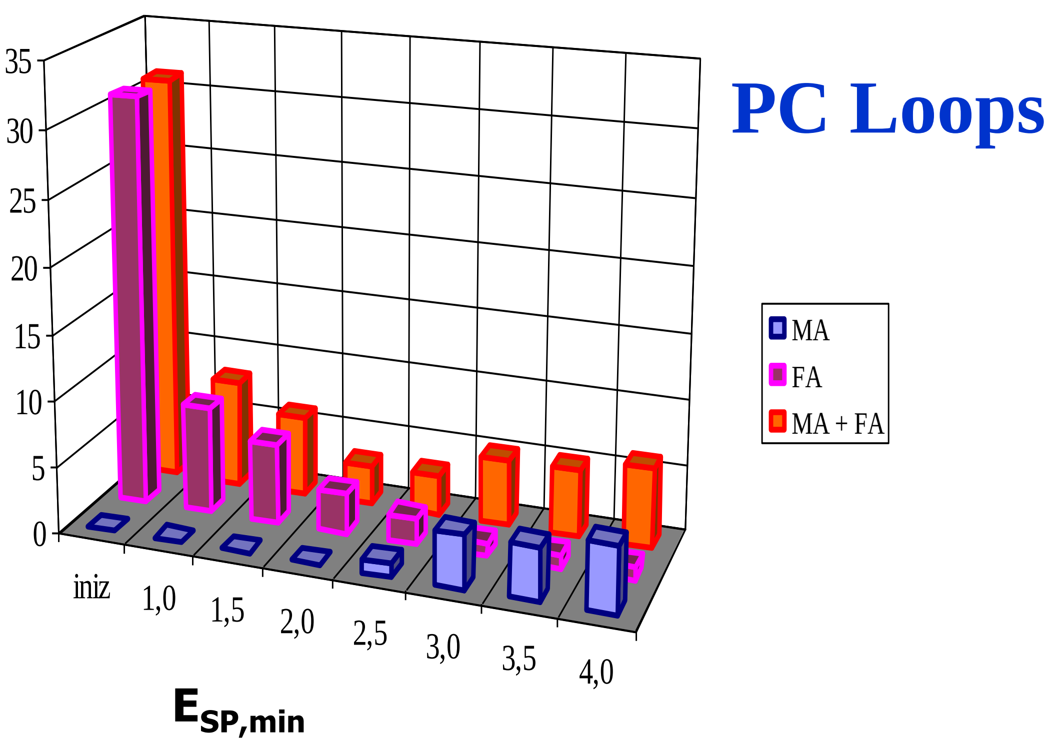
$$E_{SP} = \frac{1}{N} \cdot \sum_{1}^{N} \frac{|SP_i - PV_i|}{SP_i} \cdot 100 > E_{SP,\lim} \qquad E_{PV} = \frac{1}{N} \cdot \sum_{1}^{N} \frac{|SP_i - PV_i|}{rangePV} \cdot 100 > E_{PV,\lim}$$

… «Operators like more»

Results for E_{SP} Index (FC & PC loops)



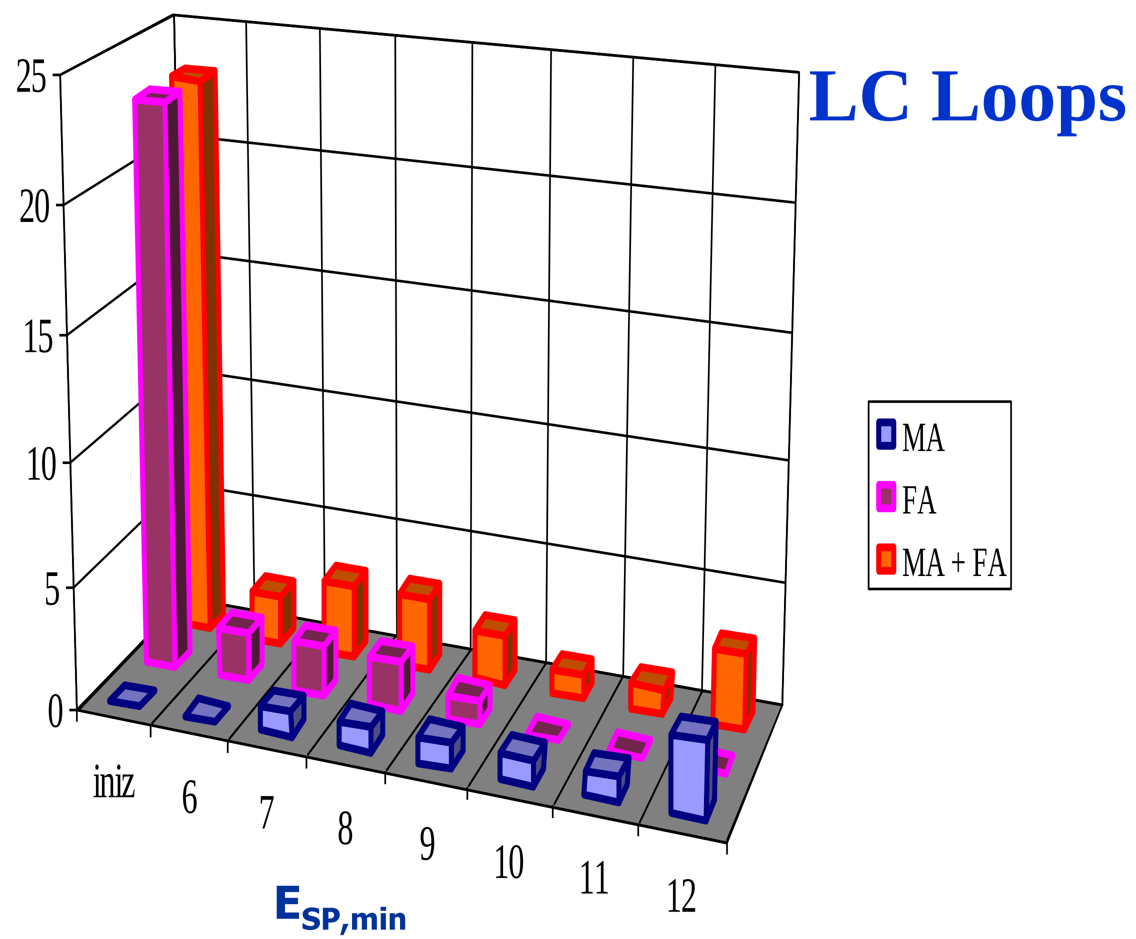
E_{SP} Errors
- Initial : 30 FA
- Final ($E_{SP,min}$= 1.0 ÷ 1.75): **6 (FA+MA)**

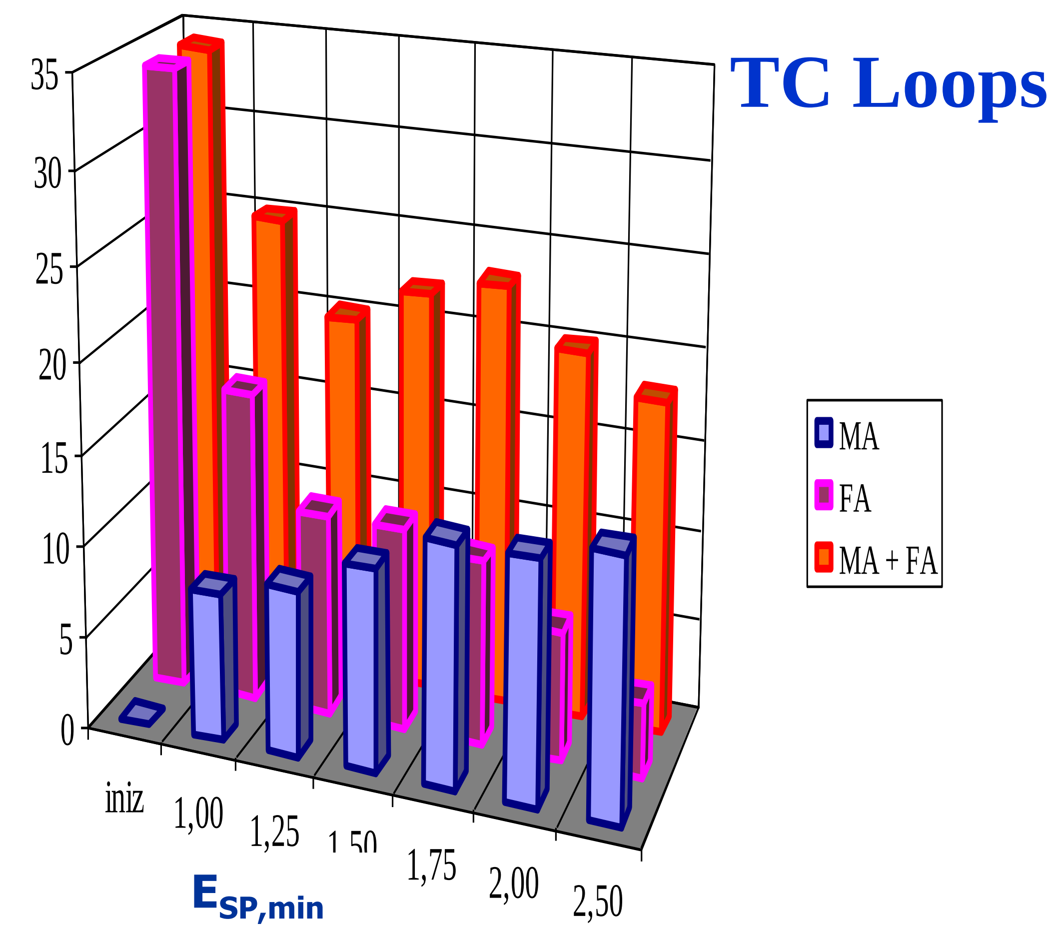


E_{SP} Errors:
- Initial : 31 FA
- Final ($E_{SP,min}$ = 2.0÷2.5): **3 (FA+MA)**

- Significant improvements in matching operator «expected» verdicts
- Relative numbers change with the adopted value of $E_{SP,min}$
- Similar behavior for the E_{PV} based index

Results for E_{SP} Index (LC & TC loops)





E_{SP} Errors:

- Increasing threshold, FA decrease with very few MA (23/26 considered Good)
- Low priority assigned to LC loops

→ LC: Easy Task..!

E_{SP} Errors:

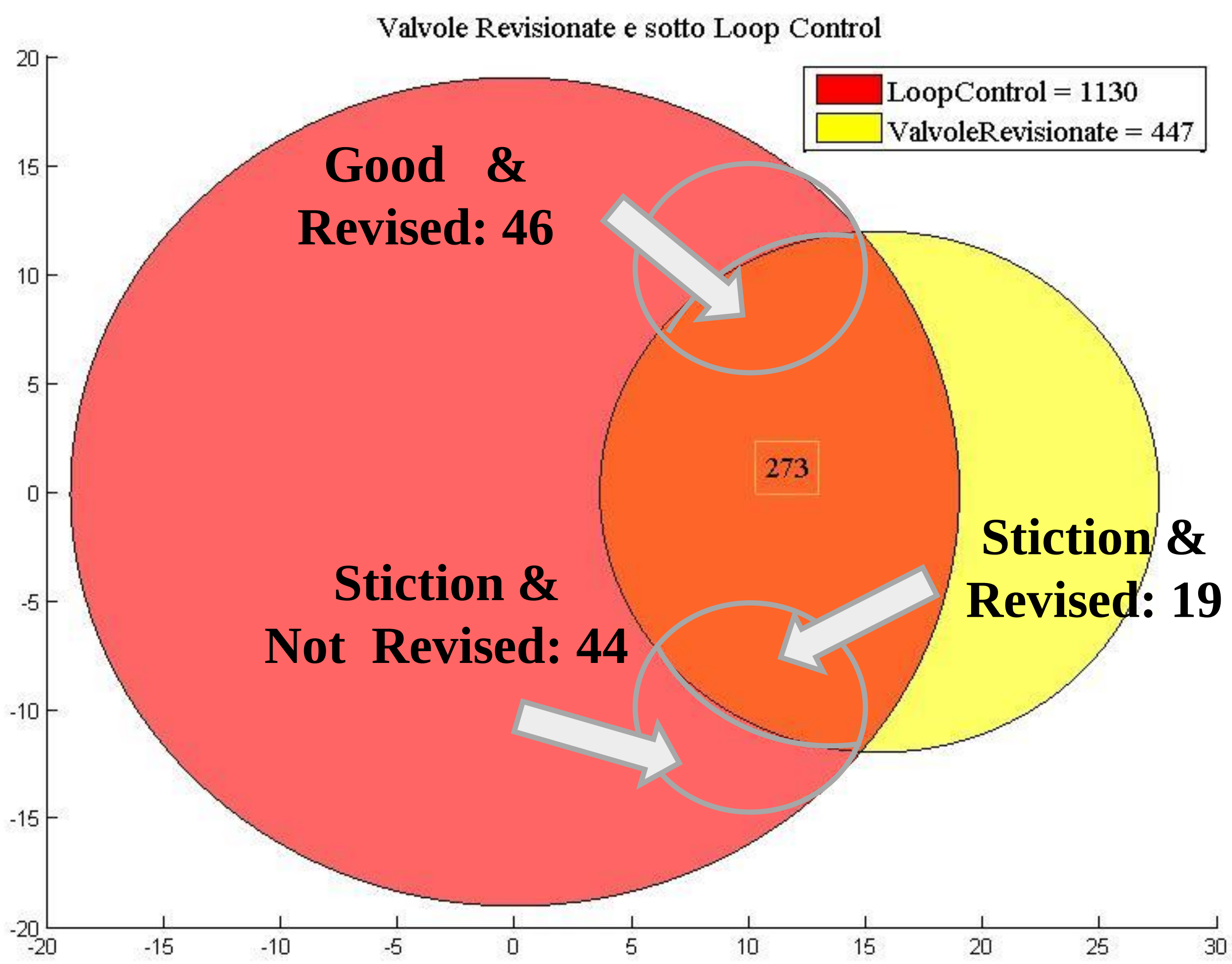
- Increasing threshold, no regular FA trend
- TC loops: more complex situation..

→TC: more work required

Benefits Evaluation in Valve Maintenance Scheduling

Previous criteria: instrumentation engineers notice and/or periodic maintenance

Partial refinery **shutdown**: revision of 447 valves; 1130 supervised by **Loop Control / PCU**



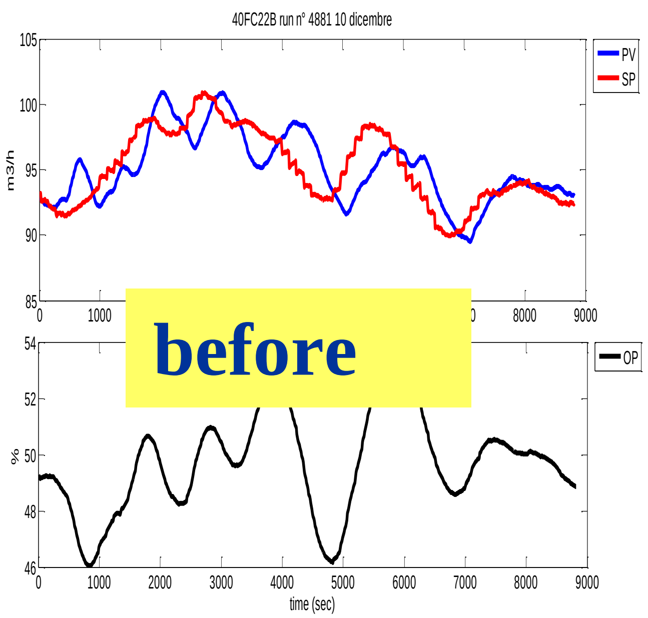
1) Not all revised valves have been indicated by Loop Control as affected by stiction:
46 Good & Revised

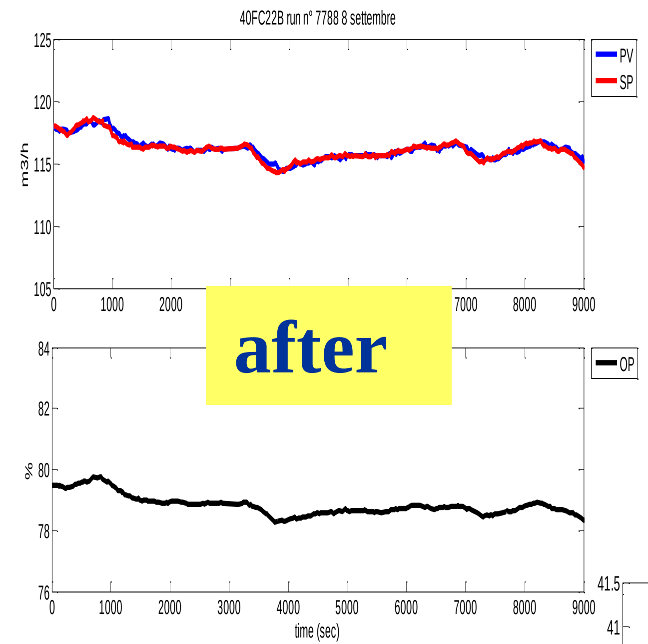
2) Some, indicated as affected by stiction have not been revised:
44 Sticky & Not Revised

3) Finally, some indicated as affected by stiction have been revised:
19 Sticky & Revised

Valve Maintenance benefits

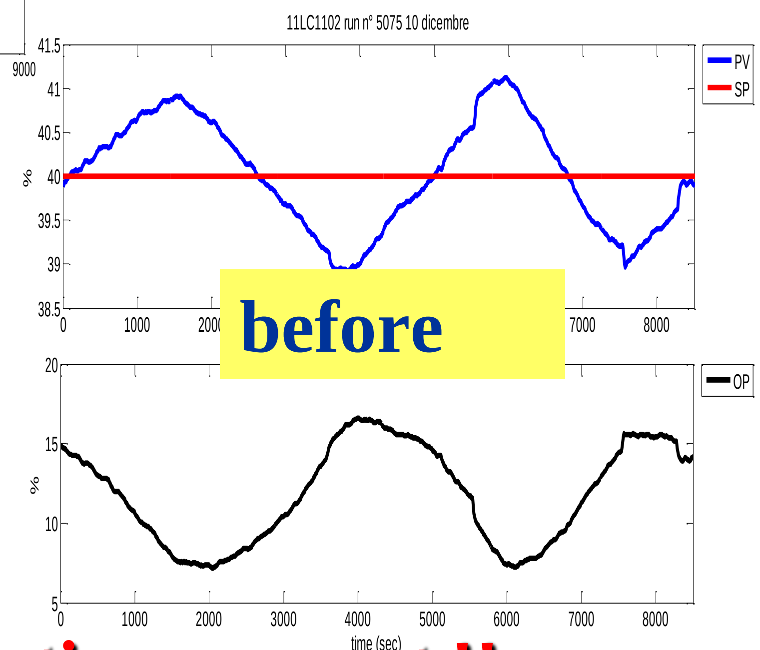
Valves indicated by Loop Control with Stiction & Revised (19):

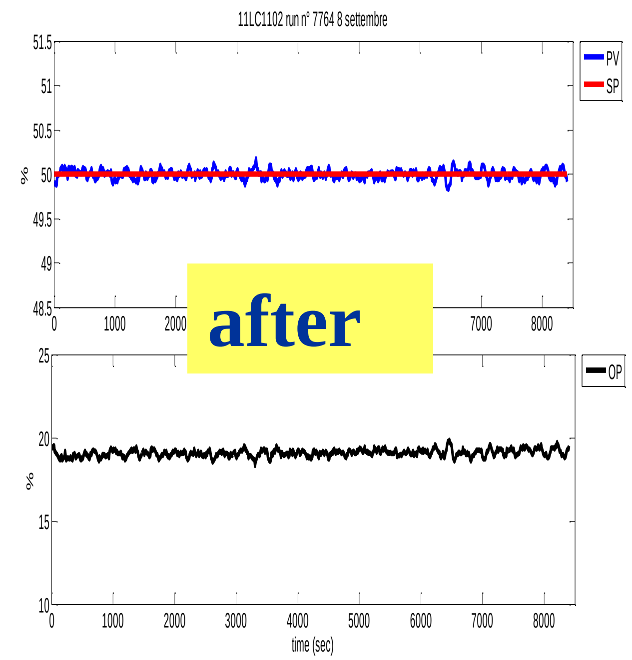




Ex#1: xxFCyyy
(Topping heater):
After maintenance:
Stiction disappears

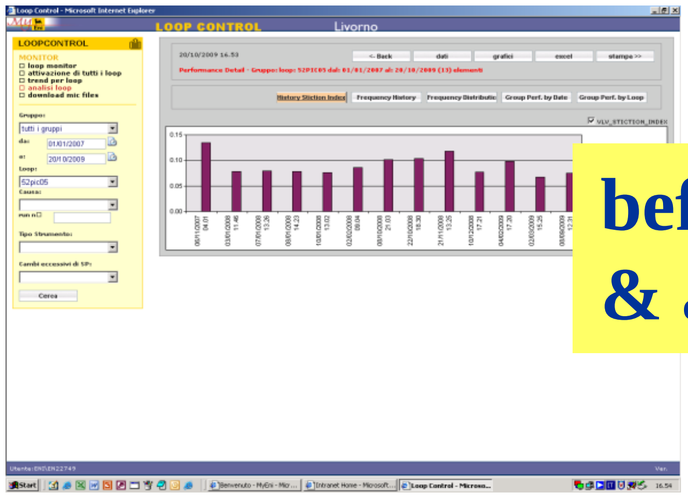
Ex#2: xxLCyyy
(Wax Vacuum Level)
After maintenance:
Stiction disappears

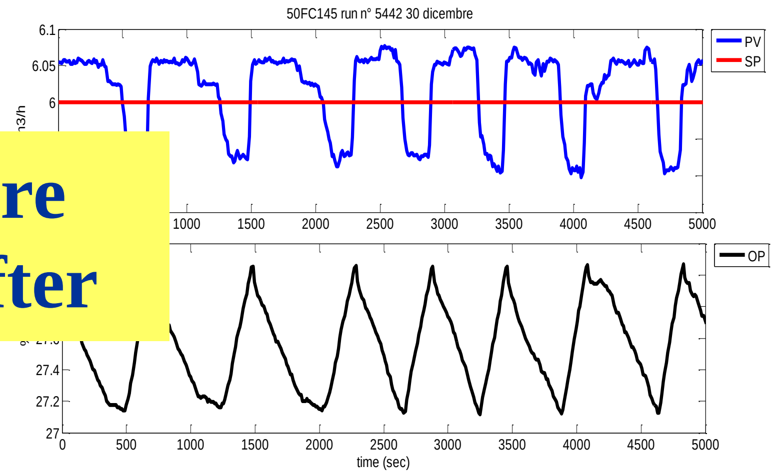




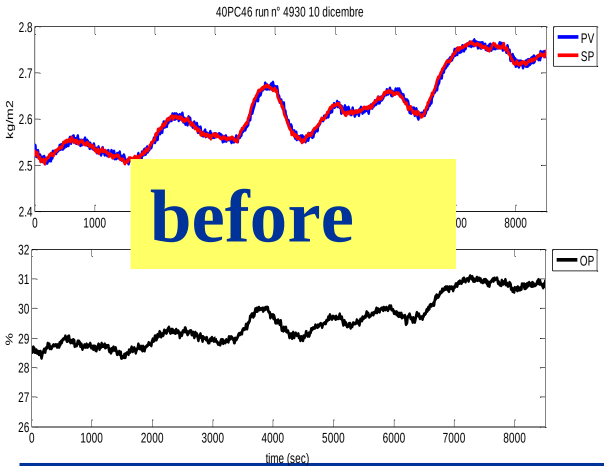
General results: Stiction indications correct !!

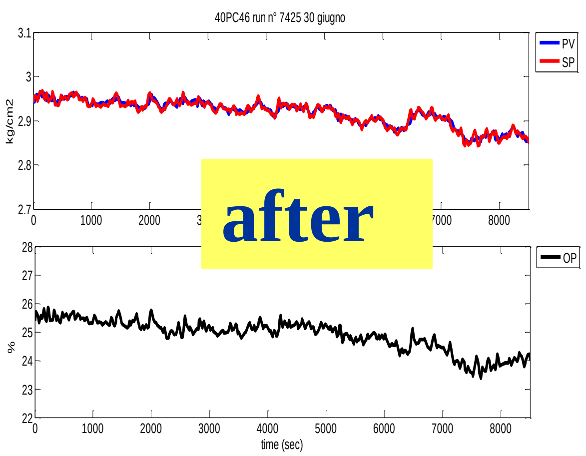
Valve Maintenance benefits





Sticky & Not Revised: 44
Ex: xxFCzzz(HD3):
Loop with evident stiction (large SI)
Maintenance was necessary !





Good & Revised: 46
Ex: xxPCzz (Topping):
Maintenance Not necessary!

Few examples shown, but in <u>most</u> cases Loop Control indications were respected…

Adopting Loop Control for valve maintenance scheduling would allow to **save money** (unnecessary revisions) & to **improve performance** (necessary revisions)

→ Loop Control now adopted …

Conclusions

Key Parameters Calibration:

- Favorable acceptance by control operators is crucial for the success of a CLPM implementation
- Necessary to re-discuss and customize some key parameters (criteria and thresholds) to discriminate between Good and Not Good loops.

→Very positive results for FC and PC loops;

→TC require more efforts to completely solve the problem.

Valve Maintenance Scheduling: Benefits of improved performance not easy to quantify..

- Much easier to quantify savings from unnecessary revisions

→ The system (Loop Control) adopted for future maintenance scheduling.

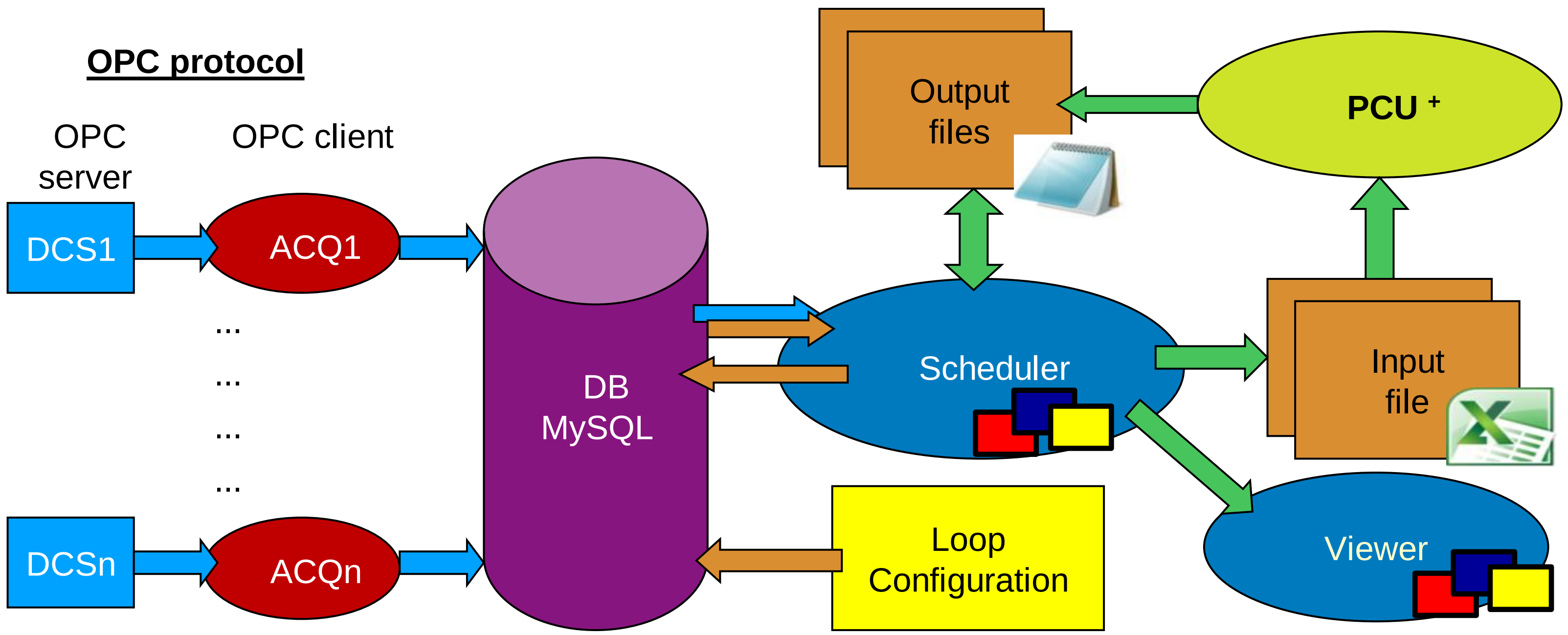
Advanced Diagnostics

Based upon additional variables made available by intelligent instrumentation (Valve Positioners and Field Bus communication)..

→ Application in Power Plants..

PCU$^+$: Tool online

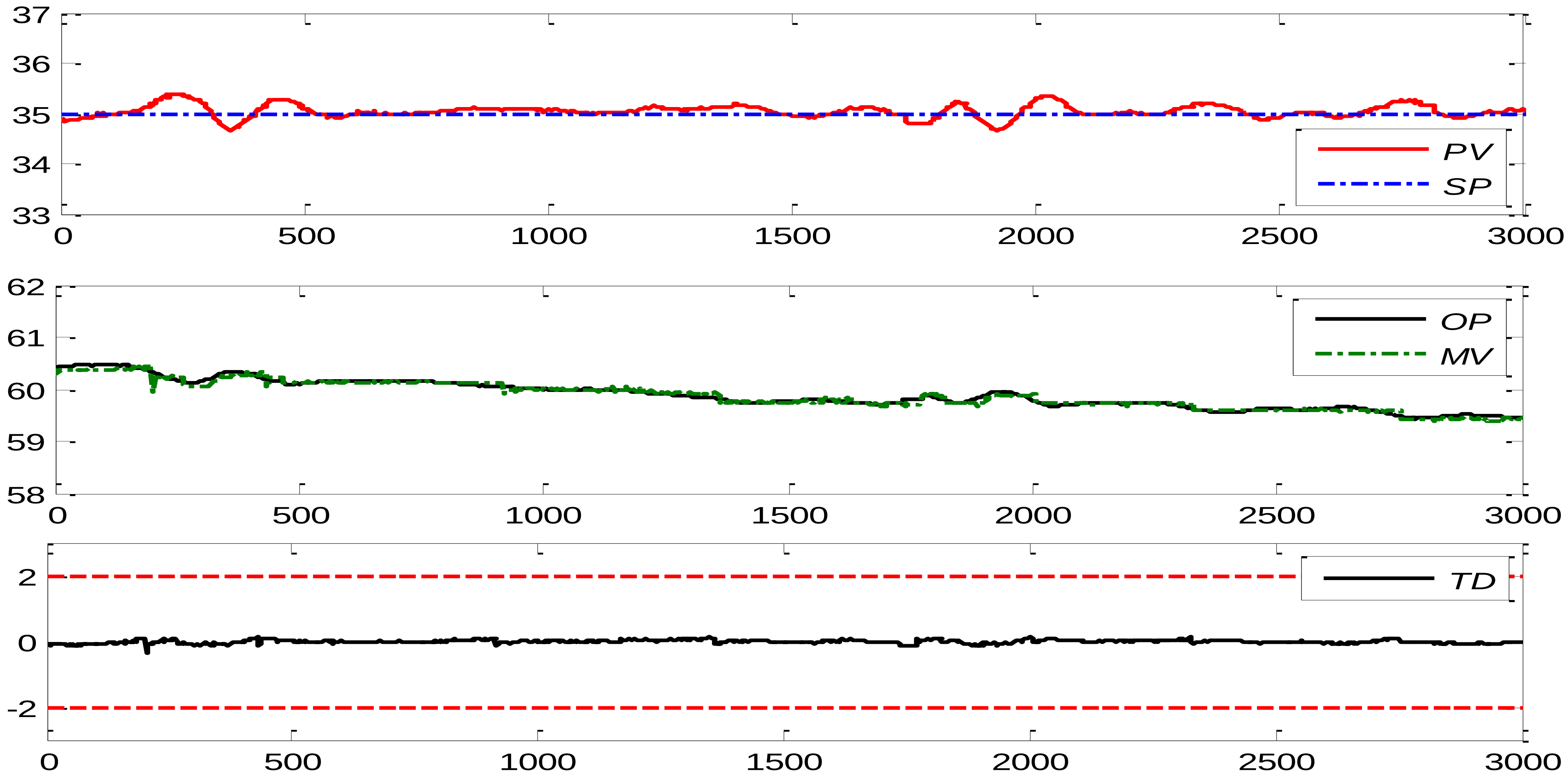
Framework, modules and logics



Viewer

Two examples follow (Power Plants)

Power Plant: pre heater - TC

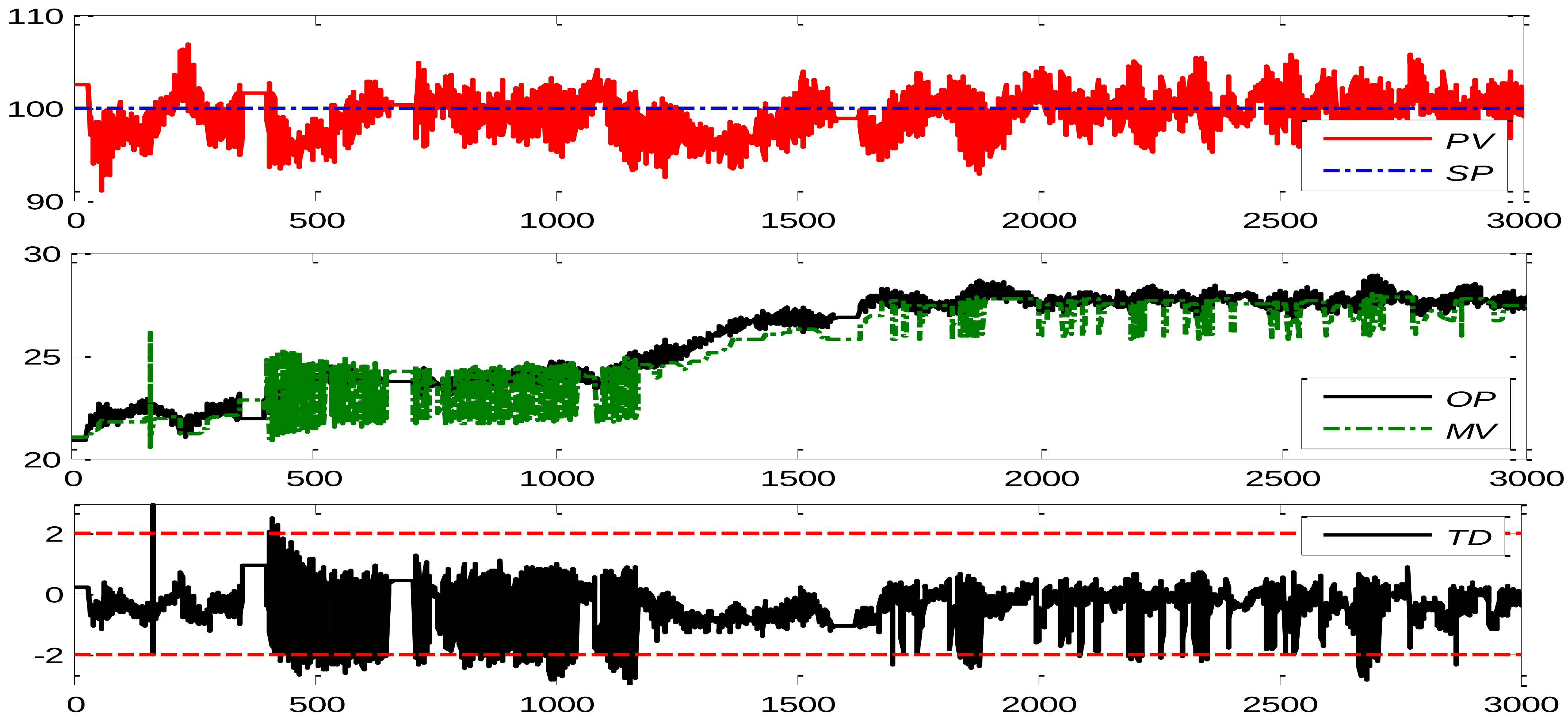


- MV very close to OP
- TD very small
- Indices I_1-I_6 smaller than Thresholds

→ Actuator Status: **Good**

Small oscillations in PV
→ Loop status: **Good**

Power Plant: Level Control



- MV presents many sticks and slips
- TD: large oscillations (larger than TD_{lim})
- Indices I_1-I_6 larger than Thresholds

→ Actuator Status: **Not Good** (**Stiction**)
Confirmed by plants operators !

large oscillations in PV
→ Loop status: **Not Good**

Feed-Back from users & incentives from Industry 4.0 benefits

1)Key Role of MAINTENANCE

Importance of: Total Cost of Ownership:
(IVS-17 (BG): Industrial Valve Summit: High Stress on TCO)

2) Reduction of Role and Numbers of Technicians (Removal!)

(Key role for: loop configuration, acquisition scheduling, parameter calibrations …)
Motivations: assigned resources are decreasing & competences are disappearing
Services Externalization.. Typical Scenarios in ENEL, ENI !!!!

3) Managing Automation & Verdicts Emission

Motivations: Requests are increasing, need for plant-wide assessments

4) Complete standardization of procedures for different plants:

- Data transfer to external archives
- Data processing and performance evaluation from outside

OSS: - Certainly feasible (technologically ...)
- Redundant? (not all data are needed ..)
- Skills outside the system ?? (Where to find them?)

5) Extending the assessment

- Not only control loops
- Economic performance index for other variables

OSS: very positive evolution

In any case, large space for:
- Cloud Computing
- Big Data Analysis
- Smart Sensors
- Communications Integration
- Augmented Reality
- Cyber Security ..

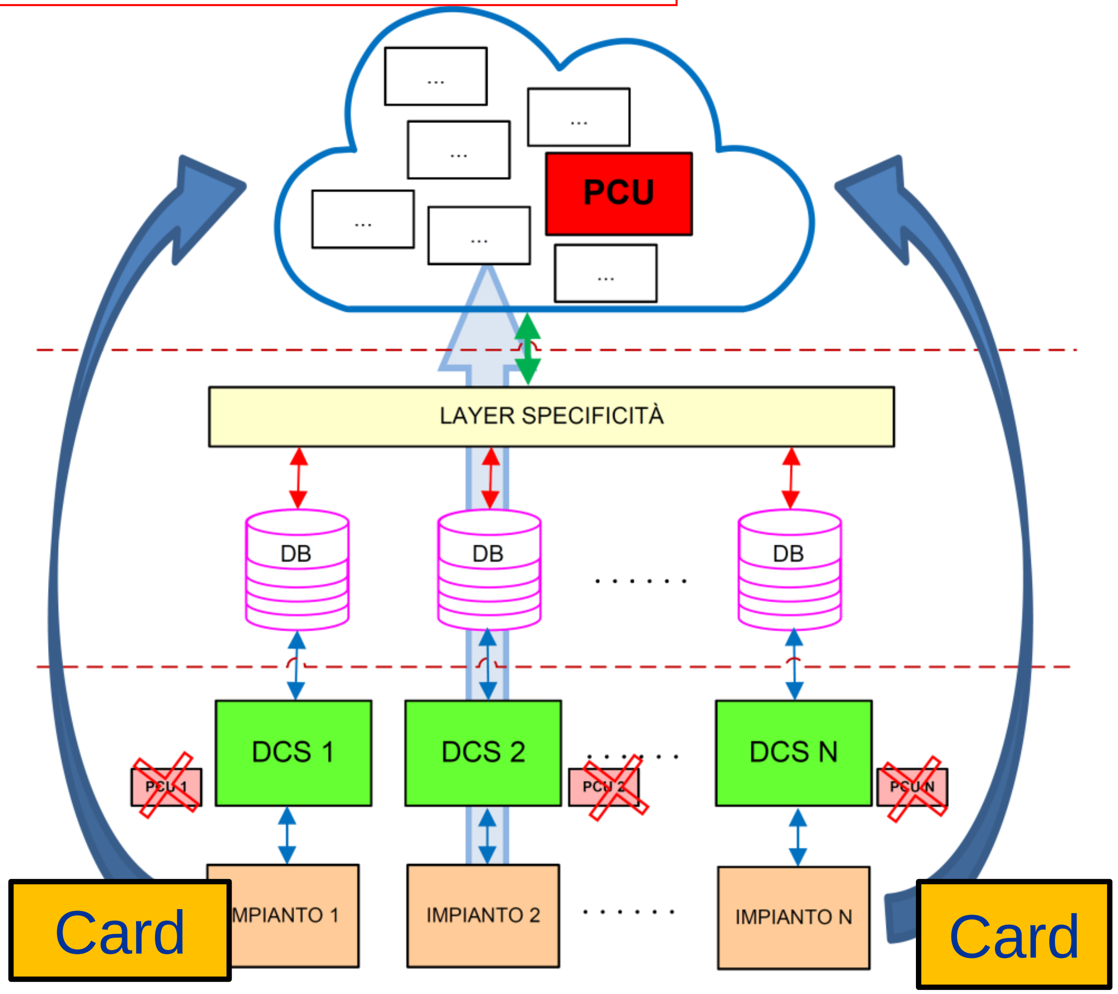
Idrolab 4.0 – Technological demo for Cloud Monitoring

Monitoring of:
- Control loops (tuning and **valve** diagnosis)
- Components diagnosis (Inverter, mechanical machines..)
- Global performance Indices (economy & environment & energy)
- Equipment status Indices (integrity, aging..)

Enormous Potential Advantages :
- Only one system ..
- Concentration of Competence
- Company resources saving

Challenges:
- Validity of available technologies to check
- Plant specificity to preserve
- Choice of measurements to transfer
- Cyber-security

Alternatives from Field to Cloud:
- “Classical” path via DCS & Database,
- “Direct” path, via Cloud oriented Card(s)



Idrolab Plant: yesterday

<u>CONFIGURATION</u>

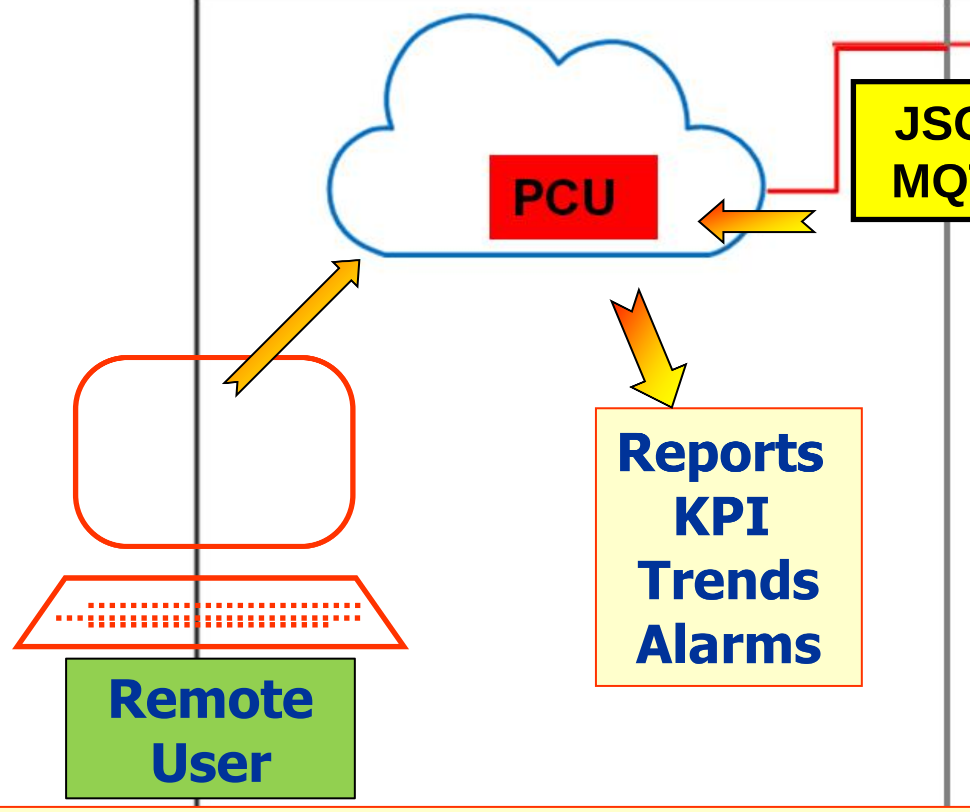
Operating @ **Polo Magona Cecina** (before @ ENEL – Livorno Research Area)

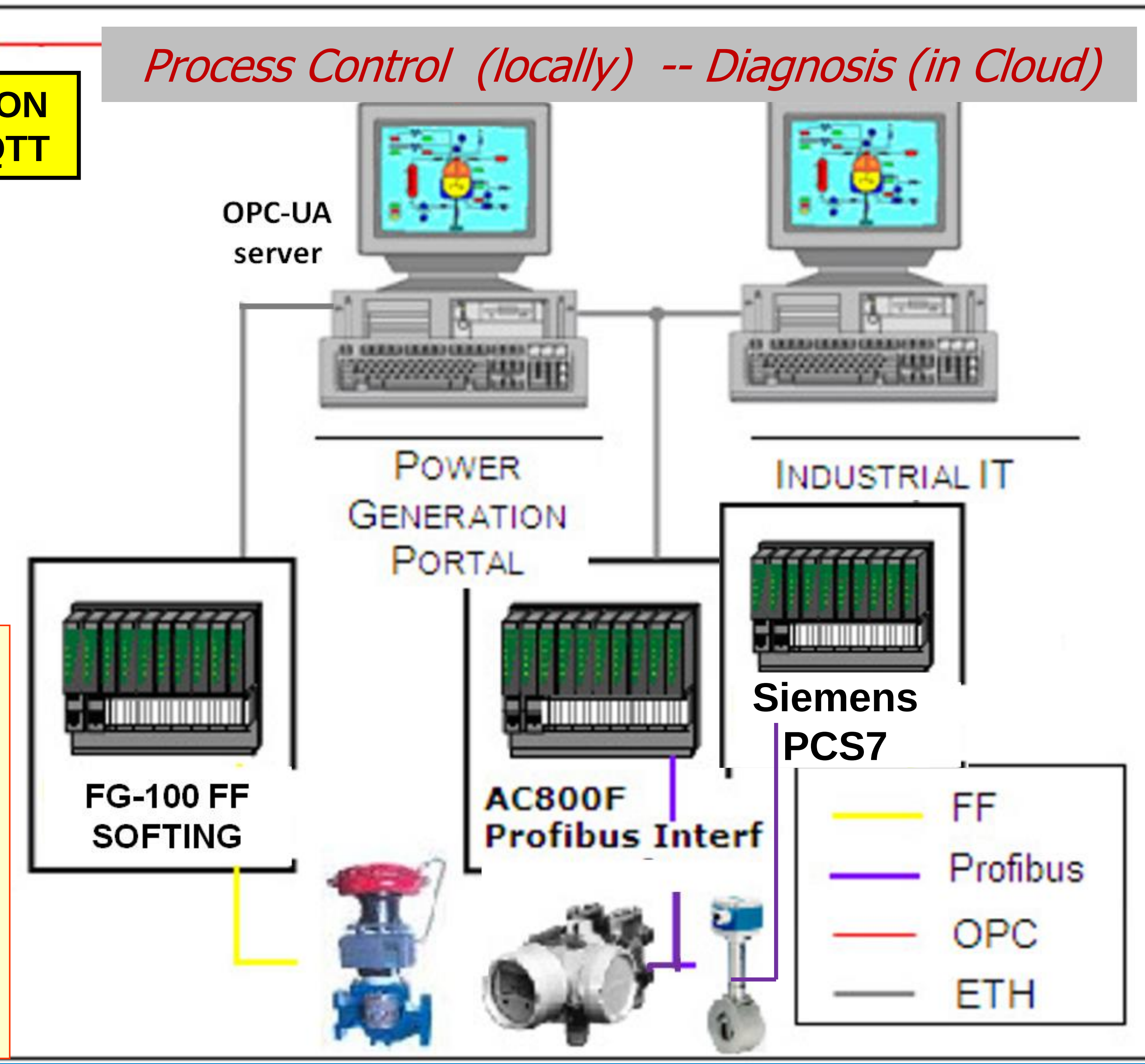
Double hydraulic circuit equipped with sensors to measure: *Pressure , Flowrate, Level, Temperature*

Also equipped with:

- **2 DCS** & related PLC: *Siemens – ABB*
- **Smart Instrumentation:** not only for control, but also info for diagnosis
- **Communication Systems via Field Bus** (Profibus, Field Foundation, Hart & Wireless Hart)
- Last generation actuators (pneumatic & electric): ABB - Auma – Biffi - Flowserve – Rotork
- Other modules: Torquemeter, Inverter, ecc..

Idrolab Plant: today-- tomorrow





Data transfer from field to cloud:
- 16 devices (sensors, valves,)
- Different protocols & brands
- By using different boards, conversion software

In cloud:
- Data Format conversion
- PCU scheduling and analysis
- Diagnosis and reports
- Archive data analysis (≠ thresholds)

Thank you!

Do you have questions?

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