Methods for Planning, Installation, Commissioning and Diagnosis of Fieldbus Installations

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Abstract - The break-through and acceptance of serial digital communication in the process industry was caused by providing high power to the fieldbus trunk. Serial communication between as many as 32 devices on one segment offers many advantages. The de-facto fieldbus standards for both PROFIBUS PA (PA) and FOUNDATION Fieldbus H1 (FF) are based on IEC 61158-2. The experiences of the first fully operational major production plants in the chemical and pharmaceutical industry show that plant-wiring concepts, shielding, training and the right tools are essential to gain the benefits of fieldbus technology. This paper describes working practice for all phases of the project: planning, commissioning, plant start-up, operation and online troubleshooting of fieldbus systems. Strategies are described that enable users to maximize the benefits of fieldbus technology.

Index Terms — Fieldbus, diagnosis, FOUNDATION Fieldbus, PROFIBUS PA, MBP, installation, commissioning, start-up, troubleshooting, High-Power Trunk, Ex-protection

I. Introduction

Fieldbus installations are replacing conventional technology not only in greenfield applications. New users to fieldbus technology often consider using it for smaller system modifications, plant expansions or simply as a field test. The FuRIOS study [1] verified the technical and commercial viability and many plants are in operation. Working with fieldbus inspired manufacturers to provide equipment for checking and testing fieldbus installations.

This paper briefly reviews fieldbus topologies that have been discussed in various publications and summarizes experiences gained in all parts of the process plant's life cycle. Necessary terminology describing the physical layer is introduced and various tools for fieldbus work are described. The paper concludes with troubleshooting examples that illustrate the fact that fieldbus is indeed a stable and useful tool for application in process plants.

II. Fieldbus Topologies

Fieldbus installations utilizing one of the two leading communications protocols, namely FOUNDATION Fieldbus and PROFIBUS PA are widely accepted in applications requiring Ex-protection. The fieldbus connects field devices such as sensing equipment and actuators with each other as well as with higher-level control systems. Both the communication signal and electrical energy powering the field devices are transmitted via the same shielded, twisted-pair cable as described in IEC 61158-2.

Though this standard describes various topologies, current installations give preference to a trunk-and-spur topology as shown in Figure 1: Trunk-and-spur fieldbus topology. The majority of users prefer connection of only one device per spur for clean system design and simplified work in the field.

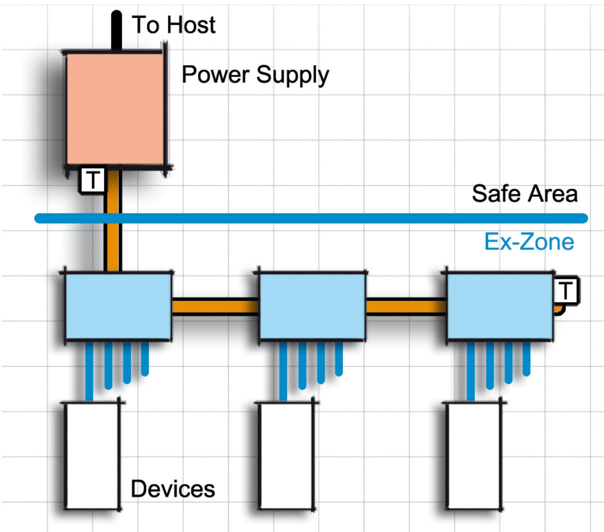

Figure 1: Trunk-and-spur fieldbus topology

A. *Certification for Ex-Applications*

Various concepts are known for simple validation of appropriate Ex-protection. FISCO [2] and Entity are the most popular in use today and described in more detail in IEC-standards IEC 60079-27 and IEC 60079-11. Cable length and number of devices connected are limited in order to achieve Ex-protection.

The high-powered trunk expands on FISCO and Entity: Unlimited energy of up to 31 V and 500 mA or more powers the trunk, which then requires protected wiring method. At the same time, active fieldbus installation technology such as segment protectors or fieldbus barriers provides non-incendive or intrinsically safe connection of spurs to the trunk.

This energy limited topology allows for hot working on the spur and the field device without requiring access to the trunk. This technology enables maximum cable lengths and the highest number of connected devices at the same time. Additionally, each segment is protected from short-circuit conditions on any spur.

Ex-protection is certified utilizing FISCO or Entity for each spur with the active component acting as power supply and the field device as power drain. Details pertaining to high power on the trunk are described in [3].

B. Advantages of Fieldbus

Fieldbus installations benefit from integration of field device data into the control system, leading to reduced capital and operations expenditures:

- Increased accuracy of measurements
- Remote configuration capabilities
- Availability of field device diagnostic data
- Reduction of many aspects of planning and installation

State of the Asset Management systems access diagnostic information of field devices. Self-supervision status of field devices is transmitted to the DCS. This includes information about device failure, out-of-spec behavior or required maintenance. Educated decisions by operations and maintenance staff increase system reliability and availability and reduce maintenance cost and number/duration of unplanned shut down.

C. Disadvantages of Fieldbus Installations

Up to 31 field devices are connected in parallel to the same fieldbus cable and utilize serial communication for transmission of data. This leads to certain disadvantages inherent to fieldbus compared to conventional technology. Users are learning to deal with these.

1. In conventional technology one cable is used per field device. Loss of communication to just one device is considered tolerable. A fault on one fieldbus segment with multiple connected devices will almost certainly cause a process upset.

2. Where a multi-meter device was sufficient to measure 4…20 mA signals, serial communication defines a new set of measurements that is not easy to detect due to the fact that data transmission signals are modulated onto the power supply.

3. Engineering, planning, installation, maintenance and project management must familiarize themselves with serial communication and its requirements.

III. Planning and Installation

Today a variety of commercial and free software tools exist enabling users to plan a working fieldbus topology. With simple drag-and-drop menus the user specifies power supplies used, cable lengths and number and type of field devices. The software determines feasibility by calculating voltage drop and current load. In a short amount of time, the fieldbus topology planning including the number of segments, cable lengths, and other items are completed.

With regards to cable installation of the trunk IEC 60079-14 states that cabling must be protected from

- Mechanical damage
- Chemical influences
- Corrosion and
- Temperature

It is the same protection as applied for installation of lighting appliances and Ex d devices. Additionally, local regulations may demand stronger requirements, which must be observed. As of this date a generally applicable international standard or guideline is not available.

Experience shows that the following aspects, if observed, generate a large payoff:

(1) Train installation personnel to gain an understanding of fieldbus technology and requirements. Wiring methods and installation material as well as field device connections will be new to most technicians;

(2) Always use cable conforming to known specifications. The most common cause for problems with fieldbus is cabling with impedance out of specification;

(3) Carefully validate installation and wiring. A particularly important factor for long-term stability of fieldbus communication is the proper use of shielding and grounding. It must be planned to achieve desired EMI-protection. Hard grounding at both ends is often used, when the plant is built in a small area such as a building block. Capacitive or one-sided grounding is implemented for process plants spread over a wide area. There is no solution that fits all applications as too many factors influence this decision. [4]

(4) Test the application before installation in the field. Novice users, in particular, will gain significant experience from laboratory testing. This point generates large savings, when experience gained can be applied immediately during installation and commissioning and many hours of troubleshooting are saved.

IV. Fieldbus Signals and Measurements

Signal and power are transmitted using the Manchester bus powered protocol (MBP). A signal current is modulated onto the power supply resulting in a transmitted signal voltage of 0.75…1.00 V p-p from the 50-ohm impedance created by the bus termination. The received signal must be greater than 0.15 V p-p. This allows for a signal loss up to a factor of 5. Rising and falling edges code logic 0 and 1.

A. Physical-layer Measurements

Signal level: Figure 2 shows a fieldbus signal level with 900 mV peak to peak. Rising and falling time is 6.4 micro sec. as measured with the vertical bars on the screen. The voltage is measured between the two leads of the twisted-pair cable. Measurement: Milli-Volts per device.

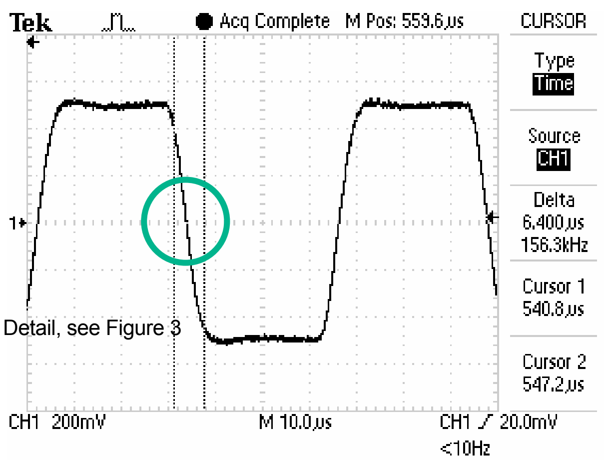

Figure 2: Near perfect signal shape

Unbalance: Where one of the leads has a resistive connection to ground the signal will be offset. This is referred to as unbalance to ground. Measurement: Percent per segment.

Noise – An undesired, random or patterned signal that is induced onto the fieldbus. It is measured as voltage.

Patterned noise typically stems from other electronic equipment such as frequency converters. Measurement: Milli-Volts per device and segment.

Jitter – The rising or falling edge of each bit is expected at regular time intervals, called bit time. During a very small time window the receiver will measure the data signal and expect the edge transmitting the bit. The deviation of the time from the expected time is called Jitter. High Jitter will cause bit errors and therefore telegrams to be lost. Most influences on fieldbus communication lead to Jitter, making it a central measurement for fieldbus diagnosis. Measurement: Milli-Second per device and segment.

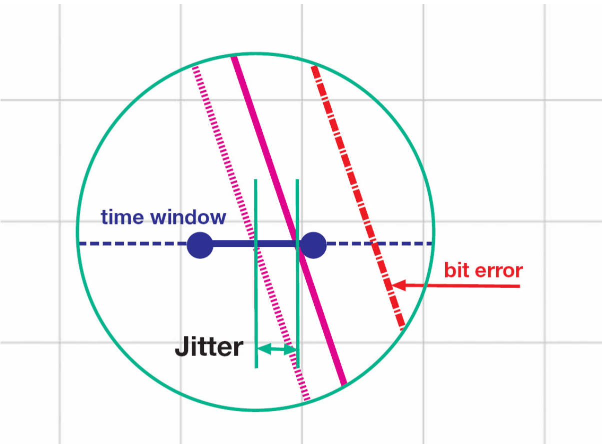

Figure 3: Jitter measured as deviation from the ideal zero crossing

B. Communication

Statistics regarding fieldbus communication are typically counters for:

- Segment live list
- CRC error counter (Cyclic Redundancy Check)
- Frame error counter (Frame = Telegram)
- Number of received frames

C. Resistance to Disturbance

Fieldbus works. Consider this somewhat fatal condition: An Unbalance of 100 % is a solid connection of one lead to ground. Power supply and data transmission will continue to function properly as both are transmitted as potential between the two leads. Only a second fault, such as the other lead connecting to ground will cause a short-circuit and communication failure. In most cases, the situation is not as trivial as in this example:

- Shorts are actually impedances that may be caused by water ingress or component aging.
- Loose wire strands reduce resistance to EMI.
- Improper bus termination causes extra load for the signal level or
- Devices are connected with the wrong polarity.

Fieldbus can be viewed has a having a budget for fault tolerance. Each bullet mentioned will take some of this budget, and when more than one condition exists without detection, the communication may become unstable. This is illustrated in the examples shown later.

D. Tools for Fieldbus Diagnosis

Tools for measuring fieldbus signals are distinguished as:

Bus tester: A simple, typically hand-held device for measurement of resistance, signal level, noise and supply voltage.

Bus analyzer: It verifies field device communication. The bus analyzer is a passive device on the fieldbus. It decodes telegrams and monitors for transmit timing and telegram types. It enables the user to verify content of telegrams as well as proper request and response cycles.

Oscilloscope: The oscilloscope is used to visualize fieldbus signals. It can trigger on a telegram, but is not able to distinguish between telegrams from different addresses. Being bulky, complex to operate and requiring a hot work permit for operation in Ex-environments, they are often used as a last resort for troubleshooting.

Online diagnostic tools: Modules plugging into the power supplies. Comprehensive measurements of the physical layer as well as communications statistics. Trending and alarming functions enable supervision during normal operation. Remote access from the control room is not only convenient but time and cost saving, since analysis is conducted with complete documentation at hand and not in harsh environments. Online tools deliver detailed diagnostic information enabling users to interpret actual conditions in the field.

Many hand-held devices are certified for hazardous area use in Zone 1. Some devices will draw power from the bus. Compared to battery-driven, passive devices the disadvantage is that fieldbus physics change and measurements are not what they would be without the device connected. Typically developed for a single purpose, more than one hand-held device is necessary to perform a complete fieldbus checkout. Devices will show a value as in or out of specification thus showing that an irregular condition exists. By doing so they can create trust in fieldbus technology. It is often simple to use.

Additionally the often fully loaded networks certified to FISCO or Entity cannot cope with the extra load from the testing device. Troubleshooting always requires personnel to be in the field, and connecting a hand-held device requires proof of proper ex-protection even if it is only for temporary use. Currently, hand-held devices are available only for FOUNDATION Fieldbus.

V. Phases of the process plant life cycle

A. Commissioning and Plant Start-up

In general hand-held devices are used to check and validate fieldbus communication. Technicians can connect all field devices simultaneously and detect duplicate addressing and proper signal levels. It is important to check for proper bus termination often too many or too few bus terminators are used. Finally the fieldbus check-out should end with measuring the current under full load conditions. On the spot engineers have another cross check of planned and actual load conditions. They know the available reserve per segment for system modifications, before documentation has been updated. End-users report that up to 30 minutes less time is required per device for fieldbus validation in comparison to conventional technology.

During plant start-up online tools enable supervision and monitoring for modifications often necessary after the initial commissioning phase. Critical loops can be supervised continuously for communications stability.

B. Troubleshooting

In the absence of online monitoring tools, trouble-shooting of fieldbus networks has been reactive. Typically, this work occurs when the communication to one or more devices is interrupted. Where a fault occurs techniques similar to those used during commissioning are applied to troubleshoot the network. Personnel must be in the field to assess the situation. A great value in troubleshooting is knowledge about the installation, which in combination with measured values creates often a complete picture about the situation and enables users to hone in on the trouble spot. In cases where multiple faults compound or where the signal is severely distorted oscilloscopes are used to display and analyze the actual waveform of the communications signal.

C. Normal Operation

Only online tools are able to supervise and alarm the user of abnormal conditions as described earlier. Integrated into the DCS system via open interfaces such as OPC, the user is able to include the fieldbus itself into supervision and asset management. Online diagnostic tools can work in real time and provide *visibility* into the health of the network and predict the *availability* of data at any given time. Plant operators are thereby enabled to proactively plan maintenance where required before communication fails, thus increasing plant availability.

Continuous monitoring is also desirable for plants where the following frequently occurs: reconfiguration of batch processes, small system modifications or maintenance during plant operation. All conditions may cause changes to the physical layer. Advanced online diagnostic tools are able to detect deviations from optimal conditions and alarm accordingly, this helping to solve cases, which are often difficult to stage or recreate in a laboratory environment.

VI. Examples of Fieldbus Diagnosis

This chapter shows fieldbus signals in characteristic situations of actual fieldbus installations. In most cases a DTM-style screen as shown in Figure 4: Physical Layer Data of Fieldbus is sufficient to detect signal noise or unbalance, the following diagrams show the actual signal shapes as measured by an oscilloscope for illustration purpose. The description by maintenance personnel is given followed by the causes found through diagnosis.

Power Supply Module Data

Label	Actual	Target	Failure
Module A	Isolated Module	Isolated Module ☑	☑
Module B	Isolated Module	Isolated Module ☑	☑

Physical Layer Data

Label	Low Out ...	Low Main...	Actual	High Mai...	High Out ...	Hyst.	Reset
Voltage [V]	9,0 ☐	11,0 ☑	29,8	30,0 ☑	32,0 ☐	1,0	Reset
Current [mA]		65 ☑	78	125 ☑		30	Reset
Unbalance [%]	-84 ☑	-84 ☐	-40	84 ☐	84 ☑	20	Reset
Min Signal Level [mV]	200 ☑	600 ☑	705			100	Reset
Max Signal Level [mV]			819	1200 ☐	1200 ☑	100	Reset
Noise [mV]			39	100 ☐	100 ☑	25	Reset
Jitter [us]			1,1	3,2 ☐	3,2 ☑	0,8	Reset

Figure 4: Physical Layer Data of Fieldbus

A. System Unbalance

Error description: The communication was stable for a long time, but then a device disappeared for several hours from the live list. Later, the device could be seen again.

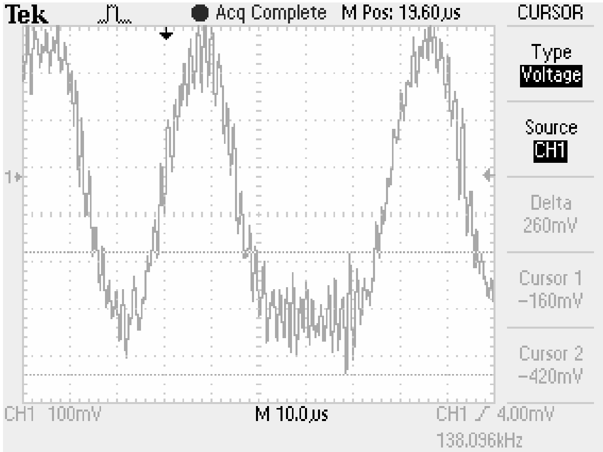

Figure 5: Signal noise and high cable capacitance

Analysis revealed: Earth potential was not wired to solid ground in the field causing an unbalance of the signal. Additionally, cable from previous installations was used. This cable did not conform to specifications since the capacitance was too high. Unbalance was measured. The significant noise level on the line, which also points to improper shielding or unbalance of one wire against ground.

B. Lack of EMC protection

Error description: The LCD's of field devices were energized but the devices were in the live list just for a short time.

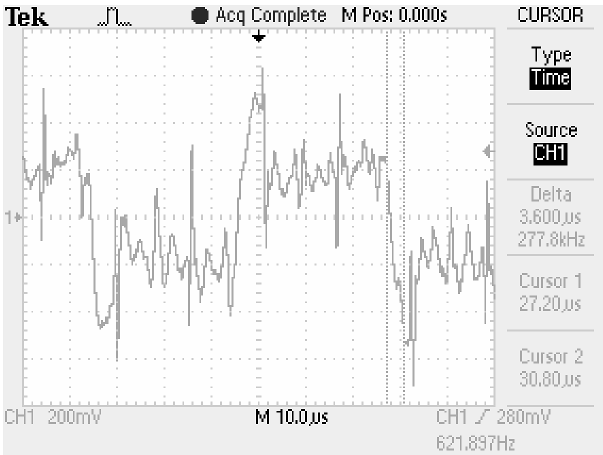

Figure 6: Lack of EMC protection

Analysis revealed: Crosstalk from a frequency converter entered through circuitry of the power supply. Again, improper cable was used. In this case the noise level and signal edges, as well as the frequency was such that many telegrams were destroyed during communication. With proper cable, slightly lower, yet significant levels of noise would not have shown at all.

C. Hardware fault at a field device

Error description: Everything was operational, but the

signal of a device was definitely asymmetric. There was no fault indication on either the handheld tools or the DCS.

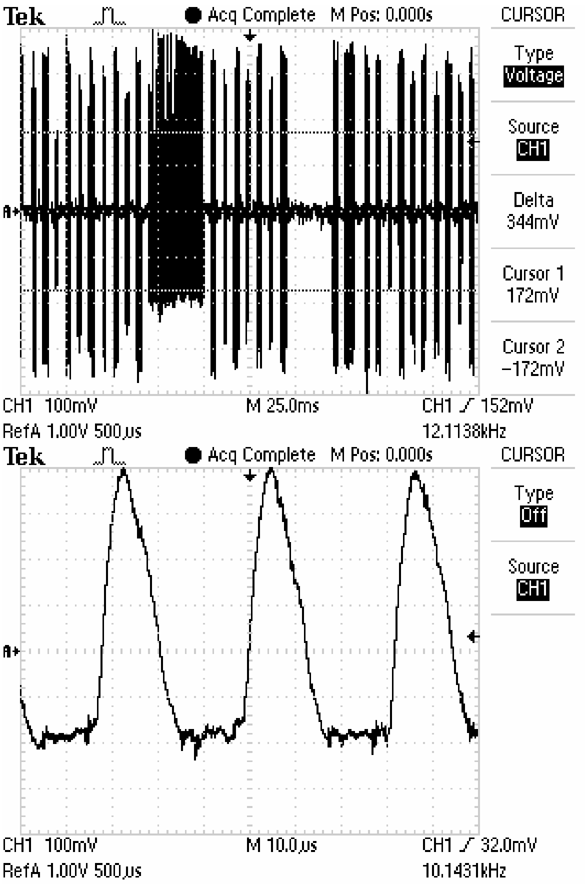

Figure 7: PCB-Diode failed in field device shown in two time scales

Communication has not failed at this point in time. A signal unbalance existed for one device only. A faulty diode cut the signal.

The examples illustrate that conditions deteriorate over time leading to temporary faults, which appear to be particularly hard to locate. Using the correct diagnostic tools reveal that they are actually multiple conditions that have compounded and exceeded the fault tolerance budget as described in Section IV.C. Resistance to Disturbance.

D. Resonance effects from a device

Error description: Significant noise was measurable. Yet the fieldbus was running stable.

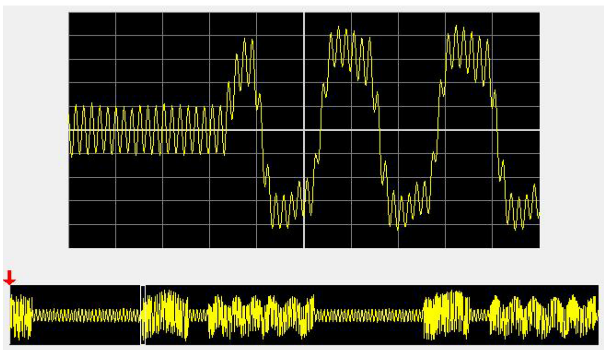
Figure 8: Noise induce by field device

Analysis revealed: A faulty device caused introduced this noise on the fieldbus. A similar device had caused the same problems in the past.

VII. Conclusions

Fieldbus topologies consistently use high-powered trunks. Fieldbus technology is described in its own terminology. Planning, measuring, validation and troubleshooting require tools that bring visibility to fieldbus communication. A new generation of measuring and diagnostic tools elevate installation and troubleshooting from trial-and-error methods to smart practice with good visibility into the health of the fieldbus network. They include the fieldbus itself into the chain of supervisory control. Process plants with very high demands for reliability will benefit from this control through its contribution to uptime and plant availability.

VIII. References

[1] Tauchnitz, T, Schmieder, W., Seintsch, S.:FuRIOS: Feldbus und Remote I/O - ein Systemvergleich. atp - Automatisierungstechnische Praxis 44 (s00s), H. 12, S.61-70

[2] Johannsmeyer, U: Investigations into the Intrinsic Safety of fieldbus systems, PTB-Bericht W-53e, Physikalisch-Technische Bundesanstalt, Braunschweig 1994.

[3] Kasten, T.: *Modern Topologies of fieldbus networks* Pepperl+Fuchs, Mannheim, Germany.

[4] Klaus Müller (editor): W*iring and Installation Guide for Fieldbus.* Pepperl+Fuchs, Mannheim, Germany.

IX. Vita

Andreas Hennecke graduated from the Bergische Universität Gesamthochschule Wuppertal as Dipl.-Ing. Electrical Engineering in 1991. He received an MBA from Rollins College of Winter Park, FL in 1998. After working in software development, project engineering and product marketing for SCADA systems and power distribution systems he joined Pepperl+Fuchs in 2005 and holds the position of Product Marketing Manager. He is a member of the PA marketing committee at the Profibus User Organization, PNO.

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