REDUCING MOTOR CONTROL CENTER FOOTPRINT THROUGH ROGOWSKI SENSOR MEASUREMENT AND SINGLE PAIR ETHERNET

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Abstract **-** Space constraints in electrical switching rooms demand innovative approaches to reduce motor control Center (MCC) footprints while maintaining functionality. This paper shall present a dual-technology solution achieving significant size and installation efficiency improvements.

Traditional protection core current transformers (PCTs) in MCC withdrawable units (WUs) consume substantial space. Replacing PCTs with Rogowski sensor measurement systems enables up to 25% size reduction in comparable-rated WUs through:

(1) smaller physical dimensions and reduced material consumption, and

(2) improved integration possibilities within WU designs.

Complementing this hardware optimization, Single Pair Ethernet (SPE) technology - proven in automotive applications - simplifies motor management system connectivity.

SPE replaces conventional RJ45-based Ethernet (Modbus TCP, Profinet) with shielded twisted-pair wiring, eliminating bulky connectors and CAT 6 cabling requirements. This reduces installation effort, improves reliability in vibration-prone environments, and further decreases space requirements.

The combined implementation of Rogowski sensor and SPE delivers measurable benefits: reduced MCC footprint, lower material costs, simplified installation, and enhanced design flexibility. Field implementation results and comparative performance data demonstrate the viability of this approach for modern low-voltage power distribution systems.

Index Terms - Motor Control Center, Motor Management, Rogowski sesnor, Single Pair Ethernet, Footprint

I. INTRODUCTION

Size of the power distribution affects overall investment costs in the infrastructure of greenfield projects.

Particularly in process driven industries such as the oil and gas industry Motor Control Centers (MCC) are used to distribute power to low-voltage motors.

MCCs house motor starters that apart from distributing power also protect and control the connected assets as the main tasks.

Typically, these motor starter which contain the components for switching, controlling and protection, are executed in withdrawable unit design (WUD).

This means that all the components of each feeder are built into a cassette-like unit using guided contacts to connect the feeder in the MCC to the distribution busbar and the connection terminals as well as the control interface.

WUD is used to improve availability and reliability of the power distribution. Component failures, maintenance works or modifications do not lead to shutdown of the complete power distribution as the affected part can be isolated and removed separately.

The design of the withdrawable units directly influences the footprint of the complete Motor Control Center. Therefore, one lever to reduce the space requirements of MCCs is optimizing the design of withdrawable units.

One core component of the WUD is the overload protection for the motor. In modern MCCs typically intelligent motor management systems are used for the task. As the protection function is current based toroidal current transformers are required to be installed alongside. Due to the design of toroidal current transformers, they can require a significant amount of space inside the WUD.

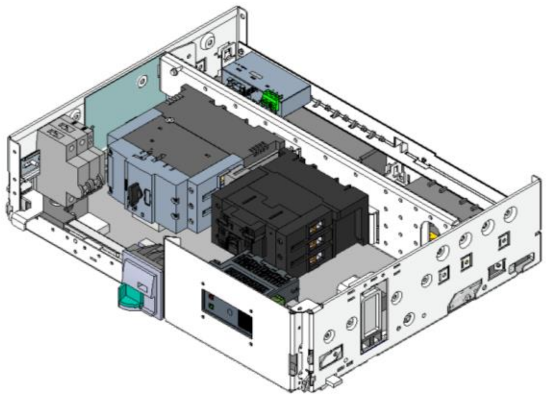

Fig. 1 Sample of a withdrawable unit

The motor management systems not only provide the protection function but also control functions and a communication interface to integrate into a process control system or distributed control system over fieldbus protocols. Fieldbus protocols have been adopting Ethernet based standards over the recent years, so that Ethernet ports usually RJ45 based became a necessity to be also integrated into the WUDs to connect the motor management system.

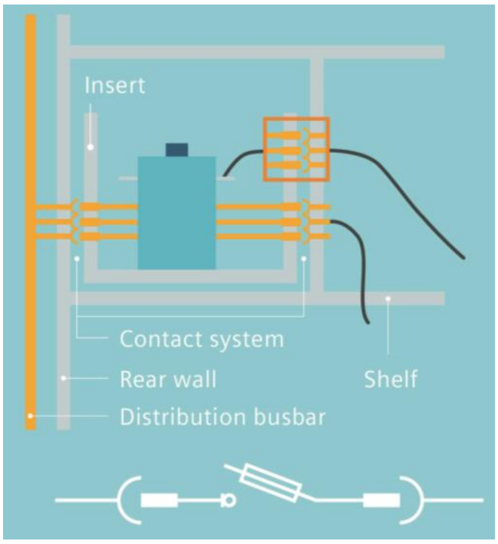

Fig. 2 Principle of withdrawable unit design

This paper presents two approaches to optimize current measurement and connectivity within WUDs. These solutions aim to reduce the size of withdrawable units, thereby decreasing the overall MCC footprint. The first section focuses on current measurement systems utilizing Rogowski sensors. The second section introduces Single Pair Ethernet as an alternative to traditional Ethernet-based communication.

II. ROGOWSKI SENSOR BASED MEASUREMENT SYSTEM

A. Operating Principle Of A Rogowski Current Sensor

The operating principle of a Rogowski sensor differs fundamentally from that of a classic toroidal current transformer. While a toroidal transformer generates an output signal proportional to the measured current, the output of a Rogowski sensor is proportional to the time derivative of the current.

This is due to the air coupled toroidal winding, which generates a voltage induced by the changing magnetic flux of the current carrying conductor. This voltage does not represent the current itself, but its rate of change.

To reconstruct the absolute current value, an integration step is required. While this can be performed using analog circuitry, modern systems primarily implement it digitally, providing additional benefits.

B. Digital Processing Of The Measurement Signal In The Frequency Domain

Once digitized, signals from both toroidal and Rogowski sensors can be evaluated very efficiently in the frequency domain. Frequency domain processing offers several decisive advantages.

1) Unified Algorithm For Different Sensor Types: A key benefit is that the same algorithm for RMS and phase angle calculation can be applied to both sensor types. Time domain processing, by contrast, would require different integration paths or analog compensation circuits.

By transforming the measurement data into the frequency domain using a Discrete Fourier Transform (DFT), the evaluation becomes largely unified:

- For toroidal current transformers, the Root Mean Square (RMS) value is obtained directly from the spectral components.
- For Rogowski sensors, the spectral values are simply divided by the angular frequency ω, which mathematically corresponds to the required integration of the differential signal.

This unification reduces hardware and firmware variants and results in a more robust and easier to maintain system architecture.

2) Spectral analysis up to the seventh harmonic: After digitization, the current spectrum is calculated via DFT - typically up to the seventh harmonic, as these are relevant for motor protection.

The fundamental frequency needed for spectral analysis is reliably determined using zero crossings of the current waveform. From the spectral components, values such as:

- RMS current
- phase angle

can be directly derived.

3) Simple Integration And Future Proof System Design: This form of digital signal processing allows the same acquisition module to be used for both sensor types. This reduces development effort and long-term maintenance costs for hardware and firmware.

C. *Sensor and Evaluation Electronics as a Functional Unit in Motor Management*

Modern MCC switchgear does not use current sensors as standalone components but as part of an integrated functional unit for motor monitoring.

1) Unified Measuring Modules: These measuring modules consist of:
   - current sensor (Rogowski or toroidal),
   - fixed or modular connection to the evaluation electronics,
   - standardized system interface for connection to the motor management system.

While toroidal transformers are often installed in the same enclosure as the associated electronics, Rogowski sensors can also be installed separately due to their flexibility. This enables optimal integration of the sensor directly in the current path while placing the electronics elsewhere to save space.

2) Use of standard components

The measuring module electronics use proven standard components - particularly ADCs and microcontrollers.

Ensuring long term availability of compatible components significantly simplifies product maintenance over the entire lifecycle.

III. SINGE PAIR ETHERNET

A. *What Is Single Pair Ethernet (SPE)?*

Single Pair Ethernet (SPE) represents an important development in network technology, influencing how data is transmitted within industrial automation environments. SPE is a standardized Ethernet technology designed to transmit data over a single pair of copper wires, differing from the two or four pairs typically used by classical Ethernet. This approach was developed to extend the benefits of Ethernet - such as robust protocols and IP connectivity - directly to the field level, connecting a range of devices that previously relied on serial communication protocols or proprietary fieldbuses.

SPE is largely driven by the requirements of Industry 4.0 and the expanding Internet of Things (IoT). SPE offers a more streamlined and potentially cost-effective cabling infrastructure, utilizing less copper and enabling smaller connectors. SPE follows the IEEE 802.3 standards, promoting interoperability and providing a consistent foundation for industrial networks.

B. *Difference Between SPE And Classical Ethernet*

While both SPE and classical Ethernet share the core principles of Ethernet communication, their physical implementations and primary application areas show clear differences. The clearest difference lies in their cable infrastructure. Classical Ethernet, such as Cat5e or Cat6, typically uses two or four twisted pairs (eight wires total) for data transmission. In contrast, SPE utilizes a single twisted pair (two wires), resulting in thinner, lighter, and often more flexible cables.

This difference in cabling also leads to distinct connectors. Classical Ethernet commonly uses the RJ45 connector. SPE, however, employs smaller, more robust connectors specifically designed for industrial environment. Or can be connected using simple standard terminals in certain applications without the need for connectors at all.

A significant differentiator is the reach or distance capabilities. Classical Ethernet (e.g., 100BASE-TX, 1000BASE-T) is generally limited to a maximum cable length of 100 meters. SPE is designed for longer distances, with versions like 10BASE-T1L capable of extending connectivity up to 1000 meters, expanding direct Ethernet connectivity without intermediate repeaters.

Regarding data rates, classical Ethernet spans from 10 Mbps to 100 Gbps and higher, serving high-bandwidth IT applications. SPE primarily focuses on lower to medium data rates (e.g., 10 Mbps, 100 Mbps, 1 Gbps) where long reach and robustness are often prioritized over maximum speed.

The method of power delivery also differs: Power over Ethernet (PoE) delivers power over multiple pairs in classical Ethernet cables, whereas Power over Data Line (PoDL) in SPE delivers power over the single data pair, optimized for the power requirements of many edge devices.

C. *SPE Versions Available*

The development of Single Pair Ethernet has resulted in several distinct IEEE 802.3 standards, each optimized for specific applications and performance characteristics. Understanding these versions is important for selecting the appropriate SPE solution for a given requirement.

TABLE I
SPE Versions

Name	Data rate	Distance	Connection	IEEE
10BASE-T1L	10 Mbps	~1000 m	Point-to-point	802.3cg
10BASE-T1S	10 Mbps	~25 m	Multi-drop	802.3cg
100BASE-T1	100 Mbps	~40 m	Point-to-point	802.3bw
1000BASE-T1	1000 Mbps	~40 m	Point-to-point	802.3bp
xGBASE-T1	X Gbps	<=15 m	Point-to-point	802.3ch

Beyond these established standards, ongoing research and development aim to achieve higher data rates and extended reaches for SPE, continuously advancing the capabilities of single-pair cabling.

D. Specifics Of 10BASE-T1L Version

Among the various SPE standards, 10BASE-T1L is a particularly relevant version for industrial and process automation due to its specific combination of features.

Its most prominent feature is its long reach, enabling Ethernet connectivity over 1000 meters, and potentially more with optimized cabling. This capability allows for direct Ethernet connection to field devices across large industrial plants, potentially reducing the need for fieldbus gateways or intermediate repeaters. This can simplify network architecture and influence infrastructure costs. The 10 Mbps data rate, while lower than some classical Ethernet speeds, is generally sufficient for many sensor, actuator, and control applications at the field level, where deterministic communication is often a priority.

Furthermore, 10BASE-T1L is designed for robustness, featuring connectors and cabling engineered to withstand industrial environmental conditions. It also provides full duplex communication, allowing for simultaneous data transmission and reception, which can enhance communication efficiency.

10BASE-T1L also supports Power over Data Line (PoDL).

Use cases for 10BASE-T1L are varied. In process control, it can connect flow meters, pressure sensors, and valves in critical infrastructure. In building automation, it enables control of HVAC systems, lighting, and access control. Factory automation can benefit from its ability to connect motor controls and distributed I/O modules. It is also suitable for remote monitoring of infrastructure and for marine and transportation applications.

While the advantages are clear, there are also some challenges and considerations. The ecosystem development for SPE, while progressing, means the availability of SPE-native devices and components is still expanding. As with any network technology, ensuring robust security measures is important to protect industrial operations.

IV. INTEGRATION IN MOTOR CONTROL CENTERS (MCC)

The integration of Rogowski sensor-based measurement systems and Single Pair Ethernet (SPE) offers substantial advantages for the deployment of motor management systems within withdrawable unit designs (WUDs). These technologies collectively contribute to improved space utilization, simplified cabling, and streamlined communication within motor control centers (MCCs).

A. Advantages Of Using Rogowski Transformers In Motor Control Center (MCC) Switchgear

Reliable, accurate, and modern current measurement is indispensable for the tasks of the motor management system. Rogowski current transformers have proven particularly advantageous for modular MCC systems. Their physical characteristics, compact design, and benefits in digital signal processing make them a future oriented solution for modern switchgear.

With the availability of small-size, cost-effective but more powerful hardware such as microcontrollers to perform the required digital signal processing it becomes more attractive to make use of the advantages.

Rogowski sensors offer several structural and functional advantages that are especially important in compact, modular MCC switchgear.

1) Wide current range and low variant diversity: A major advantage of a Rogowski sensor is its wide usable current range. Due to its air-coupled design and the absence of a magnetic iron core, the coil can measure currents with high linearity across several orders of magnitude - from low operating currents during normal operation to high motor inrush currents.

This reduces the number of different transformer types needed within the MCC. Lower variant diversity simplifies engineering, logistics, variant management, and spare parts handling.

2) Compact size and high integration capability: Since Rogowski coils operate without a ferromagnetic core, they are significantly smaller and lighter than conventional toroidal current transformers. Their compact and flexible design enables direct integration into the contact system of an MCC drawer or into other space restricted areas within the modules.

In modern MCC systems, where drawers are densely packed and modularly constructed, this small size offers a decisive advantage. It allows space efficient switchboard layouts and simplifies thermal design within the switchgear assembly.

It directly facilitates a reduction in the overall footprint of the WUD, thereby increasing packing density within the MCC and ultimately minimizing the total space requirements for the entire system.

In certain cases, a reduction of WUD size of 25% is possible. Overall reductions of MCC footprint up to 15-20% become realistic.

The reduced overall MCC size will also affect the CO_2 footprint as viewer steel, copper etc. in a similar magnitude. However, robust statements can only be made for project-specific solutions.

3) High linearity and improved measurement accuracy: Conventional toroidal transformers exhibit unavoidable effects such as hysteresis and magnetic saturation due to their ferromagnetic core. Rogowski sensors, on the other hand, provide very high linearity across the entire operating and overload range.

This high linearity is particularly important for precise protection and diagnostic systems: motor protection devices can analyze current waveforms more accurately, detect overload conditions reliably, and perform diagnostic functions such as trend analysis or condition monitoring**.**

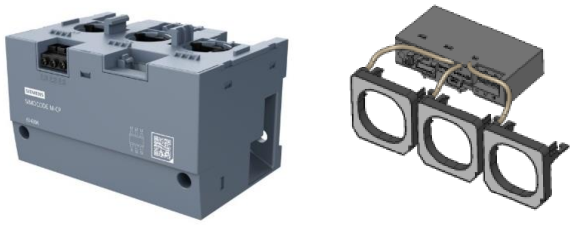

Fig. 3 Toroidal transformer (630A) and Rogowski transf.

B. Benefits Of Single Pair Ethernet For Communication

Single Pair Ethernet (SPE) significantly reduces cabling complexity and effort within WUDs by providing a robust transmission medium for communication. Specifically, the 10BASE-T1L standard permits connections via conventional terminal blocks, eliminating the need for bulky RJ45 connectors. This is particularly advantageous in industrial environments like MCCs, where robust and compact connectivity is important.

Key benefits of SPE include:

- Reduced Cabling Volume: Shielded twisted pair (STP) cables, utilized by SPE, are considerably thinner than traditional Cat6 cabling. This reduction in cable diameter simplifies installation, especially in compact designs such as WUDs, by improving handling and routing flexibility.
- Cost Efficiency: The elimination of RJ45 connectors and the use of simpler twisted pair cables contribute to a positive impact on material costs for the overall system.
- Seamless Integration: SPE-enabled switches facilitate seamless integration into existing upstream communication infrastructures by supporting both SPE and standard Ethernet connectors.
- Protocol Transparency: SPE operates as a physical layer technology, allowing for the unaltered transmission of standard fieldbus protocols such as Modbus TCP or Profinet. This means that no gateway functions or protocol conversions are required, enabling direct protocol access from the Distributed Control System (DCS) to the component level within the WUD.
- Sufficient Date Rates: For applications like motor management systems, a data transmission rate of 10 Mbps on the SPE network segment is generally sufficient. The data volumes generated by these components are typically uncritical, and required bus cycle times can be reliably met.
  Nevertheless, improved data rates can also be expected in the near future (Refer to OUTLOOK).

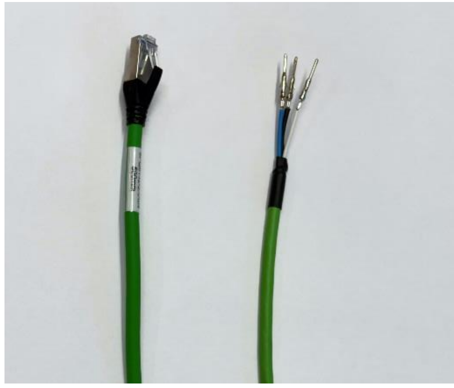

Fig. 4 Ethernet cable with RJ45 connector vs. SPE cable

C. Considerations For 10BASE-T1S In MCC Applications

While 10BASE-T1S, with its multi-drop connection capability, might initially appear to be a suitable option for MCC applications involving withdrawable units, certain limitations mitigate its advantages. Although its network expansion range of 25 meters may be sufficient for an MCC section, the drop length is restricted to 10 cm, and a maximum of 8 components can be connected on a single line [1]. The 10 cm drop limitation, in particular, presents a significant challenge for WUD designs, as it would impose unfavourable restrictions on their physical layout and flexibility. Therefore, 10BASE-T1L often proves to be the more practical and adaptable solution for these specific industrial applications.

V. OUTLOOK

Regarding data rates of Single Pair Ethernet it is worth mentioning that works on the version 100BASE-T1L (IEEE 802.3dg) are ongoing. It will enhance transmission speed to 100Mbps. Network expansion will be possible to 500m.

It is expected that standard will become available in this year (2026) [2].

With its availability 100BASE-T1L will become in interesting enhancement for MCC applications as discussed in this paper.

VI. CONCLUSION

The use of Rogowski sensors in Motor Control Centers offers clear technical, system level, and economic advantages. Their compact design, high linearity, and wide current range make them ideal sensors for modern modular switchgear. Combined with digital evaluation in the frequency domain, they provide a flexible, scalable, and future proof platform for motor management systems. Furthermore, unified digital processing allows both Rogowski and toroidal sensors to be operated using the same hardware and firmware - an important advantage in terms of reducing variants, minimizing development effort, and ensuring long term system availability.

Furthermore, SPE, particularly the 10BASE-T1L standard, offers a robust and streamlined communication solution. Its ability to transmit data over a single pair of wires, support long distances, and integrate seamlessly with existing protocols via simple terminal blocks dramatically reduces cabling complexity and material costs within MCCs.

Collectively, these innovations enable the design of more compact, reliable, and cost-effective MCCs, directly impacting overall investment costs in greenfield projects. As SPE technology continues to evolve with higher data rate versions like 100BASE-T1L on the horizon, the benefits for industrial automation and motor management systems are poised to expand further, solidifying their role in future-proof industrial infrastructure.

VII. REFERENCES

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VIII. VITA

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