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White Paper

WP00024

The Road to Plug-and-Produce

Designing a Dynamic, interoperable Compact Field Level Networking and Control Infrastructure for the Factory of the Future

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Executive Summary

Manufacturing across the world has undergone numerous ebbs and flows to find its place in modern industry. Armed with the knowledge that the face of industrial output continually changes, many industrialized countries seek a new approach to production. Industry and academia alike are united in this quest through initiatives, such as Industrie 4.0 in Germany and the Industrial Internet Consortium in the United States.

The Industrial Internet of Things (IIoT) has been recognized for its potential to facilitate a new approach to production and lead the industry to its next revolution. This "fourth industrial revolution" will manifest in the form of interconnected smart machines, production facilities and warehousing systems.

As technology has evolved to make this interconnection possible, so have the demands placed not only on technology itself, but the processes in which this new technology is used. The term "plug-and-play" carries an expectation of ease of use and reliable, foolproof operation. A plug-and-play product, as its name suggests, can simply be connected and turned on – and it works. The practical extension of plug-and-play products, when applied to the entirety of the industrial automation process, has given way to a new term: plug-and-produce.

Plug-and-produce offers a practical solution to the issues of increasing competition in the global marketplace, which demands flexibility, as well as higher resource and energy efficiencies in the way goods are produced. As companies work to get products to market faster and cheaper, simple solutions are needed to enable near-immediate implementation – with no special tools or highly trained (and expensive) engineers or electricians required.

These smarter facilities and factories build on the key drivers of Industrie 4.0 and the IIoT. In the center of Industrie 4.0 is the interconnected, intelligent factory (smart factory), which only produces what is needed. Smart machines, production lines and storage systems collaborate within a network in what's referred to as cyber physical systems (CPS). These systems are capable of autonomously exchanging information, triggering actions and controlling one another. Even components that later become part of the final product itself can carry information by communicating with machines and operators and exchanging actual condition data. The analysis data and information on components, machines and processes can trigger actions to prevent failures. This spontaneous networking of humans, machines and components enabled by a plug-and-produce infrastructure will further contribute to more flexible and resilient factories in the future[1].

This white paper will discuss the market trends driving the need for the many benefits plug-and-produce systems offer, as well as how to design a field-level system solution that can address both current and future needs. Specific vertical market examples, common implementation pitfalls to avoid and key considerations when selecting specific products will also be covered.

Market Trends in Industrial Automation

As the manufacturing and industrial automation landscape continues to change, one critical priority hasn't: the pursuit of profitably producing affordable goods that fulfill customer demands. Now, rather than only looking for new processes, a focus on increasing operating efficiencies in new, technology-enabled ways has taken hold.

The IIoT will only continue to interconnect machines, facilities and systems. This will greatly enhance the need for solutions that provide distributed control, decentralized decision-making, end-to-end transparency and virtualization. Modularity and scalability, however, are further key drivers that will be critical for the development of the smart factory of the future.

The current state of industrial automation adheres closely to the classical automation pyramid, pictured in Figure 1. In this model, field-, control-, enterprise -, and process management-level networking components rely on one another to function as the operational whole. Current processes and solutions securely transmit signals to and from actuators and sensors to a central programmable logic controller (PLC). This structure highlights opportunities for continued improvement and development of new services – we expect that approximately 80 percent of discrete control is to go to field level in the wake of Industrie 4.0 and the IIoT.

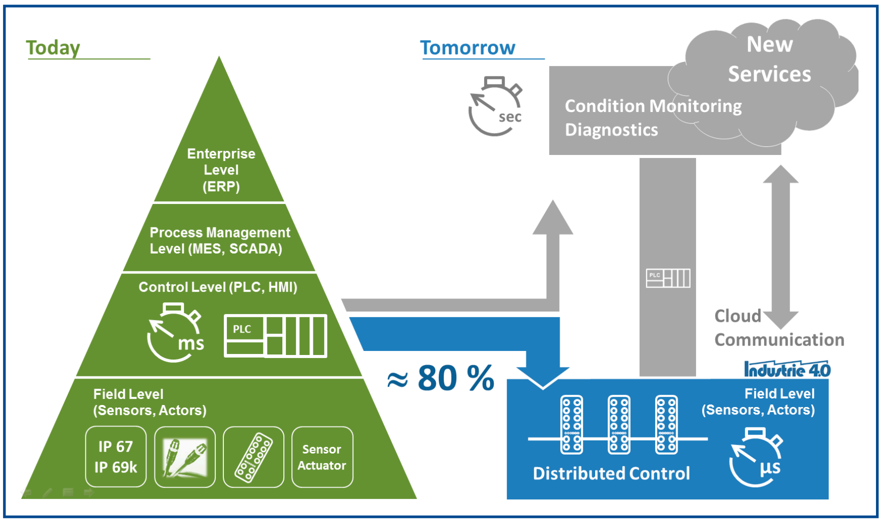


Figure 1: Impact of the IIoT on industrial automation

In practice, industrial automation is also affected by trends that have aimed to make production lines and processes as compact and modular as possible. Modular solutions by their very nature serve as a method to reduce lead times and maintenance requirements, making part replacements or repairs as simple as possible. The benefits to modularity are clear – it is the difference between having to shut down a single component versus taking an entire production line out of service for repairs. And as the market continues to push for modular, flexible systems, a dynamic, plug-and-produce infrastructure will become even more important.

Shorter and flexible production cycles also influence the necessity for changes in industrial automation. From personal customer interactions, we know that it is not uncommon for a production cycle to run for five years and then for that line to be shuttered – only to be re-started as a new need arises, sometimes years after initial production ends. With plug-and-produce, this is entirely possible, as a line's computational intelligence remains with the tooling unit rather than with a central computer and does not require software updates – even after extended time offline.

Space on the factory floor is at a premium more than ever before. The miniaturization of components, lines and related automation equipment has made the production lines themselves smaller, even eliminating the need for large switching cabinets that take up coveted manufacturing real estate. Plug-and-produce's emphasis on field-level solutions addresses this need. Saved space, as a result, can enable manufacturers to add another production line or build smaller factories to begin with. Both have financial implications, whether added revenue potential or cost savings.

The long-range goals of Industrie 4.0 and the IIoT have identified further opportunities for not only physical solutions, but new services within the scope of industrial automation. Services, such as diagnostic data and condition monitoring, will allow for cloud communication to take place in parallel with process communication, while not interfering with the standard processes.

Key Benefits of Plug-and-Produce

The concept of plug-and-produce enables discrete industrial automation applications to benefit from the following.

- **Fast, easy and intuitive installation and maintenance.** The very nature of a plug-and-produce system is simple – the system's networking and connectivity components just plug into one another and work immediately. Not only does installation happen quickly, but a broken part can easily be disconnected and a new one plugged in – all within seconds.
- **Dynamic infrastructure.** By specifying and implementing a system of interconnected, plug-and-play products, the foundation for a dynamic and flexible infrastructure is established. It not only meets today's requirements, but can easily adapt in the future as technologies and needs change.
- **Built on standards.** This foundation of a flexible and future-proof infrastructure is built on standard – not proprietary – solutions. As such, the system adheres to a common structure and ensures a seamless working relationship with its components and sub-systems. As a result, these products go through iterations more quickly, continually becoming better and better, faster.
- **Consolidation of devices.** Devices designed for global use with many regional needs or specifications in mind reduce the total number of stock items needed by machine builders. Instead of buying more devices or reconfiguring existing ones, you can use the same devices across countries, which reduces cost and complexity. These functionalities could include meeting multiple industrial Ethernet protocols or universal I/O ports that can be used for digital input or output.
- **Pre-diagnostic data.** Finally, since these products are purpose-built to provide pre-diagnostic data, which includes monitoring conditions and identifying errors, they can increase efficiency and enhance uptime – in turn creating additional cost savings.

Protection against solids		Protection against water	
X	Ingress of solid object	Y	Ingress of liquids
6	Total protection against contact, protection against penetration of dust	5	Protection against water jets (12.5 mm nozzle) from any direction
		7	Protection against the effects of temporary immersion in water (up to 1 m)
		9K	Protected against close-range high pressure, high temperature spray downs

Table 1: Defining the various IP XY levels, from IP65 to IP69K

Plug-and-Produce in Action

A basic example of a plug-and-produce architecture at work can be illustrated by a sorting conveyor.

As commonly found in current operations, a central PLC communicates with a conveyor to determine how to route a part depending on programmed responses and feedback from sensors. This conveyor setup may be repeated with several similar stations down the entire length of the sorting line, which would require hundreds of meters of cabling to connect the overall system. In a plug-and-produce setting, however, the use of distributed control units (DCUs) can automate the process – or, if networking is required, consolidating sensors can reduce the length of cabling needed.

Other practical plug-and-produce applications include:

- Robotic arms on a manufacturing assembly line often run two cables – one for communicating data and the other to supply power. Outfitting the line with a single plug-and-play cable that combines communication and power in one product will result in a smaller overall device and less weight for the robotic arm to support.
- Tool changers for equipment found in industrial automation applications are run by control tasks comprised of basic logical combinations. These tasks can be controlled through plug-and-produce products, alleviating the burden on a centralized PLC.
- More and more high-level sensors interface with Ethernet, enabling another consolidation possibility. Since these sensors no longer need a standard I/O module, an Ethernet switch can act as a de-facto I/O module to enable sensors. Instead of daisy-chaining sensors, other configurations, such as a star network topology, are possible.

As modular systems continue to be built and refined, additional proof-points will emerge furthering the validity (and eventual preference) of plug-and-produce systems in discrete automation applications.

Designing a Field-Level System Solution

The main functions and components of the industrial automation system today, such as power distribution, electrical safety and discrete control, as well as industrial networking infrastructure, are contained within switch or control cabinets. As stated previously, one goal of designing field-level solutions involves moving away from these cabinets to reclaim space that would be better utilized for additional production lines or to make smaller, more efficient factories.

To achieve this goal, and others, for field-level installations – especially those requiring high Ingress Protection (IP) levels (e.g., IP67 up to IP69K, see Table 1) – these functions need to be handled by interoperable, plug-and-produce capable, field-level devices. For example, Belden has introduced a new product family of devices for smart factories that includes active input/output (I/O) modules, I/O hubs, DCUs, Ethernet switches, connectors and cables.

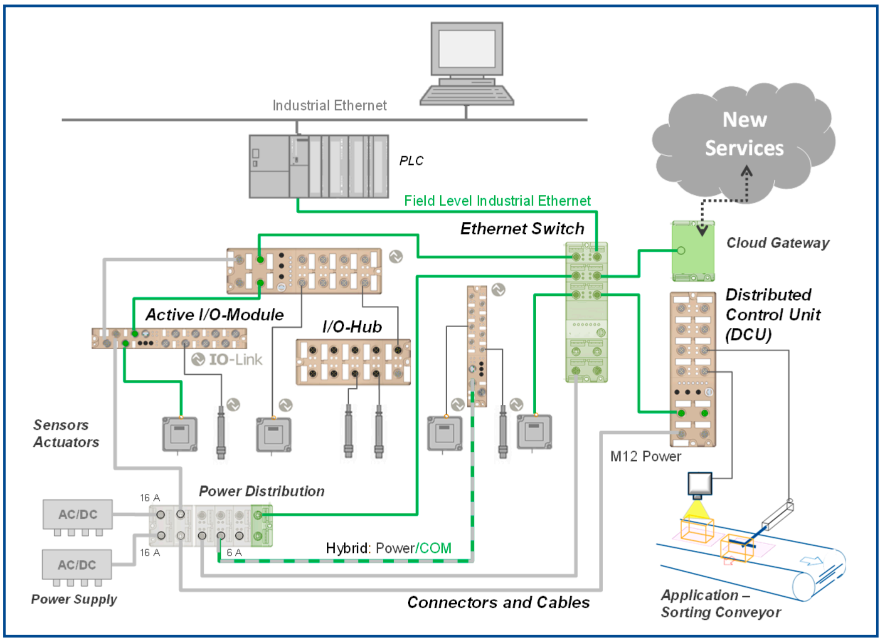


Figure 2: Schematics of collaborating, compact field-level devices

Together, these collaborating, compact field-level devices (shown in Figure 2) represent the ease of use that plug-and-produce offers – components work together to provide an effective, modular discrete automation control system. As plug-and-produce infrastructure continues to be refined, components, such as power distribution, power supply and cloud gateways, are the next practical advancements.

It is important to determine necessary capabilities in potential solutions when designing a network or system, and plug-and-produce is no exception. The following products will be required for a holistic, field-level solution system:

Active I/O Modules

Active I/O modules directly interface with sensors and actuators and transmit data to and from a PLC via an industrial Ethernet network. Regardless of which protocol is used (PROFINET, EtherNet/IP or EtherCAT), all field-level devices in a particular automation application should be built on the same protocol to ensure interoperability. The newest generations of active I/O modules provide both digital I/Os and IO-Link ports for increased flexibility and functionality. Additionally, more evolved I/O modules provide input and output forcing, which can be executed through an embedded web interface. For maintenance personnel and installers, this offers a simpler, more intuitive infrastructure. One device can recognize the condition of other devices and know their status. Simulations can be run and diagnostics can be returned to test options without running equipment.

I/O Hubs

I/O hubs are IO-Link devices that extend machine installations by connecting multiple digital I/Os per IO-Link port. For automation applications, the point-to-point communication of IO-Link is utilized for both data and power transfer for distances of up to 20 meters. Solutions are also available if longer distances or more I/O ports in a daisy chain are needed.

Distributed Control Units

Distributed control units (DCUs) collaborating within a network are cyber-physical systems (CPSs). Discrete automation systems employing DCUs are comprised of physical mechanisms controlled or monitored by computer or digital-based algorithms, like DCUs, PLCs and others. Advances in DCUs present the benefits of a physical system, as well as those of a digital one – seeking to eliminate the drawbacks of each. CPSs can be built by integrating programmable logic control into active I/O modules. In addition to simply transmitting input and output data, an enhanced active I/O module is now capable of processing data – from simple logical operations to solving more complex control problems.

Ethernet Switches

The demand for Ethernet switches in the field grows with the number of Ethernet devices. Due to this growth, the daisy chain enabled by the integrated two-port switch of most active I/O modules and high-end Ethernet sensors may no longer suffice. Currently, unmanaged switches with 100 Mbps ports are adequate for most industrial applications. However, higher data rates are expected in the course of the development of time sensitive networks.

Connectors and Cables

The field-level, plug-and-produce concept requires connections to meet international connector standards and IP protection classes 65/67/69K (according to DIN EN 60529). Over-molded circular connectors with M8 and M12 threads offer particularly good protection from moisture and dirt.

Three Implementation Pitfalls to Avoid

When projects move into the implementation stage, there may be internal and external pressures to select and install a solution very quickly. To avoid overlooking critical quality factors, consider the following three elements when making decisions. Getting these areas right will ensure a properly specified, installed and implemented plug-and-produce solution.

1. **Proprietary vs. standards-based solutions**
   For many years, legacy systems were built on proprietary technology that put limits on integration, product selection and implementation. These limits have steered product development to align more closely with industry standards in an attempt to create an avenue for interoperability – setting the stage for more progress.

   Wherever possible, choosing a solution built upon industry standards is desirable.

Today's popular industrial Ethernet protocols include PROFINET, EtherNet/IP and EtherCAT. Ideally, all field-level devices in industrial networks should adhere to the same reference architecture and respond to the same protocol for seamless interoperability.

2. **Metal vs. plastic housing**
   The availability of numerous products employing various protective coatings and casings can make choosing the right one confusing. Though each application necessitates different equipment qualities, the distinction between metal and plastic housings is particularly contentious.

   There is often a misconception that metal housing is expensive. The thought that plastic is cheaper and lighter prevails, when in practice, the weight of a module is not determined by the chassis, but by the molding – and all internal moldings are made with a plastic compound. Choosing a metal housing makes the product not only mechanically robust, but electrically robust, too, as the body or cage protects the internal components from environmental extremes. Additionally, components with metal housings integrate a screw-type connector into their construction. With plastic, an additional piece is required to make these connections; making plastic more complicated and costly in the field.

3. **Single vs. multi-protocol settings**
   Whereas some products utilize software to determine which protocol is used, a mechanical switch offers the sizable advantage of multi-protocol settings and can be changed based upon the current environment. The sheer number of different protocols installed, as well as the regional dominance of specific protocols, requires extra efforts to build globally deployable machines and equipment.

   Active I/O modules loaded with multiple protocols in one device – and therefore, capable of operating in different network systems – provide a very good solution to overcome this challenge. For example, rather than designing machines for European application, and having to re-design for use in the United States, multi-protocol settings allow for a single device type to be utilized.

Evolution of Distributed Control Units (DCUs)

As trends continue to emerge and shape the way plug-and-produce is implemented, the flexibility of DCUs begins to make more sense and becomes more intriguing. This is especially true with the Open Platform Communications Unified Architecture (OPC UA) becoming the most promising standard communication protocol for the interoperability that plug-and-produce enables.

Currently, DCUs can either be used as a slave to a central PLC, exchanging information and services, or as a standalone controller. The computational capabilities of a DCU may also be employed to process diagnostics data to feed predictive maintenance tools and other cloud services. It is in this way that the DCU can become the edge-cloud controller – the interface between the field level and the cloud.

In playing this role, the DCU executes communication, separates diagnostic data from process data, and allows cyber-physical connections – all of which alleviate the burden typically placed on the PLC. This allows for the creation of a dynamic infrastructure. Cloud communication can then occur in parallel on the existing network infrastructure and not interfere with the process communication.

How Belden Can Help

For engineers who face space and budget constraints, while also needing to meet the demands for greater power and performance requirements, Belden and its Lumberg Automation brand have developed the LioN-Power System, a field-level system solution built on plug-and-produce principles.

The suite of products works seamlessly together to enable system-side interoperability. The product family includes:

Summary of Industry Standards

- **IEC 61131**[2] is a standard for programmable controllers that is divided into nine parts, including 61131-3, which specifies the syntax and semantics of a unified suite of programming languages for programmable logic controllers, and 61131-9, a single-drop digital communication interface (SDCI) for small sensors and actuators, commonly known as IO-Link. This technology enables the transfer of parameters to devices and the delivery of diagnostic information from the devices to the automation system.
- **IEC 61076**[3] describes connectors for electronic equipment that are typically used for industrial process measurement and control, including:
  - **Part 2-101** – Detail specification for circular M12 connectors with screw-locking.
  - **Part 2-104** – Detail specification for circular connectors with M8 screw-locking or snap-locking.
  - **Part 2-111** – Detail specification for power connectors with M12 screw-locking.
  - **Part 2-113** – Detail specification for connectors with data and power contacts with M12 screw-locking.
- **DIN EN 60529**[4] describes the prevention measures taken to protect equipment from the formation of condensation within a sealed housing, and also the intrusion of water into housings vented to the atmosphere.
- **OPC Unified Architecture (OPC UA)**[5] is an industrial machine-to-machine communication protocol for interoperability.
- **UL 61010**[6] specifies safety requirements for electrical equipment for measurement, control and laboratory use (effective since April 1, 2016).

- The **LioN-Power active I/O modules** are an all-in-one, multi-protocol solution that meets both PROFINET and EtherNet/IP protocols for industrial automation settings. Until now, separate PROFINET and EtherNet/IP modules were needed – two products with very different power components. With the LioN-Power active I/O modules, only one module is needed to meet both protocols, which reduces the number of different stock items.

  The reduced weight and size of these I/O modules, combined with a robust IP67/69K rating and a 16 amp power feed, enable the device to be installed directly on machinery in longer daisy chains, which eliminates excess wiring costs. Overall, this product's features contribute to better cost efficiencies and easier handling, while simultaneously increasing the flexibility.

- **The LioN-Power DCUs** perform a range of functions – from simple logical operations to solving more complex control problems. The various models available can either be operated as a standalone controller or in collaboration with a central PLC to relieve the workload on the PLC and concurrently reduce bus communication.

  The LioN-Power DCU models are based on two different programming platforms:

  - LDMicro[7], a free software that starts with ladder logic
  - CODESYS, a development environment for programming controller applications according to the international industrial standard IEC 61131-3

  The application program can simply be uploaded via the embedded webserver of the DCU. For field installations comprised of numerous DCUs, a platform for application software updates and management via a central FTP-server is currently under development. The LDMicro-based LioN-Power DCU comes with eight physical digital inputs and eight digital outputs, whereas the CODESYS-based LioN-Power DCU has eight IO-Link ports that can also serve as digital inputs and outputs. A DCU version with additional serial RS232 connection will follow in early 2017.

- **The M12 Power Connector** is a compact and efficient solution that offers the ability of using cables from 1.5mm² up to 2.5 mm² to transmit at high power levels for long periods of time. These new M12 connectors (S-, L-, K- or T-coded according to 61076-2-111/CD IEC, see Table 2) simplify cabling efforts and save significant space on the device compared to conventional 7/8-inch connectors (see Figure 4). Cordsets with L- or K-coded M12 power connectors at both ends, and with conductor sizes of 2.5 mm², deliver the highest power transmission performance up to +125° C.

  Further space savings and easier installations can be realized with M12 Y-coded connectors (according to 61076-2-113/CD IEC) that combine 6 amps/30 volts power and Cat 5e data transfer at speeds of up to 100 Mbps all in one hybrid cordset. Accessories are available to easily integrate hybrid cabling into standard wiring systems. These include hybrid T-splitters that link both power (via the M12 L-coded connector) and data (M12 D-coded) to the M12 Y-coded hybrid connection/cable. Hybrid cabling is ideal for power hungry field components, and is superior to even the strongest Power over Ethernet (PoE/PoE Plus) cabling that can provide only up to 25.5 watts of power at 48 volts.

Example of a DCU Application: Screw-Fitting Station

The following example illustrates an ideal application for a DCU in the field.

The goal is to form a waterproof connection between a plastic cylinder and a lid that's attached by three screws. To accomplish this, a workpiece carrier will transport the plastic cylinder (workpiece) to the screw-fitting station. An O-ring or seal will need to be placed between the cylinder and the lid before they are joined together. Tightening the three fitting screws with the proper torque ensures the ideal performance of the waterproof connection.

In this application, the DCU is tasked to process the sensor inputs that detect the presence of the cylinder. In the next sequence, the DCU activates the actuator(s) that locks the workpiece in place until the three screws are located in the provided holes and the screw-fitting controller reports three valid torque values. Only then will the DCU trigger the actuator(s) to release the workpiece to its next destination.

In current set-ups, a PLC receives and transmits sensor and actuator signals, as well as the output of the screw-fitting controller through an I/O module. The DCU combines field I/O module and PLC functionality into one device in order to significantly reduce costs and simplify installation.

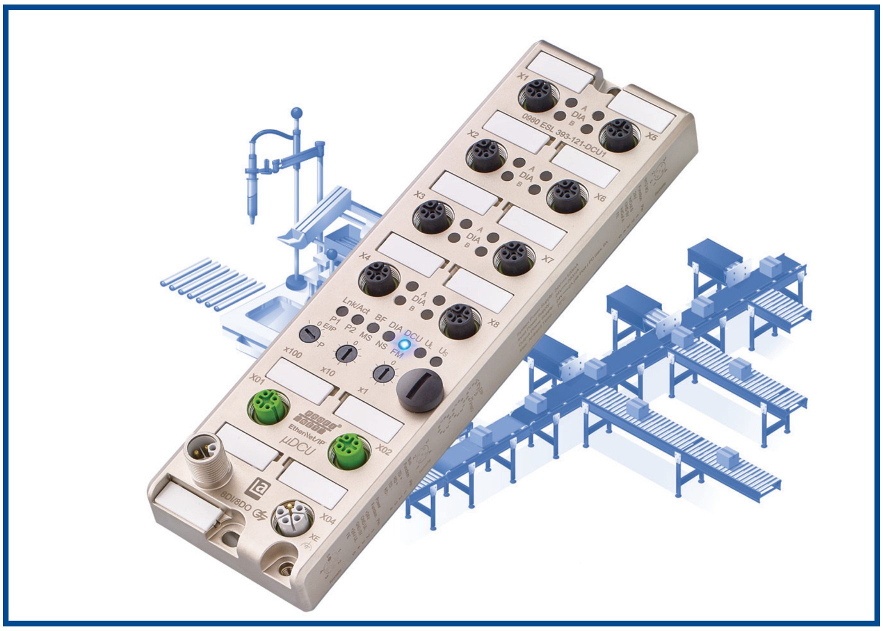


Figure 3: LioN-P distributed control unit (DCU) - application examples

- The **M8 5-pole B-coded cordsets** provide exceptional handling capabilities and ensure the highest performance in the field. With an extended power range, the cordsets ensure high performance reliability and make installation in the field easy. In addition to carrying an IP65 rating (for snap connectors) and up to an IP69K rating (screw-type versions), they meet the highest global industry standards, including DIN EN61076-2-104 specifications for use in direct current and Underwriter Laboratories (UL) 2238 for cable assemblies in industrial control and signal distribution applications.

  These cordsets are ideal for small electronic drives, sensors and miniature robotics applications in machine building, material handling, and industrial automation environments. The cordsets also reach a maximum of 4 amps of current and 60 volts on two pins, doubling the power transmission of standard specifications. This space-saving M8 technology delivers excellent performance and fast installation capability, making it one of the highest-rated products on the market.

Together, these products create a one-stop solution for meeting the demanding industrial connectivity requirements brought on by the IIoT. The LioN-Power System is designed specifically for the needs of robotics, machine building, manufacturing, power transmission, food and beverage, packaging and automotive applications.

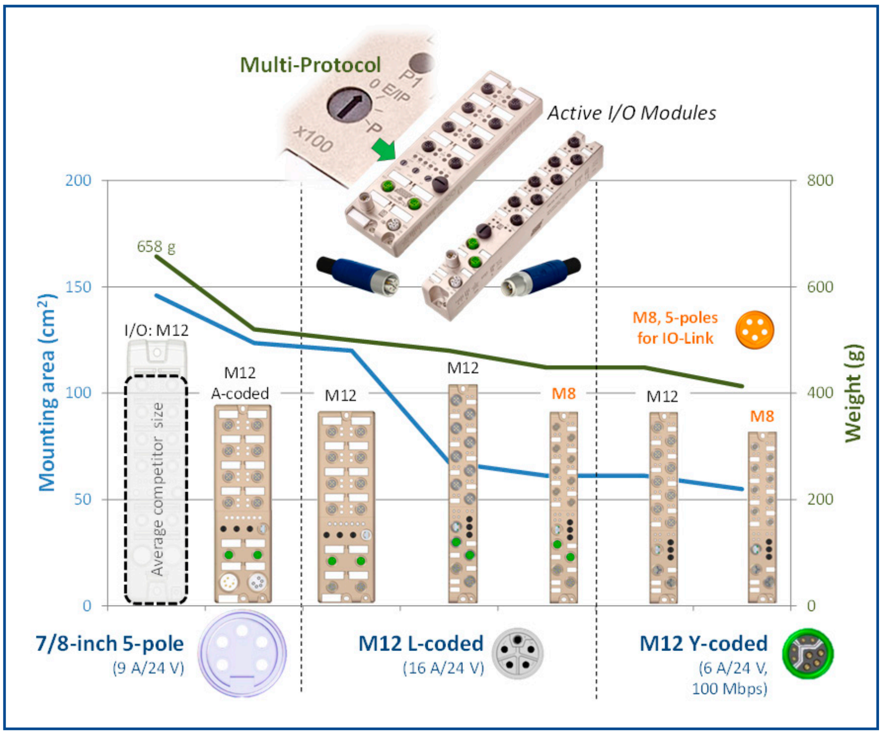


Figure 4: Miniaturization of compact field-level devices made possible by new M8/M12 connectors.

Conclusion

The long-range goals of Industrie 4.0 and the IIoT have prescribed further opportunities for not only physical solutions, but new services within the scope of industrial automation. Services, such as diagnostic data and condition monitoring, will allow for cloud communication to take place in parallel with process communication, while not interfering with the standard processes.

As new products are developed in the pursuit of achieving these goals, plug-and-produce will play an important role in the implementation of processes that enable this fourth industrial revolution. Belden's LioN-Power family of products aims to provide a modular, industrial Ethernet infrastructure, which can serve as the foundational application for plug-and-produce needs today, as well as prepare these networks for the future.

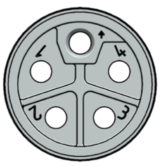
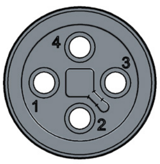
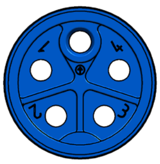
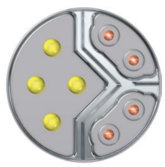
L-coded	T-coded	K-coded	S-coded	Y-coded
63 V / 16 A		630 V / 16 A		30 V / 6 A CAT5e, 100 Mbps
				
Power				Hybrid
According to 61076-2-111/CD IEC (E)				61076-2-113/CD IEC (E)
Application: e.g., for DC power distribution, power supplies, power connection for active I/O modules, Industrial Ethernet components, network devices, and direct wiring of LED and conventional lighting systems.		Application: e.g., for AC motors and drives, frequency inverters, motor control switches, auxiliary power distribution for control systems, and direct wiring of lighting systems.		Application: e.g., for data/ power connection of compact active I/O modules for installations that demand low weight, small size and easy handling.

Table 2: M12 Power and hybrid connector codings

References

1 K. Bauer et al., "Recommendations for implementing the strategic initiative INDUSTRIE 4.0 – final report." http://www.acatech.de (April 2013)

2 IEC 61131, International Electrotechnical Commission, "Programmable controllers." https://webstore.iec.ch (2013)

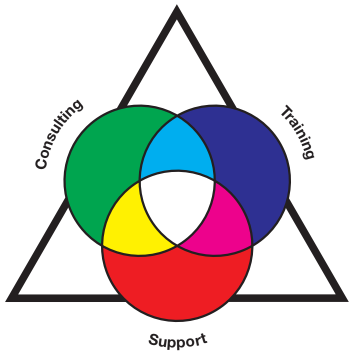
3 IEC 61076, International Electrotechnical Commission, "Connectors for electronic equipment – Product requirements." https://webstore.iec.ch (2012-2014)

4 DIN EN 60529, DKE German Commission for Electrical, Electronic & Information Technologies of DIN and VDE, Degrees of protection provided by enclosures (IP Code). http://www.din.de/en

5 OPC UA, Unified Architecture. https://opcfoundation.org (2008)

6 UL 61010, UL, "Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use." http://ulstandards.ul.com/standard/?id=61010-1_3 (April 2016)

7 Ladder Logic for PIC and AVR. http://cq.cx/ladder.pl#d (January 2016)



Belden Competence Center

As the complexity of communication and connectivity solutions has increased, so have the requirements for design, implementation and maintenance of these solutions. For users, acquiring and verifying the latest expert knowledge plays a decisive role in this. As a reliable partner for end-to-end solutions, Belden offers expert consulting, design, technical support, as well as technology and product training courses, from a single source: Belden Competence Center. In addition, we offer you the right qualification for every area of expertise through the world's first certification program for industrial networks. Up-to-date manufacturer's expertise, an international service network and access to external specialists guarantee you the best possible support for products. Irrespective of the technology you use, you can rely on our full support – from implementation to optimization of every aspect of daily operations.

About Belden

Belden Inc., a global leader in high quality, end-to-end signal transmission solutions, delivers a comprehensive product portfolio designed to meet the mission-critical network infrastructure needs of industrial, enterprise and broadcast markets. With innovative solutions targeted at reliable and secure transmission of rapidly growing amounts of data, audio and video needed for today's applications, Belden is at the center of the global transformation to a connected world. Founded in 1902, the company is headquartered in St. Louis, USA, and has manufacturing capabilities in North and South America, Europe and Asia.

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