Field Transmission Protocols for Process Industry - an analytical and comparative study

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Owing to the rapid advances in the technology, the process industry is thinking to extend the 4-20mA standard to enhance communication with intelligent measurement and control instrumentation. Keeping this in mind, an analytical and comparative overview of the compatibility of different enhanced field transmission/communication protocols, which are expected to widely use in pulp and paper industry by the year 2010, has been reported. This paper highlights the important features and architecture of data transfer protocols viz. Fieldbus and Highway Addressable Remote Transducer (HART) based communication networks used in process industries like pulp & paper, chemical, petrochemical etc. The parameter- wise characterization of different Profibus has been complied in the tabular form (Table-3). Further different parameters like, operating voltage, maximum cable length, communication methods, communication speed, maximum data size etc. have been taken into account while giving a comparative analysis of field bus, Profibus and HART (Table-4 & Table-5). The universal adoption of Field bus by the pulp and paper industry would be the most worthwhile milestone in Field bus's evolution. Mills, which have started to work with Fieldbus technology, report significant savings in hardware and installation costs. It is commonly reported in the literature that by the use of above protocols, per instrument cost saving benefits are of US$ 300-500 in initial installation/commissioning and $100-200 per year in ongoing maintenance/operations. Some cases of the use of these filed transmission protocols in a typical pulp and paper industry have been quoted in the paper.

Keywords: Highway Addressable Remote Transducer (HART), Profibus, Fieldbus, and Transmission Protocols, Pulp & Paper.

INTRODUCTION

During the period of mid-seventies, the analog systems were widely used to obtain the response of control systems. During that time, digital computing was very costly and slow compared to the situation today. As the cost of digital computing decreased and its speed of operation increased, the analog systems was gradually replaced with a digital systems/computer **[1,2]**. After the introduction of digital communication in process control, manufacturers have been forced to adapt advanced control systems like PLC, DCS etc. The selection, application and future scope of these systems are reported by Sharma et. al.**[3,4]**. As a major step in the evolution in the field of transmission protocols, the HART protocol is fostering significant innovation in process instrumentation capabilities. The enhanced communication characteristics of this important technology are reflected in the protocol name, HART that stands for "Highway Addressable Remote Terminal ". The HART Communication Foundation is an independent non-profit corporation organized to serve growing industry interest in the HART Protocol and the needs of HART users. HART field communication protocol is widely reorganized as the industry standard for digitally enhanced 4-20mA smart instrument communications. Use of the technology is growing rapidly, and today virtually all major global instrumentation suppliers offer products with HART communication **[5,6]**.

The concept of Fieldbus introduces somewhere around late nineties. Fieldbus is a process network used for interconnecting sensors, actuators and control devices to

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each other. It is a generic-term, which describes a new digital communications network, which will be used in industry to replace the existing 4-20mA analogue signals. The network is a digital, bi-directional, multi-drop, serial-bus, and communication networks used to link isolated field devices, such as controllers, transducers, actuators and sensors [7,8]. Each field device has low cost computing power installed in it, making each device a 'smart' device. With these devices not only will the engineer be able to access the field devices, but also be able to communicate with other field devices. The field devices can be accessed in the field as well as communicate with the other field devices. The basic difference between the HART and Fieldbus is that, HART is only meant for communication protocol, whereas Fieldbus is actually a system architecture including control strategy.

Highway Addressable Remote Transducer (HART)

In early days, the most common standard for pneumatic signal transmission was 3-15 psi, which mainly uses compress dry gas for the measurement and control operation. In today's industrial process control era, electronic controllers have replaced most of the pneumatic controllers. An electronic controller uses 4-20mA signal and digital algorithms to perform its corrective functions. The comparison between pneumatic and electronic systems is given in Table-1. The biggest limitation of a 4-20mA signal is, its limited capacity of sending information (measured variable). The problem was redressed by the use of 'Smart' field devices using the HART (Highway Addressable Remote Transducer) protocol. HART enhances the transmission operation, because digital data is transmitted along with the 4-20mA without interfering with it. This has two important benefits. Firstly, existing cabling and current control strategies remain secure, and secondly, the additional data-tag numbers, measured variables, range and span data, product information and diagnostics can be used during installation, calibration, maintenance and operations to cut costs substantially and improve the management and utilization of 'smart' instrument networks.

Other features of HART are enumerated below [5,6]:

- Field proven concept that is easy to understand and use
- Compatible with existing 4-20mA systems
- Simultaneous point-to-point 4-20mA and digital communications
- Alternative multi-drop mode
- Digital response time of 500mS; burst mode response of 300mS
- Open architecture: freely available to any vendor and every user

Digital Compatibility

- Access to all instrument parameters & diagnostics
- Supports multivariable instruments
- On-line device status

Analog Compatibility

- Simultaneous analog & digital communication
- Compatible with existing 4-20 mA equipment & wiring Interoperability
- Fully open de facto standard
- Common Command and data structure
- Enhanced by Device Description Language

Availability

- Field proven technology with more than 1,400,000installations
- Large and growing selection of products
- Used by more smart instruments than any other in the industry.

HART protocol operates using the frequency shift keying (FSK) which is based in the Bell 202 [9] communication standard. The digital signal is made up of two frequencies- 1200 Hz and 2200 Hz,

Table 1: Comparison between pneumatic and electronic systems.

Pneumatic Systems	Electronic Systems
Lower initial cost	Lower installation cost
Regular maintenance	Lowest regular maintenance
Highest reliability	Greater accuracy
Simple system design	Complex system design
Compatible with CV	Require I/P Converter
Less affected by corrosive atmosphere	Affected by corrosive atmosphere
Short distance Transmission	Long distance Transmission
No direct compatibility	Superior computer compatibility
Safety in hazardous locations	Very cold ambient temperature
Regular maintenance staff are required	Long term maintenance can be avoided

representing bits 0 and 1 respectively. Sine waves of these frequencies are superimposed on digital analog signal cables to give simultaneous analogue and digital communications. Because the average value of FSK signal is always zero, the 4-20mA signals is not affected. The graphical representation of simultaneous analogue and digital signals is given [5].

The signal transmission takes place through two basic modes:

Point-to-point mode:

In this mode the conventional 4-20mA signals continue to be used for analog transmission, while measurement, adjustment and equipment data is transferred digitally. The analog signals remain unaffected and can be used for the control in the normal way. HART data give access to maintenance, diagnostic and other operational data.

Multi-drop mode:

This mode requires only a single pair of wires and if possible, safety barriers and an auxiliary power supply for up to 15 field devices. Multi-drop connection is particularly useful for supervising installations that are widely spaced, such as pipelines, feeding stations and tank farms.

HART operations can be used in either mode. In point-to-point operation, the field device has address 0, setting the current up to 4-20mA. In multi-drop mode, all field devices have addresses greater than 0 and each device sets it's output current to 4mA. For this mode of operation, controllers and indicators must be equipped with a HART modem.

HART Structure

HART follows the basic Open Systems Interconnection (OSI) reference model developed the International Organization for Standardization (ISO) [6]. The OSI model provides the structure and elements of a communication system. The HART protocol uses a reduced OSI model, implementing only layers 1,2 and 7, shown in fig.1.

Layer 1, the Physical Layer, operates on the FSK principle, based on the Bell 202 communication standard:

- Data transfer rate: 1200 bit/s.
- Logic '0' frequency: 2200 Hz.
- Logic '1' frequency: 1200 HZ.

Layer 2, the Link Layer establishes the format for a HART message. It improves the transmission reliability by adding the parity character derived from all the preceeding characters; each character also receives a bit for odd parity.

Layer 7, the Application Layer, brings the HART instruction set into play.

A vast majority of existing wiring is used for this type of digital communication. For short distances, unshielded, 0.2mm two-wire lines are suitable. For long distances (up to 1500m), single, shielded bundles of 0.2mm twisted wires can be used. Beyond this, distances up to 3000m can be covered using single, shielded, twisted 0.5mm pairs.

A special size of operand is required to enable the field device to carry out

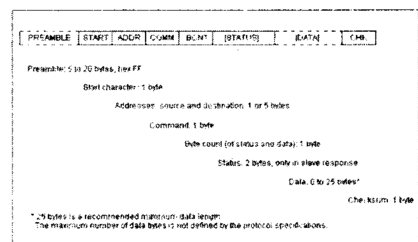

Fig.2 : Structure of HART message [5]

the HART instruction. The byte count indicates the number of subsequent status and data bytes. The functional structure of a HART message in shown in fig. 2.

Fieldbus

Introduction of Fieldbus is an impetus to the pre-existing control and transmission technology. Since digital communication was first introduced in process control, manufacturers have been forced to adapt their products to a myriad of protocols as they emerge. A standard Fieldbus has relieved device manufacturers from this task. Mistaking Fieldbus for a "digital 4-20 mA" or a better DCS is like mistaking the computer for a better typewriter. It cannot even be compared to "smart" transmitter protocols. It's a system that renders obsolete all separate signal

	OSI Layer	Function	HART
7	Application	Provides formatted data	HART instructions
6	Presentation	Converts data	
5	Session	Handles the dialogue	
4	Transport	Secures the transport connection	
3	Network	Establishes network connections	
2	Link	Establishes data link connection	HART protocol regulations
1	Physical	Connects the equipment	Bell 202

Fig. 1 : Open Systems Intercommunication Model for HART

Conditioners , isolation amplifiers, input cards, output cards, CPU cards, I/P converters, and their web of interconnecting wires, almost an entire DCS. It's a completely self-contained system expressed simply as field devices and a man-machine interface (MMI) like an operator console; a system where all controls, alarms, computation, selection, totalization and much more - performed by the field devices' microprocessors. The system is so powerful so as to overcome a process controls problems with a few 'clicks of a mouse'. Instead of the system's pressure or temperature transmitters converting a sensed digital process value to an analog 4-20mA signal before feeding it to the DCS and the rest of the system chain, Fieldbus keeps the signal purely digital all the way from the transmitter to the digital input of the control valve.

Foundation Fieldbus is an open, integrated total architecture for information integration. Foundation Fieldbus is the only protocol, which has the built-in capability to distribute the control application across the network (Figure 3). It is an all-digital, serial, two-way communication system. The user need not think of device address, memory address and bit numbers etc. Configuration may be edited on a PC and then down loaded to the devices in the field. If we want a flow transmitter to integrate, just instantiated the function block, no need to rewire or buy an additional device. Once physically connected, the links between function blocks may be changed, function blocks can be added and removed etc. Fieldbus already has blocks for all kinds of process control functionality like input, output, control and various types of computations forming an advanced set. Several of the blocks implement alarm. New blocks will keep getting added. Connection is a simple task since devices are connected in parallel and terminal number matching will be a minimum. One wire will typically connect as many as twelve devices.

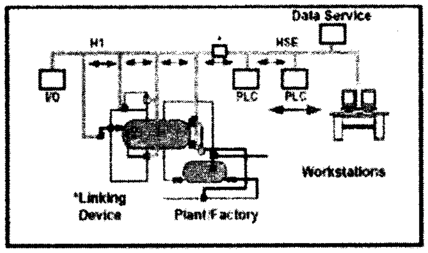

Fig. 3 : Two-way communication Fieldbus system

Procedures like calibration, range setting and diagnostics are implemented consistently between manufacturers and device types. Management Information Systems (MIS), Enterprise Resource Planning (ERP), and Human Machine Interface (HMI) packages access the fieldbus information via the data services.

Fieldbus consists of H1 and HSE (High Speed Ethernet) protocols. H1 (31.25 kbit/s) interconnects "field" equipment such as sensors, actuators and I/O. The H1 fieldbus retains and optimizes the desirable features of the 4-20 milliampere (mA) analog system such as:

- Single loop integrity
- A standardized physical interface to the wire.
- Bus-powered devices on a single wire pair
- Intrinsic safety options.

HSE (100 Mbit/s) provides integration of high-speed controllers

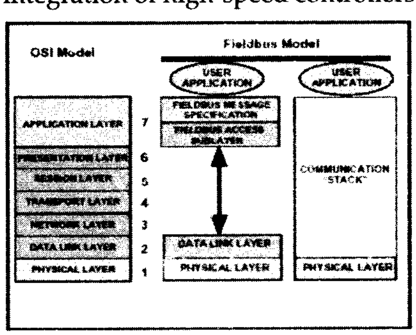

Fig. 4 : Fieldbus Structural Model

(such as PLCs), H1 subsystems (via a linking device), data servers and workstations.

Fieldbus Structure

Foundation Fieldbus technology is already changing the way systems perform control and will have an even greater impact on system architecture, interoperability and openness than the H1 technology. A schematic structural model of Fieldbus has been shown in Figure-4.

The latest field transmission protocol has following benefits:

- Lower cost of purchase and ownership
- Productivity and quality increase
- Higher integrity and accuracy
- Access to more information and diagnosis
- Easier installation and start-up
- Less hardware required.
- Freedom of component choice
- Easier to configure
- Easy for having single consistent database
- Increased capabilities due to full digital communications
- Reduced wiring and wire terminations due to multiple devices on one wire.
- Increased selection of suppliers due to interoperability

Table 2: Types of Fieldbus.

Industrial Networks	Type of Fieldbus
ControlNet	Control
DeviceNet	Devicebus
Ethernet	Enterprise
Foundation Fieldbus	Fieldbus
Prifibus-DP	Devicebus
Profibus-PA	Fieldbus
ASI	Sensorbus

- Connection to the HSE backbone for larger systems
- Reduced loading on control room equipment due to distribution of control and input/output functions to field devices.

Types of Fieldbuses

There are different types of industrial networking or ' fieldbus' technology (Table-2) in the market, which has the wide potential of being applied successfully at the industrial level.

Control

It is targeted primarily at peer-to-peer communication between higher-level control devices, such as PLCs and DCS controllers.

Devicebus

It is the largest general network category that provides communication services for smart devices that can perform multiple functions and communicate process and diagnostics information.

Enterprise

It is the traditional network backbone for the company where business is shared. It is predominantly TCP/IP on Ethernet.

Fieldbus

Generally speaking, it is a step up from Devicebus. It supports transmission of larger amounts of data, but generally running at slower communication speeds and requiring more processor power in the device. Some Fieldbus technologies also support the distribution of control functions directly in the device.

Sensorbus

It consists of the lowest level network, generally for connecting simple low cost sensors, such as on/

Table 3 : Characterization of Profibus

S.No.	Parameter	Profibus DP	PA	FMS
1	Intrinsically Safe	No	Yes	No
2	Operating Voltage			
3	Maximum Cable Length	100m-24000m	1900m	200m-19200m
4	Governing Standard(s)	EN50170 DIN 19245 p3	IEC-61158-2 DIN 19245 p4	EN 13321/1 DIN 19245
5	Communication Methods	Master/Slave Peer to Peer	Master/Slave Peer to Peer	Master/Slave Peer to Peer
6	Communication Speed	1.5-12 Mbits/s	31.25 kbits/s	9.6-500 kbits/s
7	Media Access algorithm	Token passing	Token passing	Token passing
8.	Max. Data Size	246 bytes	246 bytes	246 bytes
9	Max. Stations	127 devices	32 devices	127 devices

Table 4: Comparison between Foundation Fieldbus and HART systems.

S.No.	Parameter	Foundation Fieldbus H1	HSE	HART
1	Intrinsically Safe	Yes	No	Yes
2	Operating Voltage	9-32 VDC	*	*
3	Maximum Cable Length	1900m	100m, 2km with FO	2000m
4	Governing Standard(s)	IEC-61158-2 ISA S50.2	IEEE-802.3u ISO/IEC 8801-3	FSK Foundation on 4-20mA signal
5	Communication Methods	Client/Server Event Notification	Client/Server Event Notification	Master/Slave
6	Communication Speed	31.25 Kbits/s	100 Mbits/s	1.200 Kbits/s
7	Media Access algorithm	Token passing	Token pasing	NA
8	Max. Data size	246 bytes	246 bytes	8 bits
9	Max. Stations	32 devices	Uses IP Addressing essentially limited	15 slaves

Table 5 : Comparison between Profibus and HART systems .

S.No.	Parameter	Profibus DP	PA	FMS	HART
1	Intrinsically Safe	No	Yes	No	Yes
2	Operating Voltage				*
3	Maximum Cable Length	100m-24000m	1900m	200m-19200m	2000m
4	Governing Standard(s)	EN50170 DIN 19245 p3	IEC-61158-2 DIN19245p4	EN 13321/1 DIN 19245	FSK Foundation on 4-20mA signal
5	Communication Methods	Master/Slave Peer to Peer	Master/Slave Peer to Peer	Master/Slave Peer to Peer	Master/ Slave
6	Communication Speed	1.5-12 Mbits/s	31.25 kbits/s	9.6-500 kbits/s	1.200 Kbits/s
7	Media Access algorithm	Token passing	Token passing	Token passing	NA
8	Max. Data Size	246 bytes	246 bytes	246 bytes	8 bits
9	Max. Stations	127 devices	32 devices	127 devices	15 slaves

off swithes. It transmits very small amounts of data and requires very little processing in the sensor.

Based on the comparative study and analytical review of the existing field transmission technologies, comparison charts are drawn for Fieldbus (H1 & HSE), HART and Profibus (DP, PA & FMS). Along with the characterization of Profibus (table 3), a parameter-wise comparison between Fieldbus and HART has been displayed in table 4 and the same for Profibus and HART has been displayed in table 5.

Applications in Pulp and Paper Industry

Till date more than 25000 instruments operating on HART, Fieldbus and Profibus standards have been sold and installed in global pulp and paper industry and the sales are increasing by 35% per year [9]. There are much wider applications of these protocols in a functionality specific industry like pulp and paper. Fieldbus, as one of the most newly targeted protocols, comprises numerous function blocks for various levels of process control. Flexible function blocks perform batch, discrete and hybrid applications. More blocks are under development. Moreover, H1 and HSE are designed as complementary networks. H1 best suits traditional process control applications, while HSE is designed for high-performance control applications and mill information integration. The combined H1/HSE solution allows full integration of basic and advanced process control and hybrid/batch/discrete control subsystems, with higher level, supervisory applications. These protocols have found an important application in condition monitoring of an integrated mill. Mill-wide strategies serve to make control and automation investments on these technologies all the more significant for the success of the overall operation. M-real's Kangas mill in Finland upgraded the condition monitoring system on its coated PM-4 with a Sensodec 6S system from Metso Automation. At first, the new 6S system was selected for calender runnability and condition monitoring [8]. The effort finally culminated into highly featured profibus connectivity. In order to manage the supply chain system of a mill, which is one of the important features of Enterprise Resource Planning, Solution working on Fieldbus standards has been designed by Teito Enator, to integrate order, customer, production and quality data at the mill and provides algorithms and views to optimize profits and production accuracy. Another system, which is specifically designed to connect concurrently with different database sources, by a business unit of Kvaerner Chemetics, gives the user uniform access regardless of the data source, be it DCS, QCS scanners, servers etc. It is designed exclusively for the pulp and paper industry.

DISCUSSION

The discussion, based on parameter by parameter analysis, application and limitation of different Field Transmission Protocols reported in this paper, are given as follows:

1. Electronic transmission systems are more technically and commercially viable than pneumatic transmission systems due to lower installation cost, lower regular maintenance, greater accuracy, superior computer compatibility. But at the same time, electronic systems have complex system design, more vulnerable to corrosive atmosphere and have long distance Tx.
2. Electronic signals have limited capacity of sending information

than Fieldbus and HART.

3. Data size has a miniature value of 8 bits in case of HART. This size of data transferred can be at most 246 bytes in case of both Fieldbus and Profibus. Thus, the number of data grams transmitted at a particular pulse of time is least in HART, which accounts to its drawback, when compared to Fieldbus.

4. Due to less data size, the communication speed is least in HART, i.e. 1200 bits /s. Other protocols arranged in increasing order of communication speed are; H1, PA<FMS<DP<HSE. Since all transmission protocols other than HART have equal maximum data size (246 bytes), HSE is most preferred due to maximum communication speed.

5. Fieldbus is preferred when data size and communication speed are considered as deciding parameters.

6. Fieldbus has client-server-client communication configuration as against master-slave-master configuration in HART and Profibus.

7. Cable length is in the range of 100m in case of High Speed Ethernet (Fieldbus protocol), which is minimum among all protocols. It can be extended up-to 2kms by the use of Fiber Optics, and HART protocol thus proves its compatibility in this respect. For Profibus protocols, the range goes from few hundred meters to 2400m.

CONCLUSION

Paper discusses the key role of the field transmission protocols and monitoring functions in the modern industrial process control and operations along with a special concern towards its potential of application in pulp and paper industry. The different parameters of Fieldbus, HART and Profibus technologies has been critically studied, discussed and reported above. By relying upon the parametrical and comparative analysis, a quick selection regarding the use of a particular transmission protocol can be made, which can prove to be beneficial for the pulp and paper industry going to adopt the latest technological developments, research institutions &students for advanced studies. Pulp and paper industry at the global level is swiftly and successfully embracing this new technology but still there is a great potential of the applications of these protocols in Indian pulp and paper industry. Especially when we talk of the growing computerization and automation in Indian pulp and paper industry, it talks of the practicability and need of this new technology upon itself.

Author welcomes the updating of the information given in the paper on the regular basis to maintain the informative authenticity of the reported data, owing to the rapid changes in transmission technology in the years to come.

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