The Use of Surge Protective Devices in Protecting Digital Oilfield Assets

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Executive summary

Around the world, oil and gas companies have production and processing field equipment distributed across thousands of square miles in harsh environments. Production processing equipment and other assets, such as pipelines and storage facilities, are monitored and controlled to achieve required performance and production targets. High volumes of streaming data come from every aspect of operations and are tracked and stored daily. Multiple IT and operations technologies are applied to interpret this data – often in real time. These control and monitoring systems consist of wired and wireless communications, some powered by the grid, and others powered by solar or other sources. Duplicate and redundant systems operating in different application environments with the same data are commonplace. The systems are scattered throughout the production areas and linked back to the analysis centers at headquarters. While data gathering and control technologies are functioning, they are uncoordinated and redundant. **The need to coordinate data flow and link it to the analysis capabilities of the computer has fostered the term Digital Oilfield (DOF). For the purposes of this paper, the term DOF is defined as the coordinated gathering of operational data that is linked to advanced computer analysis and forecasting methods.**[1]

Based on the above discussion, it is clear that many of the components of the DOF already exist, but need to be improved, coordinated, and linked to improved computer analysis capability to meet the future vision of the DOF. Figure 1 illustrates one version of the DOF of the future.

INSIDE:

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This paper will examine three levels of connectivity for the DOF of the future:

- Wireless networks
- Satellite technology
- Ethernet technology

For each of these levels of connectivity the paper will:

- Discuss various operational attributes for that level of connectivity
- Discuss the protection methods used to mitigate the effect of lightning strikes (destruction of equipment) for that level of connectivity
- Discuss the use and proper placement of surge protective devices (SPDs) within the framework of the oilfield assets to minimize the downtime of those oilfield assets

Introduction

As mentioned above, present day control and monitoring systems consist of wired and wireless communications, some powered by the grid, and others powered by solar or other sources. The evolution of these control and monitoring systems to support the DOF of the future will require improved connectivity. Improved connectivity will enable better organization of the information flow of field-deployed assets to headquarters and improve the quality of the data available for analysis.

Studies indicate that wireless, very small aperture terminal (VSAT) satellite and Ethernet technologies are increasing in usage and will be more widely adopted in oilfield control and monitoring systems in the near term. In addition, these network methodologies will be enhanced in terms of efficiency, speed, and cost-savings during this time period. These networks will enable the continuing improvement required to achieve the vision of the DOF of the future.

Maintaining the reliability of these connectivity networks under normal and adverse environmental and electromagnetic conditions will be a key element in advancing the vision of the DOF of the future. Therefore, the balance of this paper will discuss the protection methods used to mitigate the effect of lightning strikes (destruction of equipment) and the

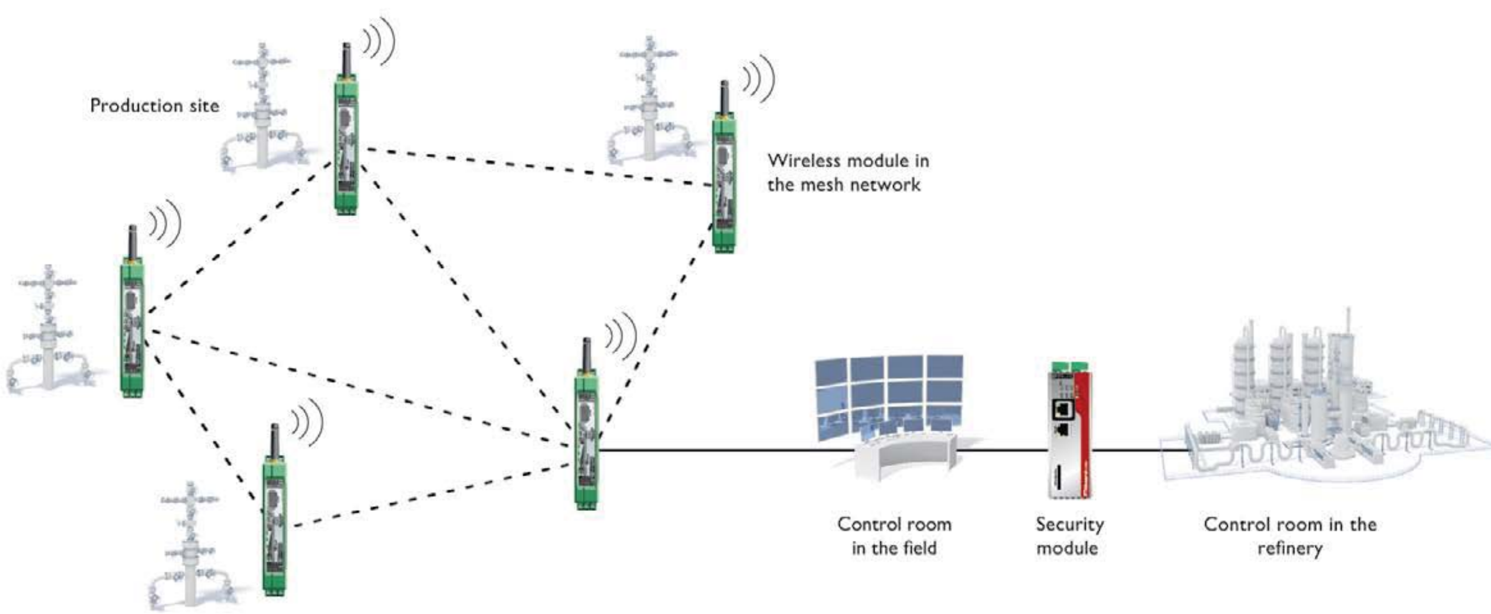

Figure 1: Digital oil field

proper usage of surge protective devices (SPDs) in each of the following network technologies:

- Wireless networks
- Satellite technology
- Ethernet technology

Figure 2 illustrates the information flow required to implement the DOF concept.

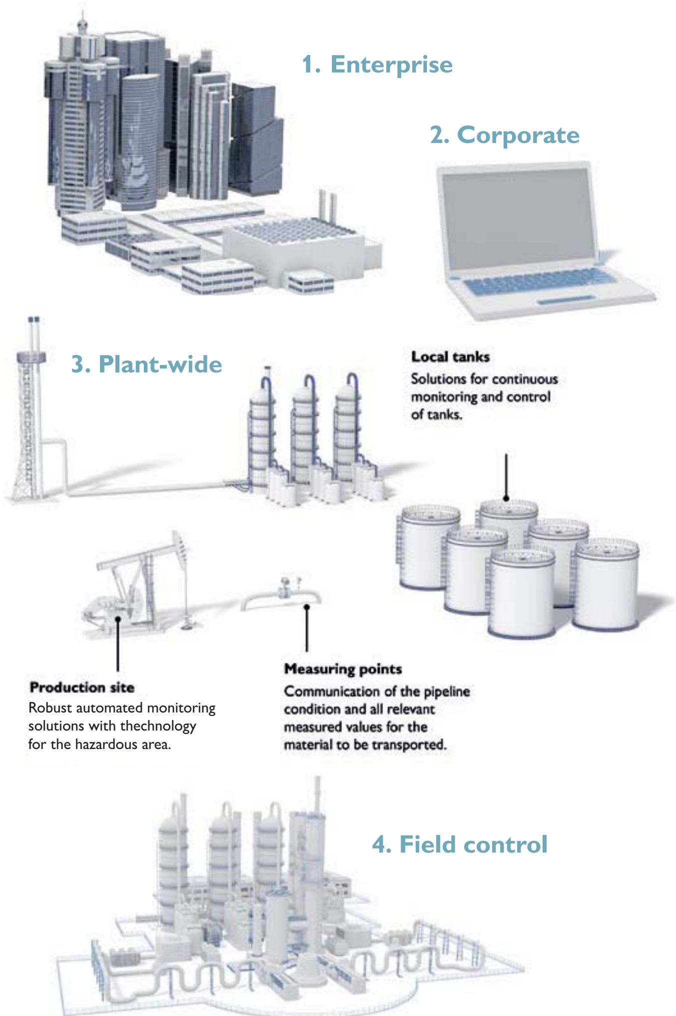

Figure 2: Levels of information flow required to implement the DOF concept

Wireless networks

In the oil and gas industry, the use of wireless technology is broad-based and pervasive. We will focus on two types of wireless networks used in the industry that are enabling the advancement of the DOF – the wide area network (WAN) and the local area network (LAN).

Wide area networks

A wide area network is a computer network that covers a broad geographical area. Computers are connected to the network via public telephone lines, leased lines, or satellite technology. In the oilfield environment, the connections between access points are usually point-to-point microwave links using parabolic antennas operating in the GHz band. The use of WANs is a main connection method for supervisory control and data acquisition (SCADA) equipment, such as pressure transmitters, flow meters, etc., that is located in the field. (Figure 3).

If a lightning strike occurs in proximity to SCADA equipment, that equipment is subject to potential failure. A lightning strike at a particular point near a SCADA equipment location will cause high-magnitude ground currents to flow. This will generate the ground potential rise (GPR)[2] at the point where the lightning strike penetrates the earth. The GPR at that point will generate a zone of influence (ZOI)[3] around the point of lightning contact. The ZOI is defined as an area bounded by equal potential voltage lines, measured from the point of lightning contact and some distant location in the earth's soil. This mechanism is explained in the two examples that follow.

In the first example, the high-magnitude ground currents will cause an unbalanced charge distribution between the ungrounded distribution/transmission pipeline and the

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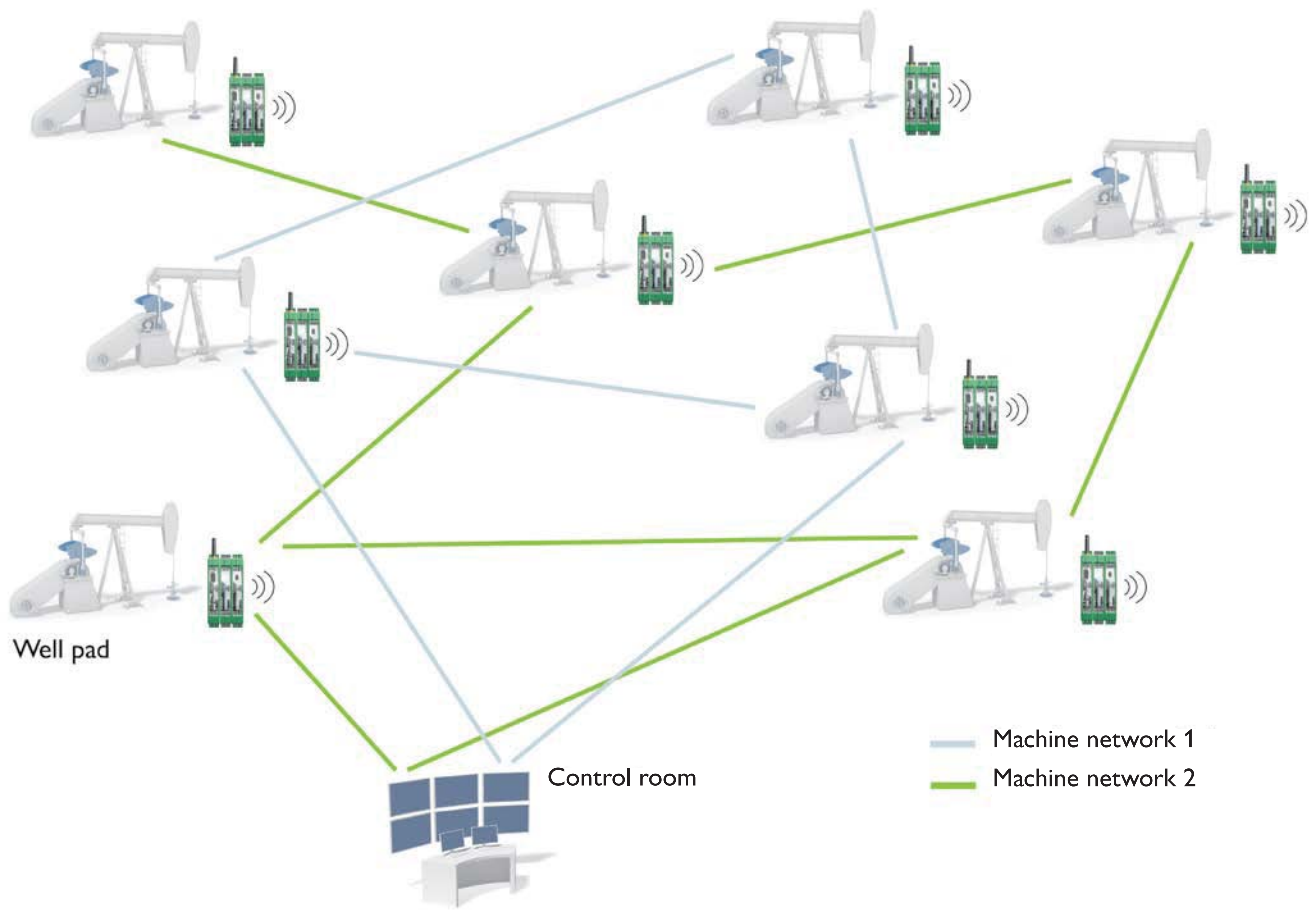

Figure 3: Typical wide area network used in oilfield operation

grounded pipeline at the gate station. The interface between the ungrounded flange and the grounded flange at the gate station will fail due to the ionization of air at the flange interface. This failure can be avoided by using an SPD that will minimize the voltage differential between the ungrounded and grounded interfaces of the flange during the lightning strike. SPDs used in this type of application are generally known as flange guard SPDs (Figure 4).

In the second application, a lightning strike at a gate station will create a ground potential rise that will

Figure 4: SPD flange guard protection

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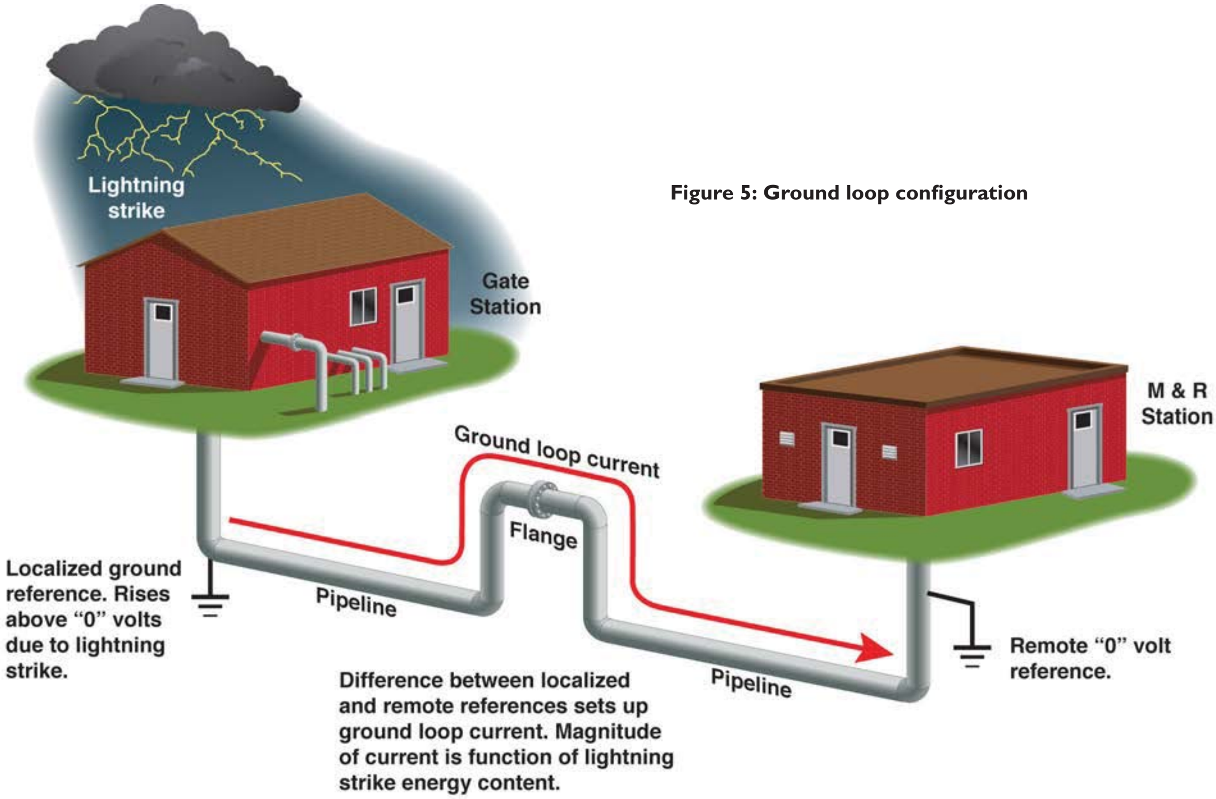

Figure 5: Ground loop configuration

generate a ZOI for SCADA equipment located within the ZOI. The magnitude of the ZOI is a function of several factors, including the energy content of the strike, the grounded or ungrounded state of the field transmitter, soil resistivity and the protection level of the transmitter. Figure 5 shows a typical ground loop configuration.

A more in-depth explanation of field transmitter SPD protection methods can be found in the paper "The Use of Surge Protective Devices in Mitigating the Effect of Lightning on the Natural Gas Pipeline Infrastructure." [4]

Local area networks

A wireless local area network (LAN) links two or more devices over a short distance using a wireless distribution method, usually providing a connection through an Internet access point. Use of cellular networks, radio networks distributed over land areas called cells and containing at least one fixed-location transceiver or cell site per network, are common in the oilfield environment.

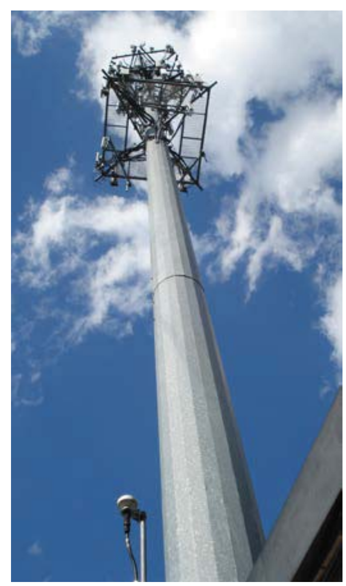

Figure 6: Typical cell tower protection scheme

Cell towers used as transceivers in this environment are susceptible to lightning strikes. Both power and signal lines need to be protected from the extremely high levels of current that are generated by a lightning strike. The level of protection varies as a function of the position of the components on the cell tower. Figure 6 shows a typical cell tower configuration and the various SPD protection modes employed at the base station and top of the tower locations to mitigate the effects of lightning strikes. Note that the protection methods include power line protection at the base station and signal protection of data and coax lines at the top of the tower antenna location.

A more in-depth explanation of cell tower SPD protection methods can be found in the paper, "Fiber–to-the-Antenna: Benefits and Protection Methods."[5].

Satellite technology

Satellite technology is primarily used on a stand-alone basis for remote, harsh applications in isolated environments, where cellular networks are not an option. The use of satellite connectivity in this environment enables the use of production applications that provide technological solutions based on real-time data, including down-hole multiphase sensors and measurement-while-drilling (MWD) operations. Satellites are also employed in the oilfield environment as backhaul elements for the wireless infrastructure and to fortify Ethernet connectivity.

Satellite implementations in a stand-alone environment include rugged, fully enclosed gyro-stabilized antenna, mounted in mobile van carriers and at fixed locations. Mobile van carrier implementations negate the need to reconfigure the system every time the system is turned on and provide a high degree of mobility in the field.

Shown below are examples of the various satellite implementations discussed above.

The electrical circuits and sub-systems of the satellite antenna are susceptible to failure if they are located near a lightning strike. The concepts of ground potential rise and zone of interference, discussed earlier in the paper, also apply to the protection of satellite technology. Protection of assets during a lightning strike includes protection of data, coaxial, and power lines at bulkhead interfaces within the satellite structure. In addition to ground potential rise failure mechanisms, inductively coupled current surges on lines entering data boxes, antennas, and power input boxes represent another potential failure mechanism and can cause failed components, equipment outages, and downtime if not protected by a properly rated surge protection device.

Mutual inductance coupling is the transfer of current from one wire to an adjacent wire due to magnetic flux linkage generated by current flow in the first line, inducing a current flow of similar amplitude in an adjacent wire. The amplitude of current generated in the second wire due to magnetic flux linkage from the first wire is a function of the amplitude and rise time of current flowing in the first wire, the separation distance between the two wires, and the length of parallel run of the two wires (Figure 7).

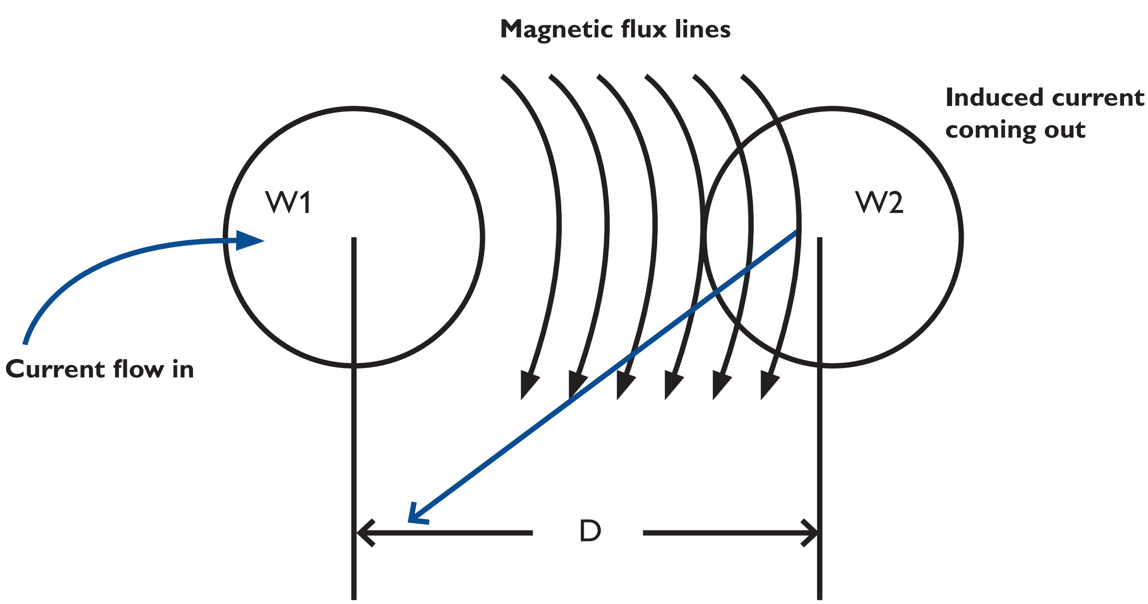

Figure 7: Mutual inductance coupling

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Wire 1 in Figure 7 is carrying a time-varying current. The current flow is generating flux lines in a clockwise direction that are perpendicular to the direction of the wire, as shown in the figure. These flux lines are radiating outward and linking wire 2, inducing a current in wire 2 is proportional to the current passing through wire 1. The magnitude of current in wire 2 is a function of D, the distance between wire 1 and wire 2. The smaller the distance between the wires, the higher the amplitude of current that is coupled into wire 2.

This inductive coupling concept occurs whenever two wires are run side by side. In the high-current environment produced by a lightning strike, an unprotected wire running parallel to a protected wire on the output side of an SPD will inductively couple high current impulses into the protected wire. When this happens, the inductive coupling circumvents the effectiveness of the SPD and reintroduces a current surge into the protected wire before the wire enters the equipment protected by the SPD, as shown in Figure 8.

To avoid this problem, run all of the wires subject to current impulses through the SPD. This includes power and signal lines. In addition, route all unprotected lines as far from the protected lines as possible

The use of the inductively coupled line principles discussed, above combined with the use of single-point grounding methods and the use of SPDs at interface bulkheads, will provide protection against equipment failures during lightning strikes and voltage surges in the satellite environment. This protection will include circuit boards, SCADA equipment, data lines, and communications equipment within the satellite environment.

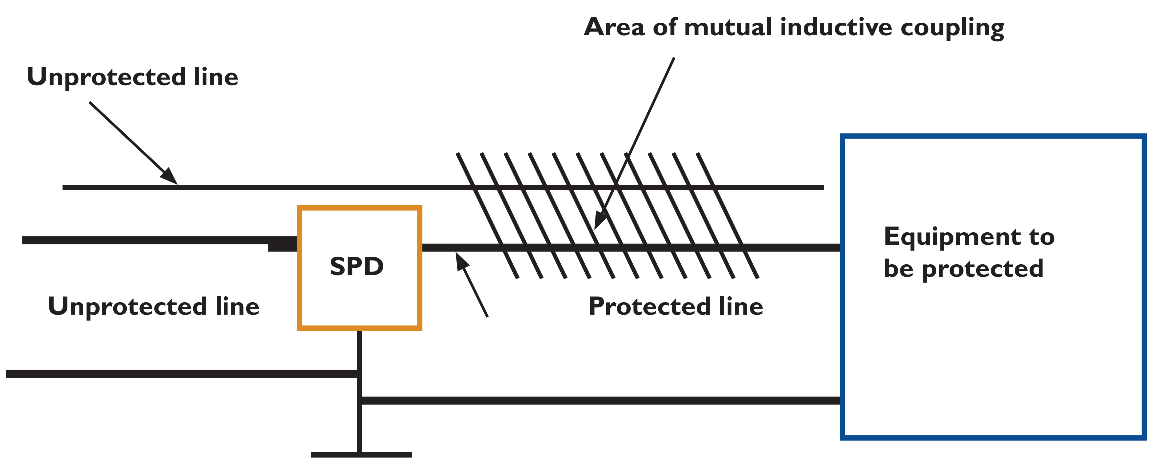
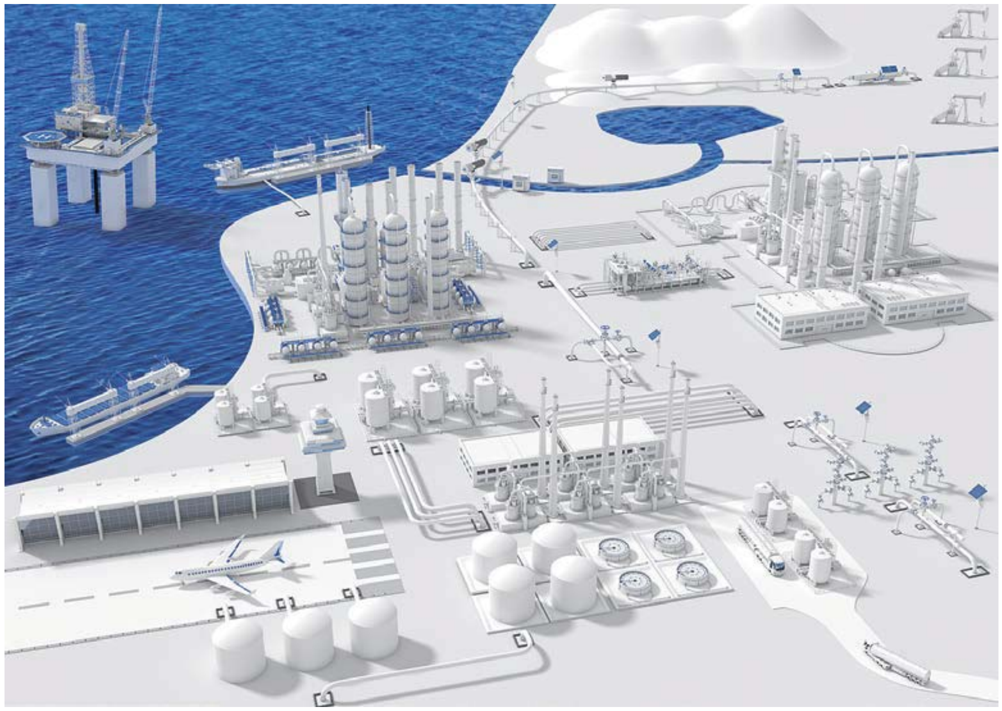


Figure 8: Mutual inductance coupling

Ethernet technology



The industrial Ethernet deployed in oilfield environments forms the backbone of a layer of connectivity that operates between the wireless infrastructure and the satellite layers of connectivity. More specifically, the industrial Ethernet network operates as a serial layer that primarily connects the SCADA domain within the oilfield environment. Figure 9 illustrates a pump station monitoring implementation of the industrial Ethernet infrastructure.

Figure 9: Today's oilfields deploy industrial Ethernet across a wide range of locations and applications, and each must be protected from surges.

According to a press release from Zion Market Research, the global Industrial Ethernet market will grow across multiple industries, including oil and gas, from \$23.96 billion in 2016 to \$58.98 billion by 2022.[6]

The adoption of the IEEE 802.3at standard, also known as Power over Ethernet+ (PoE+), increased the power capabilities of Ethernet equipment and the usefulness of Ethernet equipment as a connectivity method. The enhancements of PoE+ and typical protection schemes employed to minimize the effects of lightning strikes in the Ethernet environment are reviewed in the paper, "The Use of Surge Protective Devices in IEEE 802.3at (PoE+) Applications."[7]

Figure 10: Typical SPD for industrial Ethernet

As discussed in the earlier sections of the paper, equipment located within the zone of influence during a lightning strike is susceptible to high ground current surges, inductive coupling issues, and potential equipment failure. The industrial Ethernet network is typically protected from potential equipment failure by an SPD inserted at an interface bulkhead between the incoming Ethernet line and the networked device. These SPDs are specifically designed for industrial Ethernet applications and provide maximum protection for SCADA-style equipment in the oilfield environment. Figure 10 shows a typical SPD for an industrial Ethernet application.

Table 1 gives the electrical specifications for the industrial Ethernet SPD shown in Figure 10.

Max. continuous operating voltage, U_c	≤ 3.3 V DC
Maximum continuous voltage U_c (wire - wire)	3.3 V DC (+/- 60 V DC PoE)
Maximum continuous voltage U_c (wire – ground)	≤ 180 V DC
Nominal current, I_n	≤ 1,5 A (25°C)
Nominal discharge surge current, I_n – 8/20 µs	100 A
Total surge current (8/20 µs)	10 kA
Residual current, I_{PE}	≤ 8µA

Table 1: Industrial Ethernet SPD electrical specifications

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Conclusion

This paper has reviewed the connectivity methods used for the gathering operational data that is linked to advanced computer analysis and forecasting methods generally associated with the digital oilfield (DOF) of the future.

Specifically, the paper has examined three levels of connectivity associated with the DOF:

- Wireless networks
- Satellite technology
- Ethernet technology

For each level of connectivity the paper has:

- Discussed various operational attributes for that level of connectivity
- Discussed the protection methods used to mitigate the effect of lightning strikes (destruction of equipment)
- Discussed the use and proper placement of surge protective devices (SPDs) within the framework of the oilfield assets to minimize the downtime of those assets.

It is hoped that this paper will add to the knowledgebase of the lightning protection methods available for protection of the electronic equipment used in the digital oilfield today and in the future.

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Acknowledgements:
** Mr. Schroeder passed away in May 2016*

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