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Ingenuity for life



Condition Monitoring

for High Voltage
Transmission Lines or Cables

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Making the most of your transmission lines

Continuous monitoring of assets is used in many industries. Its purpose is to maximize performance and productive lifetime of a product or system while simultaneously minimizing its lifecycle cost. It is a core element of big data and digitalization that both become increasingly relevant levers to improve performance and to optimize asset utilization.

In the energy industry, condition monitoring is already widely used in the power generation segment. Operators can identify problems, avoid damage to turbines, or minimize downtime by monitoring of, for example, temperature, pressure, voltage or humidity levels of a plant's assets.

Continuous monitoring of High Voltage (HV) transmission lines is today largely restricted to a measurement of voltage and current. One of the main reasons for this limitation is the difficulty of economically obtaining other types of information along hundreds of kilometers of power lines. Individual sectors may be monitored using dedicated short-distance sensors, e.g. optical, vibration or temperature sensors, but require additional communication devices or gateways to transmit the data to the control center. Optical inspection by e.g. drones is another form of condition monitoring that provides information only on visible defects but is – for economic reasons – only repeated in large time intervals and cannot be executed during bad weather conditions or on underground cables. Line faults are typically localized by using detectors based on travelling wave technology.

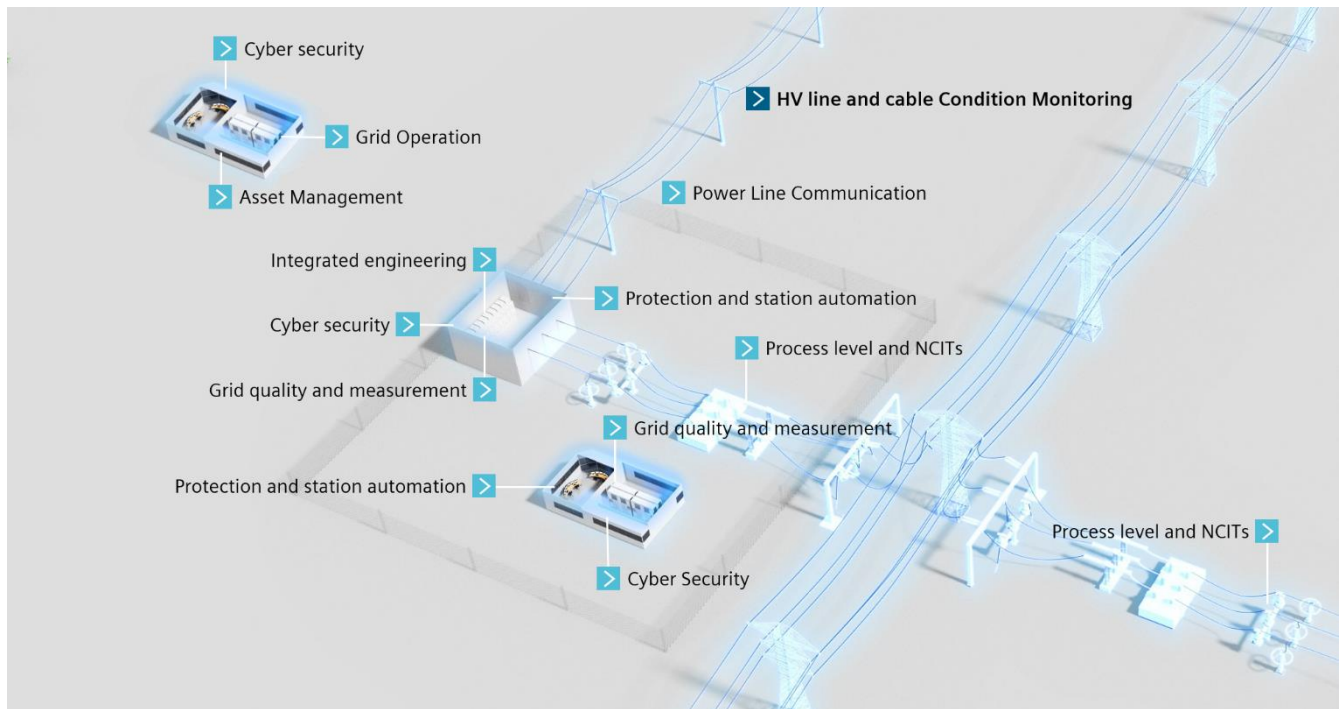
In 2019, Siemens designed and released a new approach to active condition monitoring of HV lines. Based on power line carrier communication technology, the solution uses the reflection of a radar-like pulse to sense the state of the line or cable along the full distance of the link. The result is a detection mechanism that works on powered and unpowered lines, that immediately locates massive failures such as line cuts or shorts, and that simultaneously shows the impact of slow changing events such as wear or vegetation which is growing closer to the lines.

Performance is King

1. Challenging power utility market

The competition in the energy market leads to strong cost and efficiency pressure along the complete value chain of power generation, transmission and distribution. The capital cost tied up in the power infrastructure is the largest single item accounting for up to >75% of the tangible assets¹. This increasing competitive environment requires each component to operate at its optimum performance level and to achieve its maximum lifetime. On the transmission side, this performance is – among others – determined by the best possible utilization of the transmission line, by fast resolution of line faults, and by minimizing unscheduled downtime events.

The increasing complexity in the entire energy supply chain, from generation to transmission and distribution, requires utmost monitoring and control capability. This alone can guarantee that availability and reliability of the electrical power supply is assured at all times. Without digitalization, it will be impossible to meet these challenges. Condition Monitoring combined with digitalization creates smart transmission lines that know when they reach their peak performance or when they need increasing attention and finally maintenance. Transmission network operators, in particular, will benefit from continuous real-time monitoring as it helps them to efficiently operate their key asset.



Elements of digital substations

¹ See current financial reports of TSOs or power utilities

2. Condition Monitoring as core know-how

Based on detailed and up-to-date line data, qualified decisions on maintenance intervals, operational process improvements, or network strategy can be taken. Using preventive maintenance, the operator may choose to skip an interval, to re-schedule a maintenance cycle, or to have a closer look at a certain section of his transmission network.

In case of line failure, immediate localization of the fault will allow rapid access and fast restoration of the power grid, resulting in both, minimization of revenue loss and higher customer satisfaction.

Considering the amount of data generated by continuous monitoring, especially when including and comparing historical data, we see that big data and artificial intelligence will play an increasingly important role. So, we expect an eventual merge of condition monitoring, cloud services and big data capabilities in the medium to long term future to fully reap the benefits for asset management and other operational processes.

3. Asset management at its best

A dependable and affordable electrical power supply infrastructure is one of the essential foundations of a modern society. It forms the backbone of the global economy. The immense investment combined with a typical lifetime of e.g. 35-40 years² for transmission lines makes asset management one of the core competencies in the power industry.

Besides administration of capital assets, the task of asset management is to ensure maximum asset utilization, to prolong its lifetime, and to decide when to expand or to replace the existing infrastructure. Regarding a given transmission line, efficient asset management requires continuous and up-to-date information on

- Current line condition
- Impact of load changes on the line condition
- Impact of external factors (e.g. weather, vegetation, etc.) on the transmission line
- Comparable, historical data

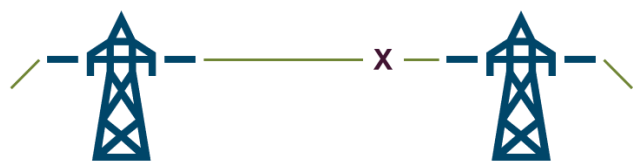
A specific aspect of condition monitoring is the identification and localization of major line faults, such as line breaks or shorts along the line. Whereas dedicated technologies exist that address this specific topic, it can and should be an integral part of a holistic condition monitoring system.

Consequently, continuous line condition monitoring is a core technology, relevant along the complete value chain, especially for asset management, operations and service.

Continuous Monitoring



Fault Location



Use cases for HV condition monitoring

² TenneT Holding B.V., Annual Report 2018

Benefits of the Siemens PowerLink CM solution

4. Beyond powered HV lines

While condition monitoring solutions on the market work reasonably well on powered lines, they typically are not usable on unpowered or grounded lines.

Why to monitor an unpowered line? One of the reasons is to ensure the line is available when needed. This particularly includes protection against copper line theft. Such circumstances are typically found in HVDC environments but also during temporary off-line conditions caused by maintenance or during construction of new power lines.

An additional benefit of monitoring a powered line under maintenance or a newly constructed line is to provide a safety check or “pre-commissioning line check” before power-up. Forgotten tools or closed breakers may result in a short circuit and will not only lead to significant damage to assets or potentially to life-threatening injuries but will also result in a major delay of the power-up.

5. Making the most of your transmission lines

PowerLink CM is a state-of-the-art, active condition monitoring solution designed to serve two main purposes:

- Fault location
- Continuous line monitoring

The first purpose is to precisely identify type and location of major line faults. The system is capable of distinguishing between high impedance (open, e.g. line break) or low impedance (close, e.g. short) faults. It keeps any kind of power line, phase, ground or metallic return, under surveillance and provides alarming as well as precise fault localization. Location information is available in real-time but can also be triggered at any time after the event.

A line break may, at first sight, be a rare event. But this is only true if one considers natural phenomena, such as lightning, earthquakes, or damage during construction. However, an intentional break is much more likely to occur. Copper theft presents one of the biggest threats³ to electrical safety systems and results in escalating costs, operational downtime and threats to life and assets. This threat is most likely to occur on unpowered lines, typically found in an HVDC environment, such as direct metallic return (DMR), or earth electrodes. But even in HVAC there are situations where this poses a threat, as explained above.

If used in continuous operation mode, variations in line impedance are monitored over time and distance. By means of such long-term statistics on a line condition even sporadic events, like ground clearance, clearance to trees, impact of climatic changes or influence of peak loads can be detected and located. This allows the identification of upcoming line issues before a serious fault condition is reached.

| Highlights | Benefits |
|---|--|
| Continuous monitoring of HVAC or HVDC lines | <ul style="list-style-type: none"> • Optimization of maintenance cycle based on actual state of HV line (preventive maintenance) • Targeted maintenance of questionable line sections • Detection of patterns (e.g. seasonal effects, recurring disturbances) • Better utilization of transmission line • Highly efficient asset management |



³ IEEE, An approach to reduce copper theft in transmission line grounding systems; 2013 International Symposium on Lightning Protection (XII SIPDA)

| Highlights | Benefits | |
|--|---|--|
| Supervision of powered or unpowered lines | <ul style="list-style-type: none"> • Protection against copper theft <ul style="list-style-type: none"> • Earth electrodes • Direct Metallic Return • Lines under maintenance • New build lines • Pre-commissioning check before link activation | |
| High precision localization of line faults | <ul style="list-style-type: none"> • Fast access to fault location site • Localization even after the fault event • Presentation of fault location site on map | |
| Identification of fault types | <ul style="list-style-type: none"> • High sensitivity to high and low impedance faults • Distinction between <ul style="list-style-type: none"> • Ground fault • Short circuit • Provisioning of appropriate maintenance material before accessing the site | |
| Single sided measurement | <ul style="list-style-type: none"> • Simple system operation • Low investment | |
| Monitoring of overhead lines up to 1.000 km | <ul style="list-style-type: none"> • Maximum line coverage at minimum investment (requires two systems) | |

6. System design

The Siemens' PowerLink CM system makes use of a power line radar concept based on power line carrier communication technology. A multi-tone signal with configurable overall bandwidth is fed several times per second into the high voltage line or cable. The signal reflections are then detected by the system.

A sudden line break or short causes a strong reflection that leads to a clearly distinguishable signal and, consequently, triggers an alarm. By measuring the phase of the reflected signal, the fault type can be identified.

Each variation of the line condition or line environment causes a change in line impedance which has direct influence on the reflected signal. This impedance diagram is recorded as a function of distance and time. The analysis of these data points allows the identification of long-term trends and changes in line condition.

In order to facilitate the analysis of acquired condition monitoring data, Siemens offers the system with a connectivity to the Siemens Cloud service EnergyIP, powered by the Siemens IoT operating system MindSphere™. If desired by the utility, the monitoring data can be transmitted into the cloud and analyzed by appropriate offline tools.

Impact on your business

7. Improve your network performance

Obtaining continuous and up-to-date line condition data is one of the key technologies for any power utility. Current and accurate knowledge of the power line condition allows a power utility, transmission (TSO) or distribution system operator (DSO) to maximize the utilization of its transmission or feeder network. Availability, reliability and lifetime of the transmission lines may safely be extended beyond today's conservative limits. Condition data that were not accessible up to this day can now provide a solid base for judging and deciding upon the network, operation and maintenance strategy. Power utilities looking for the competitive edge may find the compelling solution inside the "big data" created by this system.

Hence, the PowerLink CM solution may quickly become one of the most useful tools for efficiently achieving maximum network performance and customer satisfaction. It facilitates continuous improvement of network operations and takes asset management to the next level.

8. Strengthen your asset management

Besides power generation and distribution networks, the transmission network infrastructure is one of the largest and most valuable assets. Thus, the overall objective of asset management is to preserve this investment and to reduce its life cycle cost. Any opportunity to improve the financial return of the network is a step towards competitive leadership.

Intelligent analysis of the data available from continuous monitoring provides an efficient way towards

- Avoiding unplanned asset downtime caused by component failures
- Reducing maintenance costs and network risks
- Creating optimum maintenance strategies by prioritization and performing maintenance at the right time – and long before significant deterioration or failure occur
- Managing risks by avoiding catastrophic failures or other failure events where repair is difficult and potentially dangerous
- Optimizing asset maintenance strategies, and facilitating engineering resource planning and spares planning
- Delivering a quick payback on network investment
- Minimizing the risk of failing to deliver the contracted power output

| Use Case | Benefit | Impact |
|--|---|--|
| Precise localization of line faults | <ul style="list-style-type: none"> • Preventive measure against copper line theft • Rapid access to fault location • Fast restoration of operation | Potential annual savings per line due to precise and fast fault location ⁴ : <ul style="list-style-type: none"> • Copper line theft causes damages of hundreds of millions EUR p.a. worldwide • Line interruption causes revenue losses of up to 100,000 EUR/h/line |
| Continuous monitoring of line condition | <ul style="list-style-type: none"> • Preventive maintenance • Minimization of maintenance cycles and duration of outages • Line load optimization • Reduction of CO₂ footprint • Extension of line's lifetime | Potential annual savings/revenues per line due to continuous line monitoring ⁴ : <ul style="list-style-type: none"> • Each unplanned maintenance interruption causes revenue loss of up to 2 million EUR/d/line • Load increase of 0.1% can lead to additional revenue of up to 800,000 EUR/yr/line |

⁴ Rough estimation, based on assumption of 220kV line, 380MW

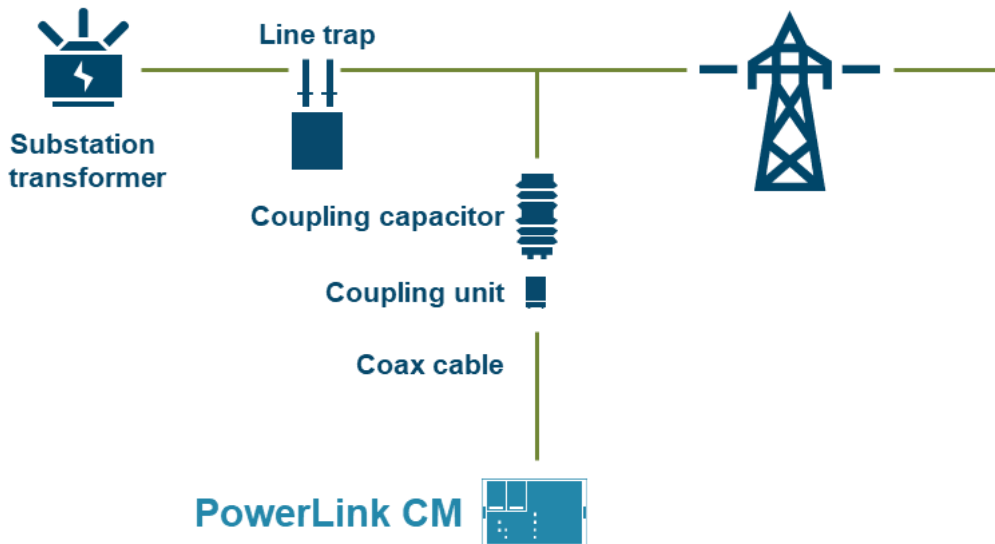
9. End-to-end network design

The implementation of an active condition monitoring solution based on power line radar technology requires some thoughts regarding network setup and national regulation on frequency use on or along the power line.

The active monitoring system PowerLink CM uses the same coupling infrastructure as other power line carrier communication devices. Depending on the actual setup, it may even be possible to share the same coupling devices. Its smart frequency management allows system operation parallel to one or more existing PLC systems. The frequency bands used by other radio sources, such as airport beacons, can be notched within PowerLink CM to avoid interference in either direction. This smart solution greatly simplifies the necessary frequency planning.

By becoming a fully integral part of a power line carrier network infrastructure and operation, PowerLink CM will generate the most benefit and will quickly become an indispensable element of the power utility's network operation.

HV substation



Prerequisites for active condition monitoring of high-voltage lines

Abbreviations

| | |
|------------------|------------------------------|
| CM | Condition Monitoring |
| DSO | Distribution System Operator |
| HV(AC/DC) | High Voltage (AC/DC) |
| IoT | Internet of Things |
| IP | Internet Protocol |
| LAN | Local Area Network |
| PLC | Power Line Communication |
| TSO | Transmission System Operator |

Siemens 2020
Smart Infrastructure
Digital Grid
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For the U.S. published by
Siemens Industry Inc.
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Alpharetta, GA 30005
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