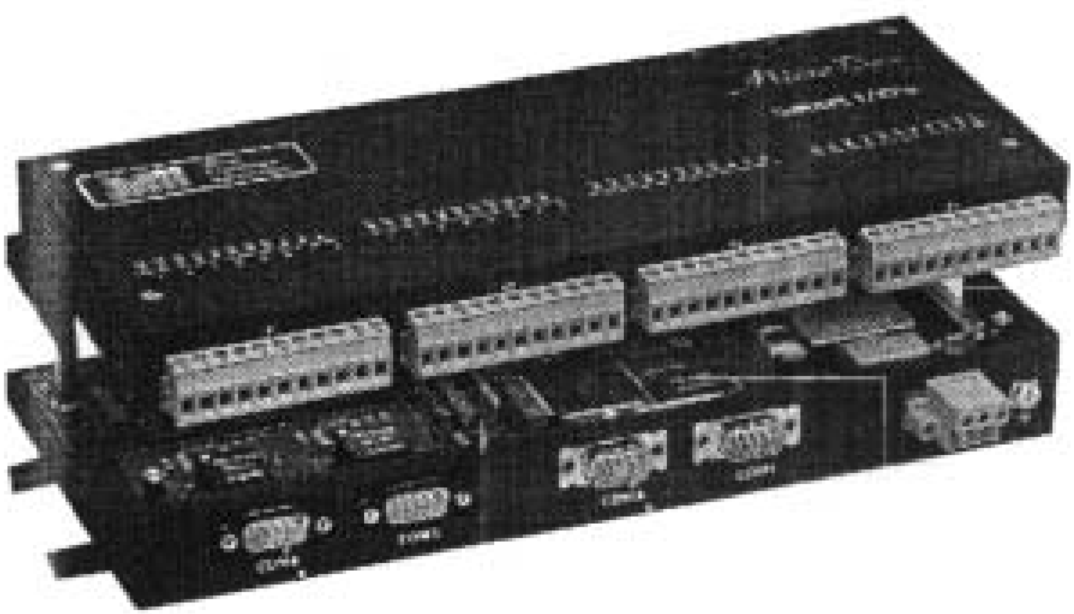
Smart Sensors and Digital Fieldbus: Market/Product Surveys and EdF's Experience Feedback

Technical Report



Smart Sensors and Digital Fieldbus: Market/Product Surveys and EDF's Experience Feedback

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Final Report, July 2002

EPRI Project Manager
J. Naser

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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EDF R&D - REME
6, Quai Watier
78 401 Chatou
France

Principal Investigator
S. Javelot

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REPORT SUMMARY

This report presents results of a survey and a set of experiments with smart sensors and digital fieldbuses. These technologies are capable of supporting improved plant performance through functional gains and economic savings. Experience with these technologies by Electricite de France (EdF) on test loops and at three fossil fuel plants is described.

Background

Nuclear power plants rely on instrumentation and control (I&C) systems for control, monitoring, and protection. The majority of I&C systems are of analog design and contain components that are or soon will be obsolete. In many instances, analog replacements are no longer available. Nuclear power plants are finding it necessary to procure digital-based designs due to equipment obsolescence or to improve performance. In fact, many plants already have retrofitted some components with modern digital designs, ranging from one-for-one replacements (for example, displays and recorders) to large-scale, microprocessor-based systems (for example, reactor protection systems). As plants move forward with I&C modernization programs, opportunities to improve plant performance through effective use of improved digital equipment occur.

New digital technology has made devices such as smart sensors and digital fieldbuses available for power plants. Smart sensors and digital fieldbuses provide higher accuracy for process variable measurements, data processing, measurement validation, and total data transmission reliability. All these advantages, including availability of industrial products and convergence of related international standards, make smart sensors and digital fieldbuses major contributors to improved performance and reliability in power plants, including nuclear power plants.

Objective

To provide a synthesis of EdF's experimental evaluations and periodic market study of smart sensors and digital fieldbus technology, which supports owner/operators performing I&C modernization projects.

Approach

EdF has surveyed the market for smart sensors since 1993 and has updated these surveys every other year (the latest survey was published in January 2000). This survey includes data on

- smart sensors specifically suited for power plants
- intelligent instrumentation (that is, smart sensors interconnectable on digital fieldbuses)
- fieldbuses for smart sensors and the status of their standardization.

The survey also includes an assessment of vendor strategies in terms of standardization and alliances, market shares, and probable evolutions.

Experiments and evaluations of complete architectures for data acquisition, processing, and transmission were performed by EdF on fossil power plants with equipment from different manufacturers and suppliers. This was done to evaluate performance and concept validation independently of specific designs and standards. Included were experiments at the

- 600-MWe fossil-fired plant of Cordemais (200 smart sensors on a WorldFIP fieldbus)
- 4*250-MWe fossil-fired plant of Martigues (installation of 6 sensors and 6 actuators interconnected on a Foundation Fieldbus network)
- 6*11-MWe Lucciana diesel plant (26 smart sensors + 40 analog inputs + 120 logic I/O on a Foundation Fieldbus network per diesel group).

Results

This report documents results of experimental evaluations and periodic market study of smart sensors and digital fieldbus technology. The report includes results from implementing these technologies at three fossil fuel plants. While the document presents technical information and comparisons, it does not recommend any specific vendor products.

EPRI Perspective

Nuclear power plants were designed 25 to 45 years ago with analog and rudimentary I&C technology. This equipment is approaching or exceeding its life expectancy, resulting in increasing maintenance costs and efforts to sustain acceptable system performance. Decreasing availability of replacement parts and accelerating deterioration of the infrastructure of manufacturers that support analog technology accentuate obsolescence problems and cause operation and maintenance cost increases. Therefore, owner/operators are beginning to implement new digital equipment in their plants. When implementing this new equipment, owner/operators should take advantage of the performance improvements offered by new digital technology. Examples of new technology that offers improved performance are smart sensors and digital fieldbuses.

Keywords

Instrumentation and control systems
Smart sensors
Digital fieldbus
Process variable measurements
Digital systems
Data access

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INTRODUCTION

The integration of digital instrumentation (smart sensors and actuators, fieldbuses, etc.) in process control systems ensures functional gains (remote configuration and diagnosis of equipment, etc.) and economic savings (lowered costs for cabling, preventive maintenance, etc.) which are important in improving the productivity of nuclear or thermal power plants. However, the use of these technologies is still subject to certain questions, particularly with respect to the credibility, reliability, continued availability and interoperability of the various options available.

This report reviews the main issues (economic and technical questions, standards, technical feedback, etc.) in an attempt to identify some answers to these remaining questions and to capitalize on the lessons from the experiments carried out in EDF's power plants. The first part of this report consists of an analysis of the smart instrumentation market. The second part completes this information with an inventory of what is currently available in the market. The third part touches on technical aspects and standards relating to fieldbuses suitable for the control of continuous processes. Fieldbuses in a sense constitute the spinal column of digital control systems. The fourth part provides technical and economical feedback from the instrumentation system set up at the Cordemais fossil-fired power plant. The fifth part completes this information with feedback from two other fossil power plants, Martigues and Lucciana, which have decided to set up smart sensors connected on fieldbuses on all or part of their process equipment.

2
ANALYSIS OF THE MARKET FOR SMART INSTRUMENTATION

The objective of this first part of the report is to identify the general characteristics of the market, to assess the factors which tend to fuel or brake development, and to position the main players in relation to the key priorities. With a view to drawing up technical specifications for future nuclear or thermal power plants, the data included in this report incorporates requirements as to continuity in the offer, prospects for standardization and probable developments in the market in the foreseeable future.

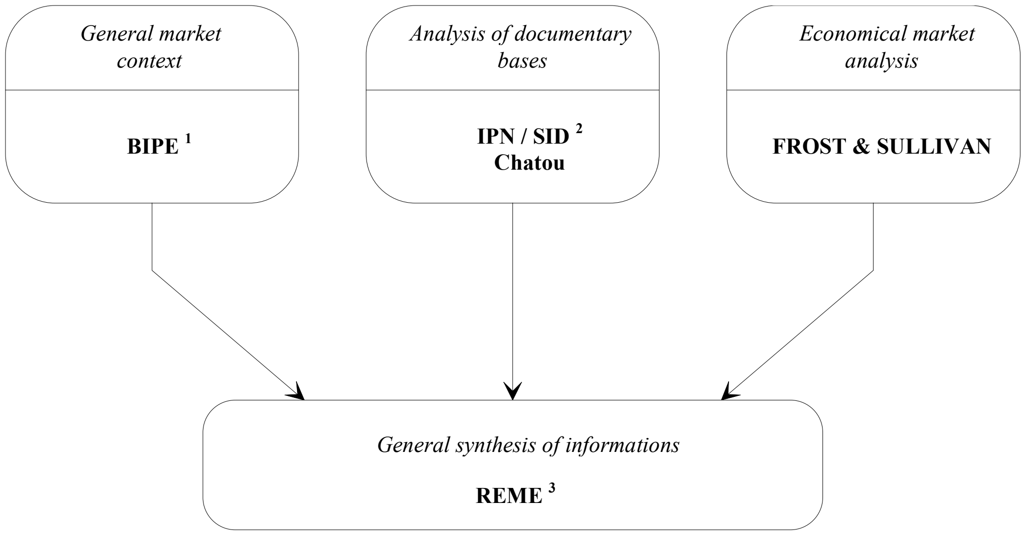
2.1 Approach

2.1.1 Approach to the study

The approach adopted to analyze the smart instrumentation market consisted of:

- an analysis of the global market,
- a general analysis of current demand,
- a global analysis of the current offer,
- an inventory of the main events, entities and factors which have shaped the market,
- a list of the main manufacturers in the market,
- prospects for further developments in the market.

Figure 2-1 presents the phases and resources of the study.



[1] BIPE: a firm specialized in economic studies and forecasts.

[2] IPN / SID: Service Information, Prospective and Normalisation / Département Systèmes Information et de Documentation (EDF R&D Documentation Center).

[3] REME: Département Retour d'Expérience, Mesures, Essais (EDF R&D Instrumentation, Process and Testing Department).

Figure 2-1
Phases and resources of the study

At our request, the firm BIPE carried out a study of the world smart sensor market in December 1998 [1].

The information databases were analyzed by IPN / SID in Chatou in the context of a scientific, technical and economic study on smart sensors and fieldbuses [2].

The economic market assessment is based on three market studies by Frost & Sullivan [3], [4], [5]. These studies essentially concern domains related to smart instrumentation: process control, communication networks, DCS, etc.

2.1.2 Scope of the study

The market studied is that of smart instrumentation installed in continuous process industries, and particularly that used for process control applications. Related markets such as those of sensors, fieldbuses and process control systems are also investigated.

It would be helpful to clarify the term *smart sensor* (or *smart instrumentation*) used throughout this document. **Smart sensors have the capacity to generate elaborate data in addition to that strictly required by their main measurement function.** They are primarily characterized by the existence of microchips, memories, etc. which give them the ability to calculate and process information, to store and to emit and receive various types of data (measurements, messages, configuration) in digital form.

2.2 General characteristics of the instrumentation market

In a market characterized by great diversity, two main segments can be distinguished (cf. Figure 2-2). The first relates to industrial sensors used in process control, measurement and automation. These products represent a 70% market share and therefore have considerable influence. The second includes non-industrial sensors used in the automotive, medical, aeronautics and mass market electronics industries [6].

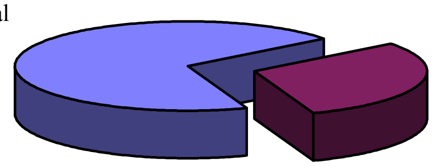


Figure 2-2
World sensor market: Breakdown for industrial and non-industrial sensors

In 1999, the worldwide sensor market was estimated at between FRF 90 and 110 billion. Yearly growth in the market for traditional sensors is around 4% where it is close to 10% for new-generation sensors based on recent technologies. However, with the European and North American markets saturated, suppliers are turning to more buoyant markets such as those in Asia and Latin America.

In this market heavily dominated by industrial instrumentation, sensors designed for continuous or semi-continuous (or batch) process applications represent around FRF 50 billion, or almost 50% of the world market. This corner on the market may be explained by the strong growth in smart sensors.

2.2.1 Details on the market for smart instrumentation

2.2.1.1 The world smart sensor market

In 1993, the world market for smart sensors used for process control applications was valued at between FRF 2 and 4 billion [8]. **In 2000, the same market represented over FRF 25 billion**, clear confirmation that this is a fast-growing sector.

Figure 2-3 shows the general trends observed and predicted for 2002 in the world smart sensor market [1]. The growth noted is in fact a two-speed phenomenon, with 12% growth in volume and 8% growth in revenue, due to a drop in prices.

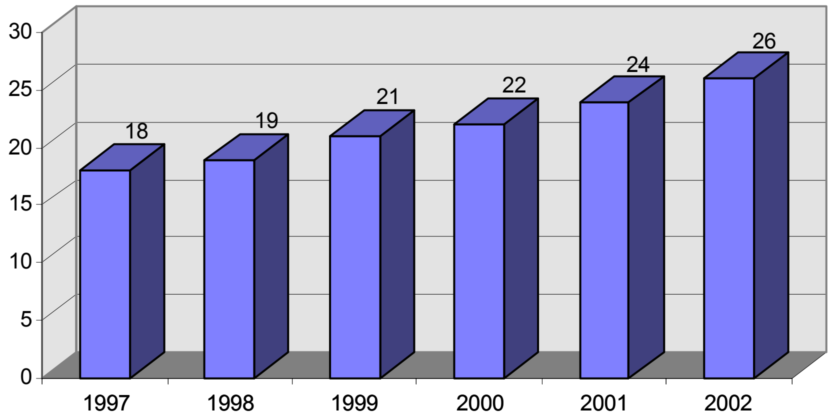


Figure 2-3
World market for intelligent process control sensors (in billion FRF)

2.2.1.2 Principal measurands

The product that dominates the smart instrumentation market is the pressure sensor (absolute, relative and differential pressure), accounting for 43% market share (in volume). This high proportion can be explained by the fact that this type of sensor has many applications in addition to simple pressure measurement (flowrate and level measurement, etc.).

Figure 2-4 shows the relative proportion of the different measurands in continuous and semi-continuous process applications [1].

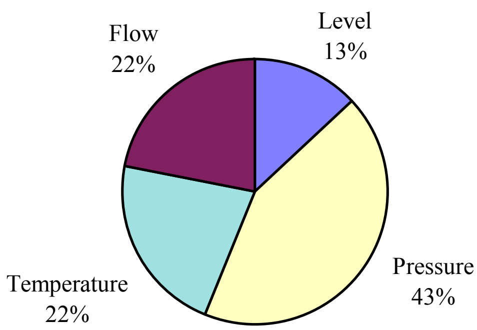


Figure 2-4
Smart sensors: relative distribution of measurands in continuous and semi-continuous process applications (in volume)

2.2.2 Geographical base of suppliers

The smart sensor market is currently dominated by three geographical regions: the United States, the largest zone, with 54% of the market, Europe and the rest of the world which respectively hold 35% and 11% of market share (cf. Figure 2-5).

These data are based on turnover (1997) of the main suppliers, considering only the principal measurands used in continuous and semi-continuous processes.

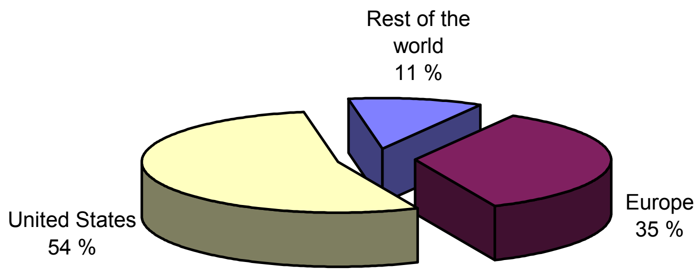


Figure 2-5
Geographical base of suppliers

2.3 Details on the demand

The objective of this section is to identify the main sectors which influence the smart instrumentation market, and to highlight reasons which motivate the main players in the market.

2.3.1 Principal sectors and outlets

Smart instrumentation is generally intended for two types of industrial applications:

- embedded applications,
- installed applications.

The instrumentation used in embedded applications is not included in the framework of this study. These concern the automotive, aeronautics and mechanical construction industries.

Installed applications, on the other hand, relate to production industries, i.e.:

- continuous process industries: heavy chemicals, petrochemicals, paper, cement, glass and energy industries
- semi-continuous (or batch) industries: foods, pharmaceuticals, treatment of water and wastes

- manufacturing industries.

Process industries are the prime outlet for smart sensors, and contribute significantly to developments in the smart instrumentation market.

2.3.2 Characteristics of potential users

The end users can generally be broken down into two categories:

- Large companies which consume a great number of sensors for their production. Generally, these companies are found in the energy, chemicals, petrochemicals and manufacturing industries (EDF, ELF Atochem, PSA, Renault, etc.). These industrial-scale users sometimes concern themselves with standardization and technical options, and can influence the market by weighing on prices. On the other hand, the sizable investments needed to install the instrumentation can slow the penetration of smart sensors in this sector.
- Small and medium-sized companies, which use a limited number of sensors. This sector is more dynamic in terms of investment, pointing to faster penetration of smart instrumentation in the future.

2.3.3 Motivations and expectations of users

In recent years, an increase in the offer of sensors compatible with fieldbuses has been seen. With these, process control by means of a single cable may at last become a reality. However, the potential industrial users are still reluctant, and rare are those who really dare to jump in. The delays encountered in standardizing fieldbuses are largely responsible. This section deals with the concerns of the users, particularly with respect to continuous and semi-continuous processes.

2.3.3.1 Expected gains and savings

The arrival of smart sensors and fieldbuses threatened the absolute supremacy of 4-20 mA sensors. What gains and savings can be expected from the use of smart instrumentation?

Ideally, the use of smart sensors and a process fieldbus should ensure the following:

- improved measurement reliability (error correction, measurement validation, etc.)
- continuous routing via a single cable of the values measured by a sensor toward a process control element and sometimes toward an actuator (decentralized control),
- data exchange for remote configuration of sensors in one direction and remote diagnosis in the other.

These additional functions provided by smart instrumentation generate potential savings which are difficult to estimate but clearly identifiable:

- lower cost of cabling,
- facilitated design of the process control system,

- improvement and lowered cost of maintenance.

Of these three benefits, the lower cost of maintenance appears to be the most advantageous. Whereas industries once relied on curative maintenance, which consisted in repairing process components once the installation was blocked, they later opted for preventive maintenance, reducing the risks of failure thanks to periodical, though not always justified repair tasks. Today, the integration of self-diagnosis functions in process components (more or less sophisticated depending on the manufacturer) makes it reasonable to envisage predictive maintenance, in which all tasks are useful and are performed before an anomaly has occurred.

2.3.3.2 Continuity in supply

Users of smart sensors are looking for the interoperability and interchangeability they were accustomed to with analog instrumentation based on the 4-20 mA loop. The desire for continuity in supplies of smart instrumentation is particularly strong in large-scale process industries, where investment in instrumentation can be considerable, and where the need for continuity in technical solutions may extend to several decades.

Widespread use of smart instrumentation remains dependent on the emergence of an international fieldbus standard. A standard was approved in January 2000 but will no doubt not meet the needs of the end users as it includes no less than eight protocols (Foundation Fieldbus H1 and HSE, Interbus-S, P-Net, Profibus, ControlNet, SwiftNet and WorldFIP). This multiplicity in communication protocols precludes the guarantee of interoperability and interchangeability of components that is required by the users. Approval of this standard is definitely a step back ten years in time, unless the market decides to impose a single fieldbus as the de facto standard.

2.3.4 Penetration of smart instrumentation

2.3.4.1 Rate of penetration of smart sensors in process industries

In 1991, 45% of the sensors sold in continuous and semi-continuous process industries were "smart". This proportion had risen to 60% by 1997. By 2002, the figure is expected to reach 90%.

In 1997, these smart sensors were more used for pressure measurement (sensors already installed) than for temperature measurement (due to the additional installation cost involved). However, sensor intelligence is not always fully utilized; industry wants to benefit from enhanced measurement functions but does not necessarily make use of the remote diagnosis and configuration functions.

Lastly, forecasts for 2002 point to the appearance of a significant market for smart sensors controlling an actuator via a fieldbus.

These figures would seem to point to widespread sales of smart sensors by 2002, which confirms the trend noted among suppliers of smart instrumentation since in 1997. Around 80% of their turnover generated by sensors was attributable to sales of smart sensors (cf. section 2.7). The intelligence of these sensors is not, however, always actually exploited. Some users renew their pool of transmitters, integrating smart sensors so as to have a guarantee of better quality in their measurements and the possibility, in the longer term, of connecting them to a fieldbus.

2.3.4.2 Factors that fuel or brake growth in the smart sensor market in process industries

The key factors that motivate the purchase of smart sensors are the following:

- technological progress: smart sensors are a means of improving measurement reliability and precision. Furthermore, they may generate gains in various domains, particularly maintenance (cf. section 4.3.1).
- economic growth: time lost due to the economic slowdown at the beginning of the 90s, especially in Europe, is encouraging a revival in investments today.
- modernization of process industries: to enhance their competitiveness, process industries must upgrade their process control architectures, particularly in the fields of chemistry, agribusiness and water treatment. Moreover, recent European directives concerning industrial pollution are obliging some industries to completely rethink their process control systems.
- creation of new installations: commissioning of new installations is another cause for growth in smart instrumentation which is a means of integrating a wide range of new technological solutions.

On the other hand, from the point of view of the users, certain factors tend to brake growth in the smart sensor market:

- difficulty in making choices: in the face of the great number of suppliers in the market, users have difficulty in making choices, particularly given the absence of any viable international fieldbus standard.
- difficulty in assessing gains: hoped-for gains due to reduced costs for cabling, system design and maintenance are difficult to assess, particularly given the absence of real feedback on large-scale installations.

2.3.4.3 Options chosen by some major users

Constantly careful to make the most of their investments and given the lack of standards in the domain, few major industrial players have undertaken to implement complex instrumentation of their production units using a fieldbus and smart sensors. Some, however, have set up test loops or pilot units.

Two of these are frequently cited as examples:

- **Brasserie Bitburger:** PNO has made much of the Brasserie Bitburger installation which consists in a Profibus PA fieldbus connected to level and pressure sensors produced by Endress+Hauser, temperature sensors and a Siemens Simatic controller.

- **Arco in Alaska:** the Alaskan oil company signed a contract in 1997 with Fisher Rosemount for the instrumentation for a production unit in Alaska. The instrumentation is composed of an FF fieldbus connected to Fisher Rosemount transmitters and valves, MicroMotion flowmeters and EIO Matic actuators. The process control architecture is structured around the Fisher Rosemount DeltaV system. This installation is considered to be the first large-scale application of the Foundation Fieldbus.

2.4 Details on the offer, and related markets

Having reviewed the current demand, we shall now look at the main characteristics of the offer today. In the following section, we will make a detailed inventory of the supply available from the main players in the smart instrumentation market.

2.4.1 General characteristics

The present supply of smart sensors is highly diversified, for two reasons:

- multiplicity in communication protocols,
- differences with respect to the internal functionalities of sensors.

Prices vary depending on the technologies used and the measurands required. Table 2-1 gives the average prices of smart pressure, temperature and level sensors used for continuous or semi-continuous processes (not including connection to the fieldbus, which costs from a few hundred to a thousand FRF).

Table 2-1
Average prices for smart sensors in continuous process applications

Measurands	Average price
Pressure	4,000 to 7,000 FRF
Temperature	1,750 to 2,500 FRF
Level	4,000 to 7,000 FRF

2.4.2 Details on the fieldbus supply

Growth in the smart instrumentation market is strongly correlated with that of fieldbuses. IEC approval of the international standard does not, however, mean that a single communication protocol will become the standard. It is therefore the market, and consequently the end users, which will determine the dominant fieldbuses. The supply of smart instrumentation will structure itself around their choices.

Nonetheless, given the forces now present in the market, it appears likely that four fieldbuses will dominate in the future: **Profibus, DeviceNet/ControlNet, Foundation Fieldbus and**

Ethernet. Table 2-2 ranks the main industrial communication fieldbuses in Europe and in the United States, on the basis of numbers of installed applications [4].

Table 2-2
Ranking of the main industrial communication networks in Europe and in the United States

System	Age (in years)	Region of influence	Rank
Profibus	10	Europe	1
Interbus	15	Europe	2
Modbus Plus	15	Europe	3
As-i	6	Europe	4
CANopen	6	Europe	5
DeviceNet	5	U.S	1
Profibus	10	U.S	2
Modbus Plus	15	U.S	3
Remote I/O, DH+	18-20	U.S	4
Foundation Fieldbus	5	U.S	5
Ethernet	17	U.S	6
ControlNet	5	U.S	7
Lonworks	8	U.S	8

Figure 2-6 shows the change in market share held by the main communication networks between 1999 and 2006 (forecasts) [4].

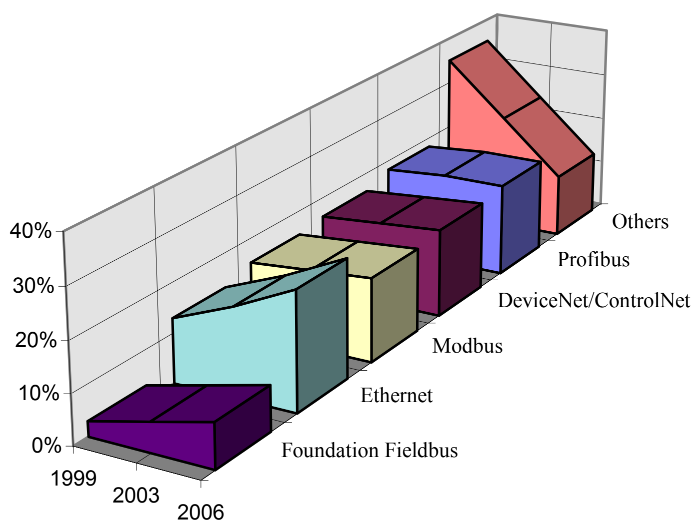


Figure 2-6
Evolution in market share for the main industrial-scale fieldbuses for continuous and semi-continuous processes between

The sharp drop in market share held by other fieldbuses (from 35% in 1999 to 13% in 2006) bears witness to a concentration around four major communication protocols: Profibus, DeviceNet/ControlNet, Foundation Fieldbus and Ethernet. The Profibus and DeviceNet/ControlNet fieldbuses dominate the market but are not credited with significant growth projections. Foundation Fieldbus and Ethernet, on the other hand, should see considerable growth between now and 2006. We should note that the Modbus fieldbus is well represented in the market but is not properly speaking intended for smart instrumentation; for this reason, we do not take it into account *(strictly speaking, there are complex, and therefore smart sensors on Modbus, but this protocol has a far less sophisticated semantic than other fieldbuses).*

2.4.3 PLC and DCS supply

The smart instrumentation market is closely linked to that of process control, PLCs and DCSs. This correlation can essentially be explained by the fact that migration of the intelligence of controllers and PLCs to level 0 of the instrumentation requires a high capacity for interaction between the two domains.

The main suppliers are characterized by significant vertical integration in their activities, providing they control the entire measuring chain from sensor to I&C architecture. The following are among the main suppliers [5]:

- ABB
- Fisher Rosemount
- Foxboro
- Fuji Electric
- Honeywell
- Rockwell Automation
- Siemens
- Yokogawa

2.5 Options chosen by the different players

The means of action chosen by the suppliers and end users in the smart instrumentation market are:

- setting up of pilot experiments,
- contribution to international standards efforts,
- participation in consortiums.

With technical solutions now well advanced, there are far fewer cooperative research projects under way than before [2]. The various consortiums will therefore now confront each other in the marketplace. However, the failure to set a real international standard may give rise to future alliances, and therefore to future projects for cooperation, leading to more complete technical solutions (fieldbuses adapted to all types of process control).

2.5.1 Pilot experiments

Industrial-scale pilot experiments are generally limited to the fields of energy, oil drilling and chemicals. The objective is to test the technical solutions proposed by the manufacturers but, for the moment, no practical use of the systems is envisaged.

- **The example of ELF Atochem:** ELF has set up a test platform on Foundation Fieldbus H1 with the aim of testing the interoperability of equipment: seven transmitters and a positioner produced by Fisher Rosemount, Smar, Honeywell, and Yokogawa were installed, together with two configurators from National Instruments and Smar, and a Fisher Rosemount DCS. The interoperability of the various components was not found to be globally satisfactory.
- **Other experiments** aimed at demonstrating the technical feasibility of smart instrumentation for process control have been carried out, particularly in the context of the oil industry. The Mobil Corporation site in Saudi Arabia set up the Honeywell TPS (Total Plant System) in 1998 to evaluate the gains in maintenance to be expected from smart instrumentation [2]. To date, no data is available on which to base conclusions as to the installation of this type of instrumentation.

2.5.2 Fieldbuses and standards

After long procedural battles, essentially under pressure from the manufacturers, the adoption of IEC international standard 61158 resulted in wide array of different and incompatible profiles. The most significant in terms of continuous process control are Foundation Fieldbus (H1 and HSE[1]), Profibus (FMS, DP, PA) and perhaps WorldFIP[2]. Absent a major change in the situation, efforts to establish a fieldbus standard are therefore a failure from the point of view of the end users.

2.5.3 Consortiums

Due to the slowness of the standardization process, consortiums have been set up composed of manufacturers wishing to impose their own technical solutions on the market. In general, these consortiums have great influence in the standardization process and are, in part, responsible for the current absence of any workable fieldbus standard. The main players are:

- **PNO:** set up in 1989; its objective is to promote the Profibus solution, most particularly by trying to have it included in IEC 61158, which they have done. PNO is headed up by PI but

---

[1] The HSE high-speed network is now on the market.

[2] WorldFIP does not appear in the list of main communication fieldbuses (Table 2-2) because there is no field equipment compatible with this protocol and only a few applications are therefore installed. On the other hand, they are very active in the field of standardization.

is essentially driven by Siemens. It has some 900 members including Siemens, ABB, Endress+Hauser, Honeywell, Landis&Gyr, Klockner Moeller, AEG, etc.

- **Fieldbus Foundation:** set up in 1994 following a merger between WorldFIP North America and ISP. A fervent supporter of IEC 61158 which has enabled it to integrate its Foundation Fieldbus in an international standard, it groups all the big names in instrumentation and I&C (except for Siemens), such as: Fisher Rosemount, ABB, Yokogawa, Endress+Hauser, Honeywell, Foxboro, Fuji Electric, etc.
- **WorldFIP:** an offshoot of the FIP club created in 1988, it consists essentially of Schneider Electric and Alstom, but has very few users (except for EDF). Because there is no compatible field equipment, WorldFIP has relatively little influence on the international scene; it may be obliged to move toward a joint solution with FF for a network solution (complementary to HSE).

2.5.4 Agreements and takeovers

In their desire to control the entire measuring chain, manufacturers are positioning themselves in markets related to smart instrumentation (DCS, PLCs, fieldbuses) by taking over other companies. The most noteworthy takeover in recent years was that of Elsag Bailey by ABB in 1998, shooting ABB to the forefront of DCS manufacturers and to second place among manufacturers of smart sensors (cf. section 2.7).

However, the takeover game appears to be somewhat stabilized in the last couple of years. The recent approval of the international fieldbus standard may give rise to new agreements among manufacturers with a view to developing complete technical solutions adapted to all types of process control.

2.6 The main manufacturers market share

Among the key players in the market for smart instrumentation in continuous and semi-continuous processes, we find on the one hand, the large groups that dominate the smart sensor market and on the other, those who control the entire measuring chain from sensor to PLC and DCS. The companies in question are: Endress+Hauser, Fisher-Rosemount (Emerson group), Yokogawa, Foxboro, Honeywell, Fuji Electric, ABB, Siemens.

2.6.1 Positioning in the DCS market

As shown in Figure 2-7, ABB comfortably controls the DCS market in continuous process control. This is due to the fact that ABB took over Elsag Bailey in 1998, doubling its DCS turnover. The Honeywell, Fisher Rosemount, Foxboro and Yokogawa groups are its main competitors in the continuous process field, while Siemens and Rockwell Automation dominate activities in semi-continuous and manufacturing processes.

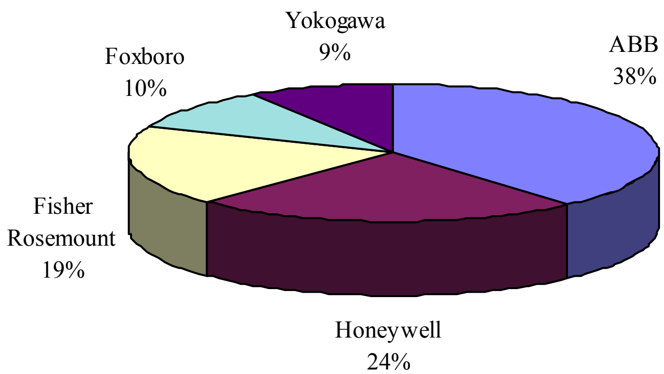


Figure 2-7
Positioning of suppliers in the continuous process DCS market (1997)

Figure 2-8 shows the proportion of turnover devoted to DCSs in relation to overall group turnover. Siemens and ABB stand out as giants with their respective turnovers of FRF 360 billion and 180 billion. These groups obviously have many other activities in addition to DCS.

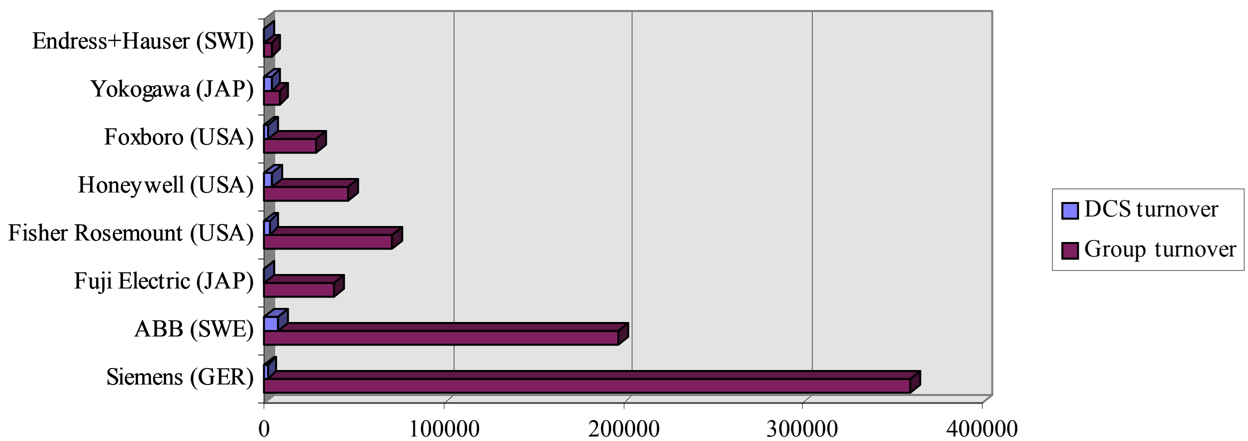


Figure 2-8
Worldwide turnover (1997) and relative DCS share in million FRF

2.6.2 Positioning in the sensor market

Only sensors used in continuous process applications will be considered here. In this market, Fisher Rosemount remains the undisputed world leader, with total turnover of FRF 8,865 million. Having acquired Elsag Bailey, ABB ranks second, before Yokogawa, Honeywell and Endress+Hauser.

Figure 2-9 shows that the proportion of turnover devoted to smart sensors now represents some 80% of total sensor turnover for all suppliers in the market. This should rise to 100% in the next 3 years [1].

Note: the proportion of turnover devoted to smart sensors is less if we consider non-smart sensors in the total, but their economic weight is limited.

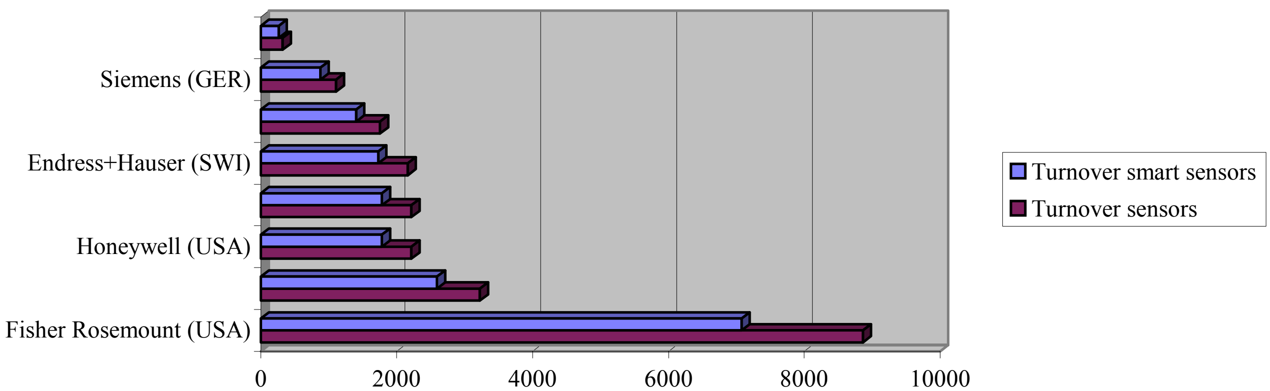


Figure 2-9
World turnover for sensors (1997) and proportion for smart sensors in million FRF

Figure 2-10 shows the relative proportion of turnover devoted to DCSs and smart sensors. With the exception of Endress+Hauser and Fuji Electric, suppliers try to position themselves in both the sensor and the DCS market, so as to have maximum control over the entire measuring chain. The most noteworthy example is ABB which, having acquired Elsag Bailey, is now in a leading position in the smart sensor market and first in the DCS market.

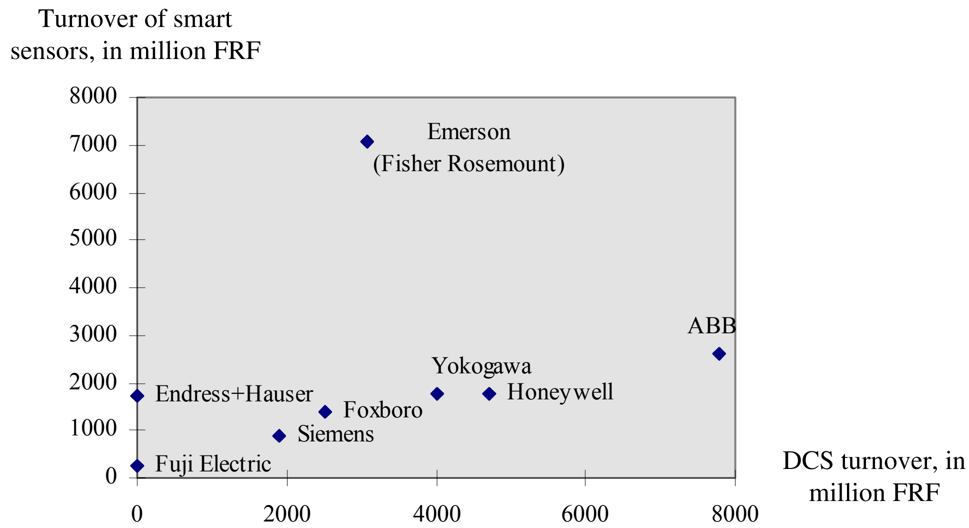


Figure 2-10
Positioning of suppliers of smart sensors and DCSs

2.7 Synthesis of the smart instrumentation market

2.7.1 General background

The smart instrumentation market is growing fast, indicating the probability that smart sensors will soon be found in all suppliers product ranges.

The suppliers are essentially based in the United States, Europe and Japan. The market is competitive, but limited to an increasingly small number of players and these continue to organize themselves into manufacturing cartels.

Continuity in supply remains a major concern for the end users, who waited in vain for a credible international fieldbus standard. For this reason, there are still relatively few large-scale applications for smart sensors on a fieldbus.

2.7.2 The players

We can distinguish three categories:

- the very large manufacturers (ABB, Siemens), highly diversified; they dominate the I&C market due to an effect of scale and build up their sensor activities by acquiring new companies;
- big suppliers (Honeywell, Foxboro and Yokogawa); very well represented in the I&C field, with significant sensor activity;

- instrumentation manufacturers (Fisher Rosemount and Endress+Hauser); strongly oriented toward sensor activities and sometimes (F-R) developing their I&C activity.

Figure 2-11 situates the three main categories of manufacturers. Since 1992, we have been seeing a trend to diversification which enables manufacturers to offer a complete measurement solution, from sensors to DCS. Thus Fisher Rosemount remains the leader in terms of sensors but now also offers DCSs. The best growth has been posted for ABB which dominates the DCS market in continuous process control and is very well positioned in the sensor market. This success is principally due to its acquisition of Elsag Bailey in 1998.

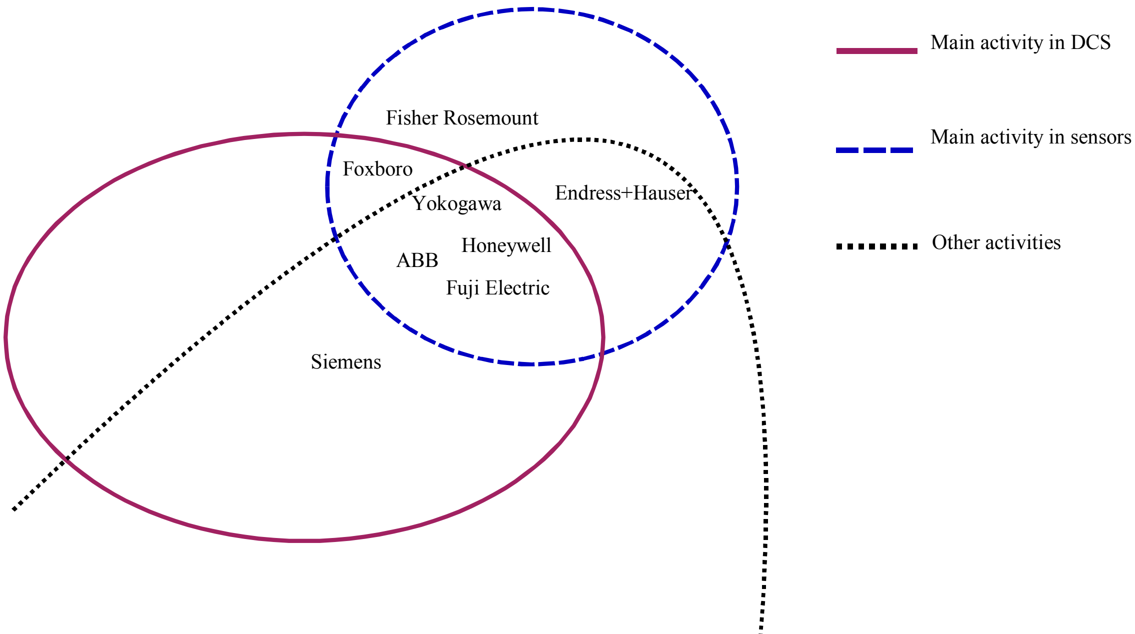


Figure 2-11
Positioning of the main smart instrumentation suppliers

2.7.3 The balance of power

The consortiums identified in 2.6 are now PNO (Profibus Nutzer Organisation) and Fieldbus Foundation. The locomotives behind the two are respectively Siemens and Fisher Rosemount. Figure 2-12 below shows the balance of power between the two consortiums, **in view of the turnover devoted to sensors** of their principal constituents. There is a clear imbalance in favor of Fieldbus Foundation, particularly in light of the clear domination of Fisher Rosemount as an instrumentation manufacturer.

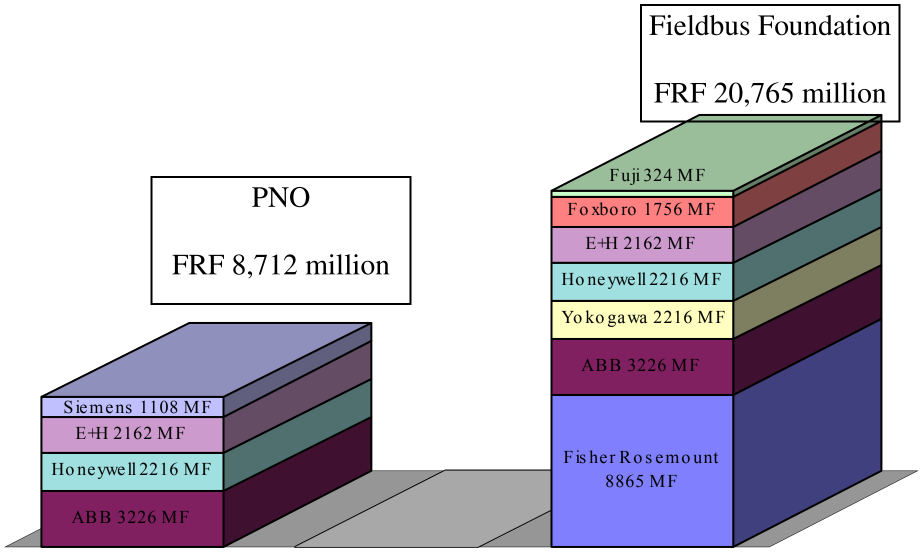


Figure 2-12
Balance of power between PNO and Fieldbus Foundation (on the basis of sensor turnover of suppliers)

However, it must be noted that this comparison is based on manufacturers sensor turnover, but that the relative importance of the players in the field cannot be limited to this data (for example, Siemens does not weigh much in the sensor market but it remains a predominant influence in the field of I&C).

It is therefore necessary to qualify this comparison, allowing for the references (number of nodes and products) available for each of the two fieldbus technologies, Profibus and Foundation Fieldbus.

Profibus, which is some ten years old, is already well established, particularly in Europe. The number of nodes is estimated at between 2,500,000 and 3,000,000 [3]. The number of products available is around 1,700 including 73 sensors and actuators.

On the other hand, Foundation Fieldbus is only five years old and has offered its products for three years; it has only 10,000 nodes, essentially in the United States [3], [4]. 114 products are now available, including 36 sensors and actuators. This communication protocol started from scratch in 1995 and very quickly moved to center stage, in particular, under the influence of Fisher Rosemount.

The balance of power between the two consortiums can be summed up as follows:

- **Profibus is a well-established fieldbus** with many products and services and several industrial applications to its credit. With the exception of Siemens, the major player in PNO, the other large firms like ABB, Honeywell or Endress+Hauser are also part of the Fieldbus Foundation consortium.
- **Fieldbus Foundation has few industrial applications to its credit**, particularly because the HSE network, designed for the controller, PLC level has not reached maturity. However, it is progressing regularly and has a promising future.
- **The presence of Endress+Hauser, Honeywell and ABB in the two consortiums reflects today trend toward generalization of the offer**. Given the absence of a workable fieldbus standard, smart instrumentation manufacturers are orienting their activities toward a complete range of products compatible with both Profibus and Foundation Fieldbus.

2.7.4 Factors and players with decisive influence

This analysis is necessary to identify the decisive factors which give various players a leadership position in the smart instrumentation market:

- **Vertical concentration:** control over the entire measuring chain from sensors to PLCs and DCSs is a major asset. Alliances and takeovers/mergers enable companies to acquire new skills in various I&C domains.
- **The importance of consortiums:** the failure of the new international standard illustrates the influence held by manufacturers in imposing their communication protocol on the IEC.

2.7.5 Factors to watch

On the strength of this study, we can identify the factors likely to have a significant impact on the market, which therefore should be closely monitored:

- **Reactions to the new standard:** the international fieldbus standard approved in January 2000 includes no less than eight protocols; this should not be satisfactory to the users, who are looking for continuity in supply. The predominance of Profibus, DeviceNet/ControlNet, Foundation Fieldbus and Ethernet will nonetheless probably be confirmed, though this will be decided in the field.
- **Strategies of sensor suppliers (multi-protocol offer):** the trend toward a solution that accepts Profibus and Foundation Fieldbus protocols is evident. However, monitoring the strategy of Fisher Rosemount, the giant in the field, will help in evaluating future orientations in this domain.
- **Consortiums:** the tug of war between PNO and Fieldbus Foundation is now a fact of life. Their capacity to exert pressure is considerable, as was evident in the recent failure to arrive at a workable fieldbus standard.

3
INVENTORY AND ANALYSIS OF THE CURRENT INDUSTRIAL OFFER

This part of the report presents the technical features of what is now available in terms of smart sensors adapted to continuous process control. This inventory of the supply is based, first, on the conclusions drawn in the first part of the report, with respect to the general analysis of the market, and, more particularly, on a selection of the main suppliers who play a preponderant role in the market.

3.1 Approach

The approach taken was to inventory and describe the industrial offer on the basis of three types of information:

- global knowledge of the market,
- monitoring of changing trends in the supply,
- a description of the products marketed by the main manufacturers selected.

3.1.1 A global look at the market

A global overview of the environment and the role of the main players is essential to orient our inventory toward the most strategic products now available.

Our general analysis of the market enabled us to identify or confirm the main manufacturers of smart sensors that correspond to the needs of our company.

The manufacturers selected were identified on the basis of a segmentation of the market for continuous process instrumentation. This includes related sectors important for CIM such as fieldbuses, DCS and supervision.

3.1.2 Monitoring of supply-side trends

This review is a corollary to our general analysis of the market. It is all the more important in that the instrumentation market is extremely sensitive to changing alliances among the players, which modify the balance of power. Restructuring, disengagement and takeovers are all important elements in any technology survey, enabling us to evaluate the level of integration of a company on the one hand and, consequently, its control over the technological chain, and, on the other, the potential for continuity in products available.

Monitoring of trends is therefore one way to integrate landmark events affecting the suppliers, both on a strategic level (market penetration and alliances between companies) and in terms of the technical options chosen by the manufacturers (innovations, positioning in relation to standards) [6].

3.1.3 Product description

Our technical description of the products is based solely on interviews and on the technical documentation of the manufacturers selected. In this respect, it is important to remember that the performance quoted is that promised by the manufacturers; in particular, some data, particularly those of a metrological nature, are presented ambiguously and must therefore be qualified. When this is the case, it is indicated in this report.

3.2 Global description of the offer

Two aspects are covered in this technical analysis of the current supply: the functionalities offered by the sensors and their possibilities for communication.

3.2.1 Elements considered

The functional description of smart sensors can be broken down into four services [10]:

- measurement,
- configuration,
- validation,
- communication.

3.2.1.1 Measurement functions

Measurement is the original role of the sensor; it involves:

- signal acquisition and processing,
- correction and compensation of secondary values (cell temperature, electronic temperature, static pressure),
- conversion into a functional measurement.

The format of presentation of the measurement (physical unit, standardized values) is also described under this heading.

3.2.1.2 Configuration functions

Configuration is the means by which the sensor complies with the conditions required for its proper functioning, on the one hand, and with the conditions of the application, on the other; it consists of:

- data concerning the identity and description of the sensor (tag, addressing, etc.)
- parameters for functioning (e.g., damping, full scale setting, etc.).

3.2.1.3 Validation functions

Validation guarantees enhanced credibility of all data provided by the sensor. It tells us about:

- the behavior of the sensor,
- the validity of the measurement, in view of the application data and the behavior of the process.

Any possibilities for diagnosis and event reports are also described under this heading.

3.2.1.4 Communication functions

Communication enables interactive exchange of data and commands with higher levels (half-duplex mode), via the fieldbus (remote communication) on the one hand, and the field pocket on the other (local communication).

3.2.2 Operating architectures for smart sensors

For a more complete presentation of this aspect, please see the third part of this report (section 4.5). Two types of architectures must be considered:

- **HART-type architectures based on point-to-point communication** (or other comparable protocols like FSK BAILEY). The modulated numeric signal is added to the traditional 4-20mA signal. In this case, each sensor is connected to a multiplexer which is, in turn, connected to the next-higher level. We should note that HART also has a somewhat marginal variant known as a multi-drop set-up, which allows for connecting up to 15 components on the same current loop (whose current is then boosted to 4mA).
- **Architectures based on a fieldbus like PROFIBUS or Foundation Fieldbus** (or even WorldFIP, under certain conditions). These architectures all tend toward a similar model composed of a low-speed fieldbus connected to level 0 and a high-speed network linking the low-speed segments with the higher-level components. (NB: depending on the size and type of the installation, it is not mandatory to use the high-speed layer; the low-speed segments can be directly connected to level 1.) These variants are illustrated in Figure 4-1.

3.2.3 General remarks

This section presents a general overview of the present supply, together with the strategic options chosen by the main manufacturers.

3.2.3.1 Increasingly widespread use of smart sensors

As the first part of this report also shows, smart sensors have become very commonplace today. They represent some 80% of the total supply for continuous process applications. According to most people interviewed, all transmitters will probably be smart within five years.

The success of the HART protocol is largely responsible for this situation. This protocol makes it possible to replace the entire existing analog pool without disruption, as it guarantees 4-20mA compatibility. This does not necessarily mean, however, that the users are making full use of the functionalities offered by smart sensors.

The manufacturers surveyed take a relatively assertive stand, saying that HART will progressively be superseded by totally digital fieldbuses. However, this transition will definitely be less gentle than the shift to HART, so that this technology would seem to have a little breathing space still.

3.2.3.2 Practical appraisal of the fieldbus sensor offer

Table 3-1 presents an overview of current supplies in smart instrumentation from the main manufacturers for measuring temperature and pressure, together with non-differential pressure devices and valve positioners.

With few exceptions, all the manufacturers surveyed propose, for each type of instrument, at least one fieldbus version (PROFIBUS or Fieldbus Foundation). HART-only instrumentation corresponds most often to old set-ups, which do not justify the investment needed for a change to a fieldbus configuration.

Table 3-1
Overview of current supplies in smart instrumentation

Instrument manufacturer	Pressure sensor					Temperature sensor					Flow sensor (non differential)					Actuator				
	Name	Type	H	F	P	Name	Tech.	H	F	P	Name	Techno.	H	F	P	Name	Type	H	F	P
ABB	600T Series	abs. + rel. + dif.	H		PA	650T series		H			COPA-XE / MAG-XE	Electromag.	H		PA DP	Contrac	Electric actuators	H		DP
	Contrans P	abs. + rel. + dif.	H		PA	Contrans T		H	F	PA	COPA-XM / MAG-XM	Electromag.	H		DP	TZID	Electropneum. positioner.	H		PA
											MAG-SM / MAG-FX	Electromag.	H	F	DP					
											COPA-XT	Electromag.	H							
											SWIRL SM	Swirl	H		DP					
											SWIRL ST / SR	Swirl	H		PA					
											MassMeter	Coriolis	H							
											TRIO-MASS / TRU-MASS	Coriolis	H		DP					
											VORTEX VM	Vortex	H		DP					
											VORTEX VT/VR	Vortex	H		PA					
											MAG MASTER	Electromag.	H							
											WEDGEMASTER	"Wedge" ?	H							
Endress & Hauser	Cerabar S	abs.+ rel.	H	F	PA	TMD 834	2 voies			PA	Promag 33, 35	Electromag.	H		PA DP					
	Cerabar M	abs.+ rel.	H			TMD 832		H			Promag 39	Electromag.	H							
	Deltabar S	dif.	H	F	PA						Promass 63	Coriolis	H		PA DP?					
											Prosonic DMU 93	Ultrason	H							
											Prowirl 77	Vortex	H		PA					
Fisher Rosemount	3051	abs. + rel. + dif.	H	F		3244 MV	2 channels	H	F		5300	Coriolis		F		DVC 5000	Valve positioner	H	F	
	1151	abs. + rel. + dif.	H			3144		H			8732	Electromag.	H							
	2088	abs.+ rel.	H			644		H			8742C	Electromag.		F						
	2090	abs.+ rel.	H								8712	Electromag.	H							
											3095 MV	Multivariable	H	F						
											3095 FT	Multivariable	H							
											MASS PROBAR	Multivariable	H							
											8800	Vortex	H	F						
Honeywell	ST série 900	abs.+ rel. + dif.	H	F		STT350	2 voies		F		SMV 3000	Multivariable	H							
						STT250		H												
Siemens	SITRANS P	abs. + rel. + dif.	H		PA	SITRANS T	2 voies	H		PA	SITRANS F	Ultrasound	H		PA	SIPOS	Electric actuators			FMS DP
																SIMODRIVE POSMO A	Positioner			DP
																SIPART PS2	Electropneum. positioner	H		PA
Yokogawa	Dpharp EJA	abs. + rel. + dif.	H	F		YTA	2 voies	H			YF	Vortex	H	F		YVP	Valve positioner		F	

3.2.3.3 Fieldbus sensors: breakdown by measurand

If one looks at all products now available from all manufacturers, the raw figures are somewhat difficult to compare as different products in a single range may be counted several times (and an exhaustive list is difficult to draw up as some 60 manufacturers are involved). However, a corrected count can give a general picture:

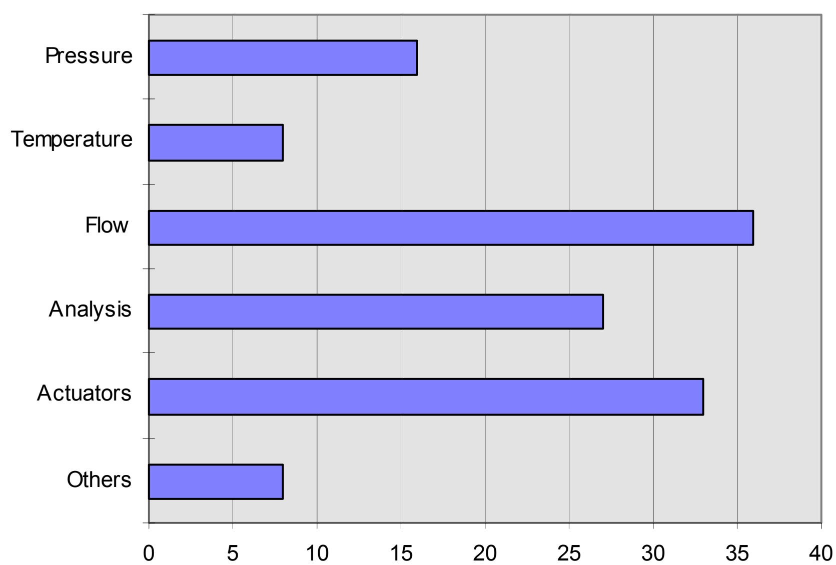


Figure 3-1
Fieldbus sensors: breakdown by measurand

Generally speaking, the electronic communication module integrated in a sensor represents a significant additional cost, which is easier to justify for a more elaborate, and therefore more expensive, component, for which the additional expense is proportionately less while the potential gains generated by the fieldbus connection are greater (maintenance, etc.).

On the other hand, the cost of this option is more critical in the case of temperature transmitters, which is one reason for the low number of fieldbus-compatible temperature sensors now available. The few models which have taken this step therefore incorporate enhanced characteristics, beginning with the presence of two measurement channels and the implementation of the corresponding advanced functions:

Calculation of the mean, the difference, the minimum and/or maximum of the two channels,

Selection at will of the measurement from one or the other channel, or the result of the calculation, Automatic shift to the unaffected channel in the event of a detected failure (short circuit, probe rupture).

Above and beyond the cost factor, the over-representation of non-differential pressure devices, physico-chemical analyzers and actuators can also be explained by the diversity of techniques available in each of these categories, and therefore by the wide variety of models offered by each manufacturer: electromagnetic, Coriolis, ultrasound flowmeters; pH, conductivity, oxygen analyzers; electric and electropneumatic actuators, etc.

3.2.3.4 Breakdown between PROFIBUS and Fieldbus Foundation

Subject to the same reservations as stated earlier, the breakdown of instruments by measurand and by compatible fieldbus for all manufacturers gives the following distribution:

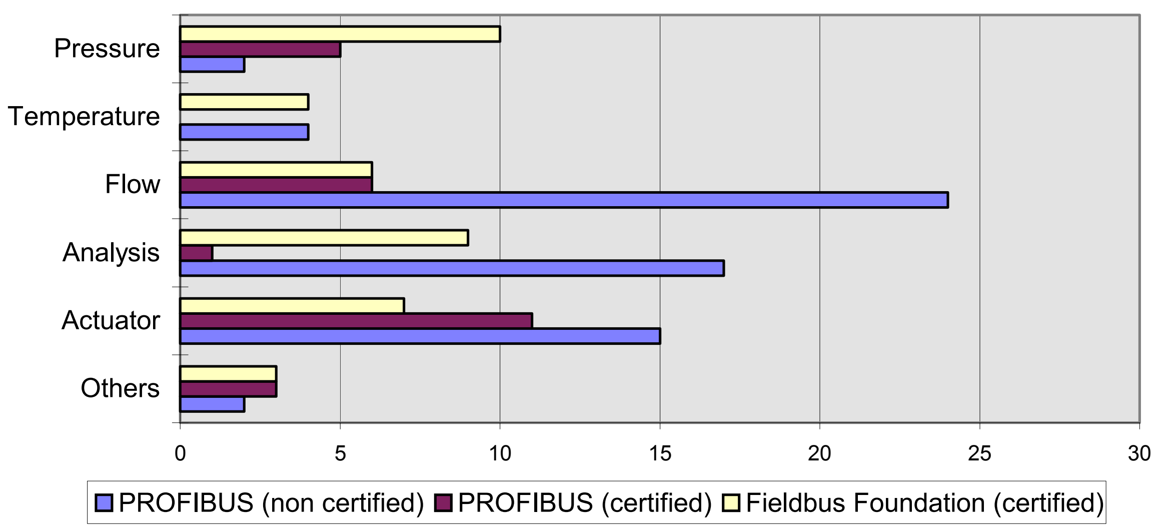


Figure 3-2
Breakdown between PROFIBUS an Fieldbus Foundation

Slightly younger than PROFIBUS (first FF products available in 1998 compared with 1996 for PROFIBUS PA), the Fieldbus Foundation has already made up for lost time, as least in quantitative terms, as regards the fundamental measurands (pressure and temperature). PROFIBUS preserves its lead, however, for more complex measurands (non-differential pressure, physico-chemical analysis) or for actuators (valve positioners).

Rapid growth in products compatible with the Foundation Fieldbus continues, and should be confirmed if the main manufacturers are to be believed.

3.2.4 The supply by manufacturer

3.2.4.1 ABB

For the measurands of pressure and temperature, ABB proposes two sensor families in each case, since its relatively recent acquisition of Elsag Bailey Hartmann & Braun:

- Pressure: "600T Series" and "Contrans P"
- Temperature: "650T Series" and "Contrans T"

This duplication in the range does not simplify the manufacturer's offer. This problem is all the more noticeable in the wide range of non-differential pressure devices (not discussed here), and in its system proposals. However, ABB promises a future concentration of its supply around a future range of 2000T pressure sensors (specifically designed for a fieldbus), and TH (HART) and TF (PROFIBUS mid-2000 and Fieldbus Foundation in 2001) temperature sensors.

At the present time, with the exception of temperature transmitters in the current 650T series, each family (pressure or temperature) offers a HART or PROFIBUS PA interface. Quite recently (end of 1999), the 600T also comprises a Foundation Fieldbus interface. This development has been simplified by the fact that the 600T series uses a modular architecture, which also enables replacing the communication module in the field without demounting the measurement device. Generally speaking, ABB says its offer will continue the trend toward Foundation Fieldbus compatibility.

While processing functions differ depending on the range, they are relatively sophisticated in pressure transmitters: in addition to classic linear conversions and square root extraction (for flow measurement on the basis of differential pressure), we find a 5^{th} degree polynomial (600T) and a curve which can be configured on 22 points (Contrans P). In particular, these functions allow for calculating level on the basis of the pressure in irregularly shaped tanks.

The Contrans P also allows for PID calculation, which is not common on the PROFIBUS PA (unlike FF).

3.2.4.2 Endress+Hauser

For the measurands of pressure and temperature, Endress+Hauser propose the following:

- Pressure: Deltabar S (differential pressure) and Cerabar S (absolute/relative pressure) (Cerabar M, only for HART, is an economical version of Cerabar S)
- Temperature: TMD832 and TMD834.

Because it has no system offer, Endress+Hauser are obliged to follow other manufacturers in their fieldbus offer. This has encouraged them to use a modular architecture, which separates the communication module from the measurement module (cell + electronic compensation module). Since 1997 they have had a complete PROFIBUS PA-compatible range, and are now in the process of providing the same for Fieldbus Foundation: pressure and radar level available since the end of 1999, temperature transmitters and other measurands (conductivity, pH, electromagnetic flowmeters, vortex, etc.) available since 2000.

It must be noted that, while they do not offer PLCs, Endress+Hauser are rather skeptical with regard to the distributed control concepts advocated by Fieldbus Foundation. The manufacturer believes that control parameters will change in accordance with the overall context of an installation, and that a centralized system is more capable of handling such change.

3.2.4.3 Fisher-Rosemount

For the measurands of pressure and temperature, Fisher Rosemount propose the following:

- Pressure: 3051
- Temperature: 3244MV

Many other instruments are available for these two measurands with HART technology (P: 1151, 2088, 2090, T: 644, 3144) but these models correspond to the manufacturers older ranges, less sophisticated in both metrological and functional terms.

As a locomotive in the Fieldbus Foundation, Fisher-Rosemount offers only interfaces with their fieldbus, as well as with HART of course, since it was theirs to begin with. This is why Fisher-Rosemount is also the supplier of the universal "HART 275 pocket", which can be used with all HART-registered components no matter who the manufacturer.

In accordance with Fieldbus Foundation function block logic, the 3051 allows for PID calculation, making it possible to integrate it in a local control loop. Moreover, for reasons common to all instruments of this type (mentioned in section 3.2.3.3), the 3244MV temperature transmitter has two measurement channels and the corresponding processing functions (mean, difference, redundancy, etc.), as well as two PID blocks. Furthermore, the 3244MV can replace the segment LAS (the Fieldbus Foundation *Link Active Scheduler*) in the event of failure in the segment.

Finally, it should be pointed out that Fisher-Rosemount products extend to other measurands (in particular for analysis), valve positioners (DVC5000) and systems, with DeltaV. The AMS software is a good option for exploiting intelligent functions in management and maintenance support in present-day parks of smart components.

3.2.4.4 Honeywell

For the measurands of pressure and temperature, Honeywell proposes the following:

- Pressure: Series 900 (and Series 100),
- Temperature: STT350 and STT250.

These instruments are part of the Honeywell TDC3000X system offer, based in particular on the use of its own DE digital protocol (similar to HART). However Honeywell is now part of the

Fieldbus Foundation and proposes optional FF interfaces for its top-of-the-range pressure and temperature sensors.

3.2.4.5 Siemens

For the measurands of pressure and temperature, Siemens proposes the following:

- Pressure: SITRANS P
- Temperature: SITRANS T

It should be noted that the Siemens range is, as they themselves admit, still incomplete as regards, for example, non-differential pressure flowmetering (only one SITRANS F ultrasound model).

Siemens is the prime backer of PROFIBUS and all of its sensors can be connected to PROFIBUS PA. It should be noted that, despite this exclusivity, Siemens integrates PROFIBUS communication functions in a module separate from the measurement module.

The SITRANS T3K module is mounted on the probe head, and offers two temperature measurement channels and the related calculation and redundancy functions.

3.2.4.6 Yokogawa

For the measurands of pressure and temperature, Yokogawa proposes the following:

- Pressure: EJA510/530 and EJA110,
- Temperature: YTA310/320.

These products are Foundation Fieldbus-compatible.

3.2.5 Features of the principal products

This section summarizes the features of the smart sensors used for pressure and temperature measurement and available from ABB, Endress+Hauser, Fisher Rosemount, Honeywell, Siemens and Yokogawa. In most cases, only the most recent series are mentioned here. The oldest sensors correspond to the smart version of traditional sensors adapted to HART, and therefore have less highly-developed functions and efficiency than the new generation.

	MANUFACTURERS NAME
	Name of the series of smart sensors
Measurands Technology	This section lists the measurands concerned (absolute, relative, differential pressure [giving level and flowrate] or temperature) This section gives the technology of the cell.
Metrological data (manufacturers specifications)	
Ranges Precision Rangeability Delay	These are the main metrological data announced by the manufacturer and are given as an indication only. In general, precision is understood as not including drift due to temperature, static pressure or aging of the sensor. NB: for a given announced feature, the available products are not all offered under similar conditions, so that accurate comparison between products can be difficult
Main functions	
Zero span, full scale setting	This heading concerns the zero and full scale adjustment mode. These settings may be made on the sensor itself or at a distance, over the fieldbus or the portable pocket
Calculation functions	Functions of linear and square root calculation and specific processing functions.
Correction of secondary measurements	These are measurements of secondary values for correction / compensation of the main measurement (they depend primarily on the cell and probe technology).
Test for measurement validation	These are tests to validate the way in which the measurement was built up (raw, secondary, functional measurements).
Test for proper functioning	These are tests to validate the intrinsic functioning of the sensor (tests on the main components, the current loop, etc.)
Communication modes	
Protocol	The protocol used.
Average prices	
Sensor price	Prices given for the sensors are only approximations (average prices for each series). They may vary considerably depending on the sensor range, resistance to the environment, materials used permitting specific connections.
Special features	
	Here we find any functionalities or design specificities which notably distinguish the sensor from other products on the market.

	ABB					
	600T Series		Contrans P		650T Series	Contrans T
Measurands Technology	p^{abs}, p^{rel}, Level dry ceramic or piezo-resistive	ΔP, Level, Q inductive	p^{abs}, p^{rel}, Level Capacitive or inductive	ΔP, Level, Q Capacitive or inductive	T RTD, TC, Ohm, mV	T RTD, TC, Ohm, mV
Metrological data (manufacturers specifications)						
Ranges	420 bar	24 bar (PN=420bar)	600 bar	40 bar (PN=400bar)	Depending on the probe	Depending on the probe
Precision	from 0.15 to 0.25%	0.1%	0.1% (0.2% >10:1)	0.1% (0.2% >10:1)	Same (typically <0.1%)	Same
Rangeability	10:1	20:1	30:1	20:1	1.5s	1s
Delay	0.2s	0.2s	0.15 to 1.3s	0.15 to 1.6s		
Main functions						
Zero span, full scale setting	Local, pocket or PC		Local, pocket or PC		Pocket	Pocket or PC
Calculation functions	Linear 5th order polynomial	Same + $x^{1/2}$, $x^{3/2}$, $x^{5/2}$	Linear, 22 point curve, PID	Same + $x^{1/2}$	Standard linearization	Standard linearization or 32 pts 1st order filter
Correction of secondary measurements	Ambient T	Ambient T + Static P	T cell	T cell	T cold junction	T cold junction
Test for measurement validation	Comparison with measuring range		NA		Rupture (other data NA)	Comparison with measuring range, short circuit, rupture
Test for proper functioning	Test of the cell, the electronics, the consistency of configuration data		NA		Defective device (other data NA)	ADC test, Autotest CPU
Communication modes						
Protocol	HART, PA (Profile NA), FF		HART PA (B Profile)		HART	HART, PA (B Profile)
Average prices						
Sensor price	NA on 14 Jan 2000	NA on 14 Jan 2000	NA on 14 Jan 2000	NA on 14 Jan 2000	FRF 2.5 thousand	PA: FRF 3.5 thousand
Special features						
	Compensation for static pressure Communication module replaceable in the field		PID Event counter Memorization of the maximum			

	ENDRESS+HAUSER			
	Cerabar S	Deltabar S	TMD 832	TMD 834
Measurands Technology	p^{abs}, p^{rel}, Level Capacitive or piezo-resistive	ΔP, Level, Q Capacitive or piezo-resistive	T: probe head (bi-sensor) RTD, TC, Ohm, mV	T probe head RTD, TC, Ohm, mV
Metrological data (manufacturer specifications)				
Ranges Precision Rangeability Delay	400 bar 0.1% 20:1 0.15s	40 bar (PN=420 bar) 0.1% to 0.2% depending on range 20:1 0.4 to 1.6s depending on range	Depending on the probe Same (up to 0.15°C)	Depending on the probe Same (up to 0.2°C) NA
Main functions				
Zero span, full scale setting	Keys or pocket	Keys or pocket	PC or pocket	PC or fieldbus
Calculation functions	Linear or programmable (21 points)	Same + $x^{1/2}$	Standard linearization. Mean, difference, selection or "smart" mode	Standard linearization
Correction of secondary measurements	T cell	T cell	Cold junction	Cold junction
Test for measurement validation	T cell correlation / Expansion	T cell correlation / Expansion	Short circuit, rupture, measuring range	Short circuit, rupture, measuring range
Test for proper functioning	From the cell (reference capacity) to the current outlet	From the cell (reference capacity) to the current outlet	Autotest	Autotest
Communication modes				
Protocol	HART, INTENSOR, FF, PA (profile NA)	HART, INTENSOR, FF, PA (profile NA)	HART	PA (profiles A and/or B)
Average prices				
Sensor price	FRF 4.5 thousand (+FRF 0.9 thousand for fieldbus sensors)	FRF 5.5 thousand (+FRF 0.3 thousand for fieldbus sensors)	FRF 1.7 thousand	FRF 2.5 thousand
Special features				
	Possibility of changing the communication module or the cell FF: AI (TB, RB)	Possibility of independently changing the communication module or the cell FF: AI (TB, RB)	Smart mode = mean of the two channels; or unaffected channel in case of failure of the other	

	FISHER ROSEMOUNT				
	3051		1151, 2088, 2090	644	3244MV
Measurands Technology	p^{abs}, p^{rel}, Level Capacitive or piezo-resistive	ΔP (Level, Q)	P	T	T (2 channels) RTD, TC, Ohm, mV
Metrological data (manufacturer specifications)					
Ranges Precision Rangeability Delay	700 bar 0.075% 100:1 0.1s	138 bar 0.075% 100:1 0.1s	Former product line (no information)	Former product line (no information)	Depending on the probe Same (min .0.1°C)
Main functions					
Zero span, full scale setting	Pocket (HART) or fieldbus (FF)				Pocket (HART) or fieldbus (FF)
Calculation functions	Linear, $x^{1/2}$ PID option	Linear, $x^{1/2}$ PID option			Correction Ro, A, B Calculation on 2 channels: min, max, delta, mean. 1st unaffected channel
Correction of secondary measurements	T cell	T cell			Cold junction + T°amb
Test for measurement validation	Comparison with measuring range				Comparison with measuring range
Test for proper functioning	Yes, not specified (CPU, CAN, etc.)				CPU, ADC, ambient T...
Communication modes					
Protocol	HART, FF		HART	HART	HART, FF
Average prices					
Sensor price	FRF 6 thousand +15 to 20% for FF	FRF 6.9 thousand +15 to 20% for FF		(2thousand)	FRF 4 thousand +15 to 20% for FF
Special features					
	Provides process T; PID block optional 50 ms response time; FF: PID, 2AI, RB				2 block PID (3AI, RB) fieldbus scheduler

	HONEYWELL		
	ST3000 900 series	STT250	STT350
Measurands Technology	p^{abs}, p^{rel}, Level, ΔP, Level, piezo-resistive Q	T: on DIN rail or probe head RTD, TC, mV, Ohms	T: on DIN rail (possibility of 2 channels) RTD, TC, mV, Ohms
Metrological data (manufacturer specifications)			
Ranges Precision Rangeability Delay	415 bar 0.1% (0.2% depending on range) 12:1 (40:1 depending on range) NA	Depending on the probe Same (min. 0.2°C)	Depending on the probe Same (min. 0.1°C)
Main functions			
Zero span, full scale setting	Pocket (HART) or fieldbus (FF)	Pocket (DE[3], HART) or system (DE)	Pocket (DE) or system (DE, FF)
Calculation functions	Linear, $x^{1/2}$	Standard linearization or programmable	Standard linearization or programmable Difference, minimum, maximum, redundancy
Correction of secondary measurements	Ambient T, Static P	External cold junction compensation Ambient T	External cold junction compensation
Test for measurement validation	yes NA	Probe rupture	Probe rupture (other data NA)
Test for proper functioning	yes NA	ADC test	yes NA
Communication modes			
Protocol	HART, FF	HART, DE	DE, FF
Average prices			
Sensor price	~ FRF 4 thousand (FRF 6 thousand for FF)	~ FRF 1.5 thousand	~ FRF 2.5 thousand for FF
Special features			
	Compensation for static pressure FF: AI, PID, RB		FF: AI, PID, RB

[3] DE is a proprietary Honeywell protocol, superimposed on 4-20mA current like HART

	SIEMENS			
	SITRANS P		SITRANS T T3K	SITRANS T TK-H
Measurands Technology	p^{abs}, p^{rel}, Level Capacitive or piezo-resistive	ΔP, Level, Q Capacitive or piezo-resistive	T (1 or 2 channels) probe head TC, linearized platinum probes	T probe head
Metrological data (manufacturer specifications)				
Ranges Precision Rangeability Delay	400bar 0.1% 30:1 0.2s	30bar (PN=400bar) 0.1% 30:1 0.2 to 0.3s	Depending on the probe Same	Depending on the probe Same (min. 0,1°C)
Main functions				
Zero span, full scale setting	Keys, PC or pocket		Fieldbus	Pocket
Calculation functions	Linear	Linear $x^{1/2}$	Linearization (std or programmable) Mean (shift to unaffected channel in case of failure) or difference (T2-T1)	Linearization (std or programmable)
Correction of secondary measurements	T cell	T cell	Cold junction	Cold junction
Test for measurement validation	Comparison with measuring range, T_ cell, T_ internal		rupture, short circuit	rupture, short circuit
Test for proper functioning	Autotest (not specified)		Autotest (not specified)	Autotest (not specified)
Communication modes				
Protocol	HART (PA now available)	HART, PA (A/B profile)	PA (B profile, v3)	HART
Average prices				
Sensor price	FRF 4 thousand (PA +FRF 1 thousand)	FRF 5.5 thousand (PA +FRF 1 thousand)	2 channels: FRF 2.2 thousand	FRF 1.4 thousand
Special features				
	Separate communication module			

	YOKOGAWA		
	EJA 510A/530A	EJA 110A	YTA (YTA310/320)
Measurands Technology	p^{abs} (510A), p^{rel} (530A) Silicon resonators	ΔP, Level, Q Silicon resonators	T (1 or 2 channels) RTD, TC, mV, Ohm
Metrological data (manufacturer specifications)			
Ranges Precision Rangeability Delay	0.1 - 2 / 1-20 / 5-100 / 50-500 bar 0.2% 100:1 0.2s	0.1 / 1 / 5 / 140 bar (PN=35 or 140 bar) 0.075% 100:1 0.2s	Depending on the probe Same (min. 0.14°C) 0.5s
Main functions			
Zero span, full scale setting	Local or pocket Pocket	Local, pocket or bus Pocket or bus	NA on 14 January 2000 (local commutator or pocket?)
Calculation functions	Linear	Linear, $x^{1/2}$	Difference, mean, redundancy
Correction of secondary measurements	NA on 14 January 2000 (process T)	NA on 14 January 2000 (process T + static P)	NA on 14 January 2000
Test for measurement validation	NA on 14 January 2000		Input signal, ambient temperature
Test for proper functioning	NA on 14 January 2000		EEPROM error, CPU error
Communication modes			
Protocol	HART, BRAIN (FF projected)	HART, BRAIN, FF	HART, BRAIN (FF projected)
Average prices			
Sensor price	FRF 3.5 thousand (FF: NA)	FRF 5 thousand (FF: NA)	310:†FRF 4.2 thousand / 320: FRF 5 thousand (FF NA)
Special features			
	FF: 2AI, RB		

3.3 Synthesis

3.3.1 Metrological performance

The introduction of digital technology in instrumentation has had a significant positive impact on metrological performance. Rangeability, for example, which typically did not exceed 5:1 for an analog sensor, now regularly reaches 20:1 (rangeability with constant precision).

Similarly, compensation of secondary measurements (temperature, static pressure) and correction of non-linearities of the cell enable significant improvement in the ranges of precision (less than 0.1%), and limit their drift over time (up to 0.15% in 5 years).

The downside is that the communication functions increase the global delay of the sensor. Added to the delay of the transmitter, it is around 500 ms for HART. On the Foundation Fieldbus, however, Fisher Rosemount promises less than 100 ms for its 3051 pressure sensor. Generally speaking, few manufacturers provide this kind of information.

3.3.2 Communication protocols

Aside from the HART protocol, now accepted by all manufacturers of smart instrumentation, only PROFIBUS and Foundation Fieldbus offer a significant range of compatible products. More products are compatible with PROFIBUS than with Fieldbus Foundation, though the latter appears destined for rapid growth in view of what most manufacturers are announcing.

While each of the two technologies benefits from significant compatibility, it must be noted that only top-of-the-range instruments have encouraged manufacturers to invest in fieldbus communication, making it a more expensive technology today in two ways (advanced metrology + communication instrumentation). This will probably be less true in the near future.

3.3.3 Modular design

Well aware of the uncertainties related to the future of communication standards, which disturb the manufacturers as much as the potential users, most manufacturers are spotlighting the modular design of their sensors:

- measuring block: generally contains the transmitter, the A/D converter and a read-only memory to store the characteristics of the cell.
- communication block: performs digital communication functions according to a given protocol (HART, Fieldbus Foundation, PROFIBUS or dedicated protocol). Often, this block also contains the processing functions.

In this way, the manufacturers protect their investments and can adapt to future developments in standards (technical changes or new trends). Endress+Hauser for example, which is all the more dependent on changes in the standards because it has no system offer, says it can adapt its range to a new protocol in less than six months. This is what it did, in fact, to open up the catalogue to the Foundation Fieldbus in 2000.

Moreover, this specificity can be to the benefit of the users:

- possibility of changing the communication module with no manipulation of measurement elements, minimizing the risk of impact on the measurement process,
- possibility of making a gradual transition from one technology to another (e.g., HART to fieldbus), with no need to double the stocks of spare parts.

3.3.4 Functions offered

The relative standardization of communication protocols (now reduced to the three main technologies mentioned above) should tend to standardize the functions available in the different sensor ranges. It would appear, however, that they are, on the contrary, remaining relatively heterogeneous.

3.3.4.1 Common core functions

The common core functions offered in one form or another by sensors adaptable to HART, Fieldbus Foundation or PROFIBUS can be more or less summed up by the so-called universal functions defined by HART. These essentially make it possible to:

- read and/or write the identifiers for the measurement point (number, description, date),
- read configuration information (measuring range, damping),
- read the value of the current and the main variable (and its unit),
- read the value and unit of any secondary variables.

Furthermore, HART also defines what it calls common practice functions which, among other things, make it possible to:

- write the configuration data (damping, measuring range, unit, transfer function),
- force the output current (for testing).

3.3.4.2 PROFIBUS functions

The functions available in PROFIBUS sensors vary in accordance with the profile respected by the manufacturer. Basically, profile A concerns the general functions of a transmitter (analog input) and corresponds more or less to HART specifications, with alarm management in addition. A profile B sensor offers somewhat more advanced functions: configurable linearization, simulation of the value provided by the transmitter, parameters specific to the measurand (e.g., cold junction compensation for a temperature sensor), etc. Most manufacturers offer profile B sensors.

However, in addition to the fact that manufacturers do not always describe in detail the profile options available in their sensor, the combinations between optional or obligatory parameters and A or B profiles (version 3 replacing version 2) result in an extremely diverse range of possible functions.

3.3.4.3 Foundation Fieldbus functions

The functions offered by Foundation Fieldbus sensors depend on the *function blocks* offered by each manufacturer. With the exception of Fisher-Rosemount which, among other things, offers a PID block in each of its pressure and temperature models, the other manufacturers generally limit themselves to the basic minimum: *resource block* (identifiers, type of sensor, versions, etc.) and *analog input* (essentially: status, conversion into physical values, damping, alarms, simulation). We need to go to the Brazilian manufacturer SMAR (which is quite modest in size) to find more sophisticated blocks such as totalizer, arithmetic functions, etc.

Some manufacturers are waiting for developments on the part of Fieldbus Foundation technology (in particular, a profile concept closer to that of PROFIBUS) before investing further in relatively costly software development.

3.3.4.4 Conclusion

Despite the relative standardization of the well-known protocols, the functions offered by smart sensors are quite diverse, depending on the range. Nonetheless, we should not be overly concerned about poor interoperability. Configuration parameters, for example, were not standardized either, at the time of analog sensors. Furthermore, software tools today can be interposed to provide a unified view of most advanced functions (diagnosis, configuration).

3.3.5 Price

Since 1994, the price of smart sensors has dropped along with that of other sensors (by some 20 to 30%). The price of HART sensors is now the benchmark, as all sensors will inevitably be digital within the next few years.

The additional cost of fieldbus communication corresponds to around FRF 1 thousand, or a 20% increase in the price of a pressure sensor, but very often a 50% increase for a temperature sensor (except for the very advanced models, whose price is already close to that of pressure transmitters).

Moreover, we should remember that fieldbus access is, at the moment, offered only by relatively recent products. As a results, there is, as in the case for HART, no fieldbus sensor offer developed in the economy ranges which provide a little less precision for a markedly lower price.

3.4 Conclusion

This overview helps us to describe the current offer in terms of the four functions expected of a smart sensor:

- Communication function: as HART is now virtually the universal protocol, all manufacturers are expanding their product lines with fieldbus compatibility, first for PROFIBUS and a little more recently for Fieldbus Foundation (except for those who exclusively advocate one or the other solution).
- Measurement function: because of the various compensations performed by the internal instrumentation, the metrological performance of smart sensors is noticeably better in terms of precision, with a corresponding reduction in temporal drift. The differences among the suppliers relate to the secondary measurements used (such as static pressure) and the configuration of the conversion into physical values (standardized, polynomial, etc.).
- Validation function: the criteria taken into account to validate a measurement are increasingly numerous (comparison with the measuring range, but also heating, various types of self-diagnosis, etc.). Some manufacturers hide (quite legitimately) behind industrial secrecy so successfully that it is difficult to compare sensors in this respect. Others mention the risk of false alarms, linked to the growing complexity of self-monitoring. In addition, fallback techniques are increasingly sophisticated (default values, last correct value, second measurement channel, etc.)
- Configuration function: this relates to reading or writing the parameters needed for the other functions. Above and beyond the functional differences which it simply repeats, this function reveals the differences in representation of configuration information, among the various protocols but also within a given protocol (e.g., optional or obligatory parameters for PROFIBUS A or B profiles [v2 or v3]).

In light of these conclusions, it would appear that the current market offer has reached maturity. The main unknowns are related to the difficulties inherent to the use of heterogeneous equipment, particularly with respect to their configuration parameters. In this respect, both feedback and evaluation of dedicated software tools must be considered indispensable.

4

STANDARDIZATION AND TECHNICAL CONSIDERATIONS

This section discusses standardization and technical considerations as they relate to fieldbuses adapted to continuous process control; these fieldbuses must be considered as the spinal column of modern digital control systems.

4.1 Approach

The information relative to standardization is based on publications on the subject [2], and has been validated with the EDF representative (R&D/IPN) on IEC Technical Committee 65 (Industrial Process Measurement and Control). The technical data on fieldbuses essentially comes from information [12] [13] [14] [15] [16] provided by the entities responsible for the various solutions. All information has been cross-checked or complemented with information collected from manufacturers or other key players.

4.2 Presentation

This section is structured in two parts. The first analyzes progress made in standardizing fieldbuses at CENELEC and the IEC, and describes a number of possible short-term scenarios. The second presents the main characteristics of four important fieldbuses, describing their main points of divergence.

4.3 Standardization

Standardization was a crucial challenge for fieldbus technology. In the face of the multiplicity of technical solutions available, which were often redundant, international standardization of one solution could have offered the guarantees users most needed in terms of continuity and interoperability.

For this reason, the attempt to draw up a standard was a source of serious conflict among a number of pressure groups, highly influenced by the main manufacturers. The latter did all in their power to influence the standard in the direction of their own technical solutions, or to neutralize any drift in another direction.

As this section relates, the most recent events in the domain leave very little hope that a solution will be found which is satisfactory to the end users.

4.3.1 A reminder about standardization

For a more detailed description of the bodies involved, please see the 1997 paper on the subject [10]. Most progress has been made recently in the International Electrotechnical Commission or IEC (for the **IEC 1158** standard), and more particularly, in the following sub-structures:

- Technical Committee TC65 ("Industrial Process Measurement and Control"),
- Sub-Committee SC65C ("Digital Communication"),
- Working Group WG6 ("Fieldbus").

The IECs work must be seen in the context of European standard **CENELEC EN 50170,** which has already been adopted but may yet incorporate other solutions.

4.3.2 The situation in 2000

IEC Standard 61158, adopted in January 2000, contains no less than eight protocols, each backed by a different group of manufacturers and totally incompatible with the others. Following the vote, a vast effort was undertaken by the IEC to harmonize the protocols, in view of the fact that the standard adopted was no more than a juxtaposition of the specifications of different protocols with no common architecture and no unity in the terminology used. The table below summarizes the standard and the protocols it includes.

Table 4-1
The IEC 61158 standard in January 2000

Layers	References	Observations
General presentation	IEC 61158-1	Prepared
Physical layer	IEC 61158-2	Defined and voted in 1993. FF, WorldFIP and Profibus PA conform
Data link layer - Services - Protocols	 IEC 61158-3 IEC 61158-4	Voted in January 2000. Each of these standards belong to different protocols. - Type 1: TS* - Type 5: FF-HSE - Type 2: ControlNet - Type 6: SwiftNet - Type 3: Profibus - Type 7: WorldFIP - Type 4: P-Net - Type 8: Interbus S
Application layer - Services - Protocols	 IEC 61158-5 IEC 61158-6	
System Management	IEC 61158-7	Prepared
Conformity test	IEC 61158-8	Standby
* FF-H1 is conform to these Technical Specifications.		

Up until mid-1999, **Fieldbus Foundation** (backed by WorldFIP) had succeeded in orienting the work of the IEC toward a solution much closer to its own choices than to those of PROFIBUS. The image of "future international standard" probably served its cause considerably and the end result was therefore a semi-failure. However, it had become urgent to make promises a reality, and Fieldbus Foundation therefore achieved a vital objective in managing, subject to a few concessions, to become integrated in a standard, and an international one at that. Incorporation of HSE constituted an unexpected bonus which was to promote the 100Mb/s Ethernet as the standardized fieldbus physical layer (in total opposition to the physical layer already approved, 1158-2).

PROFIBUS managed to sidestep the threat of an extremely unfavorable international standard. Now that integration in this standard is no longer a discriminating factor for anyone, PROFIBUS can distinguish itself from its competitors by highlighting its widespread presence in the European market. Finally, making the most of the combinations of profiles integrated in IEC 1158, it would appear that PROFIBUS might also attempt to expand its specifications (cf. section 4.4.4) so as to win over the market for manufacturing and/or critical time processes.

WorldFIP finds itself in a more delicate situation. In the past, IEC 1158 had been more favorable to WorldFIP than to PROFIBUS and revealed a certain convergence with Foundation Fieldbus. It is probable that WorldFIP will move even closer to Fieldbus Foundation (as a deterministic fast layer, for example) to consolidate its European market share, against PROFIBUS. It is less likely that PROFIBUS would solicit WorldFIP to develop a joint high-performance solution

ControlNet, a fieldbus developed for manufacturing processes and backed by Rockwell Automation, is also looking for European support and for complementarity with Fieldbus Foundation; both of these ambitions oppose it to WorldFIP. However, its non-inclusion in EN 50170 is a major drawback for its implantation in Europe.

4.3.3 Forecasts

Now that we know the finalists, it would appear that the next challenge will be to build up a broader offer (under a single brand name) that meets the needs of continuous processes as well as manufacturing and/or critical time processes. **Fieldbus Foundation** has its future HSE protocol for this, but technical limitations inherent to Ethernet may encourage it to prefer alliances with **WorldFIP** or **ControlNet**. The latter will probably seek such alliances but, setting aside cultural differences, **PROFIBUS** is also a potential ally. The latter may also choose to develop its own high-performance solution, as suggested above, using elements of the international standard.

4.4 Elements of comparison

As the preceding section has shown, technical features are far from being the only differentiating factor among the various available fieldbus technologies. Nonetheless, insofar as it is more or less accepted that incompatible solutions will continue to co-exist, it may be useful to recall the main features of the four principal fieldbus technologies used for continuous processes: Fieldbus Foundation, HART, PROFIBUS and WorldFIP.

The detailed characteristics of the four solutions are given in the annex. This section sums up the main elements of comparison.

NB: strictly speaking, HART is not a fieldbus but, except for certain extensions, rather a point-to-point digital communication mechanism. Nonetheless, its widespread acceptance in the field of smart instrumentation makes it an interesting comparison for the fieldbuses which might want to be its "successor".

4.4.1 General features

4.4.1.1 HART

Originally destined only for "point to point" communication, HART superimposes a modulated FSK digital signal at 1200b/s over an analog 4-20mA signal, thus authorizing 2 to 3 digital transactions per second. Specifications have also been drawn up for a "multi-drop" extension (able to accept up to 15 components on the same loop). In this case, the analog signal is forced to 4mA for all the sensors. In all cases, the sensors can be powered by fieldbus and installed in an explosive zone, on condition that ad hoc barriers are used.

4.4.1.2 Foundation Fieldbus and PROFIBUS

The architectures proposed by Foundation Fieldbus and PROFIBUS converge toward a similar model composed of a low-speed fieldbus, connected to level 0, and a high-speed network linking the low-speed segments with the higher-level components. (NB: depending on the size and nature of the installation, use of the high-speed layer is not mandatory; the low-speed segments can be directly connected to level 1).

For PROFIBUS, the low-speed segments are **PROFIBUS PA** technology, whereas for Fieldbus Foundation, the **H1** fieldbus is used. These two technologies differ in their data link (OSI 2) and application (OSI 7) layers, but are dependent on the same physical layer (OSI 1) standardized in IEC 1158-2 at 31.25Kb/s on twisted pair, which authorizes a combined typology (bus/star, subject to certain constraints), power supply via the fieldbus and intrinsic security, but no redundancy (except with sensors combined on two distinct segments). Both technologies offer quite similar performance: typically 10 fieldbus-powered sensors with a global cyclic update frequency of 100 ms (for all 10 sensors) with the auxiliary possibility of periodic acyclic exchanges (e.g., alarms, reconfiguration commands, etc.).

NB: some components (e.g., electromagnetic flowmeters) consume more power than the fieldbus can supply, and therefore require separate supply even when connected to H1, PROFIBUS PA or HART.

The PROFIBUS high-speed network is **PROFIBUS DP**. It can reach 12 Mb/s (with mediocre efficiency for high numbers of transactions) on twisted pair or optic fiber, and authorizes redundancy. The Fieldbus Foundation **HSE** (now being developed) will supersede the now abandoned H2 project and will probably be based on 100 Mb/s Ethernet to offer performance which should be comparable to PROFIBUS DP. In the case of PROFIBUS, as for FF, gateways link the low-speed segments with the high-speed network.

PROFIBUS FMS, initially intended for communication between cells or among complex systems, appears threatened by the more open-ended emerging technologies based on Ethernet.

4.4.1.3 WorldFIP

In the absence of any major sensor suppliers in its ranks, WorldFIP is essentially limited to high-speed fieldbus technology (1Mb/s; separation of synchronous and asynchronous traffic, possible cable redundancy) with gateways to level 0: input-output racks, HART/FIP converters and (projected) H1(FF)/FIP converters. With this latter gateway, WorldFIP would like to position itself as a high-speed network complementary to Fieldbus Foundation H1. Obviously, this positioning would put it in competition with HSE, but the technology announced for the latter (100 Mb/s Ethernet) may leave room for a more robust alternative.

NB: this complementarity can also be explained by the assets of WorldFIP as a very-high performance fieldbus (speed, determinism), adapted to manufacturing and/or critical time processes, whereas Foundation Fieldbus technology is limited, today at least, to continuous process applications.

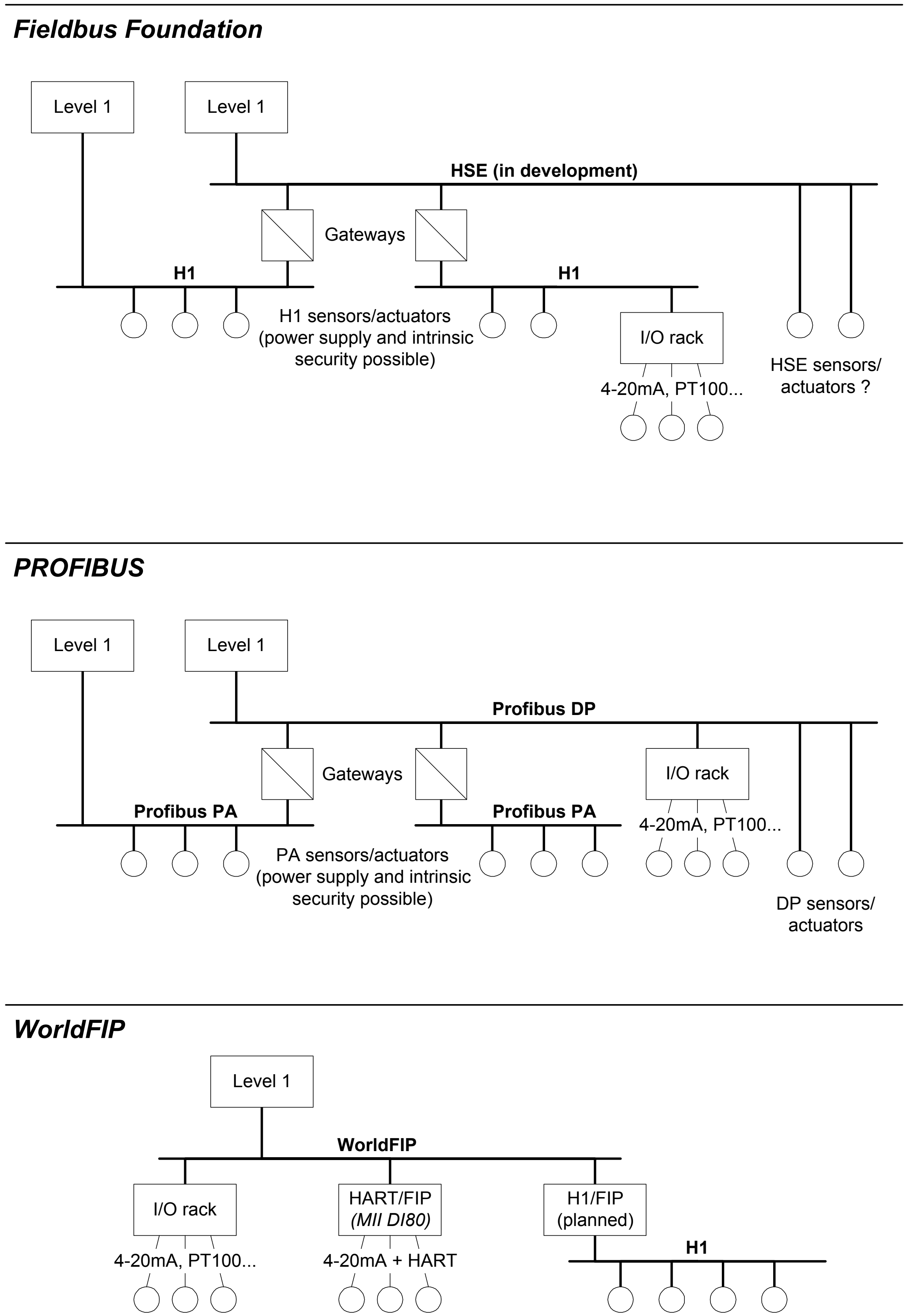


Figure 4-1
Typical Foundation Fieldbus, PROFIBUS and WorldFIP architectures

4.4.2 Interoperability and interchangeability

This section will not provide a definitive answer as to these questions but rather provide elements for reflection, describing the main mechanisms which might influence the performance of the different fieldbus technologies studied in terms of interoperability or interchangeability.

We should note that, strictly speaking, **interoperability** relates to the **possibility for different components to cooperate** whereas **interchangeability** makes it possible to **replace** one component with another. Given the reservations stated earlier, this difference will not be particularly important to the discussion that follows.

4.4.2.1 Certification procedures

Proposed by Fieldbus Foundation and PROFIBUS, the certification procedures consist in performing a series of specific tests to verify compliance of a product with the official specification. While not exhaustive, these procedures essentially avoid the most flagrant incompatibilities. However, they do not resolve certain inherent interoperability problems, as will be seen in section 4.4.2.2.

WorldFIP and HART have no systematic certification procedures. However, probably because its formalization is relatively simple and precise, we should note that HART enjoys a relatively good reputation in this domain.

4.4.2.2 Formalization of the description of data and functions

In terms of interoperability, the greatest challenge relates to the upper fieldbus layers. This section will therefore describe the fundamental principles of the four technologies studied.

4.4.2.2.1 HART

HART communication is based on three levels of commands:

- universal commands (e.g., read the component identifier, the current level, the main variable and its unit, etc.)
- common commands (*common practices*) (e.g.,: read the secondary values, specification of the minimum and maximum, forcing of 4-20mA current, etc.)
- commands specific to the component (defined by the manufacturer).

Furthermore, data and component functions are described using a Data Description Language ("DDL"). This description can be used by any master component (pocket or workstation) to enrich the man-machine interface associated with the connected component: value tags, display formats, help texts, etc.

4.4.2.2.2 Foundation Fieldbus (H1/HSE)

Foundation Fieldbus adopts the same principles as HART but the commands are replaced by the more sophisticated concept of blocks. Among others, each component has the following:

- a resource block (component name, manufacturer name, etc.),
- function blocks (analog input, digital output but also calculation of ratio, PID, etc.),
- transmitter blocks (associated to the measurement elements: type of transmitter, calibration, etc.)

This information is further enriched using "Device Descriptions" (described in DDL language, as for HART) whose generic elements (description of the resource block, for example) are provided by Fieldbus Foundation.

4.4.2.2.3 PROFIBUS (PA/DP)

With PROFIBUS, the main features of each component are described in a "GSD" file which contains the minimum information needed to use the component: versions, acceptable fieldbus speeds, number of inputs/outputs, minimum acceptable rhythm of updates, etc. However, this information is much more basic that that allowed by the DDL language, for example.

Moreover, PROFIBUS also defines a certain number of profiles that must be respected by the components. Two classes of compliance are defined:

- in class A, only the basic functions, independent of the measurand, are needed (transmitter block and analog input bloc integrating physical value, unit, identifier, etc.).
- in class B, the instrument must also conform to the profile of its category, among the following five: transmitter (temperature, pressure, level, flowrate), actuator, physico-chemical analysis, on-off input(s) or output(s). Thus a class B temperature transmitter can signal a probe rupture, integrate various types of cold junction compensation, manage redundancy between two inputs, etc.

In both cases, a certain number of parameters are required while others are optional. Version 3.0 of the specifications of these profiles was published in draft form at the end of 1999 [15].

4.4.2.2.4 WorldFIP

Historically, WorldFIP also advocates a system of profiles (in the form of "*companion standards*") but these leave considerable leeway to the manufacturers. In any event, the use of WorldFIP as a high-speed network on a higher level than HART or H1 shifts the core of the problem to these later technologies, providing their encapsulation in WorldFIP has been clearly specified.

4.4.2.2.5 Conclusion

Two approaches must be distinguished:

- HART and Fieldbus Foundation use function blocks (or commands) of which some are generic and mandatory, and others optional (and defined by the manufacturer in the case of HART).
- PROFIBUS and WorldFIP specify profiles for each category of component (pressure sensor, temperature sensor, etc.) which, with a certain degree of freedom, define the data and functions available.

Furthermore, with HART and Fieldbus Foundation, the data and functions available for each component are described in a specific language which, essentially, enables personalizing the related interfaces: tags, display formats, minimum/maximum, help texts, etc.

This latter property allows for the use of generic tools (like pockets or maintenance support software) potentially capable of functioning with all components, but this requires an operator (capable of understanding the meaning of the information proposed and described textually).

However, when purely automated sub-systems (particularly PLCs) are involved, interchangeability decreases with the use of optional or non-generic functions: a pressure transmitter fitted with a PID block cannot easily be replaced by a model which has none. These functions, however, represent a major element of differentiation between the various manufacturers.

The use of profiles appears to give a slight edge in that it enables defining generic functions <u>for each type of component</u> whereas functions <u>generic to all</u> components are more limited (essentially restricted to reading of the main measurand). Nonetheless, the wide range of possible combinations between profiles A or B, v2 or v3, together with the implementation (or lack thereof) of the optional parameters, limits the importance of such profiles.

In any event, it is clear that it would be wise to examine which of these functions are really used and how, before drawing any conclusions.

4.4.3 Other elements of differentiation

4.4.3.1 Means of fieldbus access

The three fieldbus technologies define cyclic traffic, intended for circulation of process data (measurements, instructions), and acyclic traffic for circulation of configuration data, diagnoses, alarms, etc. However, the techniques called upon are different and influence the final characteristics of each solution.

WorldFIP is based on a producer-consumer logic in which producers of data (typically the sensors) publish their data on the fieldbus and make them available to all potential consumer components (PLCs or actuators). A centralized fieldbus scheduler ensures management of the cycle for publication of these data as well as use of the remaining available time for acyclic messages (configuration, diagnosis, alarm, etc.). In this way, **the rhythm of cyclic messages is constant and independent of acyclic traffic.**

Fieldbus Foundation uses similar mechanisms (producer-consumer exchanges managed by a centralized LAS, giving it the same guarantees (but at lower speed) as to separation of cyclic and acyclic traffic.

Finally, PROFIBUS uses a master-slave mechanism with a token passing procedure, which does not permit certain functionalities (no direct exchange between sensors, therefore no distributed control, for example). Moreover, in the absence of centralized management, the **rhythm of cyclic traffic is not necessarily constant, and may vary in accordance with the intensity of acyclic traffic**. Dimensioning of the fieldbus can, however, limit this risk: number of masters, cycle period, etc.

4.4.3.2 Distributed control

Among the features that make a significant difference between the various solutions now available, Foundation Fieldbus is the only technology capable of offering distributed control as a standard option, i.e., control in the sensors or actuators as opposed to PLCs. Thus a temperature transmitter connected to an H1 fieldbus (or HSE when this becomes available), can communicate a measurement to the PID function block for a valve, which will adjust its travel as a consequence.

WorldFIP has the characteristics needed for this functionality (producer-consumer exchanges) but distributed control is not a standard option. PROFIBUS, on the other hand, given its characteristics (master-slave exchanges), does not allow for distributed control, though this may be envisaged in the future (cf. section 4.4.4).

4.4.3.3 Time-dating

The four technologies also have different solutions to the question of time-dating:

- Fieldbus Foundation integrates a mechanism for standard diffusion of time and authorizes time-dating at the source,
- PROFIBUS (PA/DP) does not diffuse the time automatically but can manage time-dating of alarms (only) at the source,
- WorldFIP has the potential for diffusing the time but this is not a standard option,
- HART has no provision for this.

4.4.4 Future projects

Fieldbus Foundation is focusing its efforts on development of its HSE high-speed variant, which is running into certain problems due to the 100Mb/s Ethernet physical layer used.

WorldFIP has announced several projects:

- FIPWEB (available): a system for access to configuration data for HART components (on HART/FIP converters) by internet/intranet for remote maintenance,
- a very high-speed link project (25 Mb/s),
- a radio-link project on UMTS (2 Mb/s),
- a FIP/Fieldbus Foundation H1 gateway project.

PROFIBUS has issued two recent statements:

- one on "alignment" with TCP/IP Ethernet (very theoretical statement with few details),
- an as-yet confidential statement concerning changes (apparently inspired by WorldFIP) aimed at offering a high-performance protocol: producer-consumer mode, centralized fieldbus scheduler, constant cycle period, diffusion of time, etc.

There are a number of questions about this project. Apparently oriented toward manufacturing and/or critical time processes, it challenges many existing technical choices. PROFIBUS could use elements of the IEC 1158 standard (PROFIBUS and WorldFIP) to build this new standardized high-performance protocol under the PROFIBUS name.

4.4.5 Points needing further study

Above and beyond the new directions announced, and which must of course be watched, this study pointed up the need for further study of the following points:

- which functions of smart instrumentation are concerned by problems of interchangeability or interoperability? Consequently, how much impact will such problems have on the different sub-systems of a DCS (for maintenance, control, supervision)?
- what is the best solution to ensure interchangeability of products on a given fieldbus: the use of profiles (PROFIBUS and WorldFIP), or the use of sophisticated data description languages (FF and Hart)?
- how easy is it really to add subscribers on to an in service installation?
- what are the benefits and ease of implementation of time-dating at the source (in sensors)?
- what are the benefits and ease of distributing control to the actuators?

In this sense, the study of systems capable of incorporating smart instrumentation is an indispensable complement to the study of the instruments themselves.

Operation feedback will also help in verifying the practical consequences of the features specific to each technology.

4.5 Conclusions

Unless things change radically, fieldbus standardization must be seen as a failure for the users, as the standard incorporates a great number of mutually incompatible technologies which relate to extremely different domains. The most significant technologies today in the field of continuous process control are Fieldbus Foundation (H1 and HSE), PROFIBUS (FMS, DP, PA) and WorldFIP.

Despite their multiplicity, they all seem to converge toward a similar global architecture based on a high-speed network (DP, HSE or WorldFIP) linked by couplers to low-speed segments (H1, PA) which are dependent on the IEC 1158-2 standard physical layer.

WorldFIP offers the best features for the high-speed segment (producer-consumer model, determinism, effective speed, etc.) but does not yet offer access to the low-speed segments (except for HART) and has insufficiently specified applicative layers (poorly defined profiles, etc.).

Fieldbus Foundation proposes a technology superior to that of PROFIBUS for the low-speed segment (producer-consumer model authorizing distributed control, centralized scheduler ensuring a guaranteed cycle period, time distribution functions, etc.) and a relatively sophisticated data description model (*Function blocks* and *Device Descriptions*).

The instrument profile description proposed by PROFIBUS could give good guarantees in terms of interoperability and interchangeability. This system, however, suffers from the presence of several classes of conformity and many optional parameters.

These comparisons should be qualified in view of the new developments that have been announced or that may see the light for these three technologies, both from a technical point of view (method of fieldbus access for PROFIBUS; profiles for Fieldbus Foundation; access to low-speed segments for WorldFIP) and from the point of view of future alliances that might be formed.

Furthermore, it would be advisable to weigh the economic criteria presented in the earlier part of this paper: PROFIBUS has a stronger sales presence today, essentially concentrated in Europe, but the recent and rapid expansion of Fieldbus Foundation, especially in the United States, is also quite impressive.

5

TECHNICAL AND ECONOMIC FEEDBACK FROM THE INSTRUMENTATION SYSTEM AT CORDEMAIS

The EDF R&D Department has set up test instrumentation in Cordemais unit 4 ("advanced pulverized coal-fired boiler" project), including a sub-system of 263 measuring channels, operational since June 1998, and based on a "smart sensors and fieldbus" architecture [18].

This section, in addition to describing the digital instrumentation set up at Cordemais, evaluates the benefits and drawbacks resulting from this instrumentation technology for the different items during each of the phases "Procurement", "Set-up and commissioning" and "Operation and maintenance".

5.1 Description of the instrumentation

5.1.1 Specifications

The instrumentation presented in this section corresponds to test measurements distributed all over the boiler (the operation measurements are not detailed). The measurements are of the pressure, flow and temperature type (thermocouples). Their number and distribution over the boiler are shown in Figure 5-1. The metrological and time characteristics of the variables to be measured are listed below by type of sensor or transmitter.

Table 5-1
Metrological and time characteristics of the variables to be measured

Measurement type [range]	Precision required	Nominal acquisition cycle	Other acquisition cycles envisaged
pressure values (absolute, relative or differential) [4-20 mA]	± 0.3 %	10 seconds	1 second upon event
flow rates [4-20 mA]	± 1 %	10 seconds	1 second upon event
mobile cane transmitters [4-20 mA]	± 1 %	not applicable	1 second upon event
differential temperatures measured with fluxmeters [0-5 mV]	± 1°C	10 seconds	1 second upon event
absolute temperatures measured with fluxmeters [0-15 mV]	± 1°C	10 seconds	1 second upon event
absolute smoke temperatures [0-40 mV]	± 3°C	10 seconds	1 second upon event

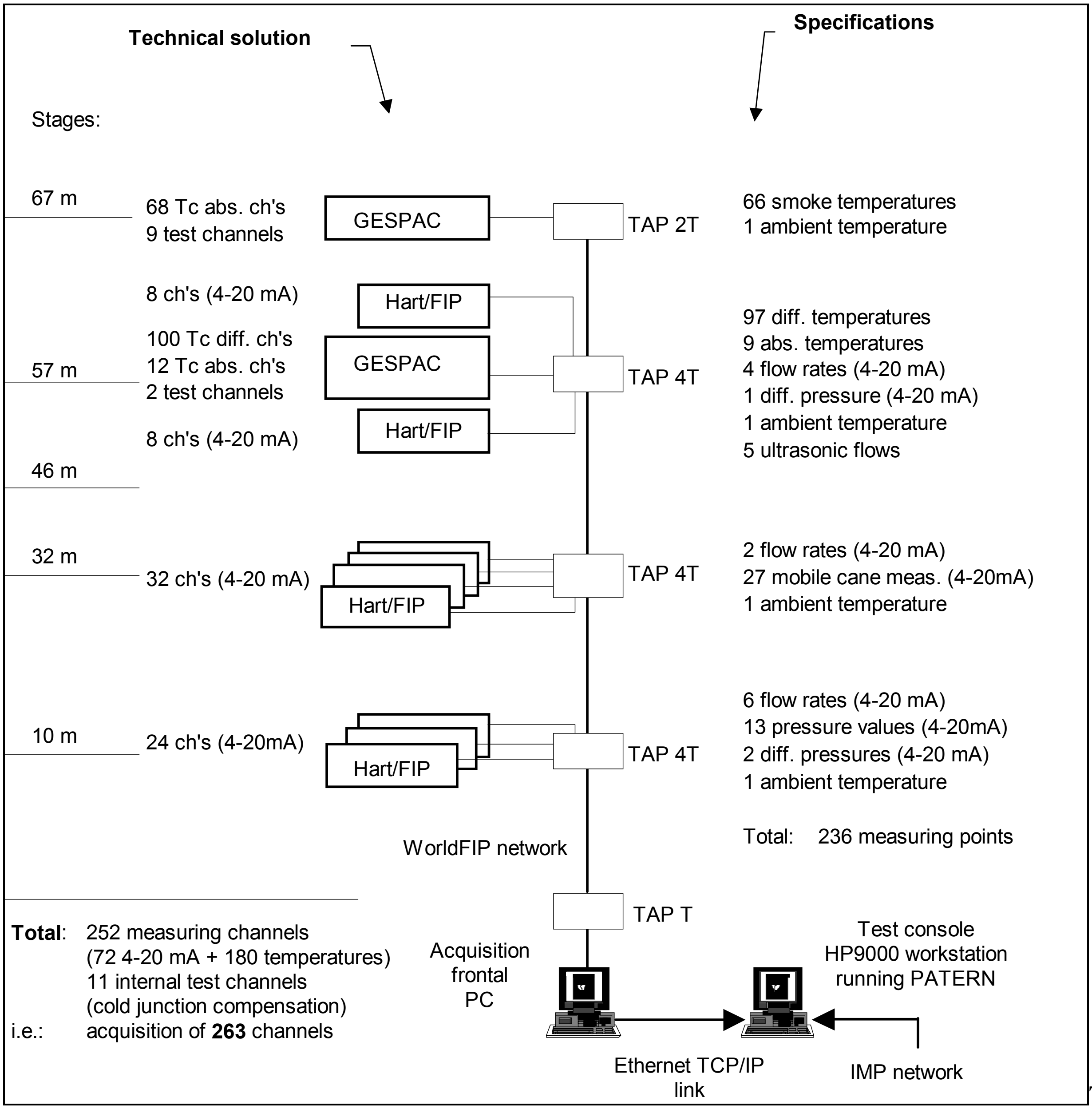
The measurement characteristics show that the measuring signals depend on the sensor family by which they are output and have very different amplitude variation ranges:

- pressure and flow rate measurements generate analog signals within the 4-20 mA standard range,
- the amplitude variation range of absolute temperature measurements is from 0-15 mV, i.e., from 0-375°C for fluxmeter pyrometers and from 0-40 mV, i.e., from 0-1000°C for smoke insertion pyrometers. These very low voltages are to be converted into standardized temperature values by the conditioning unit implemented. These conditioning units must also perform the cold junction compensation,
- differential temperature measurements are to be performed by millivoltmeters, without linearization of the signal (e.m.f conversion standardized temperature) and without cold junction compensation (since both leads connected are of the same material / nature). The variations in amplitude are of 5 mV.

5.1.2 Technical solution

The technical solution is based on a WorldFIP field network, Micro-Gate MII interfaces for the 4-20 mA measurements performed with or without smart sensors, Gespac Systems interfaces for the temperature measurements and an acquisition front panel set up around FIPDESIGNER, the FIPbusVIEW library and LabVIEW [19].

The hardware structure of the digital instrumentation is shown in Figure 5-1. The overall structure of the test instrumentation which includes, in addition to the FIP network, a second network of the SNet type for the acquisition of ANA and TOR measurements, is shown in detail in Figure 5-2.



T

AP: multi-input connection point for FIP subscribers

Figure 5-1
Structure of the digital instrumentation

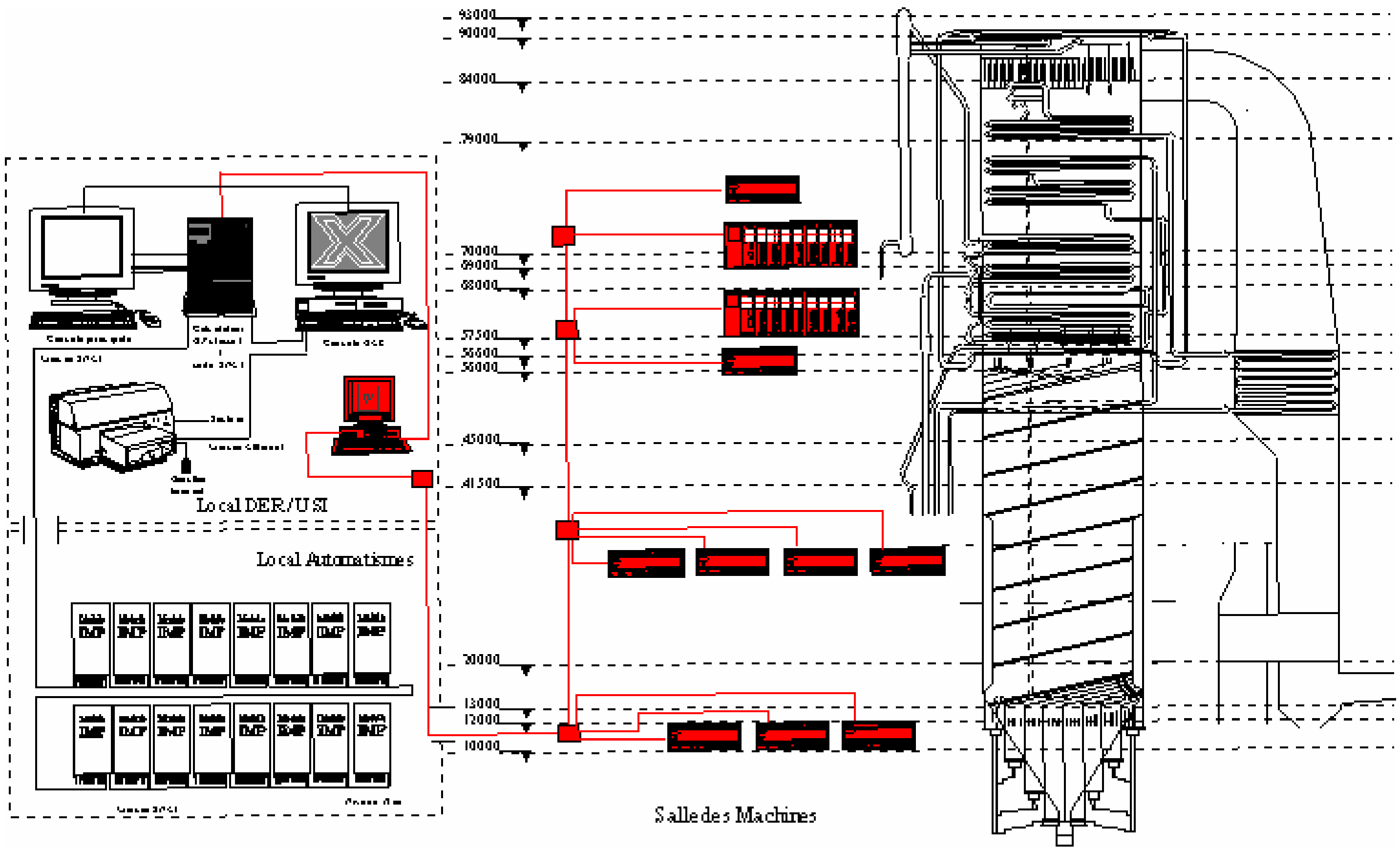


Figure 5-2
Structure of the overall instrumentation

5.1.3 Micro-Gate MII hardware

5.1.3.1 Presentation

The Micro-Gate array shown in Figure 5-3 is made up of a Central Processing Unit and a WorldFIP interface arranged in the lower part, along with eight 12-bit analog-to-digital converters in the upper part. Its main mechanical and electrical characteristics are as follows:

- thermoplastic housing—dimensions: 258.6 *x* 116.7 *x* 56.9 mm
- maximum power consumption: 12 W at a supply voltage of DC 48 V
- operative range: from -20°C up to +70°C at 10 to 90 % relative humidity of air free of condensation
- precision: ± 3 LSB (value) within the range from 0 to 22 mA
- non linearity: ± 1 LSB

Two different mounts are possible (with or without power supply by current loop)

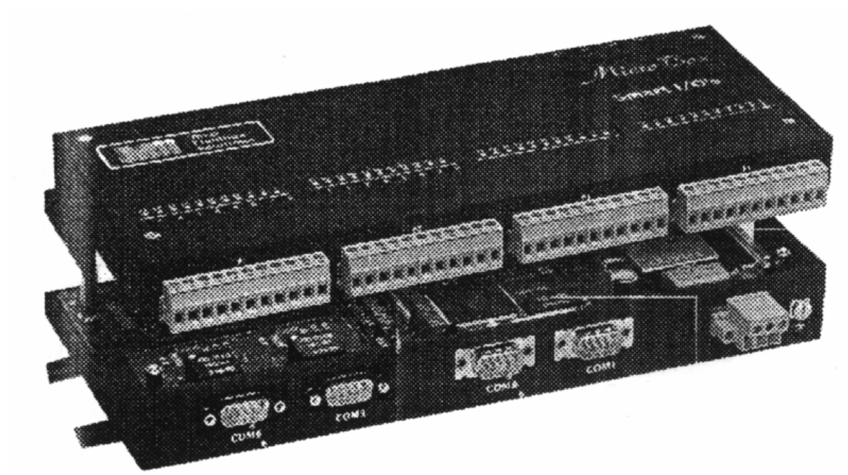


Figure 5-3
Presentation of the Micro Gate array

5.1.3.2 Operation and precision

The Micro-Gate converter supports two functions:

- Conversion of the eight analog 4-20 mA signals into 8 digital values which are then transferred to the WorldFIP network. Each converter generates 1 periodical FIP variable containing the 8 converted values. These variables have the following structure:

FIP Preamble	8 measured values + validants	FIP Postamble

Calibration of the converters set up at Cordemais has proven that the precision is better than ± 0.1% of the MR (Measurement Range) [21].

- Exchange of HART information [17] with the smart sensors through the use of the WorldFIP acyclic messaging feature. These messages may contain measurement or configuration data. Their structure is as follows:

FIP Preamble	HART Messages	FIP Postamble

The information exchanged between the sensor and the acquisition front panel do not undergo any format change. Measurement precision is solely conditioned by the sensor. Configuration messages address the sensors only, not the A/D converters (the calibration of the analog-to-digital conversions is impossible); the converters do not perform any HART frame decoding.

5.1.4 Gespac Systems hardware

5.1.4.1 Presentation

The racks supplied by Gespac Systems are made up of a common basic structure and a modular part.

Basic structure

- 19" industrial rack with motherboard
- PC-type 486SLC-2 CPU
- WorldFIP communication interface

Modular structure

Depending on the number of channels to be conditioned, a corresponding number of universal boards is inserted into the motherboard. Each of these universal boards comes with a connector to plug in a "measurement" daughterboard. At Cordemais, two types of "measurement" boards are used:

- PGBTCD-4: measurement board for absolute temperature measurement by means of thermocouples
- PGBMVR-1: measurement board for very low voltage (millivoltmeters)

Each of these "measurement" boards can condition 4 channels.

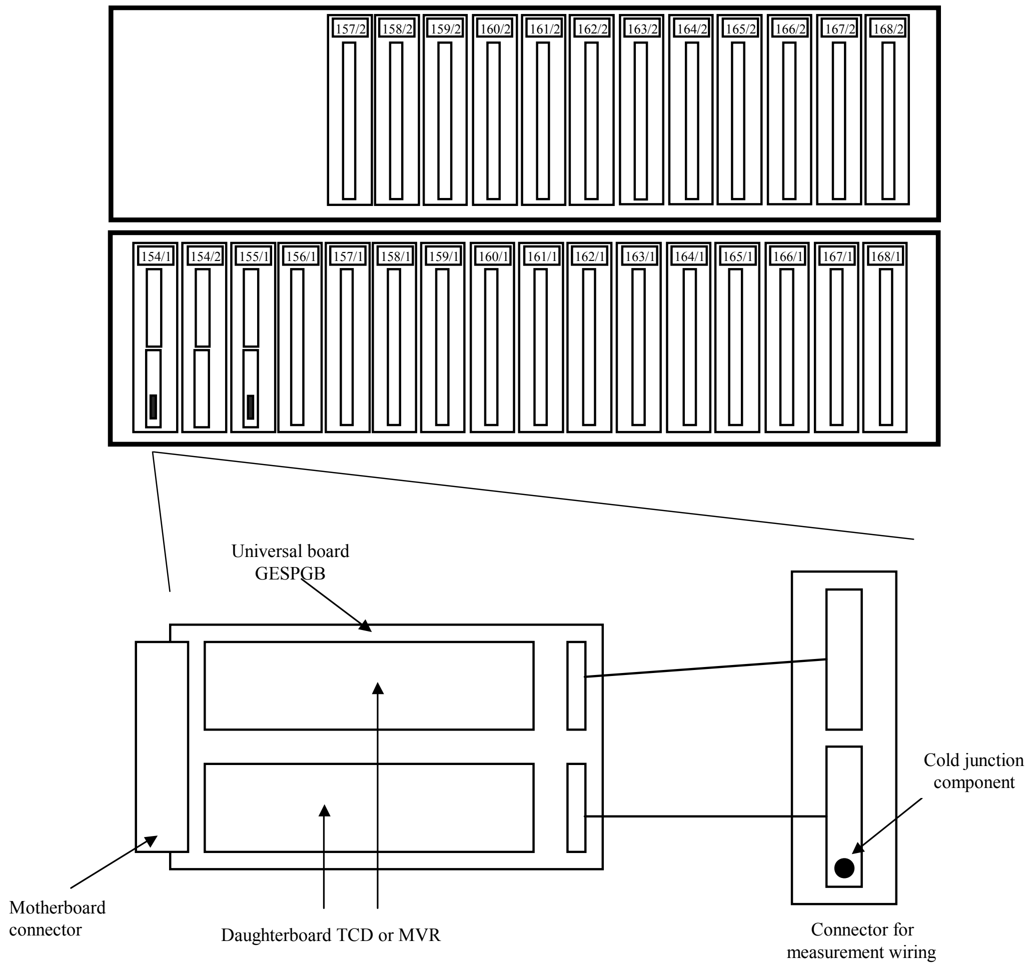


Figure 5-4
Rear panel of Gespac n°2 rack and magnified view of a measurement board array

5.1.4.2 Operation and precision

Each input is fitted with an instrumentation amplifier and an A/D converter (no multiplexing). For the absolute temperature inputs, a cold junction compensation device is provided per group of 4 or 8 inputs. The components of this device are not capable of providing cold junction compensation at temperatures under 0 °C.

The acquisition boards use 21-bit double converters (AD7710), the measuring time being 300 ms and the measurement error ± 1 bit between 0 and 70 °C. An instrumentation amplifier with a differential input ensuring a gain from 1 to 128 positioned upstream of each converter serves to reduce the full scale and ensure a common mode rejection of 100 dB. Table 5-2 describes the converter ranges and resolutions depending on the input types. The gain of 32 adopted for the application allows one to obtain the resolutions shown in Table 5-3.

Table 5-2
Converter ranges and resolutions

Input type	Board type	Measuring range	Resolution gain 1	Resolution gain 32	Resolution gain 128
thermocouple	PGBTCD-4	-10 to +2490 mV	38 µV	1.2 µV	0.29 µV
voltage	PGBMVR-1	-2500 to +2500 mV	76 µV	2.4 µV	0.59 µV

Table 5-3
Resolution of the temperature measurements

Input type	Voltage deviation of the thermocouple	Resolution at a gain of 32
couple J between 200 and 300 °C	5.548 mV / 100 °C	0.021 °C
couple K between 500 and 600 °C	8.088 mV / 100 °C	0.015 °C
couple J differential between 200 and 300°C	5.548 mV / 100 °C	0.043 °C

The "PGBCAL" software allows one to connect a console and a keyboard to the front panel of the racks, so that one can:

- access the measurements of every channel,
- change the voltage-to-temperature conversions (so as to keep in line with changing standards),
- modify the measurement filtering (number of samples used for averaging) and the generation time of the FIP variables,
- enable or disable boards,
- calibrate each channel.

To improve the precision of the Gespac racks, EDF R&D has calibrated these racks [22]. The performances reached by rack n° 2 are:

- **absolute temperatures:** the deviation between the true and the measured values remain under 0.25 °C within the operating range from 15 to 35°C. The maximum deviation determined with raw data is of 0.5 °C at an ambient temperature of 45°C .
- **differential temperatures:** the maximum deviations between true and measured values are lower than 10 µV (<0.2°C).
- **FIP communication:** the WorldFIP interface allows one to read the cold junction temperatures for each input group, along with the absolute temperatures and the voltages

output by the differential thermocouples. These measurements are performed according to periodical variables, one for each universal board, with the following content:

FIP preamble	Measurements	FIP postamble

The Gespac racks support the cyclic FIP traffic only, no message can be sent to these components and remote configuration is not supported.

5.1.5 Acquisition front panel

5.1.5.1 Software environment

The two software programs FIPDESIGNER and FIPbusVIEW [19] are the basis of the application around which a specific software application was developed with a view to operating the digital instrumentation at Cordemais.

FIPDESIGNER is run in a Windows 95 environment. The data acquired via the WorldFIP network are not processed with FIPDESIGNER. For instance, the conversions of the 4-20 mA signals performed by the Micro-Gate arrays are expressed in number of points coded on 16 bits, 12 of which are data bits. Likewise, the messages forwarded to the HART sensors [21] are not "encoded".

5.1.5.2 Functioning of the acquisition front panel

This is the particular software program developed for the digital instrumentation at Cordemais [19]. Its main functions are shown below and illustrated with a mimic diagram and screen copies taken from [20].

- **Display features**

The display features include a graphic operator-instrumentation interface and a display of the measurement values of each instrument that can be accessed by opening its front panel (then displayed in a window). On the main mimic screen shown in Figure 5-5, 72 indicators represent the 4-20 mA signals output by the 9 HART/FIP arrays and two indicators are assigned to the 180 temperature channels managed by the 2 Gespac racks.

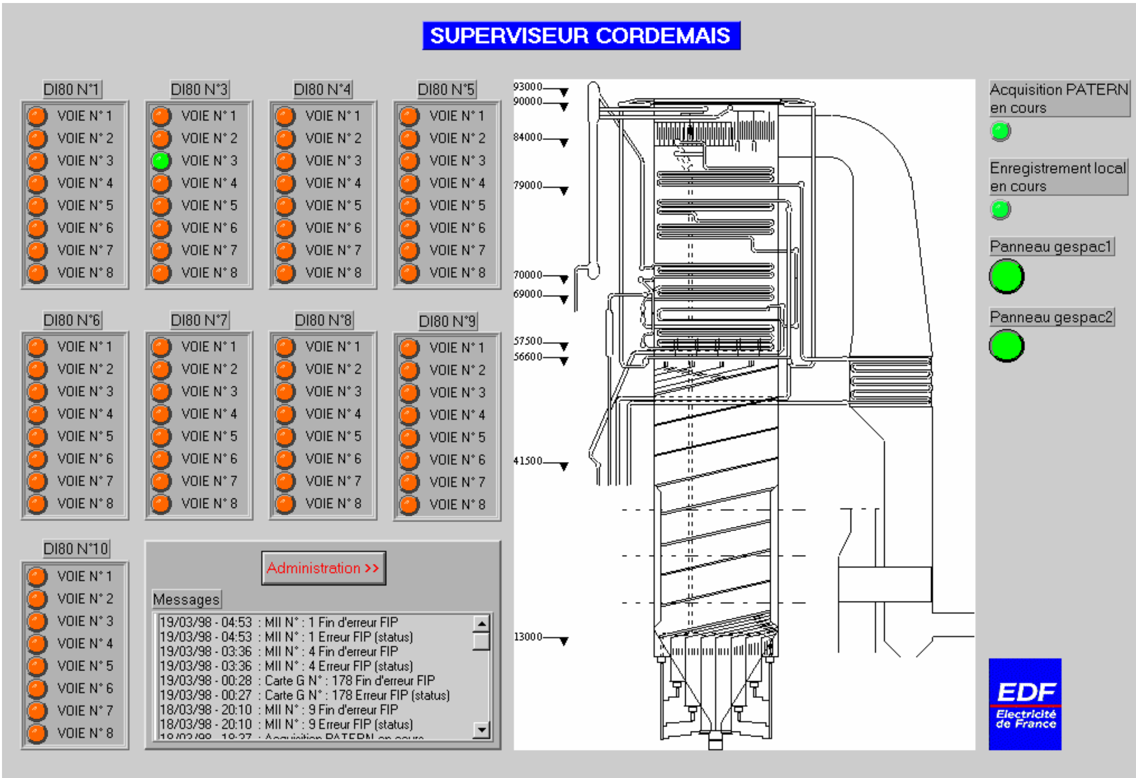


Figure 5-5
Mimic screen of the acquisition front panel at Cordemais (main screen)

- **Sensor configuration**

Thanks to a "test file", the acquisition front panel knows the instruments connected to the network and controls the configuration of the smart sensors. The acquisition front panel can be dynamically configured via the WorldFIP messaging system.

In the case of any HART type sensor (pressure or flow transmitter), calling up the sensor by selecting its indicator on the main mimic screen causes the instrument front panel window to open, so that one can call up any of the HART commands shown in Figure 5-6.

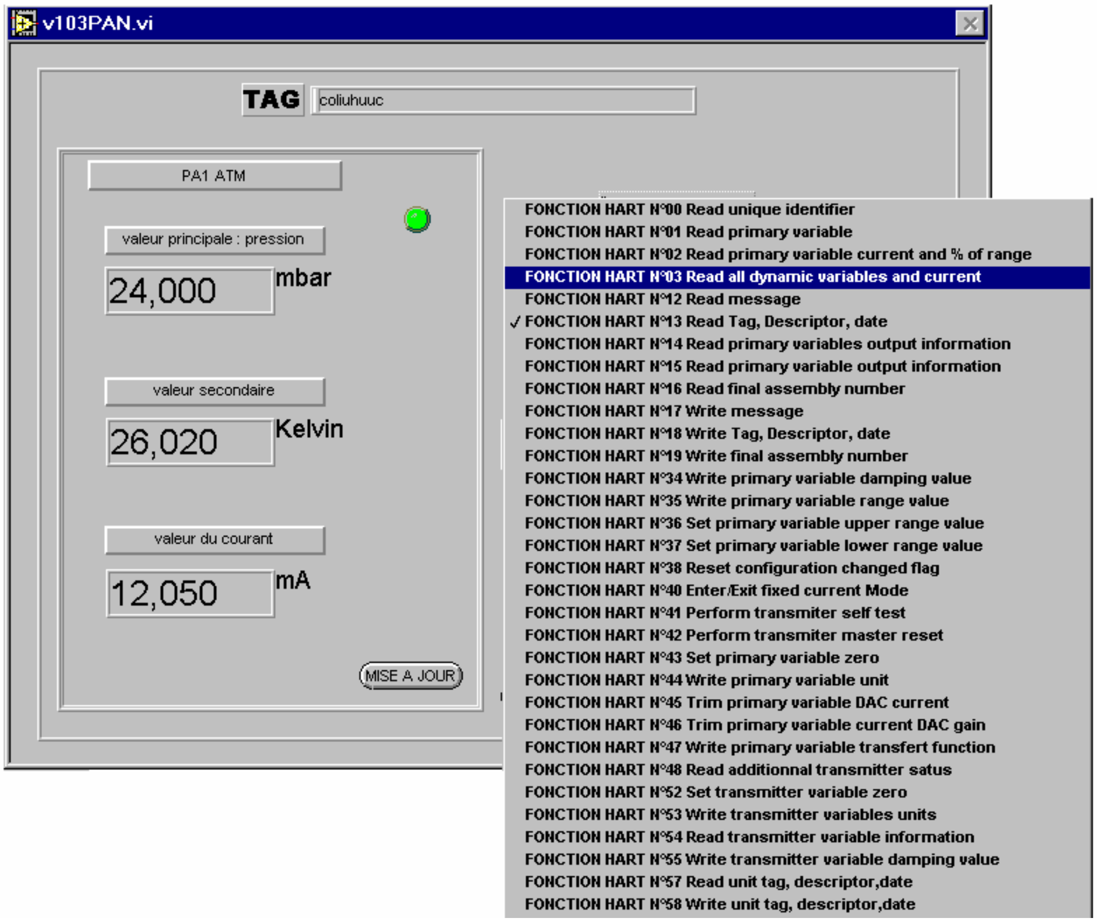


Figure 5-6
Front panel of a HART type sensor

- **Acquisition**

All measurement values are acquired via the periodical variables of FIP. The structure of the FIP data is defined by the file *.cnf generated in FIPDESIGNER.

- **Instrument status management**

The status indicators are up-dated by means of colour codes which depend on the sensor threshold, user or various faults. The colour codes assigned to the booleans are as follows:

- red: FIP communication error—the channel cannot be used

- orange: analog channel beyond the limits of the 3-21 mA range

- yellow: HART communication impossible—the analog value remains unusable

- blue: user thresholds are exceeded—analog measurements and HART messaging are OK

- green: instrument present and operation normal

- **Communication with PATERN**[4]

All measuring values specified in the channel file provided by PATERN are transferred to PATERN. The transfer frequency and time are determined by PATERN.

- **Local measurement storage**

Recording of measurement values as physical units takes place at the request of the operator. The acquisition time is programmable (minimum value: 500 ms with the PATERN connection activated).

Both of these functions can be accessed, whenever necessary, via the graphic interface shown in Figure 5-7.

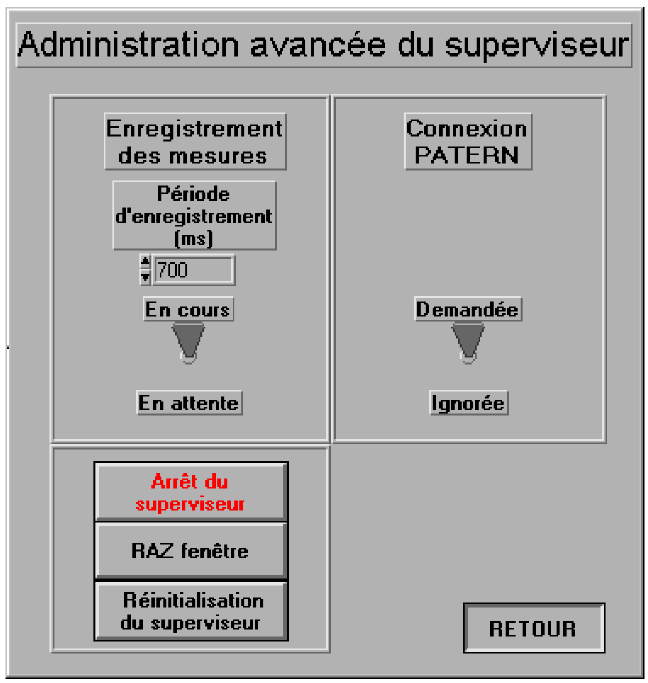


Figure 5-7
Advanced administration window of the acquisition front panel

- **Event recording**

All events concerning the instrumentation are recorded (start-up, initialization, faults / errors, status changes, connections with PATERN, etc.). The events are displayed in the "administration" window and logged in a "*.log" file created on start-up.

[4] PATERN is a data acquisition software, used in each EDF nuclear power plant.

- **Configuration management**

The test files allow one to start the acquisition according to pre-defined configurations (range settings, damping time, etc.). Should discrepancies between the test file and the sensor configurations be detected on start-up, the supervisor will request the operator to choose either the sensor configuration or the test file configuration, as shown in Figure 5-8. If the operator decides to adopt the sensor configuration, the test file will be modified accordingly. If he adopts the test file configuration, the sensor configuration will be changed accordingly. The test file can be saved upon test completion.

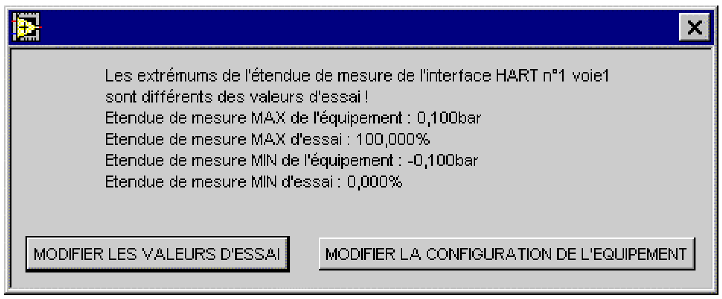
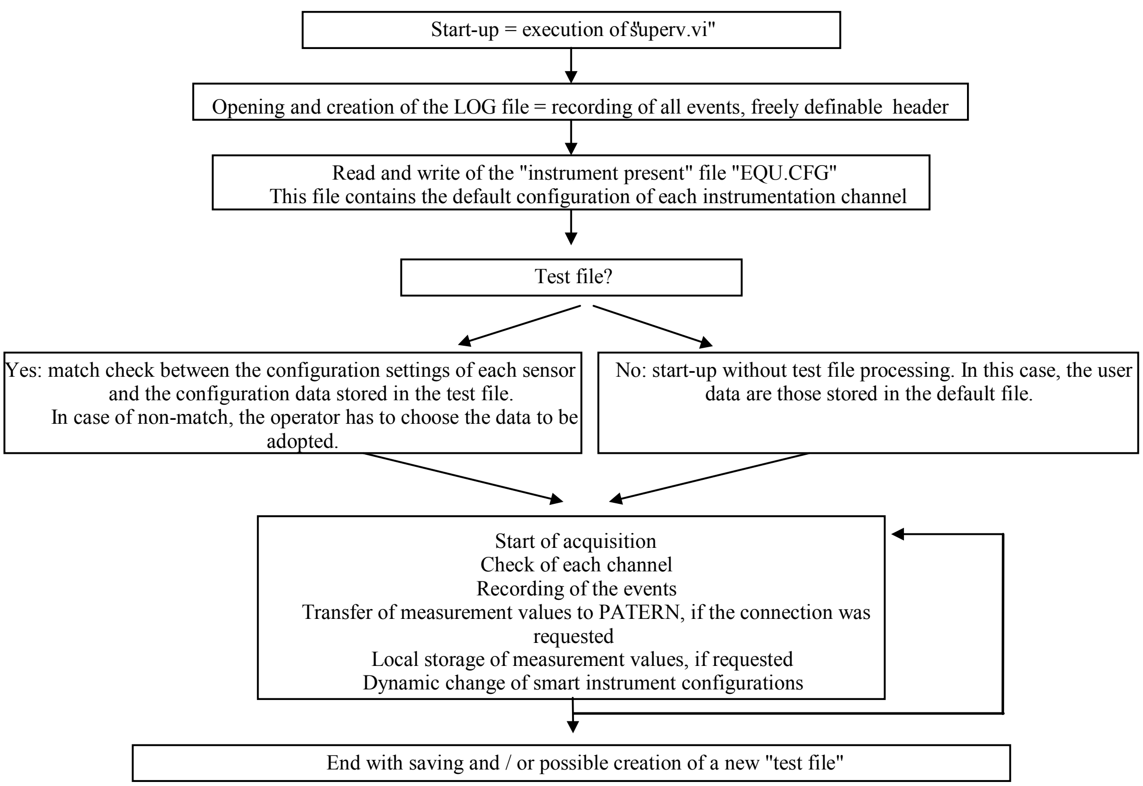


Figure 5-8
Warning message prompting the operator to make the sensor configuration data match the test file data

5.1.5.3 Functional diagram of the acquisition front panel

FIPDESIGNER is assumed to be active in the background.



5.2 Hardware procurement

5.2.1 Hardware costs

Table 5-4
Hardware costs

Manufacturer / Supplier	Hardware	Unit price (FRF)	Number of channels	Cost per channel (FRF)	Quantity	Total cost per item (FRF)
MII	Micro-Gate	12,000	8	1,500	9	108,000
Gespac Systems	rack 1 rack 2	124,000 144,000	68 112	1,800 1,300	1 1	124,000 144,000
Cegelec	board CC121	3,130			1	3,000
Entrelec	4-subscriber FIP connectors 2-subscriber FIP connectors	2,327 824			3 2	7,000 1,000
Radiospares	FIP cable (305 m reel)	2,390			2	5,000
Ascome	subscriber link FIP cable	395			12	5,000
Total						**398,000**

The total cost of the hardware amounts to FRF 398,000[5] for 252 measurement channels and 11 internal function control channels (cold junction compensation), i.e., a total of 263 acquisition channels.

Hence, the average cost of one channel amounts to FRF 1,500 (exclusive of sensors, power supply, cable laying, software development expenditure and remuneration of EDF R&D workforce).

5.2.2 Software

Table 5-5
Costs of the software programs

Software firm	Software program	Total cost per item (FRF)
HLP Technologies (owned by EDF)	FIPDESIGNER FIPbusVIEW	0 0
National Instruments	LabVIEW	0 or 40,000
Silicomp Ingénierie	Acquisition front panel	289,000

[5] approximate exchange rate 1 USD = 6.5 FRF

The software programs FIPDESIGNER and FIPbusVIEW are marketed by the company HLP Technologies under EDF license and therefore free for EDF. Thus, a developer holding the run time distribution license is not obliged to buy LabVIEW.

For Cordemais, the acquisition front panel software was rewritten on the basis of the program developed for the EVEREST test loop (EDF owned and operated test loop). Its implementation with new instrumentation systems would not require the program to be rewritten entirely, it would be necessary only to adapt the software to the number of measuring points used by the new instrumentation system. For this reason, the software item can be partially considered as an investment.

5.2.3 Comparison with competing REME solutions

The EDF REME Department usually builds its instrumentation systems using so-called "Standard Chains", either analog or partially digital without making use of the sensors' intelligence. The detailed description of the structure of these standard chains can be found in [1,2]. For the Cordemais test instrumentation, two architectures were conceivable.

5.2.3.1 "PATERN and CVP" solution

The following figure shows the structure of the instrumentation based on the CVP 400 solution (SFERE).

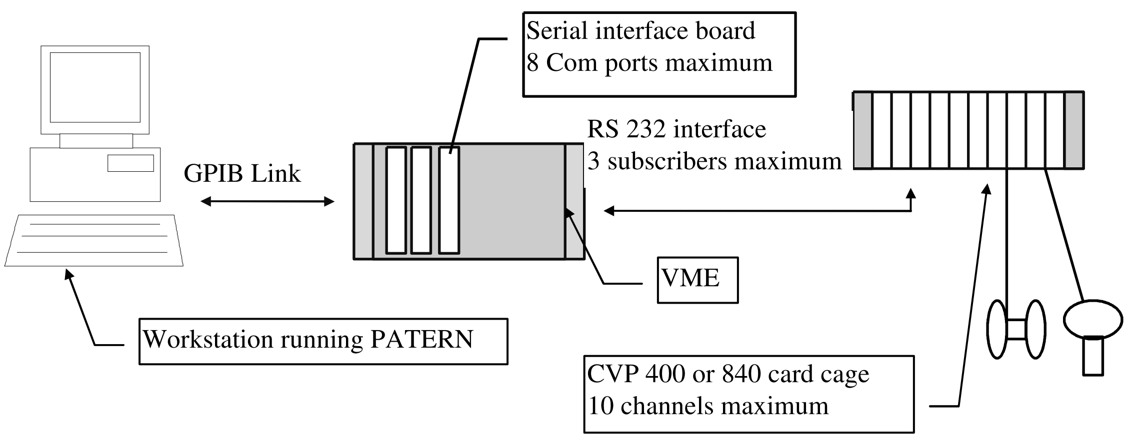


Figure 5-9
CVP 400 +PATERN solution: hardware architecture

The connections between the sensors and CVP conditioning units are analog. One CVP rack can house 10 CVP's, one RS232 address can group 3 CVP racks. The serial interface boards (VME) can control 8 serial links, i.e., (8x3x10) 240 measurement channels. A VME card cage can hold 5 serial interface boards, thus; the maximum number of measurement points amounts to (5x240) 1200 channels for an acquisition cycle of 10 seconds at best. Beyond this limit of 1,200 channels, a new VME card cage is necessary. When exceeding 30 channels per level (boiler stage), an extra serial link is required between the VME (local acquisition) and the boiler stage, in other words, up to 200 m of serial link cable (FRF 2,000), with, in addition, the remuneration of the workforce (FRF 8,000) laying the cable. The configuration of the CVP can be performed with the PATERN software.

If this solution had been adopted, the hardware costs would have been as follows:

Table 5-6
Cost of the "PATERN and CVP" solution

Hardware	Unit price (FRF)	Maximum number of channels	Quantity	Total per item (FRF)
Workstation	100,000		1	100,000
VME card cage	50,000	1,200	1	50,000
Serial interface expansion boards	5,000	240	2	10,000
CVP Rack	2,300	10	26	60,000
CVP 400	2,500	1	252	630,000
Junction cables	FRF 1,010 / 100 m		30	30,000
Total (FRF)				**880,000**

5.2.3.2 "PATERN and IMP" solution

The following figure shows the structure of the instrumentation based on the "IMP" solution (SOLARTRON):

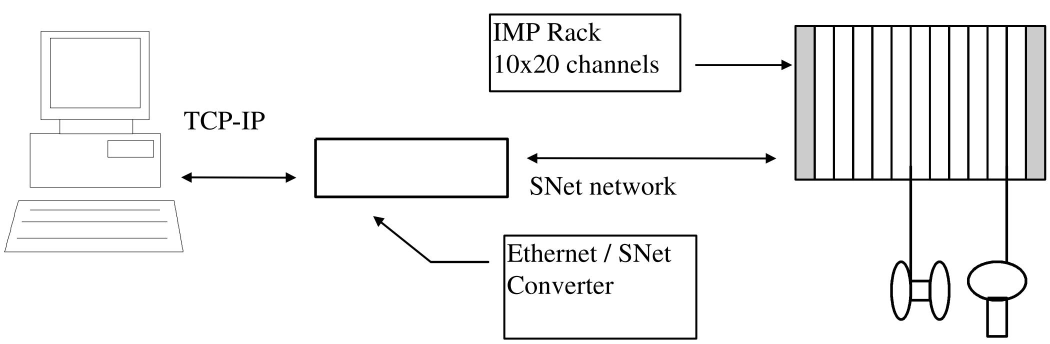


Figure 5-10
"IMP + PATERN" solution: hardware architecture

The IMP's (20 channels) can be conditioned per 10-unit rack. The IMP's are controlled (configuration and acquisition) by PATERN via the Ethernet/SNet converter. A SNet network can support 50 IMP's, i.e., 1,000 channels. When more than 1,000 channels are needed, an additional SNet network has to be connected to the workstation running PATERN. The acquisition cycles are 1 second. The junction cables between the sensors and IMP's are analog.

Table 5-7
Cost of the "PATERN and IMP" solution

Hardware	Cost per unit (FRF)	Number of channels	Cost per channel (FRF)	Quantity	Total per item (FRF)
Workstation	100,000			1	100,000
Ethernet/SNet converter	18,000			1	18,000
IMP card cage	5,000	200		1	5,000
IMP	15,000	20	750	14	210,000
Junction cables	12 FRF / m			500 m	6,000
Total (FRF)					**339,000**

5.2.3.3 "PATERN + HP3852" solution

This is the so-called "wired" solution: each sensor is connected to the acquisition center HP3852 (HEWLETT PACKARD) by a pair of wires.

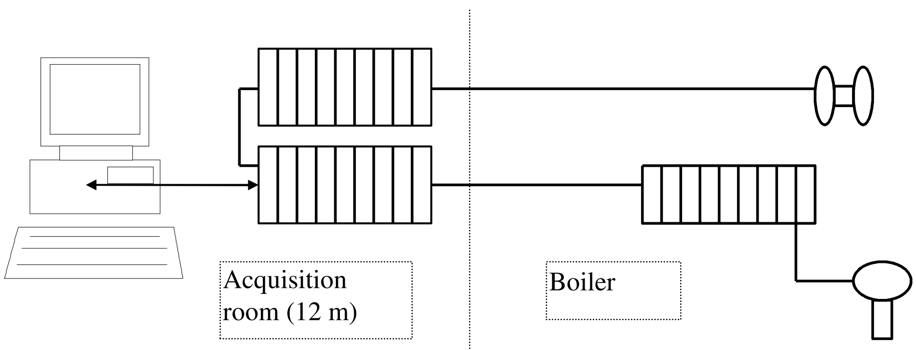


Figure 5-11
"PATERN and HP3852" solution

An acquisition scanner HP 3852 can condition 180 measuring channels (9 boards with 20 channels each). When more channels are to be processed, the expansion unit HP 3853 allows one to condition 200 additional channels (10 boards with 20 channels each). Junctions between the sensors and the acquisition scanner are wired and analog (each sensor is connected to the scanner by a pair of wires). Given the high wiring installation cost and its metrological performance (sensitivity to electromagnetic interference and drop in the analog signal voltage), REME seldom makes use of this type of measuring chain. The implementation of CVP conditioning units is indispensable for each temperature channel, as microvolts cannot be conveyed over several hundred meters.

Table 5-8
Cost of the "PATERN and HP 3852" solution

Hardware	Cost per unit (FRF)	Number of channels	Cost per channel (FRF)	Quantity	Total per item (FRF)
Workstation	100,000			1	100,000
Acquisition scanner HP 3852	34,000			1	34,000
Voltmeter board	15,000			1	15,000
Expansion HP 3853	34,000			1	34,000
Scanner boards	9,000	20	450	13	117,000
CVP rack	2,300			18	41,000
CVP	2,500	1	2.5	173	432,000
Junction boards	13,400 for a 305 m reel			21	281,000
Total (FRF)					**1,054,000**

5.2.3.4 Power supplies

Whatever the technical solution adopted, IMP, CVP, FIP or HP3852, an AC 220 V power supply, representing a fixed cost budget item, is required for every single rack assigned to each stage. However, depending on the solution, the costs of power supplies vary as stated hereinafter:

- IMP solution: the transmitters (4-20 mA) require one power supply per channel, i.e., an extra cost of FRF 750 per channel;
- CVP solution: the CVP racks are directly power-supplied by the mains and supply each sensor with 24 V, i.e., no extra cost (FRF 0.00);
- FIP solution: the Gespac racks are directly supplied by the mains and the HART/FIP converters are supplied with 48V, a supply voltage they distribute to their 8 inputs; this represents an extra cost of FRF 4,000 F for 4 power supplies,
- HP3852 solution: the transmitters (4-20 mA) require one power supply for each channel, i.e., an extra cost of FRF 750 F per channel; the CVP racks for temperature measurement are mains-supplied.

5.2.3.5 Cost comparison

The comparative costs listed below take account of the conditioning units, their junction cables, workstations or microcomputers, software programs and power supplies. These costs are exclusive of the sensors (supply and installation), their point-to-point junctions (supply and installation) with the conditioning units, EDF R&D labor costs.

Table 5-9
Cost comparison

Instrumentation	Hardware (FRF)	Software (FRF)	Cables (installation) (FRF)	P. supplies (FRF)	Total / item (FRF)	Number of channels	Cost / channel (FRF)
Front panel + FIP	402,000	150,000*	34,000	4,000++	586,000	263	2,230
IMP	339,000	0**	34,000	45,000+++	373,000	252	1,480
CVP	880,000	0**	68,000***	0	948,000	252	3,760
HP 3852	1,054,000	0**	174,000+	45,000+++	1,273,000	252	5,050

* Basis: adaptation of existing software requiring 1 month of development (FRF 7,000 / day)
** No writing-off of software costs
*** Given the configuration, coefficient 2 is applied here
+ On the basis of 4.1 km of cable and an installation labor cost of FRF 4,200 per 100 m
++ 4 power supplies, one per rack, cost per unit: FRF 1,000
+++ On the basis of FRF 750 per single channel power supply and the 60 4-20 mA channels at Cordemais

From the aforementioned result the following approximate costs per channel:

- FRF 1,500: IMP
- FRF 2,200: FIP (FRF 1,500 without the software)
- FRF 3,800: CVP
- FRF 5,000: HP 3852

Note: this estimate corresponds to the costs of test measurements performed on the configuration set up at Cordemais.

5.3 Installation and commissioning

5.3.1 Structure

The structure of the instrumentation includes 3 levels:

- sensors,
- conditioning units (Micro-Gate or rack Gespac Systems),
- acquisition front panel.

This structure is equivalent to the simplest solution based on PATERN and IMP's. The "PATERN and CVP" solution has an additional level (sensors, CVP, VME, PATERN) and thus makes the architecture more complicated.

5.3.2 Wiring

Benefits result from the:

- reliability of the network wiring: within the junction boxes, the junction wires are held in place by jaws (no terminal screws),
- time saved for each connection: junctions are made instantaneously, no preliminary stripping of insulation required,
- support of hot plug and unplug of instruments: such operations can be carried out while acquisitions are under way and has no influence on the acquisition cycles. With the IMP's or CVP's, the acquisitions must be stopped before one may remove or add any physical instrument and on completion of such an operation, the system must be reset.

5.3.3 Commissioning

The commissioning operations are generally time-consuming and comprise the following stages:

- Location of wiring errors; every sensor is first disconnected from and then reconnected to its measuring channel,
- Metrological check of the channels (performed at the same time as the previous operation); a calibrator is set up on each channel and three different electric voltage signals (values) are sent through the line. The measurements are acquired by PATERN and then verified by post-processing,
- Identification of each sensor (serial number) and check of its analog output signal.

The whole of these operations require a minimum time of 10 minutes per channel, to which must be added the time it takes the operators to get to the different locations (5 to 10 minutes to access a unit stage). In the commissioning phase, these times are optimized by a commissioning program (grouping of checks by stage or cabinet, etc.).

With the digital instrumentation set up at Cordemais, such checks are not necessary, since the sensors are smart. They are performed automatically during the initialization phase of the instrumentation. Moreover, they can be repeated at any time during operation, without disturbing the acquisition cycles. The acquisition front panel performs this task in about 1 minute.

BENEFITS:

- About 30 smart sensors (pressure and flow rate) are implemented in the test instrumentation. Thus, the minimum benefit in terms of time savings amounts to 30*10 minutes, i.e., 5 work hours. On the assumption that all measurement points would be fitted with smart sensors, the time saved would amount to 252*10 minutes, in other words over 1 man week (exclusive of the added time needed to get to the different locations).
- When the digital instrumentation set up at Cordemais was put into operation first, several wiring errors were automatically identified by the acquisition front panel.

5.3.4 Data availability

For the three solutions IMP, CVP and HP3852, the measurement data are available only on the workstation running PATERN and other computers of the PC type can access these data via a client-server connection. For each connection (i.e., a given client within a particular environment), a specific code has to be developed to access the PATERN server.

With the FIP solution, the data can be accessed at three levels:

- on the workstation running PATERN, as in the case of the previous solutions,
- on the "acquisition front panel" PC: the client / server connection is managed by Windows, thus, the coding is, a priori, easy,
- directly on the WorldFIP network, as the access to the data is unrestricted. This connection entails the disadvantage that the data conveyed are raw measurement data (not corrected by calibration), but it has the advantage of being fast (as fast as the network transfer rate, i.e., a couple of milliseconds) and not increasing the workload of the acquisition front panel PC or the workstation.

5.4 Operation and maintenance

5.4.1 Benefits expected from smart instrumentation

All the benefits expected from digital instrumentation featuring smart sensors are effectively provided by the digital instrumentation set up at Cordemais. These benefits are based on the communication features and are, for instance:

- controlled configuration for every smart sensor, automatic during the initialization phases and operator-initiated during operation,
- sensor faults are processed by their built-in self-diagnostics feature (fault identification, etc.),
- increased measurement credibility:
  - in absolute values through comparison of the current loop analog signals with the digital values (read as close as possible to the measuring sensor)
  - clock-controlled WorldFIP routines provide continuous refreshing of the data output by the sensors and promptness for the benefit of the data user.

5.4.2 Examples of faults eliminated with digital instrumentation

Since the commissioning of the digital instrumentation at Cordemais, various operating faults which remained overlooked until then, could be identified:

- oscillations of measurement channels: as the acquisition front panel does not filter the measurements very much (acquisition cycle in the order of 500 ms—average of 10s for PATERN) has allowed EDF to identify 3 channels for which calibration was inadequate. The oscillations of the physical value of the process to be measured caused the analog output of the sensors concerned to become saturated (these sensors were calibrated with respect to the average value of the process). For these sensors, two types of operation were performed since the acquisition front panel*:* either an increase of the attenuation (or "damping") coefficient constant of the sensor or a different calibration (adaptation of 4-20 mA conversion to a given range of physical values to be measured).

- improper connection of a measurement channel: one measurement channel of a sensor was disconnected from one conditioning unit and reconnected to another. Previously, two acquisition channels coexisted in PATERN for a single sensor.

BENEFITS:

- Concerning the faults mentioned first, the improvements are metrological, given that with conventional instrumentation, these faults might never have been detected. The benefits can also be expressed in terms of labor time. With a portable programming console, the sensor settings require about 30 minutes vs. 1 to 2 minutes when the same operations are performed with the acquisition front panel.
- As for the second fault, the benefits cannot be expressed in terms of cost but in terms of consistency of the PATERN configuration and the instrumentation set up.

5.4.3 The users' opinion

The instrumentation is followed up locally by staff members of the DTG (Division Technique Générale - General Engineering Department). After 6 months of operation, they express the following opinion about digital instrumentation*:*

- Generally speaking, the product is under utilized by DTG, on the one hand because of the fact that its major faults were eliminated upon commissioning and, on the other hand, because of the fact that since that time, there have not been many faults and the few that have occurred have been identified immediately (example: the channel out of order identified by PATERN). Full utilization by the operators of the features supported by the acquisition front panel together with the smart sensors would require extensive on-site training (given the great number of functions provided and the difficulty in assessing the complex communication protocol).
- However, specifics test were carried out in the course of October 1998 on an instrumentation sub-set (approximately 40 measurements performed at the fastest possible acquisition time). A fast acquisition system using the basic features of the acquisition front panel was developed and the system acquisition times were of the order of 10 ms. Full development of the software took 2 hours (modular software architecture, macro-functions).

5.5 Conclusions and prospects

The operational feedback on the digital instrumentation at Cordemais shows that the technical and economic benefits provided can be substantial. These benefits can be expressed in terms of*:*

- measurement quality (absolute precision, credibility, acquisition cycle, etc.),
- new operation and maintenance help functions,

- optimization of the labor time during the commissioning and operation phase of the instrumentation.

By way of example, the use of the operation help functions could be extended as follows*:*

- generation of systematic check sequences (independent of any operator action) of the values output by the digital sensors and the analog 4-20 mA loops, so that possible internal shifting of the sensors could be detected. Such information could automatically generate re-calibration requests,
- the precision of the Micro-Gate converters could be verified automatically through the transmission, by the sensors, of calibrated values (example*:* a 4 mA followed by a 20 mA signal).

After 6 months of operation, the hardware and software constituents of the digital instrumentation at Cordemais have not shown any malfunction. Only the Micro-Gate converters had to be reset after wiring errors (polarity reversal of their inputs).

Making full use of digital instrumentation (with respect to the great number of new functions) requires in-depth training of the operators (digital technologies, smart sensors, etc.).

The multivariable transmitters 3095 MV, today used as differential pressure transmitters, will possibly be implemented as flowmeters (fitting of thermometer wells in the circuits for temperature measurements) during unit shutdown.

6
TECHNICAL FEEDBACK FROM THE MARTIGUES AND LUCCIANA FOSSIL-FIRED POWER PLANTS

This section presents feedback from the fossil-fired power plants Martigues and Lucciana, which have decided to set up installations based on smart sensors and fieldbuses on all or part of their process equipment.

6.1 Approach

Operational feedback from the Martigues and Lucciana fossil-fired power plants presented in this report takes account of the three subsequent phases both projects have actually gone through*:*

- a preparation phase during which the sites and equipment (sensors, actuators, fieldbuses, automation systems, etc.) subject of the analysis have been identified, so as enable the project team to proceed with the following step, i.e., to organize the structure of the data to be collected [23];
- a data collection phase which has consisted of on-site visits and meetings with the project initiators;
- an analysis phase followed by the summary of the data collected.

The three subjects discussed during the meetings and re-discussed in this report are the following*:*

- methodological aspects: summary of the different phases of the life cycle of a project aimed at the implementation of smart instrumentation;
- technical aspects: description of the major technical data of the existing system;
- economic aspects: presentation of the costs and lead times inherent to the project.

6.2 Presentation of the power plants concerned

6.2.1 The Martigues power plant

Table 6-1
General presentation of the Martigues power plant

General data	4 units fired with Very Low Sulfur Content fuel oil, each with a capacity of 250 MW.
History	Unit 1 was commissioned in 1971; the three other units were commissioned subsequently in 1972, 1973 and 1974.
Current status	Unit 4 has been shut down since 1984; the three other units are operational. In general, the power plant is started up within 24 h for the following reasons: rise in the Durance river level (preventing the operation of the hydropower stations), strike or shutdown of the power plant at Gardanne, drop in the output of the nuclear power plants of the Rhône valley, forest fires requiring the operator to cut off of some power lines to allow the passage of Canadair fire-fighting aircraft.
Instrumentation concerned	The fuel oil heaters (2 per unit) are fitted with one ΔP sensor and one condensats level control valve, to increase the efficiency of the unit.

6.2.2 The Lucciana power plant

Table 6-2
General presentation of the Lucciana power plant

General data	Six diesel sets, each with a capacity of 11 MW. Pielstick PC3 18-cylinder V-engines, Jeumont-Schneider generators.
History and current status	The power plant was commissioned from 1973 to 1978. It currently comprises 6 generator sets plus two additional sets that can be re-started if need be. The electric power generated by EDF in Corsica comes from the two fossil-fired power plants at Lucciana and Vazzio, along with several hydropower plants; the remaining part of the power demand can be supplied by the interconnected network Italy – Corsica – Sardinia and various power producers. Lucciana generates approximately 14% of the total gross energy, Vazzio 40%, the hydropower stations 27 % and the remaining 23% are supplied by the interconnected network. The Lucciana power plant currently employs 87 people.
Future of the power plant	Further to a combined cycle power plant construction project, it was planned to shut down the Lucciana power plant in 1995. A disagreement that arose between EDF and the Corsican Territorial Assembly caused the project to be stopped. This led to the decision that Lucciana be kept in operation until 2013. For this reason, an expert evaluation was performed in 1995 to determine the refurbishment measures to be taken to increase the power plant's lifetime. This was precisely the framework in which the modernization of the control system was decided.

6.3 Summary of the data collected

6.3.1 Methodological aspect

This section is the study of the different phases of the project's life cycle, from the initial motivations that led to choosing smart instrumentation, up to the maintenance of the instrumentation, and, in-between, all the phases of selection, procurement, installation and commissioning.

6.3.1.1 General organization of the projects

6.3.1.1.1 Martigues power plant

The project was initiated in March 1998 and integrated in a programmed investment aimed at refurbishing the instrumentation, however the technology to be adopted was initially not defined.

The choice of the project "carriers" naturally fell on the instrumentation set-up team of the Maintenance Department. A tandem was set up, made up of one member of this team and a person from EDF R&D / REME to draw up the specifications and a manufacturer bid ranking grid, to select a bid and take part in the on-site commissioning of the system. The call for tender was organized by the Unité Energie Méditerranée located in Marseilles.

The involvement of the instrumentation set-up team of the power plant was decisive for making a success of this project. More particularly, the decision to investigate the smart instrumentation and field bus solution was inspired by the regular follow-up of all articles published by the press and also motivated by a very keen interest in this technology.

The other potential participants in the project, such as the operator and management of the power plant have not been involved much in the project, except for taking the final decision, of course.

6.3.1.1.2 Lucciana power plant

The refurbishment project for the instrumentation and control system was decided further to the expert evaluation carried out in 1995, with the objective of identifying the refurbishment measures required to increase the lifetime of the power plant.

As was the case for the Martigues power plant, it was the switchgear and instrumentation set-up team of the Maintenance Department which was chosen to steer the project. This team has made its contribution to the drawing-up of the specifications, the commissioning of the system and its technical follow-up in the subsequent operational phase. The call for tenders was organized by the GICA at Montpellier.

Table 6-3 shows the subsequent stages of both projects along with the contributions made by all of the participants:

Table 6-3
The two projects: stages and participants

Stages	Martigues Power Plant	Lucciana Power Plant
1. Drawing up of the specifications	Maintenance Department + R&D	Maintenance Department
2. Preparation of call for tenders	Unité Energie Méditerranée	GICA at Montpellier
3. Receipt and analysis of bids	Maintenance Department + Headquarters Department	National management / Headquarters Department + GICA + Maintenance Department
4. Selection of the best bid	Maintenance Department + R&D	Headquarters Department
5. Final decision	Headquarters Department	Headquarters Department
6. On-site commissioning of the system	Maintenance Department + R&D	Maintenance Department
7. Technical follow-up in the operational phase	Maintenance Department	Maintenance Department

6.3.1.2 The identification and expression of the needs

6.3.1.2.1 Martigues power plant

The objectives that motivated the refurbishment of this control system / loop and the implementation of smart instrumentation are as follows:

- Provide the possibility of optimizing the fuel oil temperature in the boiler, increase the unit's efficiency and reduce the emission of pollutants to the atmosphere.
- Perform an initial test of smart instrumentation and field buses to assess in particular the benefits in terms of metrological accuracy and maintenance costs.
- Make it possible to extend the refurbishment to other control systems / loops by taking advantage of its enhanced modularity provided in particular by the fieldbus.

It was not possible to take the economic stakes into account. The potential savings in terms of wiring and maintenance costs were nonetheless identified, but appeared not to be decisive, given the relatively small size of the system (6 sensors and 6 valves).

The evaluation of the aforementioned stakes enabled the teams involved to define the criteria to be used for the assessment and selection of the bids. The open-endedness of the product, its upgradability and guaranteed lifetime were taken into account.

The identification of these needs was reflected in the drawing up of the specifications. This task was performed by the switchgear and instrumentation set-up team with support from EDF R&D.

The choice of a system based on smart instrumentation and field buses was explicitly imposed on the team. An additional constraint was identified: the transfer of the measurement data to the Panorama monitoring system used by the operator. The other elements set forth in the specifications rather concern the organizational aspects of full project management.

The fairly vague definitions in the technical specifications constrained the manufacturers to obtain more detailed information before being able to draw up a valid technical proposal. This process allowed us to assess the commitment and motivation of the manufacturers who were willing to bid.

6.3.1.2.2 Lucciana power plant

The principal goal that had motivated the project was the refurbishment of the instrumentation and control system, to increase the power plant's lifetime.

The second issue to be tackled was to further EDF's knowledge of the process (in particular of the diesel engines) through the acquisition of additional data and the achievement of advanced operating diagnostics.

Finally, the economic aspects (savings achieved on wiring, maintenance, etc.) were certainly taken into account; however, they were not accurately reckoned by means of calculation bases or other methods.

The drawing-up of the specifications was achieved by the switchgear and instrumentation set-up team of the Maintenance Department, supported in particular by the work achieved at the Cordemais and Martigues power plants. The technical specifications prescribe an instrumentation and control system including the definition of level 1 (PLC) and level 2 (monitoring and status recorder system).

These specifications let the manufacturers freely define new instrumentation aimed at improving the knowledge of the process. Thus, a good knowledge of the process and—more particularly—of the Pielstick diesel engines, was an implicit requirement. A lesson learned was that it was important to have engine specialists as part of the project.

6.3.1.3 Bid analysis and contract awarding

6.3.1.3.1 Martigues power plant

Table 6-4 lists the companies invited to tender, along with the broad outlines of their proposals. Insofar as the decision to modernize the existing instrumentation by replacing it with smart instrumentation, the invitation to tender was sent to manufacturers deemed capable of proposing mature products which had already been marketed for a certain time.

Table 6-4
Companies invited to tender for the Martigues project

Companies invited to tender	Technical features
Fisher-Rosemount	Mixed solution including both smart and conventional analog instrumentation, Delta V system, Foundation Fieldbus.
Smar	Mixed solution including both smart and conventional analog instrumentation, Syscon system, Foundation Fieldbus.
Alstom	Declined to tender
Elsag Bailey	Declined to tender
Siemens	Declined to tender

The technical evaluation of these bids was performed by means of an analysis grid (Appendix A.2) taking into account the following aspects:

- general characteristics,
- technical data of the different levels (level 0, 1 and 2),
- the company's technical skills,
- the company's quality system,
- quality of the offer (details, deadlines, quality of the contact, etc.)

The technical offers received from Fisher-Rosemount and Smar were quite similar, with a slight advantage for Fisher-Rosemount that offered better lifetime guarantees and technical skills acknowledged by EDF. In addition, their system permitted, in the case of partial refurbishment, to mix analog and digital components thanks to the input / output boards which can be plugged into the Delta V housings. From a commercial viewpoint, the offers were almost identical.

6.3.1.3.2 Lucciana power plant

Table 6-5 lists the companies invited to tender, along with the broad outlines of their proposals:

Table 6-5
Companies invited to tender for the Lucciana project

Companies invited to tender	Technical features
Pielstick (the engine manufacturer)	Conventional analog solution, PLC "April" manufactured by Schneider Electric.
CMR (supplier of the old relay-based instrumentation and control system)	Conventional analog solution, PLC manufactured by Schneider Electric.
Alstom	System P320 backed up by WorldFIP[7] field bus.
Fisher-Rosemount	Mixed solution including both smart and conventional analog instrumentation, Delta V system, Foundation Fieldbus.
Siemens	Declined to tender

Concerning the bids made, the technological differences are quite pronounced. The companies Alstom and Fisher-Rosemount each made a proposal mixing fieldbus-connected smart instrumentation and conventional analog instrumentation, thus offering new features (predictive maintenance of the instrumentation, fairly accurate and detailed event log, etc.). As for the proposals made by Pielstick and CMR, these were entirely based on conventional analog technology and rather focused on improved knowledge of the process (especially Pielstick with respect to the engine). The choice was then made on the basis of the commercial aspects of the bids and Fisher-Rosemount appeared to be very competitive.

The awarding of the contract to Fisher-Rosemount is probably due in part to its highly competitive offer, but also to the choice of implementing an advanced and upgradable technology. However, it appeared that this company did not have the skills required to achieve the functional analysis and define the instrumentation to set up for the engine follow-up. Thus, EDF asked Fisher-Rosemount to go into a partnership with a company that had diesel engine maintenance expertise. Consequently, Fisher-Rosemount turned to the company BEALAS, a specialist in the maintenance of diesel engines.

6.3.1.4 Installation and commissioning

6.3.1.4.1 Martigues power plant

Wiring: laying of cables and wires was fairly easy. All that had to be done was to mount the cableways for the H1 network and then check the network at different points for continuity (there are tools available to perform this check).

[7] The system P320 manufactured by Alstom is set up on the Everest loop of REME. The connection between the PLC and the instrumentation is made through HART / FIP interface sets which communicate via the WorldFIP network, called S8000 at Alstom.

Sensors and actuators: Saunier & Duval was entrusted with the fitting of the sensors, whilst the valve mounting was sub-contracted to the company Berthier (except the digital positioners of the valves). As these sub-contractors were placed under the command of Fisher-Rosemount, there was no need for EDF to dialogue with several contractors. The configuration of the equipment was partly factory pre-set. In particular, the setting of the control loop (AI, PID, AO, parameterisation) was performed beforehand on an engineering workstation and then was directly downloaded into the sensors.

Installation time: globally, the system set-up did not affect the re-start of any of the units. It should be noted that some components (sensors, etc.) could be set up while the unit was operating, without these components having to be connected to the process.

Problems encountered: minor problems of network continuity that were rapidly solved.

6.3.1.4.2 Lucciana power plant

SDEL, a partner company of Fisher-Rosemount provided the following services:

- *Dismantling:* marking-out of the existing wires and cables along with checking the drawings for accuracy, disconnection of all of the external cables from the racks at terminal level and dismantling of these racks.
- *Mounting of the new racks:* supply, positioning, mounting and grounding of the racks.
- *Sensors:* dismantling of the existing sensors and fitting of the new ones.
- *Wiring:* supply, laying and connection of the cables between the sensors and racks (exclusive of the Foundation Fieldbus) followed by a wiring check.
- *Consoles:* mounting and fixing of the new consoles in the control room.
- *Monitoring system:* installation and connection of the data processing hardware (power supplies / outlets and data links with the racks).

Some of the existing cables were re-used for All Or Nothing data and the connection of conventional analog components. The new cables laid are for the field buses and the connection of smart components.

Installation time: the installation in the first unit was achieved during a 6,000-hour inspection and maintenance shutdown that usually takes 5 weeks. Setting up the new instrumentation system took an additional week, a time that can be deemed globally satisfactory.

6.3.1.5 Qualification of components

Since the constraints of a fossil-fired power plant are not as demanding as those of a nuclear power plant, the application of qualification procedures is not as extensive. The manufacturer simply certifies that his components are capable of operating under certain environmental conditions. Nonetheless, it must be noted that the Lucciana power plant requested additional information from Fisher-Rosemount to make sure of the components' good resistance to certain environmental constraints (hydrocarbons, vibrations, temperature, see 4.2.9).

6.3.1.6 Training

At both Martigues and Lucciana, the following training lessons were learned:

- The information should not be too general and should meet the specificities of the plant. In particular, the demonstration models used should be identical with the system installed, thereby preventing the users from feeling really concerned about model differences and identifying the benefits provided by the new features.
- The documentation should be in the language of the end user.
- The personnel involved still remain very close to the process and may find it difficult to change over to computerized interfaces.
- Some staff members (operation and maintenance personnel) do not accept this technology very well, as they fear it will lead to a loss of process knowledge.

6.3.1.7 Quality Assurance

These two projects were not integrated in a Quality Assurance procedure. This is probably due to the fact that the sites have not been made aware of this kind of approach.

6.3.2 Technical aspect

The goal of this section is to highlight the technical features of smart instrumentation and more particularly those features which set smart instrumentation apart from conventional instrumentation.

6.3.2.1 General features of the system

6.3.2.1.1 Martigues power plant

Each unit is fitted with two fuel oil heaters, on which the following Fisher-Rosemount components are set up*:*

- a differential pressure sensor model 3051 CD (including an indicator) for level measurement, positioned as close as possible to the branch pipe (between 4 and 9 m),
- a digital valve positioner Fieldvue DVC 5000 F.

The architecture of the system is shown in Figure 6-1. The network Foundation Fieldbus is made up of two H1 segments. The first segment is assigned to units 1 and 2 (8 components) and the second to unit 3 (4 components). Communication in these two segments is managed by two communication boards fitted in the DeltaV system. The data are then uploaded via an Ethernet link to the DeltaV PC located in the control room. Finally, an OPC link via Ethernet was created to transfer these data to the already existing Panorama monitoring system.

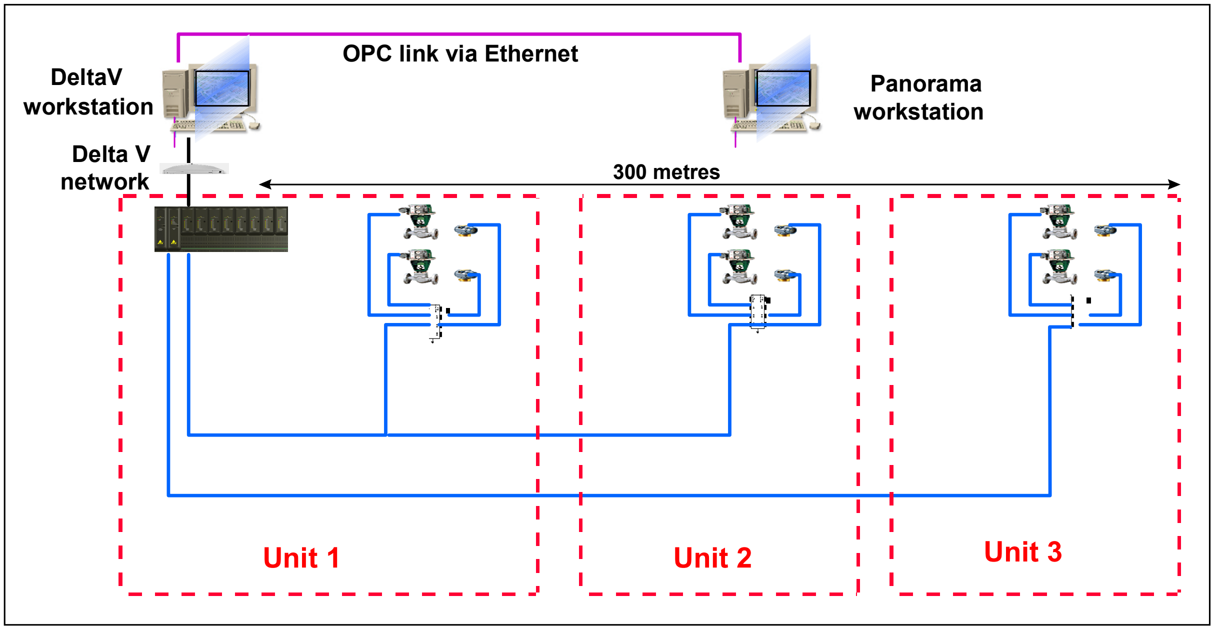


Figure 6-1
Simplified diagram of the Martigues system architecture

6.3.2.1.2 Lucciana power plant

The instrumentation arrayed at the Lucciana power plant is made up of fieldbus-connected smart sensors, analog 4-20 mA sensors and AON inputs / outputs (the control of the process is fairly simple, which is why this system has (and does not require) any control valve fitted with a digital positioner).

Instrumentation arrayed on one unit:

- 18 smart temperature sensors model Fisher-Rosemount 3244 connected to a FF network,
- 8 smart pressure sensors model Fisher-Rosemount 3051 connected to a FF network,
- 40 analog inputs,
- 120 logical inputs / outputs.

The data are collected either in the diesel rack (as for engine-related data) or in the generator rack. It is the DeltaV system fitted with analog input / output and AON boards, along with digital communication boards of the Foundation Fieldbus network that make it possible to manage all these data and transmit them to the higher level via a redundant Ethernet link (maximum length: 100 m). This link could have been a fibre optic loop, in fact redundant (in case of breakage, the data is conveyed in the opposite direction), but Fisher-Rosemount did not deem it useful to adopt this solution, given the short distances to be covered (<20m) between the configuration / operation PC's and the DeltaV controllers.

Figure 6-2 shows a simplified diagram of the system architecture. The control room is fitted with one workstation dedicated to operation (animated mimic diagrams, front panel, alarms, records, etc.) and another workstation on which it is possible to configure all of the acquisition functions, positioners, diagrams and charts, smart components, etc. This workstation can also be used as a redundant operation console. A printer allows the operators to produce hard copies of reports and alarms. A maintenance laptop PC for diagnostics can either be used in the control room or connected to the control cabinets (diesel and generator racks).

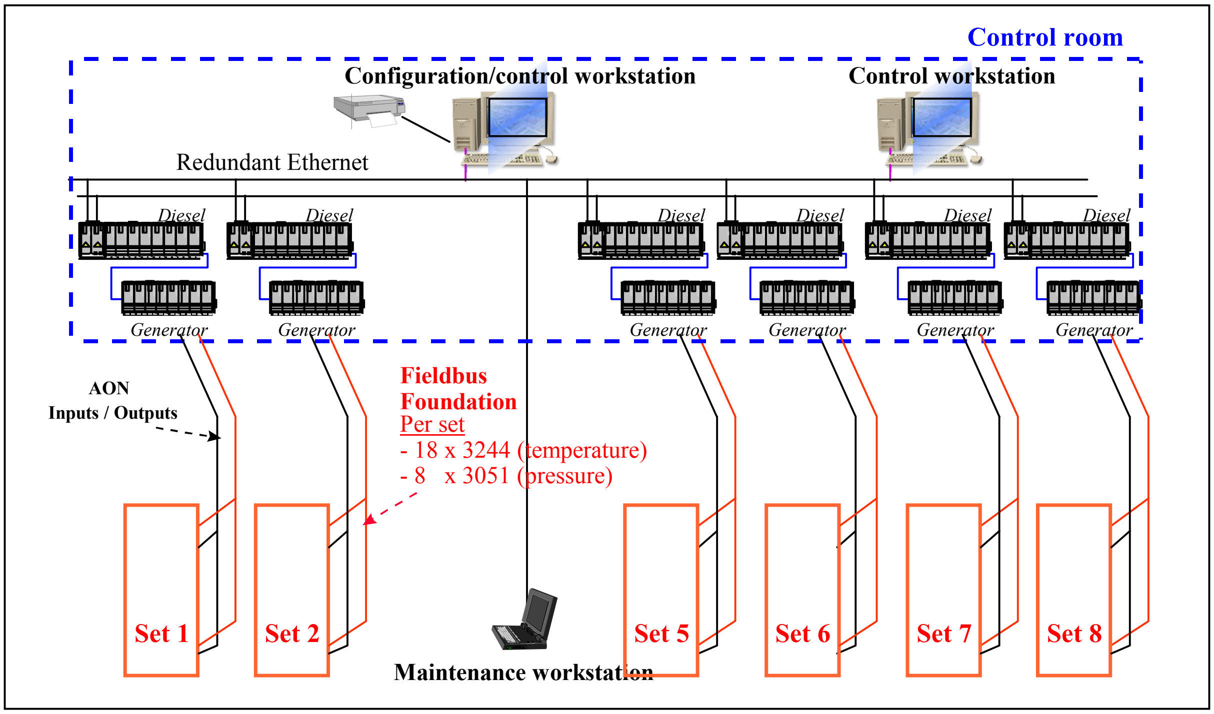


Figure 6-2
Architecture of the Lucciana system

6.3.2.2 Operational characteristics of smart instrumentation

The transmitters implemented (model 3051 and 3244 manufactured by Fisher-Rosemount) have a rated precision comprised between 0.075% and 0.1% of the measuring range. The manufacturer guarantees a drift lower than 0.1% for 5 years, i.e., regular maintenance of these components is no longer necessary. After their first year of operation, the components set up at Martigues have still not undergone re-calibration.

6.3.2.3 Advanced functions

6.3.2.3.1 Martigues power plant

- *Computing features:* calculation of the level based on a differential pressure is a sensor-integrated function.

- *Distributed positioning:* calculation of the PID is also a function integrated in the sensor model 3051. Hence, the latter forwards the set value to the digital positioner that acts directly on the valve.
- *Monitoring of thresholds:* no particular alarm assigned to measurements.

6.3.2.3.2 Lucciana power plant

The collection of these data was not possible. Indeed, the lack of openness shown by the manufacturer does not allow the EDF personnel to master the advanced features of the instrumentation. This being stated, one better understands the fears expressed by some users who consider that this new system causes a loss of process visibility, along with advanced features which, however, have still not been mastered at the present stage.

6.3.2.4 Configuration features

Given the quite short operating times, the re-configuration feature of the sensors is not used very much. Unlike the aforementioned feature, (re-)loading the initial sensor configuration was tested and appreciated. This function provides significant time savings for the system along with the possibility of replacing a component and then downloading its proper configuration.

This configuration is performed from a PC set up in the control room. The configurable parameters are as follows:

- Component name and function,
- Zero and range adjustment,
- Unit of measurement,
- Computing functions (conversion law, variable calculation, etc.),
- Alarm threshold (two high levels and two low levels per measurement).

This configuration can be performed during operation, via the acyclic[7] fieldbus traffic, provided that the change is not likely to jeopardize the smooth operation of the instrumentation and control system.

6.3.2.5 Operating safety

The fault data (alarms) are accessed via a PC set up in the control room. These alarms are ranked by order of priority, managed and time-stamped at the source within the controller. The alarm priority characteristics are defined globally for the system. For example, one can assign a color, flashing and sound to any of the high-priority alarms.

[7] The communication frames of the Foundation Fieldbus are made up of cyclic data (measurements) and acyclic data (configuration parameters, alarms, etc.).

The Fisher-Rosemount smart transmitters model 3051 and 3244 used by these two applications are capable of transmitting two alarm types:

- The process-related alarms (threshold high, low, very high, very low, sensor fault, etc.). These alarms are displayed on the operation interface.
- The detail diagnostic alarms, which can be displayed in the AMS (EEPROM problem, faulty electronic or mechanical component, maintenance operation to be carried out soon, etc.).

However, in the plants considered, the most used alarms are those related to the process. The advanced diagnostic capabilities are not really used for the moment. All in all, it still seems to be too early to draw any conclusion as to the reliability of these systems.

6.3.2.6 Interoperability and interchangeability

The plants discussed here make exclusive use of components from Fisher-Rosemount, hence they provide no information as concerns interoperability.

However, it is possible to provide some information concerning the interchangeability of the two systems: should the Martigues power plant wish to replace its differential transmitter model 3051 by a different transmitter (typically from another manufacturer), it would then be necessary to download the former transmitter's configuration onto the new one. It is simply required that the new transmitter have a PID function block, which is the case for about half of the transmitters certified by the Fieldbus Foundation. Should the replacement transmitter be fitted with a very uncommon function bloc[8], the interchangeability with a "standard" component could be jeopardized. This is certainly what may diminish the degree of interchangeability of a Foundation Fieldbus-certified sensor.

6.3.2.7 Expandability and upgradability

The Martigues power plant had identified the interest of making use of an open-ended system that could be expanded to other control loops. Thus, the Maintenance Department team proposed an expansion to the superheater chain which makes it possible to adjust the final temperature of the steam conveyed to the turbine. Theoretically, this temperature must be adjusted to 565°C. Should the temperature reach 600°C, it could cause the boiler to be perforated. Hence, mastering this control loop is absolutely essential. The instrumentation concerned is made up of 5 temperature measurements, 2 pressure measurements, 4 valves, some additional analog, and AON measurements.

This refurbishment operation has been deferred, as the Headquarters Departments in the fossil-fired power field do not wish further development to take place for the time being unless a policy is defined in this area.

[8] The typical example for this is the Smar company which is very advanced in this field and integrates a large number of function blocks in its sensors. When a special function block is used for positioning, for instance, it will be difficult to replace such a component by a "standard" model.

In addition, it must be stated that it still remains possible to add a sensor to the network segment (typically to have an additional measurement) via some changes in the control loop arrangement. However, there are still physical limits (for example, the maximum number of components set up on one and the same segment), but the advantage of this kind of change made on smart instrumentation is that with the latter, connecting a sensor to the fieldbus is easier than laying a cable up to a cabinet that is not necessarily located in the vicinity.

6.3.2.8 System support

At the Martigues power plant Fisher-Rosemount could permanently "view" the application via a switched network connection. This feature enabled its staff to show a good capacity for reaction whenever specific and uncomplicated problems occurred.

6.3.2.9 Resistance to environmental constraints

The environmental constraints are distinctly more numerous at the Lucciana power plant than at Martigues. For this reason, the Lucciana team desired to get the following information even before the on-site set-up of the system.

- *Resistance to hydrocarbons:* the cables used are sheathed with PTFE, a material capable of withstanding hydrocarbons for over 15 years. Concerning the sensors, their resistance exceeds 10 years, since they have tight IP 65-compliant enclosures. It should be noted here that components with this enclosure protection rating are used in oil refineries and offshore platforms, thus providing an additional guarantee as concerns their lifetime.
- *Resistance to vibrations:* this constraint is fairly significant at Lucciana, since some of the sensors are directly fitted to the engine. The trials performed by the manufacturer allow him to certify that the vibrations within the range from 15 to 2000 Hz (in any axis) have an effect on the measuring range used that is lower than 1/1000. Nonetheless, Lucciana has decided to improve the resistance to vibrations by fitting "pigtails" on each measuring point (this meant increasing the price by FRF 4,400 per set).
- *Permissible temperature range:* The transmitter model 3051 manufactured by Fisher-Rosemount is rated for the following temperature range: from -40°C to 85°C as for the ambient temperature and from -40° to 121°C at the mounting location of the sensor. The mounting of "pigtails" decreases the sensor cell temperature by approximately 10°C. Fisher-Rosemount also offers another version of this sensor, the model 3051CG, the cell of which resists a maximum temperature of 149°C (extra cost: FRF 250 per sensor).

6.3.2.10 Sub-systems

This aspect solely concerns the Lucciana power plant, the Martigues power plant being autonomous. The sub-system at Lucciana is the Neyrpic engine speed controller which adjusts the engine speed and power in a way that ensures its optimum coupling with the generator. The users have not identified any particular problem due to the interconnection of this sub-system with the instrumentation system.

6.3.3 The economic aspect

6.3.3.1 Project budgets

6.3.3.1.1 Martigues power plant

Table 6-6
Budget of the Martigues project

Supplies	**FRF 165,100**
6 pressure transmitters model 3051CD Fieldbus	FRF 40,200
6 stainless steel 3-way manifolds	FRF 5,100
6 digital valve positioners model Fieldvue DVC 5000	FRF 32,000
Delta V Input / Output Interface (mainboard, M3 controller, H1 board, power supply board, license)	*not established*
Operation / configuration PC	*not established*
Miscellaneous connecting equipment (2 junction boxes, 2 terminations, 12 transmitter connectors, 12 junction box connectors)	*not established*
Engineering services	**FRF 33,000**
Project management	FRF 25,000
Creation of a mimic board	FRF 3,500
PID setting	FRF 4,500
Special discount of 11%	**FRF - 21,791**
Total (supplies and engineering)	**FRF 176,309**
Installation work	**FRF 87,500**
Training (2 groups of 5 persons for 4 days at the Fisher-Rosemount's agency in Bron, exclusive of hotel expenses)	**FRF 52,000**
Grand total	**FRF 315,809**

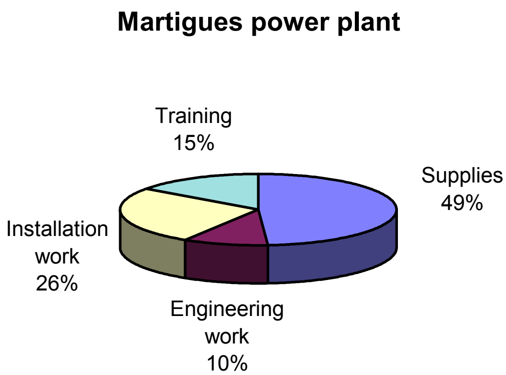
The supplies make up 49% of the overall budget, engineering services 10%, installation work 26% and training 15%. The low cost of the engineering item was due to the fairly simple nature of the system which did not involve a great number of components and complex control features. Unlike the previous item, the cost of the supplies make up half of the overall cost, which might be considered high; this is probably due to the extra cost to be paid for smart instrumentation (the price of which exceeds by 20% the one to be paid for conventional solutions, but a downward trend can be noticed). The comparison with a conventional instrumentation system might have been unfavorable to the smart instrumentation solution, since the potential benefits—disregarding those brought in for the operation—are rather to be found in the wiring and commissioning of the system and this system is not large enough to take full advantage of these benefits.

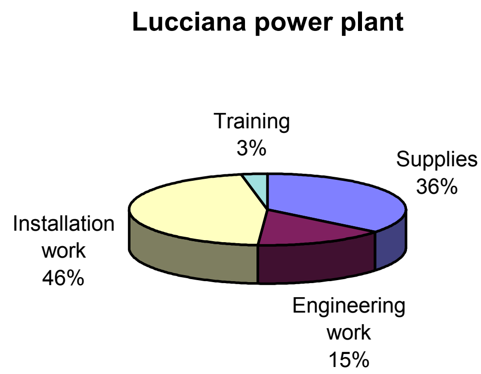
6.3.3.1.2 Lucciana power plant

Table 6-7
Budget of the Lucciana project

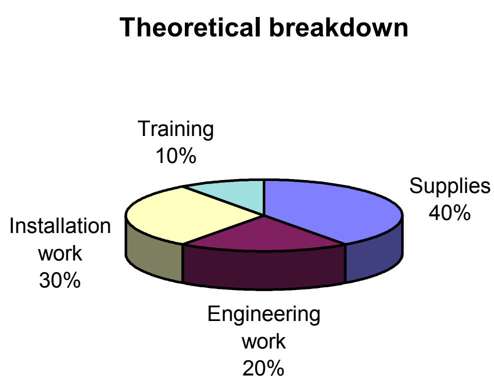
Supplies	**FRF 1,660,150**
Instrumentation (smart sensors, analog sensors, All Or Nothing inputs / outputs) *Per set* - 18 FF temperature sensors model 3244 - 8 FF pressure sensors model 3051 - 40 analog inputs - 112 All Or Nothing I/O	FRF 700,500
System (communication, operator workstations, licenses, printers, M3 controllers, H1 communication board, I/O boards, power supplies, Fieldbus cables and connectors, etc.)	FRF 820,000
Laptop PC + diagnostic software	FRF 60,100
Furniture (2 tables) and console for the control room	FRF 35,000
2 Uninterruptible Power Supplies	FRF 3,200
Spares	FRF 41,350
Engineering services	**FRF 703,000**
Fisher-Rosemount engineering services	FRF 403,000
Services provided by the engine specialist Bealas (functional analysis, <u>unforeseen at project start</u>)	FRF 300,000
Installation work	**FRF 2,136,000**
Training (50 operators for 1 day and 15 maintenance technicians for 2 days)	**FRF 174,000**
Grand total	**FRF 4,673,150**

The supplies make up 35% of the overall budget, engineering services 15%, installation work 45% and training 3%. The strain put on the "Supplies" item is due to the fact that installation work included the supply of the racks and a part of the wiring (lump sum / package deal with the company SDEL). It can be seen that the cost of the engineering services slightly exceeds the cost for the Martigues power plant, but it accounts for 15% only. As for the "Training" budget, it is fairly low, but one might have to review this statement, since the users are not satisfied and wish to attend further training sessions.





The charts above reveal large differences in the breakdown of the budgets. However, given that the items "Installation work", "Supplies" and "Training" are somewhat distorted, it can be considered that the most typical breakdown is that of Martigues, but this judgment has to be toned down a bit, since this system is not very extensive and some of the costs are not correctly assessed (the cost of supplies is too high with respect to the cost of "Installation" item). This being stated, it is possible to imagine the following theoretical breakdown, which is to be seen as an attempt to correct the specificities of the systems discussed:



It is regrettable that the comparison with a conventional analog solution could not be made for these projects, but it is important to remind the reader of the following points:

- the 20 to 30% savings announced by some manufacturers for smart instrumentation do not always appear very realistic. Besides, some manufacturers are now beginning to moderate these statements or even to refute them. These manufacturers rather mention savings in the area of 5 to 10 %, while insisting on the future savings in operating costs.
- the benefits provided by smart instrumentation with respect to maintenance and ease of operation remain very difficult to assess, since they involve a large number of parameters

difficult to quantify (changes in working methods, improved measuring quality / accuracy, improved reaction capability, etc.).

6.3.3.2 Project schedules

6.3.3.2.1 Martigues power plant

Table 6-8
Schedule of the Martigues project

Project initiation	March 1998
Drawing-up of specifications and call for tenders	May-June 1998
Receipt of bids	July-August 1998
Bid selection	September 1998
Signature of contract	October 1998
Start-up of unit 1	July 1999
Start-up of unit 2	October 1999
Start-up of unit 3	December 1999

6.3.3.2.2 Lucciana power plant

In 1995, an expert evaluation was initiated to determine the refurbishment measures to be taken to increase the power plant's lifetime. In the following, the modernization of the instrumentation and control system was decided. The drawing-up of the specifications and launch of the call for tenders took place in 1999, the bid receipt in May 1999 and the initial start-up of the first unit in July 2000.

6.4 Conclusions

The quite recent start-up of these systems (September 1999 for Martigues and July 2000 for Lucciana) does not yet allow EDF to come to conclusions assessing the benefits this technology provides for operation or maintenance. On the other hand, it is possible to identify the lessons that can be drawn from the organization of such a project and from the impact these smart sensors may have in an environment where the activities are very closely related to the process:

- the implementation of this technology has a strong impact on the users' activities, so it is necessary to involve them to a considerable extent from the very start; otherwise, it will be more difficult for them to adapt to the new system.
- the manufacturers offering smart instrumentation solutions are not process specialists. They master their technology, but in general have no skills that would enable them to define the

instrumentation required to ensure proper monitoring of such or such subset, or even to obtain a more detailed diagnosis than with the old system. Consequently, the contribution of a specialist capable of making a functional analysis of the process is necessary as early as the initial stage of the project.

- the on-site installation of the hardware and equipment items seems to be facilitated, in particular thanks to the quick configuration features (download of a configuration) to the network-based diagnosis tools which make it possible to identify any wiring problem more quickly than on the previous systems.
- training the future user is very important and should not just be limited to a general presentation of the possibilities of the tool.
- concerning the costs, it seems to be reasonable to make the following breakdown of the overall budget of one system:
  - 40% for supplies,
  - 20% for engineering fees,
  - 30% for installation fees,
  - 10% for training.

A
APPENDIX

A.1. Comparative tables

The information given in the following tables comes essentially from the technical documents produced by those responsible for the technologies: Fieldbus Foundation, Hart Communication Foundation, PROFIBUS International, WorldFIP Organization. Where possible, this information has been cross-checked and/or completed with information provided by the manufacturers. Nonetheless, all missing or dubious information or that provided by other sources (always indicated) is identified with a question mark. All information in these tables (in particular concerning the number of sensors available, of references, etc.) was up to date on December 1, 1999.

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFI BUS	WorldFIP
General characteristics				
Variants / associated networks (higher-level networks, etc.)	2 versions: - One basic version (known as H1) at 31.25 kb/s - One rapid version being developed (known as HSE) based on Fast Ethernet at 100†Mb/s, replacing an H2 version at 1 and 2.5 Mb/s (project dropped) NB: unless otherwise indicated, only H1 is described in the rest of this table	2 applications: - point to point (signal superimposed on a 4-20 mA signal) - multidrop (on 4 mA current for all subscribers)	3 variations	4 profiles: - 1: Plug & Play - 2: Configurable and Controllable Simple Devices - 3: Configurable and Controllable Devices - 4: Complex Devices
			- DP: between process control systems, and distributed I/O	
			- FMS: for communication on cell level or between complex systems	
			- **PA**: for linking of sensors and actuators; may be used in an IS zone ñ this is the adaptation of the DP protocol to IEC 1158-2 (layer 1)	
			Layer 1 of FMS and DP is called H2; that of PA is called H1	

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFIBUS	WorldFIP
Prime market				
Sector	Process industries (petrochemicals, chemicals)	Wherever there is 4-20 mA current	Process + manufacturing industries	Energy; transport; automobile manufacturing; service industries
Geographical region	US, Japan and, to a lesser extent, Europe and Latin America	Worldwide	First Germany; now extended to central and northern Europe + China/Japan + US	France and, to a lesser degree, Italy, UK. Non-existent elsewhere (except in subsidiaries of Schneider and Alstom/Cegelec)
Background	1994: Creation of FF from ISP and WorldFIP North America 1998: Launch of the HSE project	1986: Introduction in industry 1988: Creation of the HART User Group	1987-1990: Creation and fine-tuning 1989: Creation of PNO	1984: Launch of the FIP project 1988: Creation of the FIP club 1993: Creation of WorldFIP
Developments announced / Strategy	Historically a strong supporter of IEC 61158, wanting a single standard (unlike EN 50170). Following the events of 1999, prepared to back a multi-protocol IEC 61158 providing this integrates its own protocol	To remain the de facto standard for a long time to come	To avoid any threat due to the publication of IEC 61158: - either by integrating PROFIBUS in the standard (as in EN 50†170) - or by delaying or preventing publication of this standard Uncertain future for FMS (too closed to Ethernet)	Announces its desire to align itself gradually with IEC 61158, as it is published Positions itself as complementary to sensor/actuator fieldbuses like Hart or FF Seeks alignment with FF (WorldFIP is a member of FF)

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFIBUS	WorldFIP
Organization				
Body(ies) responsible for the protocol and all new developments	Fieldbus Foundation	Hart Communication Foundation (HCF)	PI (at the head of 22 Regional Profibus Associations including PNO) PNO: German section of PI, charged by the latter with developing and maintaining the standard	WorldFIP Organization
Main participating companies	**120** members Manufacturers: Fisher-Rosemount, Yokogawa, Yamatake, National Instruments, Endress+Hauser, ABB Users: Du Pont de Nemours, Shell, Procter & Gamble, JPL, Monsanto	**117** members All the big names in instrumentation & control: ABB, Allen Bradley, Endress+Hauser, Fisher Rosemount, Foxboro, Fuji, Honeywell, Krohne, Micromotion, Moore, Pepperl & Fuchs, Siemens, Smar, Toshiba, Yamatake, Yokogawa	**900** members 200 in Germany, 130 in the US Behind its development, 21 German companies and universities: ABB, AEG, Bosch, Honeywell, Kloeckner-Moeller, Landis & Gyr, **Siemens**, Pepperl & Fuchs	**125** members 33 times Schneider + 19 times Alstom / Cegelec (through their subsidiaries), over 22 universities or research centers + 3 WorldFIP offices! Practically no users (except for EDF) No other big names in instrumentation & control Some companies have left (Elf, Atochem, Endress + Hauser in 98) While remaining a member, Schneider left the Board of Directors in 1998.

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFIBUS	WorldFIP
User involvement				
In technical decisions	End Users Advisory Council meets 2 to 3 times yearly		In PNO Technical Committees and Working Groups	Very limited (practically no end users in WorldFIP)
Technical backup available (in addition to websites)	7 Regional End User Councils (EUC) in North America, Europe, Japan, Latin America, Australia, New Zealand, and Singapore		3 Mailing lists 4 PROFIBUS Competence Centres in Germany, Austria, Poland and Switzerland	3 technical centers (France, Italy, China)
Efforts at standardization				
Scope of standardization (in terms of ISO layers covered)	1, 2 and 7, and user application model	1, 2 and 7	DP: 1, 2, and user interface	1, 2 and 7
			FMS: 1, 2 and 7	
			PA: 1, 2, and user interface	
			The 3 variations use the same layer, 2 (FDL)	
Progress in standardization Europe: EN 50170 ratified in 1996 (Vol. 1: P-NET, Vol. 2: PROFIBUS, Vol. 3: WorldFIP) International: IEC 61158	USA: ISA SP50 International: IEC 61158	Not standardized The FSK principle used corresponds to Bell communication standard 202	Europe: EN 50170 volume 2 (covering FMS and DP), completed by amendment n_2 (covering PA) and EN 50254 (describing PROFIBUS DP as a profile of EN†50170) Already standardized in Germany under DIN†19245 International: IEC 61158	Europe: EN 50170 volume 3. This standard replaces French standards C46 601 to C46 607, integrating layer 1 of IEC 61158-2 International: IEC 61158

Criteria \ Fieldbus	Fieldbus Foundation	HART® FIELD COMMUNICATIONS PROTOCOL	PROFIBUS®	WorldFIP
Companies offering compatible products	**21** including Fisher-Rosemount, Fuji, National Instrument, Yokogawa, Honeywell, Foxboro, Pepperl & Fuchs, ABB, Smar, and Endress+Hauser	**> 55** including ABB, Endress+Hauser, Foxboro, Honeywell, Krohne, Moore, Fisher Rosemount, Siemens, and Yokogawa	**250** including ABB, Endress+Hauser, Krohne, Pepperl & Fuchs, Siemens and Smar	**64** - 41 approved by WorldFIP Organization (no doubt for specific products not in their catalogue) - 16 French - and **only 7 non-French**
Numbers and types of products in the market (in September 99)	**114 products and services** (only some, ~40, are registered) **- 36 sensors or actuators** - 24 accessories or miscellaneous - 14 interface modules - 12 analyzers - 9 services - 7 IHM (sub) systems - 4 PLCs - 4 maintenance products - 4 development products	**> 250 sensors and actuators**	**1,726 products and services** (only some, < 400, are certified) - 468 distributed I/O systems - 240 accessories - 174 process control components - 150 PLC modules - 136 PC modules - 118 IHM (sub) systems - 102 services or documents - 75 speed variators **- 73 sensors or actuators** - 67 software tools - 47 pneumatic components - 27 Industrial PCs - 15 position controllers - 34 miscellaneous	**320 products** - 70 accessories - 47 control cards (PC primarily) - 44 "sensors or actuators" including 21 speed variators and various types of measurement devices - 39 distributed I/O systems - 37 PLCs or small dedicated control systems - 25 software tools - 24 fieldbus components - 20 IHM (sub) systems - 14 gateways **→ Instrumentation: virtually non-existent**
Number of installations	NA	NA	250,000	6,000
Number of devices installed	10,000? (*source: Frost*)	3/4 of all sensors built today are HART? (*source BIPE*)	2,500,000 devices ~ 85% DP ~10% FMS ~5% PA	100,000 nodes (ordered or installed) ☞: 1 device may represent several nodes (e.g.,: PLC with distributed I/O racks)

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFIBUS	WorldFIP
Date of first availability of such products	1998	1986	1996 for PROFIBUS PA	1993
Availability of chips, tools for development, configuration and maintenance	No pocket yet available	Pocket produced by Fisher Rosemount	(pocket project?)	Low level products" (Hardware: FULLFIP2; FIPIU2; FIPCO1; MicroFIP; or software: FIP Device Manager; FIPIULIB; FIPLIB; FIPSPY; FIP Analyser; FIP Scanner)
Procedure to verify compliance of a product with the standard	Registering of compatible products after interoperability tests. Products then given an "FF mark". FF maintains a list of all compatible products	None	Testing (hardware, functional, behavior on failure, addressing, diagnosis, interoperability, CEM) by an accredited laboratory according to testing and certification procedures defined in "PROFIBUS guidelines" Followed by certification by the PNO (period of validity: 3 months)	None
Interoperability / interchangeability				
System characteristics / existing configurations enabling evaluation of the interoperability of subscribers from different manufacturers	Use of: - "device description" (DD) and "device description language" (DDL) borrowed from Hart, and developed by Fisher Rosemount	Use of: - 3 classes of commands (universal, common and specific) for slave components	PROFIBUS DP and PROFIBUS FMS may be used simultaneously on the same cable.	Use of 4 profiles of increasing complexity, in addition to sub-profiles: and companion standards (for individual subscriber types).

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFI BUS	WorldFIP
	- standardized function blocks (E_{TOR}, E_{ANA}, S_{TOR}, S_{ANA}, PD, PID, Integrator, set point generator, logic alarm, analog alarm, step by step controller)	- 6 classes of conformity for master components, - "device description language" or DDL	PROFIBUS PA products can be connected to PROFIBUS DP fieldbuses with couplers.	The profiles (beginning with 2) and even the companion standards leave (too) much freedom in selection of the variables exchanged
			For DP and PA, use of: - GSD (file containing information enabling the use of configuration tools independent of the supplier) - Identity numbers, describing the type of component (managed by PROFIBUS organization)	
System characteristics / existing configurations enabling evaluation of <u>interchangeability</u> of subscribers from different manufacturers	Same as for interoperability	Same as for interoperability	DP: Same as for PA FMS: little significance, due to the high level of FMS	Little significance, due to the absence of instrumentation in the WorldFIP offer
			PA: Use of profiles like transmitters (P, T, Q), valves (etc.), defining the parameters which may be read or written	

<table>
<tr><th>Criteria \ Fieldbus</th><th>Fieldbus Foundation</th><th>HART FIELD COMMUNICATIONS PROTOCOL</th><th>PROFIBUS</th><th>WorldFIP</th></tr>
<tr><td colspan="5">Characteristics</td></tr>
<tr><td>Method of access</td><td>H1: Producer-Consumer with centralized fieldbus scheduler

(the role of scheduler can be adopted by any other "link master" the event of failure of the first).</td><td>Master-Slave</td><td>- Token ring system between master (or active) components, like PLCs, and configuration tools

- Master ñ Slave, with passive components

- or combination of these 2 modes</td><td>Producer ñ Consumer, with centralized fieldbus scheduler</td></tr>
<tr><td>Speed

(see also below, performance)</td><td>H1: 31.25 kb/s

HSE: 100 Mb/s</td><td>1,200 b/s</td><td>H2 (DP & FMS): from 9.6 kb/s to 12 Mb/s
<table>
<tr><th>kb/s</th><th>m</th></tr>
<tr><td>9.6</td><td>1200</td></tr>
<tr><td>19.2</td><td>1200</td></tr>
<tr><td>93.75</td><td>1200</td></tr>
<tr><td>187.5</td><td>1000</td></tr>
<tr><td>500</td><td>400</td></tr>
<tr><td>1,500</td><td>200</td></tr>
<tr><td>12,000</td><td>100</td></tr>
</table></td><td>Standard: 1.0 Mb/s

Variant: 31.25 kb/s; 2.5 Mb/s; and (optic fiber only) 5†Mb/s

(project: 25 Mb/s)</td></tr>
<tr><td></td><td></td><td></td><td>H1 (PA): 31.25 kb/s</td><td></td></tr>
<tr><td>Topology</td><td>Linear (1 or several segments interconnected with repeaters) + deviations</td><td>Point-to-point or multidrop (on 4mA current for all subscribers)</td><td>Linear (1 or several segments or sections interconnected with repeaters) + deviations</td><td>Linear (1 or several segments or sections interconnected with repeaters) +deviations</td></tr>
</table>

Criteria \ Fieldbus	Fieldbus Foundation	HART FIELD COMMUNICATIONS PROTOCOL	PROFIBUS	WorldFIP
Physical medium	Pair (twisted or not)	Twisted pair	H2: RS485 (twisted pair) or optic fiber	Twisted pair or optic fiber
			H1: twisted pair	
Fieldbus connection	T socket or junction box	No specific equipment	"9-pin D sub plug" connection or equivalent	Tap boxes
Detection and/or correction of errors	parity?	2-dimensional horiz/vert. parity (1 bit/octet + 1 octet/frame)	DP: Hamming distance = 4 PA: parity?	CRC 16
Coding	Manchester biphase-L	Frequency signal (according to the FSK principle, based on the Bell 202 communication standard) superimposed on the 4-20 mA signal	PA: Manchester biphase-L DP: RS485	Manchester
Functions				
Distribution of time and time-dating by subscribers	Yes, standard option Cyclic diffusion of a time-distribution message by the LAS	No	DP: No FMS? PA: no automated diffusion of time. Only alarms are time-dated at the source	Possible, but not covered by the standard
Possibility of distributed control	Yes, called for in the standard	No	No	Possible, but not covered by the standard

Criteria \ Fieldbus	Fieldbus Foundation	HART® FIELD COMMUNICATIONS PROTOCOL	PROFI® BUS	WorldFIP
Possibility of power supply for sensors / actuators by fieldbus, and maximum power (+ mains voltage)	**Yes on H1**, no on HSE	Yes	No for DP	No for the 1MHz version
			No for FMS	
			Yes for PA	
Available interfaces with other fieldbuses			HART	HART (FF planned)
Performance				
Maximum size				
Of main fieldbus	H1: from 200 to 1900 m per segment, depending on the type of cable (including the cumulative length of all segments)	3000 m (with a section of 0.5 mm^2)	DP: from 100 to 1,200 m per segment depending on the speed PA: from 500 to 1,900 m depending on the level of protection against explosion More by optic fiber	- from 500 to 1,900 m per segment depending on speed, with a maximum of 5 segments - more with optic fiber b/s — m 31.25 k — 1 900 **1 M** — **750** 2.5 M — 500
Of deviations	From 1 to 120 m depending on the number of subscribers	Included with the main fieldbus	DP: deviations possible only if speed < 1.5 Mbits/s	

Criteria \ Fieldbus	Fieldbus Foundation	HART® FIELD COMMUNICATIONS PROTOCOL	PROFI® BUS	WorldFIP
Number of repeaters	4	No repeaters	3 maximum for DP	4
			4 maximum for PA	
Capacity				
maximum "logical" number of subscribers (masters or slaves)	32 per segment 240 in all	2 masters (including 1 pocket) and: - In point to point: 1 slave - In multidrop: 15 slaves	32 per segment 126 in all	256 per segment
allowing for power supply or SI constraints	12 if supplied by a fieldbus 6 in SI zone	?	on PA, if subscribers are in EX zone: 8 (Ex IIC, I) or 22 (Ex IIB)	Not applicable
Distribution between synchronous and asynchronous transmissions	Yes	No	Yes	Yes
Update frequency (typical)	10 ms per component	2 to 3 queries per second	PA: 10 ms per component	Components often multi-variable ñ varies greatly with the number
Minimum guaranteed response time	?	500 ms	DP and FMS: Depends on the speed of the network and the number of subscribers. May be as low as 2 ms with speeds of 12 Mb/s	Components often multi-variable ñ varies greatly with the number
Dependability				
Redundancy possible in the medium	H1: No; HSE: yes	No	PA: No; DP: Yes	Yes

Criteria \ Fieldbus				
Diagnoses available	NA	NA	NA	Specified in companion standards
Auto-configuration / online insertion of subscribers / remote reinitialization	The LAS maintains a Living List (= adds and removes subscribers) → periodical checks to detect new subscribers (Requires a free node)	NA	No online detection of new subscribers	Requires modifying the configuration of the fieldbus scheduler
Supports Intrinsic Security	Yes (with insertion of a barrier between the safe zone and the EX zone)	Yes (using barriers capable of transmitting the FSK signal in both directions)	Yes, with PROFIBUS PA only	No
Economic criteria				
Extra cost of a sensor with a fieldbus connection, compared with 4-20mA	+20% (~1000 FF for a flowrate sensor, ~400 FF for a temperature sensor)	Negligible (new-generation sensors are systematically digital)	+20% (~1000 FF for a flowrate sensor, ~400 FF for a temperature sensor)	NA (no sensors) (for information: 8 channel HART/FIP gateway ~10 thousand FF)
License policy	Membership in FF entitles the member to discounts on some services (documentation, magazines, training, etc.)	Specifications may be accessed on request	Certification of a product: free for PNO members, $2000 for the others	

A.2 Manufacturer bid analysis grid (Martigues power plant)

PRODUCT ASSESSMENT
General product characteristics
Open-endedness
Upgradability
Long product lifetime guaranteed
Product is widely used
Product has references at EDF-GDF
Product is innovative
Sub-total
Technical assessment of the product
Product assessment by an EDF laboratory
Sub-total
Level 0
Is level 0 built around a field network?
If yes, does it comply with the international standards?
Use of smart sensors via acquisition modules fitted with digital input boards
Use of smart sensors directly connected to the field bus.
Support of smart actuators
PID included in the field components
Supply voltage: 48V
Predictive maintenance
Sub-total
Level 1
Time-stamp precision
Acquisition cycle
Sub-total
Level 2
Support of sensor remote configuration via the monitoring
Storage cycle
Predictive maintenance
Compatibility with PANORAMA
User-friendliness of software
Sub-total
ASSESSMENT OF THE SUPPLIER AND HIS OFFER
Technical skills of the company
Company is used to working with EDF
Company fully masters the product and its integration
Training provided
Sub-total

Quality system
Company has its own quality system
Company has independent certification
Sub-total
Offer assessment
Global offer quality (detail level, description, etc.)
Quality of the contact
Offer received in due time
Offer complies with specifications
Acceptance / commissioning conditions are specified (in two phases: at the manufacturers' works and on site)
Sub-contracting terms are clearly defined
Detailed on-site work schedule
Offer includes mounting and wiring
Sub-total
SUMMARY
General product features
Product assessment
Technical skill of the company
Quality system of the company
Bid assessment
<u>Overall assessment</u>
COST
<u>Supplies</u>
Configuration - monitoring system (FRF)
Actuators (per unit) (FRF)
Sensors (per unit) (FRF)
Field network (FRF)
<u>Services</u>
Design
Mounting
Total mounting + design
Training
PANORAMA communication tests
Documentation
Total exclusive of mounting (supplies+supervision+config. System)
Total exclusive of mounting (supplies+superv.+config.+positioners)
total including mounting + positioners
total including mounting + positioners + indicators
total including mounting + positioners + indicators + training
idem + shut-off valves
idem + OPC licence and Panorama tests
Ranking with respect to the best bid
Total

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Target:
Nuclear Power

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EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
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